MONTICELLITE-CLINTONITE BEARING ASSEMBLAGES AT THE SOUTHERN BORDER OF THE ADAMELLO-MASSIF

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Abstract. — Some lenses of marly dolomites are localized in the contact zone between gabbroic cumulates and the intermediate intrusions of the Re di Castello Pluton at the southern border of the Tertiary, calcalkaline Adamello Massif. The following mineral assemblages formed in these lenses as a result of a high temperature contact metamorphism: monticellite-forsterite-clintonite (near the contact with the gabbroic cumulates) and forsterite-diopside-clintonite (away from the contact).

A later intrusion of intermediate plutonic rocks locally produced retrograde overprinting with the formation of chlorite and serpentine, as well as the breakdown of monticellite. Calculated phase diagrams show that the first contact metamorphism took place under monticellite facies conditions and a high value of X_{CO_2} in the fluid. The second phase, on the contrary, took place at about 550° C and a low value of X_{CO_2}.

In the case of coexistence of monticellite and forsterite grains, the substitution of forsterite in the structure of monticellite and vice versa has been used as a geothermometer. Chemical profiles through monticellite and forsterite grains show homogeneous distribution patterns for a temperature around 850° C in cases where no retrograde overprinting is obvious. Assemblages affected by retrograde overprinting result in a division of the temperature distribution pattern into the cores of the grains with temperatures between 800 and 900° C and into a border zone with = 550-650° C.

These two metamorphic events in the same carbonate rocks suggest that the gabbroic cumulates, as well as the intermediate intrusions, have crystallized in situ at a very shallow crustal level (max. overburden 2 km).

Riassunto. — Nella zona di contatto tra i cumulati gabbrici e le intrusioni intermediarie del plutone di Re di Castello al bordo meridionale dell'Adamello appaiono lenti di dolomia argillosa. In queste ultime, come conseguenza del metamorfismo di contatto di alto grado dovuto all'intrusione dei gabbri, si formarono le seguenti paragenesi: monticellite-forsterite-clintonite (xanthofillite) (vicino al contatto) e forsterite-diopside-clintonite (lontano dal contatto).

Una seguente intrusione di rocce intermediarie porta localmente ad una metamorfosi retrograda sovrapposta con formazione di clorite e serpentino, così come il « breakdown » della monticellite. Diagrammi di fase calcolati mostrano che la prima metamorfosi di contatto si sia svolta ad un valore di X_{CO_2} alto e ad alte temperature.

La seconda fase raggiunse invece circa 550° C con un valore di X_{CO_2} basso.

Nel caso di coesistenza tra forsterite e monticellite, si può usare la sostituzione della forsterite nella struttura della monticellite e viceversa, come misura della temperatura. Profili di temperatura misurati in grani di monticellite e forsterite nelle paragenesi che non hanno subito una metamorfosi retrograda, mostrano una distribuzione omogenea con temperature che si aggirano tra gli 850 e i 900° C. Nelle paragenesi marcate da metamorfosi retrograda le misurazioni diedero una divisione della temperatura in due parti. Un settore centrale con temperature di 800-900° C e un bordo di 550-650° C.

Questi due differenti metamorfismi negli stessi carbonati dimostrano che sia i cumulati gabbrici così come le intrusioni intermediarie cristallizzarono in situ in un livello crostale molto alto (copertura massima 2 km).

1. Introduction

In the Lago della Vacca area, at the southern border of the Tertiary, southern Alpine, calcalkaline Adamello intrusion (Alpi Bresciane, Northern Italy) occur some lenses of high temperature contact metamorphic, siliceous, argillitic marbles. The area lies within the Re di Castello Pluton, the southernmost intrusion of the Adamello massif, which intruded the southern Alpine basement and the Permian and Lower to Middle Triassic sedimentary pile 47 to 40 m.y. ago.

The igneous rocks in this area have been studied and described by different authors (e.g. G.B. Dal Piaz, A. Bianchi, E. Cal-

Fig. 1. — Geological map of the Lago della Vacca area at the southern border of the Adamello massif (Re di Castello Pluton).

LEGARI, D. COLBERTALDO, R. MALARODA).

In the western and northern part of the studied area the rocks mainly consist of intermediate plutonic rocks with the local name Re di Castello-Tonalite (fig. 1). The tonalite corresponds to a fine- to medium-grained biotite-hornblende tonalite with a large number of femic, endogenic xenoliths. The tonalites are internally heterogeneous and show transition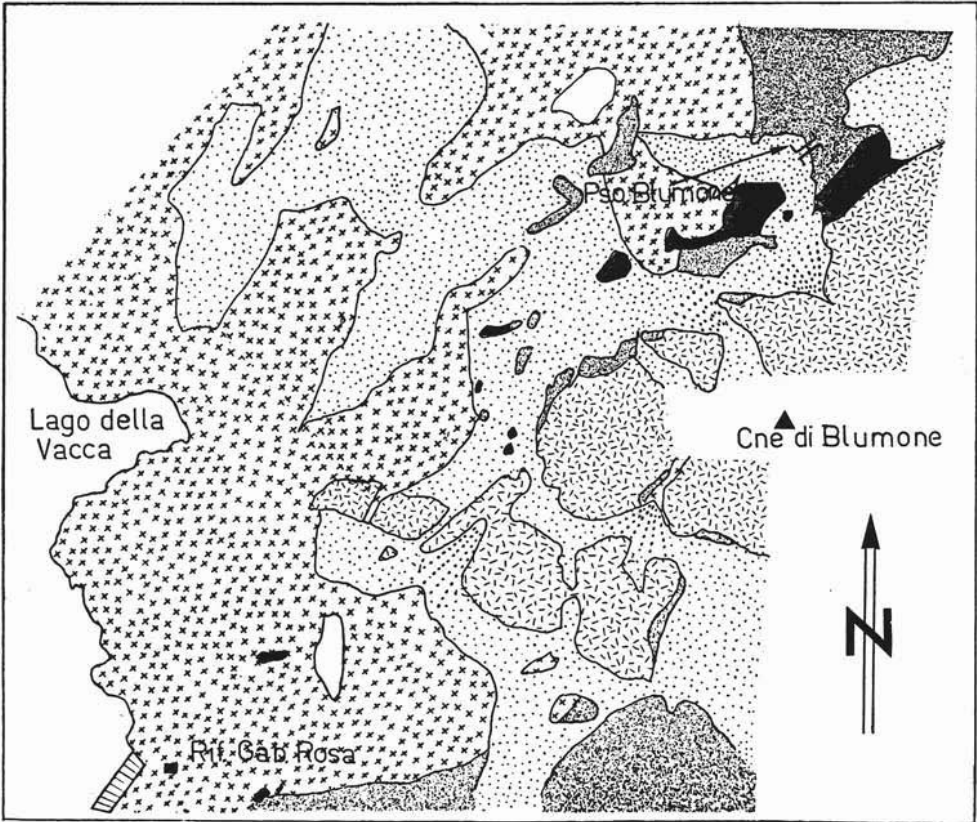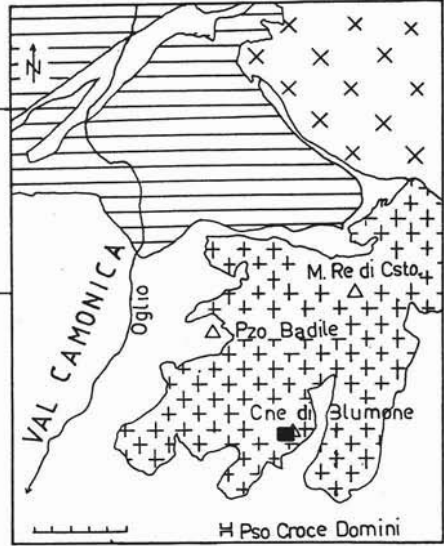s to diorites along fluidally oriented zones (e.g. near the Rifugio Gabriella Rosa). Lenses of gabbroic rocks (cumulates) or clusters of hornblende and plagioclase crystals with clear affinities to the nearby cumulates of the Cornone di Blumone are locally concentrated along more or less straight zones.

The eastern part of. the area is composed of gabbroic rocks of the Cornone di Blumone. This complex mainly consists of coarse-grained titanomagnetite-clinopyroxene-hornblende-plagioclase (An 80-90)-gabbros which display cumulate structures. Olivine-chromiferous spinel-cpx-opx-hbl-cumulates occur at the base of this complex or isolated in the tonalites. The whole complex has been affected by a post-accumulation event of brecciation and hornblenditisation which has also produced pegmatitic dikes consisting of enormous hornblende and plagioclase crystals. The cumulates are clearly older than the tonalites as indicated by stopping phenomena at the contact as well as intrusion into the cumulates from the side and below. In addition, the tonalites cross-cut the mafic complex in large dikes.

The sedimentary carbonate lenses are localized in the northeastern part near Passo Blumone between the cumulates and the tonalites. To the southwest, the more or less straight zone of lenses intersects the tonalites and are accompanied by cumulate lenses and the so-called « diorite a tozze » containing quadratic hornblende. These diorites contain abundant hornblende and plagioclase crystals coming from the cumulates. The southern part of the sedimentary lenses seems to follow the old contact with the cumulates. However, these cumulates are broken up and have been intruded by the tonalites, resulting in « diorite a tozze » and some lenses of less affected cumulates. The sedimentary carbonate lenses have dimensions ranging from a few dm to 300 m long at the Passo Blumone.

In this large lens, an old sedimentary layering can be observed. Layers consisting of clinopyroxene and clintonite, partially with boudinage structures, alternate with forsterite-monticellite layers, each approximately 5 cm thick. This layering corresponds to primary argillitic and dolomitic layers. A 5 m thick layer of Predazzite (calcite-brucite rock), corresponding to a dolomite, is found at the Passo Blumone. D. COLBERTALDO and R. MALARODA have placed these rocks in the Lower Anisian (Formazione di Angolo inferiore). However, in the author's opinion due to total overprinting of the primary mineral assemblages and the lack of fossils or direct contact to the sediments in the Alta Valle del Caffaro (R. MALARODA, 1955; U. ROESLI and P. ULMER, 1982) no definite age can be determined. Based on lithological aspects, both Lower Anisian and Lower Ladinian (Form. di Livinalongolo) or Upper Anisian to Lower Carnian (Form. di Esino s.l.) ages can be postulated.

2. Some mineralogical aspects

The mineral determinations have been made by thin section observations, XRD and electron microprobe analyses of the mineral species.

The following minerals have been found:

1. *Fassaitic pyroxene* (diopside series)
2. *Olivine* (forsterite content 92-95 %)
3. *Calcite*
4. *Herzynitic spinel*
5. *Chlorite* (clinochlore composition)
6. *Andraditic garnet* (always accompaning monticellite as an inclusion)
7. *Clintonite or xanthophyllite*

Clintonite was discovered and has already been described from this area and from nearby (Costone di Valbona) by A. BIANCHI, O. HIEKE and E. SANERO (1940, 45, 46). Clintonite is a green, calcium brittle mica with a phlogopite structure (trioctahedral) with the approximate formula $Ca(Mg,Al)_3(Al,Si)_4O_{10}(OH)_2$. Clintonite is a relatively rare mineral. This is more the consequence of the specific bulk composition

of the rock which permits the formation of this mica rather than thermodynamic conditions, as clintonite has a large stability field (J. RICE, 1979, and this work). Clintonite will only be formed if enough magnesium, calcium and alumina is available and only a minimal amount of potassium is present, otherwise the formation of phlogopite would be preferred. These conditions are fulfilled by an argillitic dolomite with kaolinitic or montmorillonitic clay minerals instead of illitic clay.
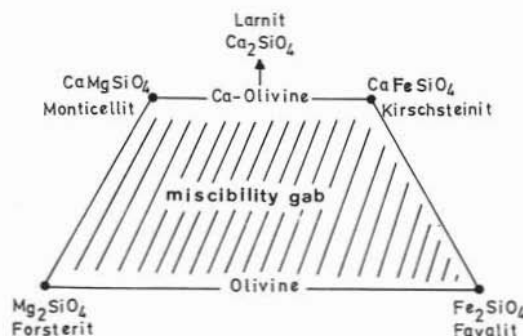

Fig. 2. — Composition diagram of the olivines and Ca-olivines in the system Mg_2SiO_4-Fe_2SiO_4-Ca_2SiO_4.

8. Monticellite

As yet this mineral has not been described from the Adamello aureole. Monticellite appears near the contact with the cumulates or in the middle of the lenses isolated in the tonalites. It forms only under high temperature, contact metamorphic conditions in carbonate rocks. Monticellite is an orthosilicate which has the same space group ($Pbnm$) as olivine and a similar structure to latter. The difference with olivine lies in the dimensions of the cation sites in the crystal lattice. Olivine has two similar sites for Mg and $Fe(II^+)$. Monticellite has a larger one for Ca and a smaller one for Mg and $Fe(II^+)$. This also explains why monticellite and olivine show a large miscibility gap (fig. 2).

R. WARNER and W. LUTH (1973) have experimentally investigated this miscibility gap. Their experiments were carried out from 1-10000 bar and 800-1400° C. Fig. 3 shows the experimental solvus for 2 kbars which is practically symmetric and attains a maximum
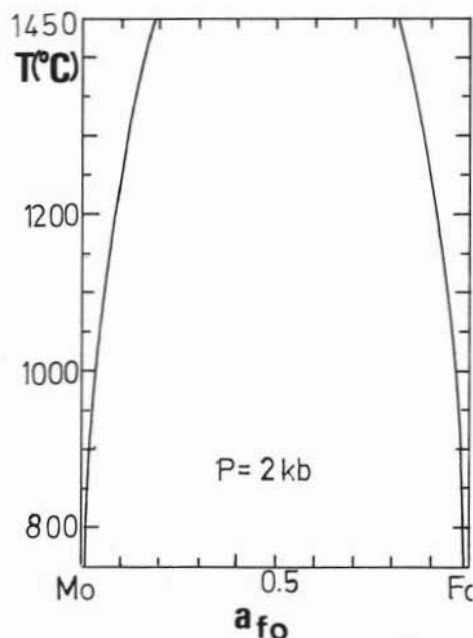

Fig. 3. — Experimental solvus between forsterite and monticellite at 2 kbars in a temperature versus activity (of forsterite)-diagram. (From R. WARNER and W. LUTH, 1972).

solubility of the components (forsterite and monticellite) of about 18 % between 1300 and 1400° C according to the existing pressure. In the constructed phase diagram (fig. 4), it can be seen that monticellite reacts to merwinite ($Ca_3Mg[SiO_2]_2$) and forsterite at 1320° C and 10 kbars. The solid solution behaviour of coexisting forsterite and monticellite can be used as a geothermometer (see chapter 4).

3. The parageneses

The mineral assemblages can be divided into two groups. One group shows one high temperature metamorphic event with a few water bearing minerals and is found near the contact with the gabbroic cumulates in the P.so Blumone area. A second group shows two different metamorphic events: an older one which corresponds to group one and is overprinted by H_2O bearing minerals of a second retrograde event. These rocks are localized in the isolated lenses in the tonalites and near the contact zone between tonalites and sediments.
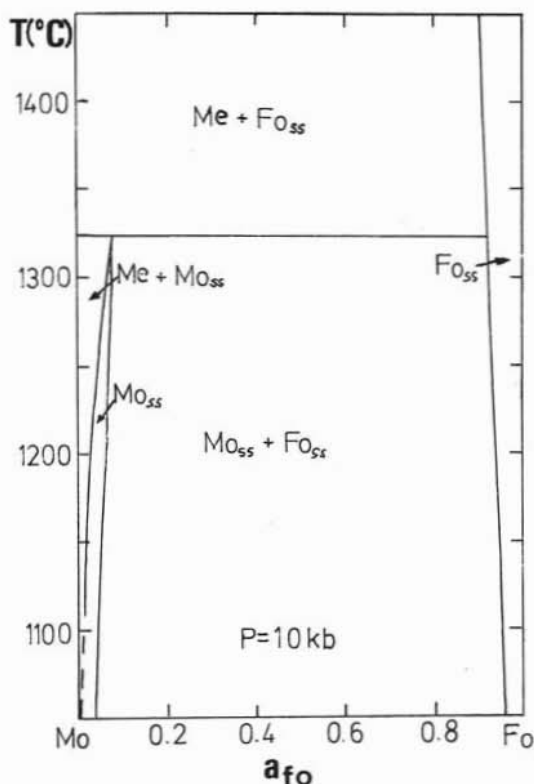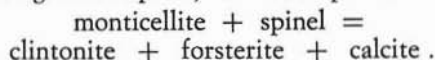
Fig. 4. — Phaserelationships in the system monticellite-forsterite at 10 kbars in a temperature-activity-diagram. (From R. WARNER and W. LUTH, 1972).

Fig. 5. — Micrograph of diopside free clintonite bearing monticellite rock from P.so Blumone. - Di = diopside, Mo = monticellite, Fo = forsterite, Chl = chlorite, Ct = clintonite, Sp = spinel.

GROUP 1

Monticellite, forsterite, calcite, clintonite, + diopside, + spinel

Fig. 5 shows a thin section of this rock. The spinel rims have been replaced by clintonite suggesting·that the following reaction, although incomplete, has taken place:

monticellite + spinel =
clintonite + forsterite + calcite .

In order for this interpretation to be correct the monticellite must have been formed before the clintonite. This is confirmed by the presence of monticellite inclusions in the forsterite grains. More commonly the opposite situation is observed: inclusions of forsterite and diopside and/or calcite are found in monticellite grains as relicts of the reaction:
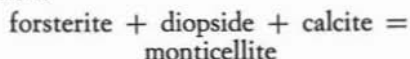
forsterite + diopside + calcite =
monticellite

corresponding to the formation of monticellite.

Diopside, forsterite, clintonite, calcite, + spinel

Away from the contact with the cumulates, in the same lens, one finds coexisting diopside, forsterite and calcite rather than monticellite. Fig. 6 shows another clintonite-bearing reaction:

spinel + diopside + calcite = clintonite.

In this rock no forsterite appears. However, in parageneses containing forsterite exactly the same reaction took place. This demonstrates, that neither forsterite nor chlorite is involved in this reaction, as suggested by J. RICE (1979). Forsterite and spinel coexist only if diopside is absent in the mineral assemblage.
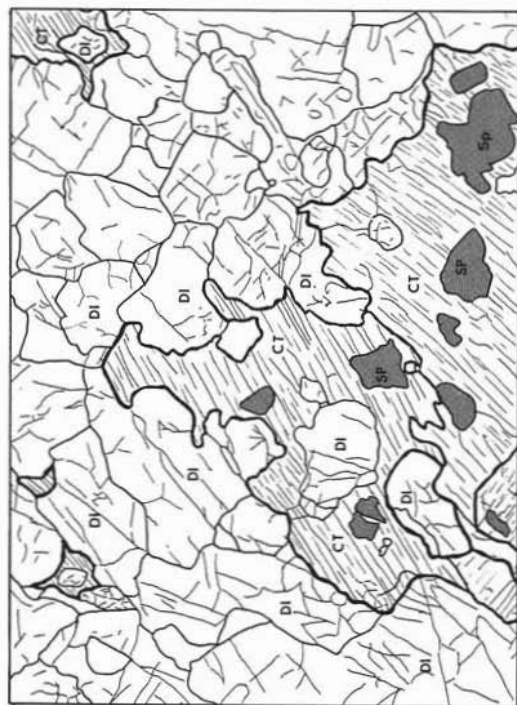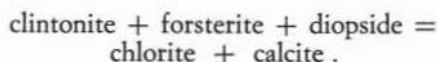
Fig. 6. — Micrograph from a monticellite-forsterite free clintonite bearing diopside rock from Pso Blumone.

GROUP 2

Chlorite, serpentine (on forsterite) and calcite have mainly been formed as retrograde assemblages.

Clintonite, diopside, forsterite, calcite, chlorite, + spinel

This rock sample is taken from the same lens as the those previously discussed along the contact with the tonalitic rocks. Fig. 7 shows the formation of chlorite and calcite by the breakdown of clintonite, forsterite and diopside after the reaction:

clintonite + forsterite + diopside = chlorite + calcite .

In the lower right, relicts of the clintonite forming reaction are preserved as inclusions of consumed spinels and diopsides in clintonite grains.

Monticellite, forsterite, clintonite, chlorite, calcite, + spinel

Fig. 7. — Micrograph from a monticellite free chlorite bearing rock from Pso Blumone.

This assemblage can be found in the isolated lenses in the tonalites. Diopside is no longer present after formation of monticellite, and chlorite has been formed by the breakdown of monticellite, forsterite and clintonite after the reaction:

clintonite + forsterite + monticellite = chlorite + calcite .
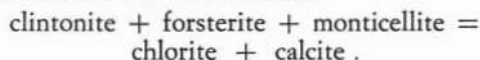
Monticellite, diopside, forsterite, calcite

Along veins in some monticellite rocks, at the P.so Blumone, the breakdown of monticellite to forsterite, diopside and calcite is observed. All these are retrograde and fluid-consuming reactions have not attained equilibrium, as the fluid must have been consumed before hand. Chlorite is not homogeneous under the microprobe and shows strong chemical gradients towards the bordering mineral species.

4. Geothermometry

When forsterite and monticellite coexist, the substitution of the forsterite component
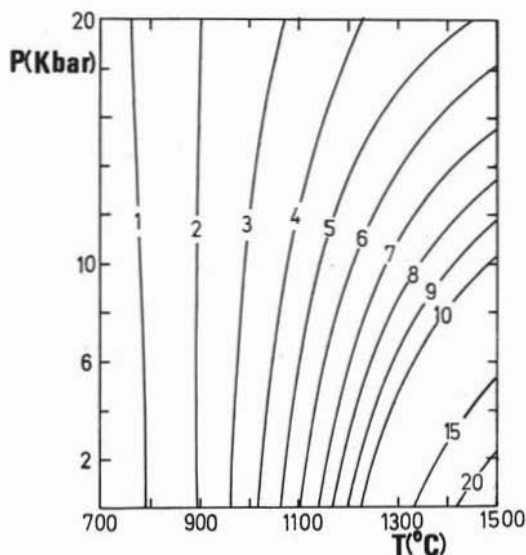
Fig. 8. — P-T diagram with isopleths of monticellite activity in forsterite. (From R. WARNER and W. LUTH, 1972).

in the monticellite structure and vice versa can be used as a measure of the temperature attained during the contact metamorphism. The experimental results from R. WARNER and W. LUTH (1972) have shown (fig. 8) that the activity of monticellite in the forsterite solid solution at temperatures lower than 1100° C is practically independent of the existing pressure, thus within this temperature field no assumption of the existing pressure must be made. Fig. 9 depicts the data points from experiments for 2000 bars plotted in a $-lnK$ (K = activity of one species in the structure of the other species) versus $1/T$ plot for both sides of the solvus. The extremely good linearity in the first case is a further argument for the use of this solid solution series as a geothermometer.

The equations of the straight lines transformed in terms of temperatures in centigrade are:

(a)

(b)
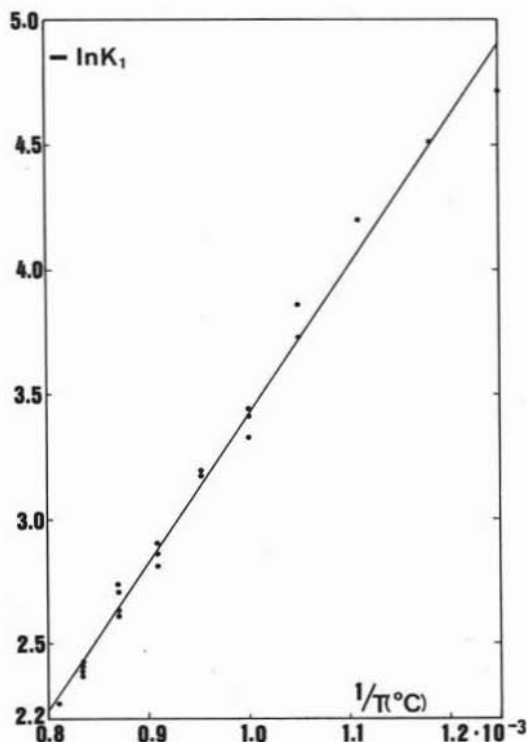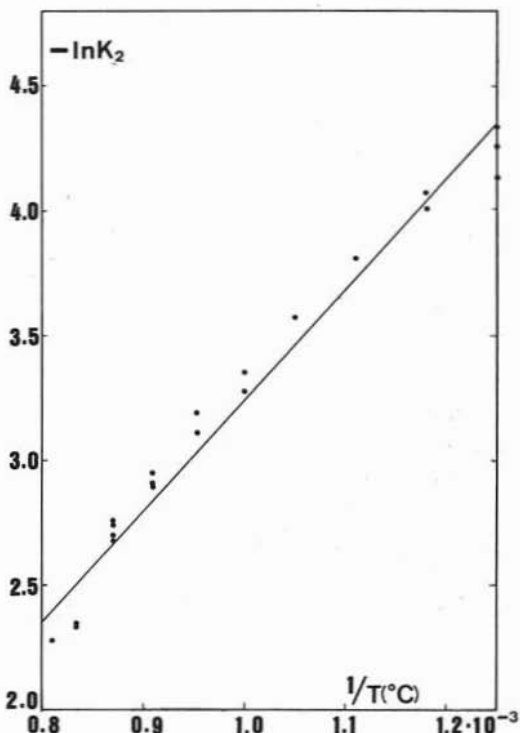
Fig. 9. — (a) lnK_1 versus $1/T$ plot for the experimental data at 2 kbars; lnK_1 = activity of monticellite in forsterite. - (b) lnK_2 versus $1/T$ plot for the experimental data at 2 kbars; lnK_2 = activity of forsterite in monticellite.
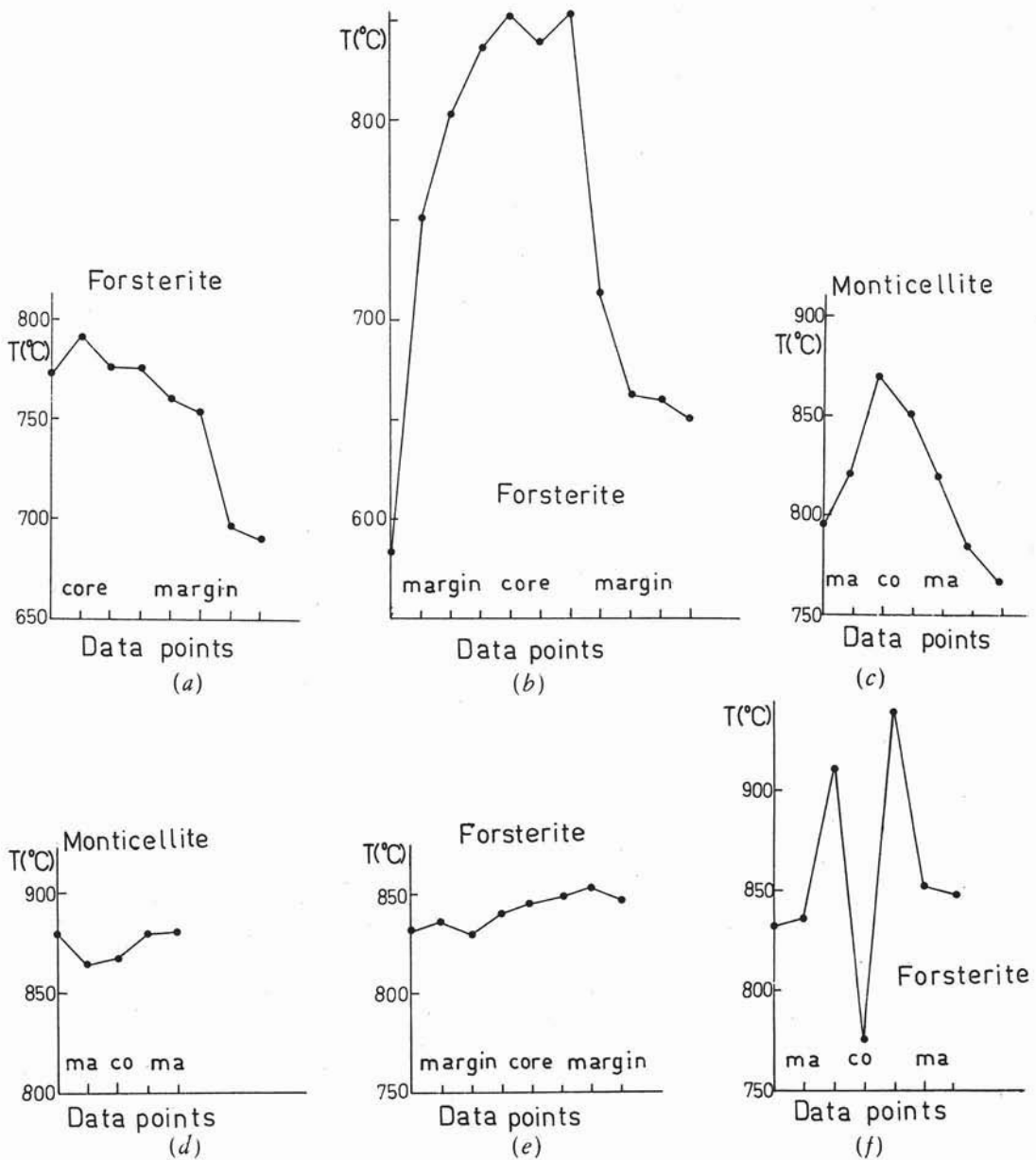
Fig. 10. — (a) Temperature profile through a forsterite grain. - (b) Temperature profile through a forsterite grain. - (c) Temperature profile through a monticellite grain. - (d) Temperature profile through a monticellite grain. - (e) Temperature profile through a forsterite grain. - (f) Temperature profile through grain 10 (e) with fine focussed electron beam.

$$(1) \qquad T(°C) = \frac{5587.87}{2.4659 - ln\,a_{fo}^{mo}}$$

$$(2) \qquad T(°C) = \frac{4429.16}{1.1791 - ln\,a_{mo}^{fo}}$$

Results

Some profiles have been made through forsterite and monticellite grains using an *ARL*-electron microprobe with wave- and energy-dispersive detection systems are presented in fig. 10 in terms of temperatures. They can be separated into two different groups:

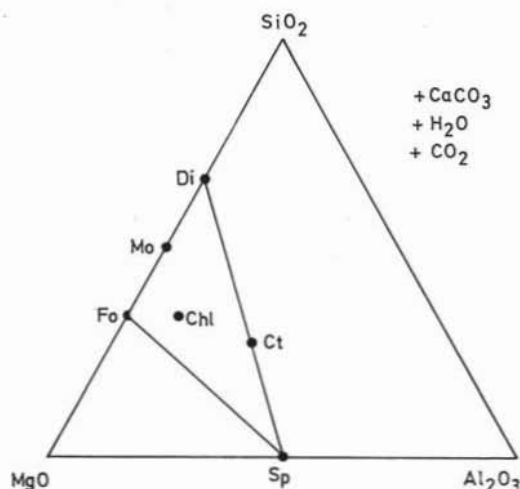Fig. 11. — SiO_2-MgO-Al$_2$O$_3$ diagram projected from calcite and fluid.

Fig. 12. — Solid solutions in clintonite and clino-pyroxene according to electron microprobe analysis in the system SiO_2-MgO-Al$_2$O$_3$.
Di = diopside, Mo = monticellite, Fo = forsterite, Chl = chlorite, Ct = clintonite, Sp = spinel.

10 (a), (b) and (c) represent profiles from rocks which have been affected by retrograde overprinting. These profiles show a core with temperatures between 800 and 900° C and a border zone with temperatures ranging from 550° to 650° C.

The profiles 10 (d) and (e) represent rocks without any visible overprinting of the primary assemblage and show a homogeneous temperature distribution pattern around 850° C.

Geothermometry confirms the observations from thin sections that two different metamorphic events have occurred, of which the second one has not affected all the rocks.

Fig. 10 (f) shows the same forsterite as 10 (e) but analysed with a fine focussed electron beam (1 μm). The homogeneous distribution pattern is lost in the central part of the grain. X-ray distribution patterns of Ca-Kα rays show that the central part of the forsterite has exolved calcium-rich lamellae. However they are too fine to determine exactly (monticellite?). Exolution is limited to the central part of the grain and is probably the result of cooling after formation at high temperatures, as it is known for clinopyroxenes (Diallag).

5. Phase relationships

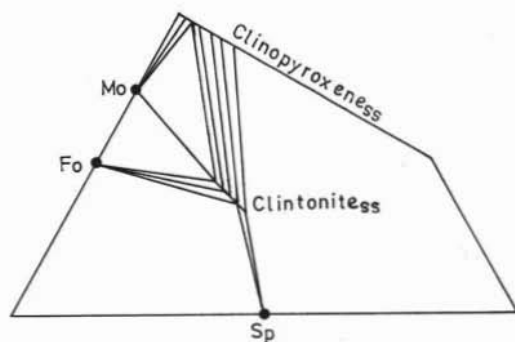In the literature only two studies one from J. RICE (1979) on the Boulder aureole and one from K. BUCHER (1976) on the Bergell aureole, have been published concerning clintonite-bearing marbles, however both without any monticellite occurrence. Therefore petrological studies on the phase relationships have been made here.

The following relevant phases have been chosen:

Forsterite, diopside, clintonite, monticellite, spinel, chlorite and calcite plus a H$_2$O-CO$_2$ fluid.

The best diagram for presentation is a SiO_2-Al$_2$O$_3$-MgO diagram projected from calcite and fluid (Fig. 11). This is an idealized diagram, showing only the magnesium end members. The minerals are presented as points neglecting tschermak exchange vectors in the phases.

A more realistic diagram is presented in fig. 12 based on electron microprobe analyses, but without chlorite. Clinopyroxene and clintonite show a strong dependence on the coexisting assemblage and vary in the direction of the tschermak exchange vector.

Magnesium endmembers have been used for the calculation of the reactions:

forsterite	Mg$_2$SiO$_4$
diopside	CaMgSiO$_6$
monticellite	CaMgSiO$_4$
spinel	MgAl$_2$O$_4$
chlorite	Mg$_5$Al$_2$Si$_3$O$_{10}$(OH)$_8$
	(clinochlore)

and clintonite has been set on the tieline diopside-spinel. According to electron microprobe analyses and thin section observations
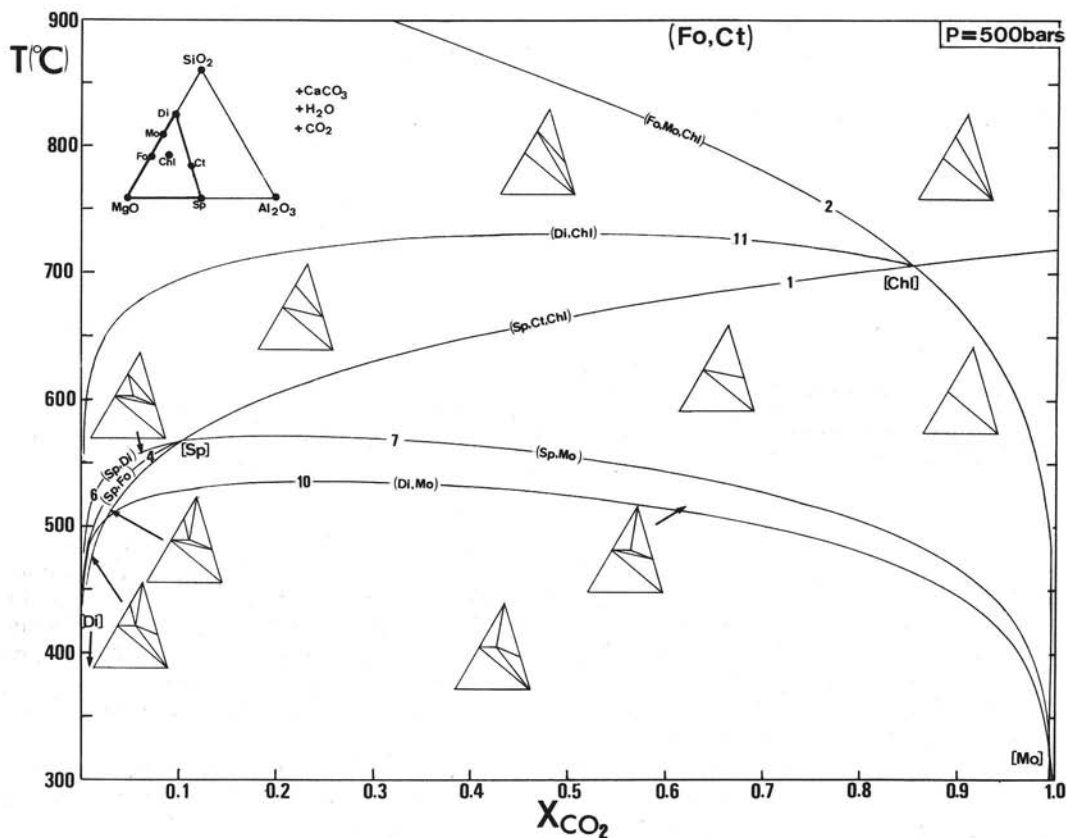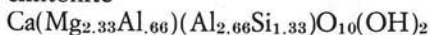
Fig. 13. — T-X_{CO_2} diagram at 500 bars for the system SiO_2-MgO-Al_2O_3-CaO-H_2O-CO_2 with the phases forsterite, diopside, monticellite, clintonite, chlorite, spinel, calcite, H_2O and CO_2.

(no forsterite or chlorite involved in the formation of clintonite) the composition is:

clintonite
$Ca(Mg_{2.33}Al_{.66})(Al_{2.66}Si_{1.33})O_{10}(OH)_2$

In this system (6 phases, 3 components) with two degenerations, 11 reactions can be calculated, Tab. 1). When available, thermodynamic data from HELGESON et al. (1978) have been used in the calculation of the stable T-X_{CO_2} sections. A new enthalpy value for chlorite was calculated from an experiment of T. WIDMARK (1980). Since no data are available for clintonite, the entropy and heat capacity terms have been estimated and the enthalpy is calculated from an experiment of G. HOSCHEK (1976). The pressure was fixed at 500 bars according to stratigraphic considerations (about 2 km of overburden at the time of intrusion).

Fig. 13 shows the stable T-X_{CO_2} section at

500 bars constructed after the method of H.W. DAY (1972) and checked in the temperature range from 350-800° C.

6. Discussion of the results in the T-X_{H_2O} diagram

The first high temperature contact metamorphism can be associated with certainty with the formation of the cumulates (temp. up to 900° C) which developed at extremely high X_{CO_2}, as indicated by the formation of monticellite before clintonite. This means that reaction 1 occurred before reaction 2. During this primary phase of metamorphism, an annealing texture of monticellite formed together with spinel grains. In a second phase, X_{CO_2} diminished. Large crystals of clintonite formed by consumption of monticellite and spinel. Clintonite was mainly formed by attaining reaction 11 in a monticellite-bearing assemblage. Diopside must have been con-

TABLE 1

Reactions and reactions parameters for the system SiO₂ - MgO - Al₂O₃ - CaO - H₂O - CO₂ with the phases

Reactions:

1. (Ct,Sp,Chl) : Fo + Di + 2Cc = 3Mo + 2CO₂

2. (Chl,Mo,Fo) : 2Di + 5Sp + Cc + 3H₂O = 3Ct + CO₂

3. (Fo,Di)   : 2Chl + 3Ct + 7Cc = 7Sp + 10Mo + 11H₂O + 7CO₂

4. (Fo,Sp)   : 5Chl + 7 Di + 21Cc = 25Mo + 3Ct + 17H₂O + 21CO₂

5. (Fo,Ct)   : Chl + Di + 4Cc = 5Mo + Sp + 4H₂O + 4CO₂

6. (Sp,Di)   : 5Chl + 7Cc = 7Fo + 4Mo + 3Ct + 17H₂O + 7CO₂

7. (Sp,Mo)   : 15Chl + 13Cc = 25Fo + 4Di + 9Ct + 51H₂O + 13Cc

8. (Ct,Di)   : Chl + 2Cc = Fo + 2Mo + Sp + 4H₂O + 2CO₂

9. (Ct,Mo)   : 3Chl + 2Cc = 5Fo + 3Sp + 2Di + 12H₂O + 2CO₂

10. (Di,Mo)   : 3Chl + 2Sp + 3Cc = 3Ct + 5Fo + 9H₂O + 3CO₂

11. (Di,Chl)   : 3Ct + 2Fo + 3Cc = 6Mo + 5Sp + 3H₂O + 3CO₂

equilibrium constants of the reactions:

No.	lineare dependence			equilib. constants			cₚ-coefficients		
	a	b	c	A	B	C	D	E	F
1	1	-	-	-11503	17.504	0.15317	-1.523	-.00101	186633
2	-	1	-	+13432	-15.132	-0.21967	-5.633	-.00456	171444
3	-	-	1	-94484	147.118	1.56700	-6.110	-.01326	705379
4	-	3.5	2.5	-189198	314.830	3.1487	-34.99	-.01718	2363502
5	-	0.5	0.5	-40526	65.993	0.67367	-5.871	-.00870	438412
6	-7	3.5	2.5	-108677	192.308	2.07647	-24.33	-.01008	1057071
7	-25	10.5	7.5	-280019	506.910	5.6167	-66.89	-.02619	2424679
8	-1	0.5	0.5	-29023	48.490	0.52050	-4.348	-.00333	251779
9	-5	1.5	1.5	-64063	110.461	1.25515	-9.998	-.00797	382070
10	-5	2.5	1.5	-50631	95.330	1.03548	-15.63	-.00341	553514
11	2	-1	-	-36438	50.139	0.52601	2.586	-.00659	201812

reactions 5 : (Fo,Ct) is metastable

$$\log K_n = a \log K_1 + b \log K_2 + c \log K_3 = \frac{A_n}{T} + \frac{B_n}{T} + \frac{C_n}{T} (P-1)$$

$$c_n = D_n - E_n T + F_n T^{-2}$$

Fo = forsterite, Di = diopside, Mo = monticellite, Ct = clintonite, Chl = chlorite, Sp = spinel, Cc = calcite, H₂O and CO₂.

sumed before forsterite and calcite during the formation of monticellite (reaction 1) and so reaction 2 could not take place. On the other hand when diopside is present reaction 2 has taken place and all the spinel was consumed or rimmed so that reaction 11 was blocked.

The rocks further away from the contact never attained reaction 1 and clintonite formed only by reaction 2 during the second phase. The change in the fluid composition could be the result of the total consumption of the carbonates so that the supply of CO_2 from the carbonates was diminished, or a H_2O rich fluid was intruded from outside. The second retrograde metamorphism took place at a low X_{CO_2} value and lower temperatures (around 550° C), which is reasonable for contact metamorphism initialized by an intermediate plutonic rock. The reactions were retrograde and fluid consuming, and

stopped before equilibrium could be attained. The equilibration of monticellite and forsterite at grain boundaries confirms the observations in the T-X_{CO_2} diagram, as far as monticellite is only stable at temperatures as low as 550° C, if the X_{CO_2} is < 0.1. The low value of the X_{CO_2} is on one hand the product of H_2O rich fluids coming from the tonalitic rocks which carry much more volatile components than gabbroic cumulates, and on the other hand the result of the total consumption of the carbonates during the first metamorphic event.

7. Conclusions

The sediments, originally consisting of marly dolomites, show two different metamorphic events with clear age differences and local and petrological association with the different plutonic masses. The first metamorphism took place progressively towards the contact with the gabbroic cumulates of the Cornone di Blumone and attained temperatures around 900° C at the contact, at a high X_{CO_2} value of the fluid involved.

The second metamorphism started from the tonalite intrusion near the contact and along veins, and resulted in a retrograde overprinting. The fluid composition was on the water-rich side and the temperature attained about 550° C which is typical for this tonalite contact metamorphism and has been confirmed by carbonate geothermometry made by U. ROESLI (1982) in the same region.

As a consequence, the tonalites of the Re di Castello, as well as the mafic-ultramafic cumulates of the Cornone di Blumone have crystallized in situ at a very shallow crustal level. In other words, the cumulates have not been dragged up from depth by the tonalite intrusion. The arguments are: the maximum depth for marly dolomites of this kind is 2 km at the time of intrusion (40 m.y. ago). The carbonates clearly show two different metamorphic events related to the surrounding plutonites. The cumulates had totally cooled down when the tonalites were intruded.

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