Canadian Mineralogist
Vol. 19, pp. 469-477 (1981)

AMPHIBOLES FROM THE RENZY LAKE ULTRAMAFIC COMPLEX, SOUTHWESTERN QUEBEC

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Abstract

The complex metamorphic and deformational history of the ultramafic rocks at Renzy Lake (southwestern Quebec) has resulted in the formation of two separate assemblages of coexisting amphiboles, hornblende–tremolite and actinolitic hornblende–cummingtonite. The granulite-facies hornblende peridotite is highly fractured and brecciated into polygonal blocks whose margins show distinct and characteristic mineral zonation [hornblende peridotite : bronzite : phlogopite : actinolitic hornblende : plagioclase] developed outward toward the enclosing paragneiss. Colorless tremolite forms sporadic rims and marginal patches on hornblende grains and subgrains in the metaperidotite. It is developed within pre-existing grain and subgrain boundaries, and seems to have been formed by metasomatic replacement contemporaneous with the development of the mineral zoning. The well-defined hiatus in composition exhibited by the hornblende–tremolite assemblage is not related to a calcic amphibole miscibility gap. Cummingtonite occurs as rims and marginal patches, lamellae and overgrowths on actinolitic hornblende grains in the mineral zoning sequence. Textural details suggest that the rims, patches *and* coarse ($\bar{1}01$) lamellae were formed by metasomatic replacement during a subsequent amphibolite-facies event.

Keywords: amphibole assemblages, granulite facies, metasomatism, calcic amphibole miscibility gap, cummingtonite replacement, Renzy Lake, Quebec.

Sommaire

L'évolution complexe, par métamorphisme et déformation, du massif ultramafique du lac Renzy (Sud-Ouest du Québec) est à l'origine de la formation de deux assemblages distincts d'amphiboles coexistantes: hornblende avec trémolite, et hornblende actinolitique avec cummingtonite. La péridotite à hornblende, équilibrée dans le facies granulite, est fortement fissurée et bréchifiée en blocs polygonaux qui montrent une zonation minéralogique distincte et caractéristique (péridotite à hornblende → bronzite → phlogopite → hornblende actinolitique → plagioclase) en direction des paragneiss encaissants. Une trémolite incolore se présente en bordure discontinue et agrégats marginaux dans les grains et sous-grains de hornblende dans la métapéridotite. Elle ne serait formée, au contact de grains et sous-grains pré-existants, par remplacement métasomatique lors du développement de la zonation des minéraux. L'hiatus de composition entre hornblende et trémolite n'a rien à voir avec une lacune de miscibilité entre amphiboles calciques. La cummingtonite se présente en bordures et en taches marginales, lamelles et surcroissances sur la hornblende actinolitique dans la séquence zonée. D'après les indications texturales, les bordures, les taches et les lamelles ($\bar{1}01$) épaisses résulteraient d'un remplacement métasomatique lors d'une recristallisation métamorphique tardive dans le facies amphibolite.

(Traduit par la Rédaction)

Mots-clés: assemblages d'amphiboles, métasomatisme, facies granulite, lacune de miscibilité, amphiboles calciques, remplacement de la cummingtonite, lac Renzy (Québec).

Introduction

In recent years it has become apparent that study of the chemistry and phase relations of amphibole assemblages may result in greater appreciation of the conditions of metamorphism of amphibolite- and granulite-facies rocks. Attention has been focused on two key problems: (1) the Al content of calcic amphiboles (and interpretation of coexisting hornblende and actinolite), and (2) coexisting calcic and Fe–Mg–Mn amphiboles (and interpretation of coexisting phases within the amphibole quadrilateral).

The question of a hornblende–actinolite miscibility gap has been debated frequently in the literature since Hallimond (1943) first suggested its existence. A well-defined hiatus in the composition of calcic amphiboles from lower-amphibolite-facies rocks has been established, and many workers have interpreted it in terms of an equilibrium amphibole solvus under these conditions (Hallimond 1943, Klein 1969, Hietanen 1974, Misch & Rice 1975, Immega & Klein 1976). However, the state of equilibrium of many of the two-phase assemblages studied to date has been questioned, as hornblende commonly occurs as a rim or overgrowth on grains of actinolite. Patchy replacement of actinolite by hornblende has also been reported (Klein 1969). Separate homogeneous grains of hornblende and actinolite are rarely observed (Klein 1969), and a possible lamellar relationship has been observed in only one locality (Cooper & Lovering 1970). Thus, Grapes & Graham (1978) related the coexistence of actinolite and hornblende to the coupling of specific reactions during the prograde transition from greenschist to amphibolite facies.

Complex intergrowths of calcic and Fe–Mg–Mn amphiboles have been documented by many investigators and variously ascribed by Ross *et al.* (1969) to (1) primary intergrowth of two amphibole phases, (2) partial alteration or replacement of one amphibole by another, (3) overgrowth of one amphibole on another, and (4) exsolution or unmixing of two amphiboles from a pre-existing homogeneous amphibole.

Largely because of (1) the frequent occurrences of well-defined lamellae, (2) the apparent textural and chemical similarity with the established exsolution behavior of quadrilateral pyroxenes and (3) the experimental verification of an actinolite–cummingtonite solvus (Cameron 1975), an exsolution origin for amphibole intergrowths has been favored in most contemporary studies (*e.g.*, Jaffe *et al.* 1968, Ross *et al.* 1969, Robinson *et al.* 1969, Papike *et al.* 1974, Gittos *et al.* 1974, Immega & Klein 1976, Stephenson & Hensel 1979). However, Stephenson & Hensel (1979) suggested that the coarse intergrowths of amphiboles from the Wongwibinda complex that show wide grain-to-grain variations in the relative proportions of the two phases may have resulted from simultaneous homoaxial growth. Also, in metamorphosed quartz diorite from the Frood mine, Sudbury, Ontario (Fleet & Barnett 1978), cores and lamellae of cummingtonite occur in grains of *relict* primary (magmatic) hornblende, and blue-green hornblende occurs as an apparent alteration rim to massive cummingtonite.

In the present study, coexisting hornblende–tremolite and actinolitic hornblende–cummingtonite assemblages are described from metasomatically zoned granulite-facies peridotite at Renzy Lake, southwestern Quebec. Both amphibole assemblages are interpreted to have resulted from metasomatic replacement: hornblende by tremolite and actinolitic hornblende by cummingtonite.

The Renzy Lake Ultramafic Complex

The Renzy Lake ultramafic complex, in Hainaut Township, southwestern Quebec, is a small sill-like body of granulite-facies peridotite enclosed by paragneiss (Johnson 1972). It appears to have originated as a layered peridotite–pyroxenite complex, and is now intensely deformed to a general synclinal shape with steep, overturned folds on the eastern margin. Approximate maximum dimensions are 900 m long, in the direction of the fold axes, 300 m wide and 100 m thick.

Johnson (1972) divided the Renzy Lake ultramafic body into two units: a border zone and a layered interior. The border zone is discontinuous and most prominently developed along the north and west margins, where it is up to 15 m wide. It consists of coarse grained hornblende poikiloblastically enclosing minor rounded olivine, diopside and bronzite. The rocks of the rhythmically layered interior vary in composition from dunite [apparently representing horizons of cumulus olivine: Johnson (1972)], to hornblende lherzolite and hornblende olivine websterite. Hornblende occurs as a poikiloblastic matrix to rounded olivine and pyroxene, and exhibits throughout the complex a complete range of deformation behavior, from subgrained without marked subgrain rotation, to subgrained with rotation, to granoblastic recrystallization. Aspects of the pyroxene mineralogy have been discussed elsewhere (Fleet *et al.* 1980).

The Renzy Lake ultramafic body is highly brecciated along its northern rim and along axial plane fracture zones, where the brecciation is associated with copper–nickel sulfide mineralization. The breccia consists of rounded blocks of ultramafic rocks set in a quartzofeldspathic matrix. Within the fracture zones, individual ultramafic blocks are lenticular and flow-banded. The paragneiss fracture fillings are generally wedge-shaped. They pinch out with penetration into the ultramafic body, passing continuously over a distance of perhaps several metres into plagioclase–calcite–quartz–garnet veins with mafic and ultramafic linings, to ultramafic veins 10 to 20 mm wide within massive peridotite, and finally to healed fractures marked only by a narrow bleached zone observed on fresh rock surfaces.

Mineral Reaction Zones

Thin-section examination reveals that the ultramafic breccia blocks have a characteristic

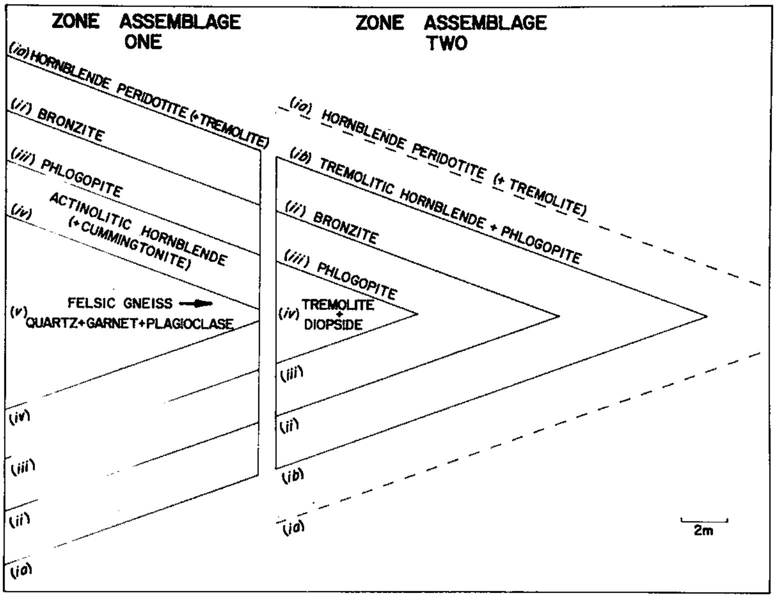

FIG. 1. Mineral zoning of ultramafic breccia blocks at Renzy Lake (see text); vertical scale greatly exaggerated.

zonation of minerals adjacent to the paragneiss veins. The detailed mineralogy of the zones varies somewhat with fracture penetration; it is convenient to recognize two extreme assemblages (Fig. 1). *Zone assemblage one*: the sequence of zones from peridotite to paragneiss is *ia*) hornblende peridotite, *ii*) bronzite, *iii*) phlogopite, *iv*) actinolitic hornblende, *v*) felsic vein–plagioclase (An_{17}) or garnet passing outward into plagioclase–calcite–quartz–garnet and, eventually, to paragneiss. *Zone assemblage two*: the sequence of zones from peridotite to vein interior is *ia*) hornblende peridotite, *ib*) tremolitic hornblende peridotite (with phlogopite), *ii*) bronzite, *iii*) phlogopite, *iv*) tremolite and diopside.

Zone *ib* tremolitic hornblende is generally similar to the recrystallized zone *ia* hornblende. Adjacent grains have the appearance of recrystallized rotated subgrains. However, tremolitic hornblende grains close to the contact with zone *ii* tend to be oriented with *Z* axes approximately normal to the zone boundary. Zone *ib* has not been recognized in zone assemblage one, where hornblende plus tremolite (below) appear to be in direct contact with zone *ii*. Zone *ii* bronzite ($En_{80}Fs_{20}Wo_0$) is equigranular in zone assemblage one and is present as large (3–5 mm) poikiloblastic grains with *Z* axes normal to the zone boundaries in zone assemblage two. Phlogopite has a cross-cutting relationship with adjacent phases in zones *ib* and *iii*; in consequence, zone *iii* is less well defined than the other zones. Zone *iv* actinolitic hornblende occurs as large (2–7 mm) equidimensional to blade-like grains that have *Z* axes approximately normal to the zone boundaries in unsheared samples. Adjacent to the contact with zone *iii* phlogopite, zone *iv* tremolite grains are blade-like and oriented normal to the zone boundary. In the interior of zone *iv*, the tremolite is fine grained (0.05–0.1 mm) and forms a matrix to large, ragged and open poikiloblasts of diopside ($En_{46}Fs_6Wo_{48}$).

The mineral zoning of the breccia blocks and the border zone are interpreted as the products of intense metasomatic reaction between the ultramafic rocks (dominantly hornblende peridotite) and the quartzofeldspathic paragneiss. Mineral zones *ib* through *v* are thought to have formed contemporaneously, under constant pressure–temperature conditions, although there remains the possibility that phlogopite is a retrograde phase. Petrological and geochemical aspects of the metasomatism will be discussed later.

Results of representative electron-microprobe analyses of the characteristic amphiboles of assemblages one and two are reported in Table 1 and Figures 2 and 3. A complete tabulation of amphibole analytical data may be obtained from the Depository of Unpublished Data, CISTI,

TABLE 1. REPRESENTATIVE ELECTRON MICROPROBE ANALYSES OF RENZY LAKE AMPHIBOLES

	1	2	3	4	5	6
SiO_2	47.5	54.8	52.4	54.5	51.5	54.7
TiO_2	0.5	0.2	0.2	0.0	0.1	0.0
Al_2O_3	9.4	3.5	4.5	2.5	4.4	0.3
FeO	6.6	4.1	5.3	4.7	13.1	20.4
MnO	0.1	0.1	0.2	0.2	0.5	1.1
MgO	18.2	21.5	20.6	21.3	16.6	19.7
CaO	13.0	12.8	12.9	12.7	10.2	0.9
Na_2O	2.0	0.6	1.2	0.6	0.9	0.0
K_2O	0.5	0.1	0.2	0.2	0.2	0.0
	97.8	97.7	97.5	96.7	97.5	97.1
recalculated on basis of 23 oxygen						
Si	6.74	7.59	7.34	7.64	7.45	7.90
Al	1.26	0.41	0.64	0.36	0.55	0.10
	8.00	8.00	8.00	8.00	8.00	8.00
Al	0.31	0.16	0.07	0.06	0.21	0.00
Ti	0.05	0.02	0.02	0.00	0.01	0.00
Fe^{3+}	0.21*	0.03*	0.20*	0.08*	0.04*	0.04*
Mg	3.86	4.44	4.30	4.46	3.57	4.23
Fe^{2+}	0.57	0.45	0.45	0.47	1.54	2.42
Mn	0.01	0.01	0.02	0.02	0.06	0.27
	5.01	5.11	5.06	5.09	5.43	6.96
Ca	1.98	1.90	1.94	1.91	1.58	0.14
Na	0.54	0.17	0.31	0.17	0.25	0.00
K	0.09	0.02	0.04	0.04	0.04	0.00
	2.61	2.09	2.29	2.12	1.87	0.14

1. zone ia hornblende (15264)
2. zone ia tremolite (15264)
3. zone ib tremolitic hornblende (PT794F)
4. assemblage two, zone iv tremolite (PT794E)
5. assemblage one, zone iv actinolitic hornblende (15279)
6. assemblage one, zone iv cummingtonite (15279)

* Fe^{3+} calculated by procedure of Papike *et al.* (1974)

National Research Council of Canada, Ottawa, Ontario K1A 0S2. Analytical procedures and specifications are similar to those reported in Fleet & Barnett (1978). Both the spatial distribution and chemical composition of the amphiboles are consistent with progressive reaction between hornblende peridotite and paragneiss under granulite-facies conditions. The amphibole of zone *iv* is tremolite in zone assemblage two, where it is remote from the paragneiss, but is a more iron-rich actinolitic hornblende in zone assemblage one, where it is closer to the paragneiss. Also, in zone assemblage two, reaction with the high-temperature (and presumably K-bearing) fluids converted the hornblende of zone *ia* to an Al-depleted tremolitic hornblende plus phlogopite in zone *ib*.

In addition to their characteristic amphiboles, both zone *ia* and *iv* contain a sporadically distributed second amphibole phase, tremolite in zone *ia* and cummingtonite in zone *iv*. In the following sections, the hornblende and tremolite of zone *ia* and the actinolitic hornblende (or tremolite) and cummingtonite of zone *iv* are referred to as "coexisting" amphiboles. However, this does not imply that either amphibole assemblage was formed under equilibrium conditions. Amphibole nomenclature in the present study follows the system of Leake (1978).

Coexisting Amphibole Assemblages

Hornblende and tremolite

Tremolite occurs as continuous and discontinuous rims and marginal patches on hornblende grains and subgrains (Fig. 4). In plane-polarized light, there is sufficient contrast between the colorless tremolite and pale green hornblende to impart a blotchy appearance to many

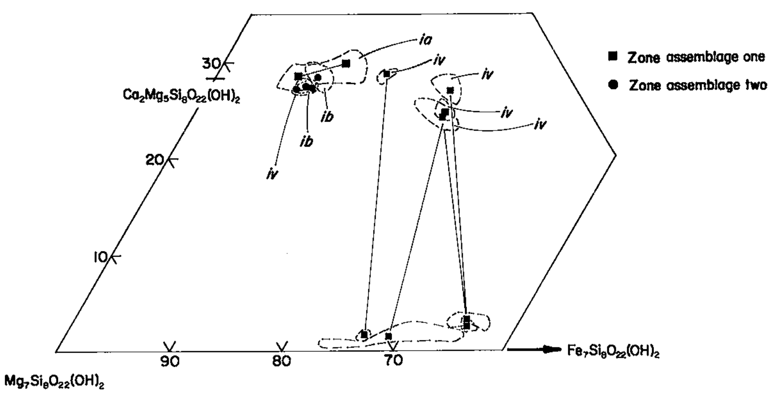

FIG. 2. Results of electron-microprobe analyses of Renzy Lake amphiboles projected onto part of the amphibole quadrilateral. Broken lines indicate composition fields; symbols in italics refer to mineral zoning illustrated in Figure 1 and in text; compositions are in mol. %.

thin sections. Although the two phases are in virtual optical continuity, the higher birefringence of tremolite ensures a distinct and colorful contrast between them with crossed nicols. The boundary between the hornblende and tremolite areas of individual grains and subgrains is generally smooth and well rounded; in appropriately oriented grains, it is marked by a distinct Becke line. The relative proportion of tremolite to hornblende varies markedly both with sample location, from approximately 5 to 25% tremolite, and from grain to grain within individual thin sections. Results of a representative electron-microprobe analysis of zone *ia* tremolite are included in Table 1, and additional data on coexisting hornblende–tremolite compositions are given in Figures 2 and 3.

Actinolitic hornblende and cummingtonite

Cummingtonite has been observed only in association with the characteristic zone *iv* amphiboles. It occurs as rims and marginal patches on actinolitic hornblende and tremolite grains, as lamellae within actinolitic hornblende grains and as overgrowths on actinolitic hornblende grains. Cummingtonite is readily distinguished from zone *iv* actinolitic hornblende on the basis of its colorless appearance in plane-polarized light, its higher birefringence and characteristic twinning.

The rims and marginal patches of cummingtonite are not restricted by grain boundaries, as is generally the case for the association of tremolite with hornblende. Rather, in plane-polarized light, cummingtonite patches resemble "bleached" regions, within massive actinolitic hornblende, that cross-cut grain boundaries. The boundary between cummingtonite rims and

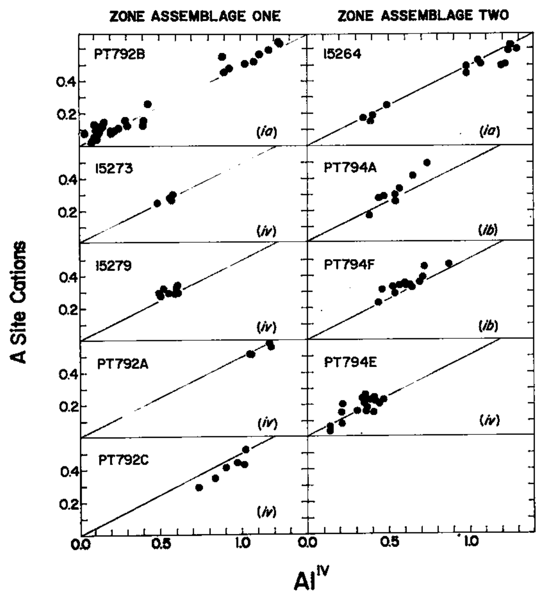

FIG. 3. Variation of total *A*-site cations with Al^{iv} cations for selected Renzy Lake assemblages; symbols in italics refer to mineral zoning illustrated in Figure 1 and in text.

patches and actinolitic hornblende is variously smooth, ragged or step-like (Fig. 5b). Ragged, island-like inclusions of actinolitic hornblende occur in cummingtonite adjacent to ragged boundaries, and lozenge-shaped inclusions occur adjacent to step-like boundaries (Fig. 5a). Stepped boundaries are associated with and partly defined by (101) lamellae of cummingtonite in the adjacent actinolitic hornblende phase (Fig. 5a, b). Patches of cummingtonite are also localized along fractures that transect some actinolitic hornblende grains, displacing the

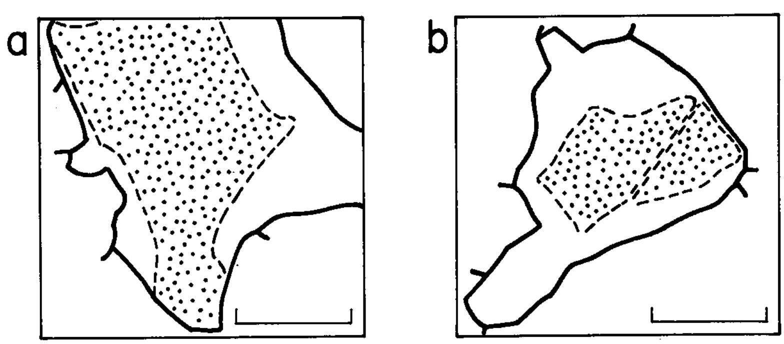

FIG. 4. Tremolite (clear) as rims and marginal patches on hornblende grains (heavy boundary) and subgrains. Relict hornblende is stippled; scale bar is 0.2 mm.

($\bar{1}01$) lamellae. These patches tend to spread laterally between pairs of ($\bar{1}01$) lamellae.

Three distinct sets of cummingtonite lamellae are observed, sporadically distributed in actinolitic hornblende; these are (1) coarse ($\bar{1}01$) lamellae, (2) fine (100) lamellae, and (3) fine ($\bar{1}01$) lamellae. Coarse (0.02–0.005 mm) ($\bar{1}01$) lamellae occur in sets of several individuals sporadically distributed within individual grains (Fig. 5a, b, c, d). They consistently originate at grain boundaries or at the boundaries of cummingtonite patches and commonly extend across the grains. Fine (100) lamellae tend to be evenly distributed within individual grains and to extend continuously from grain boundary to grain boundary, except where they are interrupted by coarse ($\bar{1}01$) lamellae (Fig. 5d). The fine ($\bar{1}01$) lamellae are relatively short and

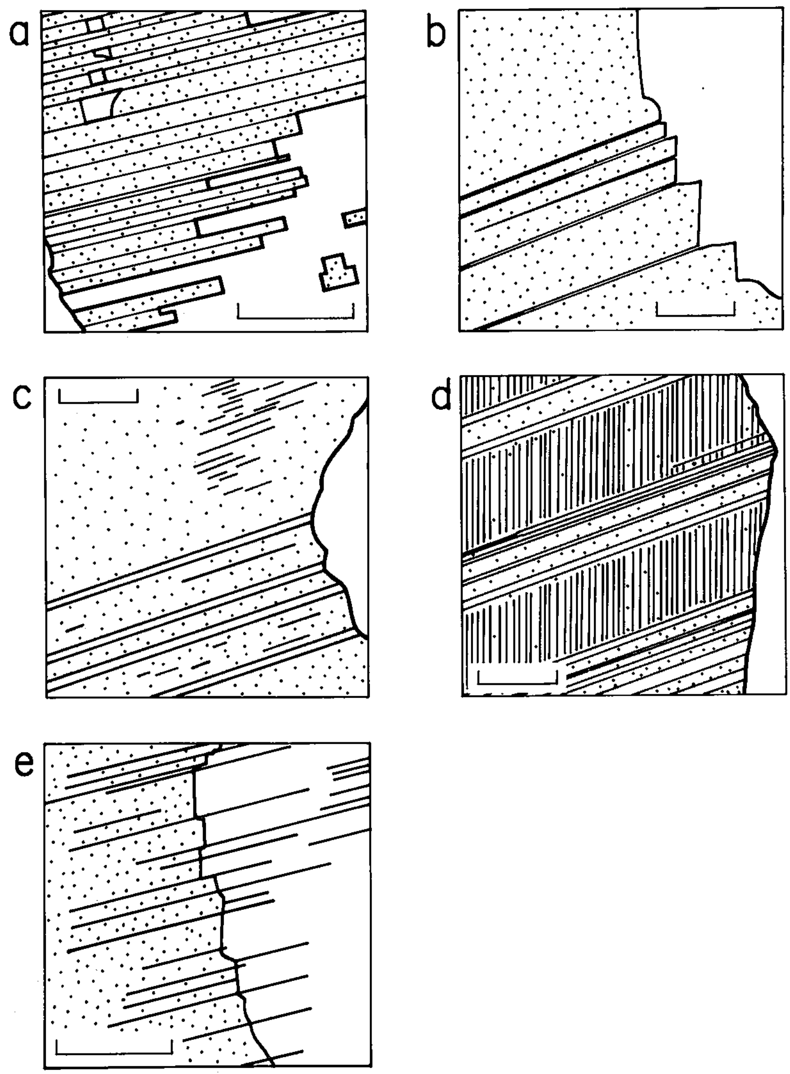

FIG. 5. Marginal patches and lamellae of cummingtonite (clear) in actinolitic hornblende. Relict actinolitic hornblende is stippled; Z axis is vertical; (100) cummingtonite lamellae in (*d*) are vertical; ($\bar{1}01$) cummingtonite lamellae and ($\bar{1}01$) actinolitic hornblende lamellae in (e) are inclined. In (a) and (e), the scale bar is 0.2 mm; in (b), (c) and (d), the scale bar is 0.05 mm.

located away from grain boundaries in clusters (Fig. 5c) that sometimes coalesce to resemble ragged inclusions of cummingtonite within actinolitic hornblende. As is expected from previous studies on lamellar and rod-like inclusions in chain silicates (Robinson *et al.* 1971, 1977, Fleet *et al.* 1980), all three sets of lamellae are actually inclined to the crystallographic planes that characterize them. Furthermore, the fine ($\bar{1}01$) lamellae are inclined at a larger angle to the *Z*-axis direction than the coarse ($\bar{1}01$) lamellae (110 and 106°, respectively), which seems to imply that they are a later and lower-temperature product (Robinson *et al.* 1977). A few ($\bar{1}01$) lamellae of actinolitic hornblende are present in cummingtonite patches. These are invariably related spatially and generally continuous with coarse ($\bar{1}01$) lamellae of cummingtonite (Fig. 5e).

Cummingtonite also occurs in certain rocks as overgrowths (or *Z*-axis extensions) of blade-like actinolitic hornblende grains. The contacts between the two phases are extremely penetrative, but are not extended as (100) lamellae of cummingtonite in actinolitic hornblende.

As in hornblende–tremolite assemblages, the relative proportions of the two coexisting amphiboles vary markedly both with sample location, from approximately 5 to 50% cummingtonite, and from grain to grain within individual thin sections.

Discussion

Calcic amphiboles

The compositional variation of Renzy Lake calcic amphiboles within the amphibole quadrilateral (Fig. 2) is consistent with progressive metasomatic reaction between hornblende peridotite and paragneiss. The relative Mg-enrichment of the Al-poor calcic amphiboles of zone assemblage two is probably related to the preferential incorporation of Fe^{2+} in aluminous calcic amphiboles (Fleet & Barnett 1978).

The chemical compositions of zone *ia* tremolite and zone *ib* tremolitic hornblende in zone assemblage two are virtually identical; there seems to be no basis for assuming that they were formed by *separate* metamorphic (metasomatic) processes. The presence of bronzite in the reaction zones suggests that metasomatism occurred under granulite-facies conditions. Hence, all of the Renzy Lake calcic amphiboles seem to be granulite-facies products. The textural relationships of zone *ia* amphiboles indicate positively that the tremolite phase developed by metasomatic replacement of pre-existing hornblende. As the tremolite replacement follows subgrain as well as grain boundaries, it seems that the hornblende had already been deformed and metamorphosed to granulite-facies conditions *before* metasomatism occurred. Thus the Renzy Lake ultramafic rocks may have been subjected to two separate granulite-facies events. Alternatively, metasomatism may have been broadly contemporaneous with the deformation and metamorphism of the zone *ia* hornblende, and may simply have developed transgressively.

The granulite-facies metasomatism was expressed principally in the development of the mineral zones, the recrystallization of hornblende adjacent to zone *ii* bronzite and, further inward, the replacement of the hornblende matrix by zone *ib* tremolitic hornblende. Calcic amphibole composition was controlled very largely by the local availability of Al, and this in turn appears to have been regulated by the diffusion of K from the enclosing paragneiss. Metasomatism of the amphiboles may be represented by the schematic reaction hornblende + K + $H_2O \rightarrow$ tremolitic hornblende + phlogopite. Inward from zone *ib*, metasomatism continued by diffusion of fluids along fine fractures and finally along grain and subgrain boundaries to produce the hornblende–tremolite assemblage of zone *ia*.

Coexisting hornblende and tremolite

Taken collectively, the results of electron-microprobe spot analyses of Renzy Lake calcic amphiboles (Fig. 3) do appear to document a continuous compositional variation in the series tremolite (actinolite), tremolitic (actinolitic) hornblende, hornblende. This would seem to support the generally subscribed hypothesis that the solid solution of tetrahedrally and octahedrally coordinated aluminum in calcic amphiboles is continuous above lower-amphibolite facies (Misch & Rice 1975, Immega & Klein 1976).

However, the zone *ia* amphibole assemblage, which logically seems to have developed above lower-amphibolite facies, exhibits a well-defined hiatus in composition (Fig. 3). This observation appears to contradict the solvus interpretation for the coexistence of tremolite and hornblende in lower-amphibolite-facies rocks. Alternative explanations, (1) that as zone *ia* tremolite and hornblende are out of equilibrium, this compositional hiatus has no bearing on the existence of a solvus, and (2) that the critical temperature of the solvus is higher in Mg-rich calcic amphiboles, appear less plausible.

Our data on calcic amphiboles tend to support the suspicions of Grapes & Graham (1978) that two-phase calcic amphiboles in lower-amphibolite-facies rocks are not coexisting in equilibrium. However, one aspect of the coupled reaction mechanism proposed by Grapes & Graham to explain the coexistence of actinolite and hornblende seems obscure. During the prograde transition from greenschist to amphibolite facies, the production of a more calcic plagioclase consumes Al and should not by itself cause the Al content of the amphibole to increase abruptly. The change in composition of both plagioclase and amphibole simply occurs in response to the final breakdown of epidote and chlorite. Hornblende develops by the replacement and overgrowth of pre-existing tremolite; as in zone *ia* of the Renzy Lake ultramafic body, there was insufficient thermal energy available to recrystallize and homogenize the entire amphibole assemblage. Hornblende–actinolite assemblages seem completely analogous to the blue-green ferrotschermakitic hornblende – green ferrohornblende assemblage in metamorphosed quartz diorite from the Frood mine, Sudbury, Ontario (Fleet & Barnett 1978).

In conclusion, it is emphasized that the present concept and the existence of a calcic amphibole solvus under lower-amphibolite-facies conditions are not mutually exclusive. We simply state that natural coexisting hornblende and actinolite were apparently not in good chemical communication at the time the second phase developed, and that they are not the products of simultaneous crystallization or recrystallization. Final resolution of the question of the calcic amphibole miscibility gap will depend on the incontrovertible establishment of equilibrium in two-phase assemblages.

Coexisting actinolitic hornblende and cummingtonite

The textural relations of the rims and marginal patches of cummingtonite on actinolitic hornblende grains can be rationalized most satisfactorily by proposing an origin by metasomatic replacement. Particularly persuasive pieces of evidence are (1) the step-like actinolitic hornblende–cummingtonite boundaries, which apparently indicate that replacement by cummingtonite was controlled by pre-existing coarse ($\bar{1}01$) lamellae, (2) the ragged and lozenge-shaped inclusions of actinolitic hornblende in cummingtonite, which we interpret as relict areas, (3) the localization of cummingtonite along fractures in actinolitic hornblende grains, and (4) the marked grain-to-grain and sample-to-sample variation in the proportion of cummingtonite present. This textural evidence is supported by a nonsystematic relationship between the chemistry of the coexisting amphiboles in certain rocks; for example, cummingtonite in 15273 exhibits a very wide variation in *mg* number (Fig. 2).

The cummingtonite replacement documents a hydrothermal or metasomatic event after granulite-facies metamorphism of the Renzy Lake rocks. Whether this event was retrograde, suggesting continuous fluid circulation with decrease in pressure and temperature, or prograde, with subsequent reactivation of the metasomatic system, is uncertain.

Recognition that the rims and marginal patches of cummingtonite are replacement textures brings into question the origin of the cummingtonite lamellae. Most previous investigators have assumed that cummingtonite lamellae in calcic amphiboles are formed through exsolution from pre-existing homogeneous solid solutions. However, lamellar morphology should not be assumed to be synonymous with exsolution processes, as lamellar and linear inclusions may also form through replacement or reaction (*e.g.*, Smith 1974, chapter 19; Fleet *et al.* 1980). Replacement processes do not necessarily result in ragged or irregular interfaces. There is a prominent structural control on reactions within chain silicate grains, which is well illustrated in recent elegant studies on biopyribole assemblages (Veblen & Buseck 1980, Nakajima & Ribbe 1980).

The characteristics of the coarse ($\bar{1}01$) lamellae of cummingtonite in zone *iv* actinolitic hornblende are more consistent with replacement than exsolution. The lamellae are sporadically and unevenly distributed, and consistently originate at grain boundaries or at the boundaries of cummingtonite patches. On the basis of the evidence available, the fine ($\bar{1}01$) lamellae appear to be a product of exsolution. The origin of the fine (100) lamellae is uncertain, although the regularity of their spacing (wavelength) would seem to be consistent with phase separation through unmixing.

In summary, then, cummingtonite in Renzy Lake rocks postdated crystallization of the coexisting calcic amphiboles. Cummingtonite developed largely by metasomatic replacement and possibly by homoaxial overgrowths of pre-existing actinolitic hornblende.

ACKNOWLEDGEMENTS

This study was supported by a Natural Sciences and Engineering Research Council of Canada operating grant to M.E. Fleet. We thank R.A. Stewart for drafting Figures 1 to 3 and acknowledge the helpful comments by Associate Editor A.C. Turnock and two referees.

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Received February 1981, revised manuscript accepted March 1981.