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**Autor:** Tex, E. den

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## Two ovardite occurrences in the Piemonte Ophiolite Nappe of the Cottian Alps (NW Italy) and their significance for the process of ovarditization\*

by E. den Tex<sup>1</sup>

### Abstract

A melange-type association of crossite-schist and ovardite, and a monomictic ovardite-breccia are described, both from localities near Usseaux in Val Chisone (Prov. Piemonte, Italy). It is attempted to strike a chemical balance for the ovarditization of the crossite schist with the aid of electron-microprobe analyses of (nearly) contiguous crossite-, chlorite- and albite grains. It is concluded that the system subject to this type of ovarditization was virtually closed (except for water), since actinolite, epidote/clinozoisite, titanite and phenigite may account for excess  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{\text{tot}}$ , and  $\text{Si}^{4+}$ , and for deficiency in  $\text{Al}^{3+}$ , over the balanced reaction-equation:  $2 \text{crossite} + 2 \text{aq.} \rightleftharpoons \text{chlorite} + 4 \text{albite}$ .

The breccia is interpreted to imply a two-phase ovarditization process: one during or before the latest penetrative deformation phase, and the other after the last brittle event of the Alpine orogeny, when the Dora Maira Massif received its final uplift.

*Keywords:* Ovardite, ophiolite, Piemonte, electron microprobe analyses, optical methods.

### Introduction

In the first Ph.D. thesis supervised by E. Niggli (DEN TEX, 1949/50) the influence of hydrothermal solutions on mafic rocks in the Belledonne Massif (French Alps) was part of the subject. For a contribution to this volume it seems appropriate to treat a similar problem in a related area.

Ovardite is a metabasic rock closely affiliated with the characteristically Alpine prasinite family as defined by KALKOWSKY (1886). The name ovardite was coined by STRUVER (1873) for rocks from Torre d'Ovarda in the Italian province of Piemonte. Its principal constituents are albite and chlorite, which may be accompanied by considerable amounts of calcite or quartz, and by a selection of minerals typical of the prasinite-, blueschist- and eclogite families. Their albite metablasts are char-

acteristically ovoid in shape and frequently poeciloblastic, enclosing all other constituents of the rock. Thus, ovardite genesis is generally held to be the latest metamorphic event in the Western Alps (NICOLAS, 1969; BEARTH, 1967; ELTER, 1971). On the other hand some ovarditic rocks and their constituent albites are clearly strained and they may exhibit a foliated or gneissose fabric, indicating that they were formed during or before the latest penetrative deformation phase ( $D_3$ , table 1) of the Alpine orogeny. A summary of the magmatic, metamorphic and tectonic history of the mafic rocks in this part of the western Alps is given in table 1.

As far as I am aware ovardites and ovarditic gneisses (sometimes referred to as albite-chlorite gneisses or "chloritoschistes feldspathiques") occur exclusively in the Mesozoic cover series of the internal Western Alps, spe-

\* Dedicated to Professor Ernst Niggli on the occasion of his 70th birthday.

<sup>1</sup> Rijksmuseum van Geologie en Mineralogie, Garenmarkt 1<sup>B</sup>, 2311 PG Leiden, Holland.

cifically in the calcareous schistes lustrés or "calcescisti" of Italian authors, and in the lower Casanna schists of Permocarboferous age in Val d'Hérens, Val d'Hérémence and Val de Bagnes in the St. Bernard Nappe of the Swiss canton Valais (VALLET, 1950). They are unanimously considered to be the metasomatic products of prasinites showing, as they do, all stages of transformation, but the process of ovarditization is variously attributed to fluids rich in CO<sub>2</sub> and H<sub>2</sub>O (NICOLAS, 1966), to reaction between prasinites and albitite veins (BEARTH, 1967), or to the presence of microsystems containing fluids rich and poor in CO<sub>2</sub>, the chemical potentials of which are internally buffered by the prasinitic and ovarditic assemblages themselves (CHATTERJEE, 1971).

### The occurrences near Usseaux in Val Chisone

Between 1973 and 1979 I conducted a mapping and research campaign in the NW periphery of the Dora Maira Massif in the Italian province of Piemonte, carried out by M.Sc. students of petrology in the State University at Leiden (Fig. 1). Ovarditic rocks were encountered in most of the subareas mapped by them, but two graduates: M.T. OTTEN (1978) and H. BROUWER (1979) have studied their ovardites in particular.

Two of the most interesting ovardite occurrences, described by Otten, will be dealt with hereinafter in view of their significance for the process of ovarditization. For a comprehensive account of the ovardite problem the reader is referred to DEN TEX (in prep.)

Tab. 1 Episodes of mineral growth in ovardites, prasinites, metagabbros etc. related to the Alpine deformation phases (D<sub>1-4</sub>) and the magmatic and metamorphic events of the Alpine orogenic cycle.

Deformation phases			D <sub>1</sub> isoclinal folding		D <sub>2</sub> crenula- tion folding		D <sub>3</sub> retro- charriage		D <sub>4</sub> brittle event uplift
Mineral species									
augitic cpx									
omphacite									
chloromelanite									
lawsonite									
zoisite/orthite									
glaucophane/crossite									
blue-green amphibole									
actinolite/tremolite									
chlorite									
albite									
quartz									
calcite									
oxychlorite									
clinozoisite									
pistacite									
Mineral species									
magmatic and meta- morphologic events	mag- matic event	eclogite facies event	blueschist facies event	greenschist facies events 1st phase    ovarditization    2nd phase					

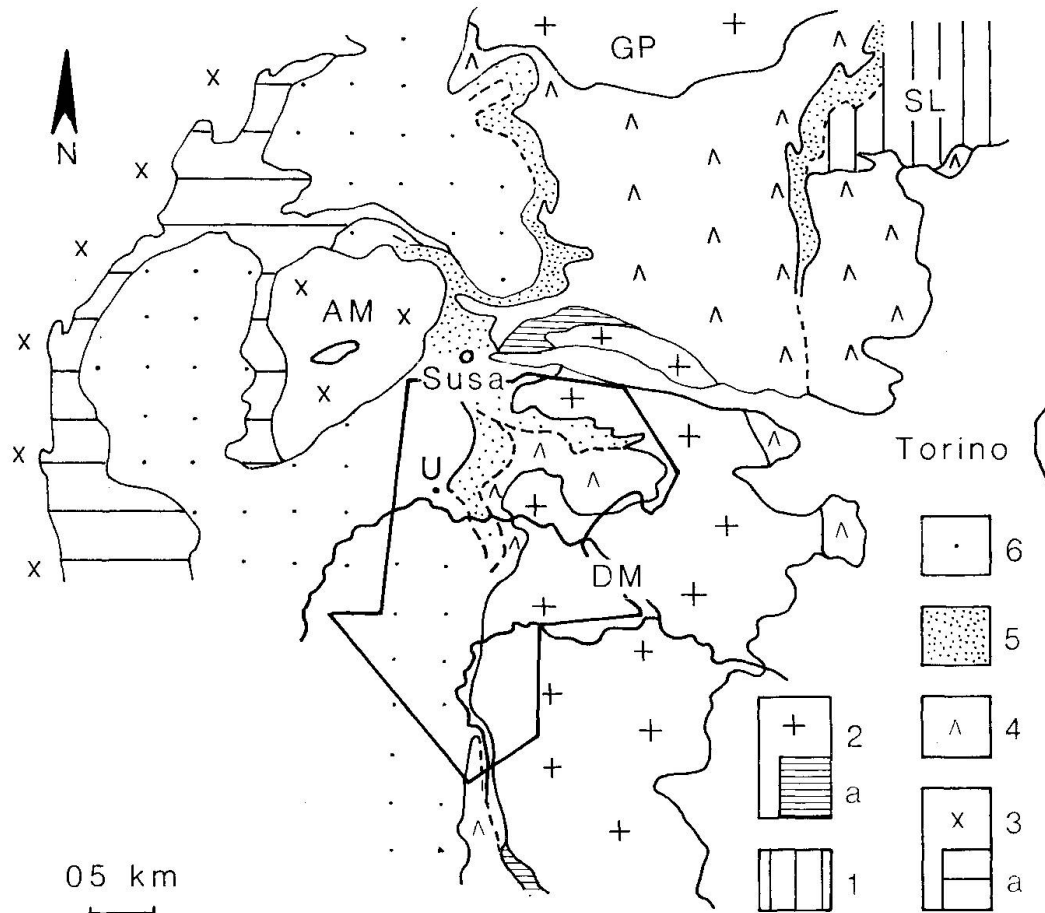


Fig. 1 Tectonic sketch map of the internal Western Alps.

DM = Dora Maira, GP = Gran Paradiso, AM = Ambin massif, U = Usseaux.

- 1 = Sesia Lanzo zone
- 2 = Dora Maira and Gran Paradiso Massifs
- 2a = Mesozoic cover of 2
- 3 = Briançonnais and Ambin Pennine units
- 3a = Mesozoic cover of 3
- 4 = Piemonte ophiolite nappe
- 5 = schistes lustrés with gneisses
- 6 = undifferentiated schistes lustrés

Source area of ovardites studied by the author and his associates outlined. After U. POGNANTE (1984).

**Ovarditized crossite schist**

In a section of the schistes lustrés, 300 m NW of Usseaux (Fig. 1) a peculiar suite of rocks (Fig. 4c) was described as follows by OTTEN (op. cit. pp. 99-102): "Underneath mica-schists a schistose serpentinite is situated. At the contact with underlying crossite-prasinite a tremolite-chlorite schist occurs. The crossite in the prasinite is rigorously oriented and fairly heavily altered into chlorite, except in a vein where crossite is enclosed by apatite. Apart from crossite this rock consists principally of albite and chlorite, but without the characteristic ovardite texture. Below the prasinite lies a layer

that contains blocks of crossite schist that are embedded in a matrix of ovardite. Both components of this association exhibit the ovoid ovardite texture. Ellipsoidal lenses of serpentinite, embedded in talc schist, constitute an additional component of this layer. Possibly this association of rocks represents a metamorphosed polymictic ophiolite breccia or melange." Under the microscope the crossite-schist from the blocks differs from the ovardite matrix in the measure of chloritization of the crossite: weak in the blocks and virtually complete in the matrix.

Crossite is microcrystalline to fine-grained, nearly all crystals being zoned with a bluish to

Tab. 2 Optical data of zoned crossite crystals from various crossite-bearing schists in the schistes lustrés of Val Chisone. From OTTEN, 1978, table 3, p. A9.

	TRÖGER (1971) Mg-Fe <sup>3+</sup> crossite	OTTEN (1978) crossite in various schists		BORG (1967) Mg-(Fe <sup>2+</sup> , Fe <sup>3+</sup> ) crossite
		core	rim	
2 V <sub>x</sub>	2-40°	6°	65-70°	-5 to +80°
c ^ Y	0-5°	6°	12-20°	0-12°
birefring.	.015	.018	.011	.007-.015
dispersion	ρ > υ		ρ << υ	ρ ≤ υ, ρ < υ
pleochroism				
X	dark blue	colourless	colourl./pale yel.	yellow
Y	purple	pale blue	light blue	blue
Z	ultramarine	pale violet	violet	violet

violet rim and a lighter coloured to colourless core. Otten's optical data of crossite from various schists in his subarea are listed in table 2. Having more Fe<sup>2+</sup> in the lattice than pure members of the glaucophane/magnesio-riebeckite series of solid solutions, they are not in accordance with TRÖGER'S (1971) data on crossite (Tab. 3a and BORG, 1967). In a few instances crossite has a (partial) outer rim of actinolite. The crossite needles are rigorously oriented with their long diameters parallel to quartz-rich laminae or to the crenulated foliation (D<sub>1</sub> overprinted by D<sub>2</sub>) (Fig. 2 and 3).

Albite is present in the form of "eyelets" of approximately 1 mm diameter. It contains numerous inclusions and has grown both during or before, and after the crenulation phase (D<sub>2</sub>), as is evidenced by crossite trains respectively bending around and being enclosed by an albite metablast (Fig. 2 and 3). Evidently at least two generations of albite are present in this crossite-schist.

The composition of albite in two sections (4166 and 4168) was determined on the universal stage using Rittmann's zone method. The average extinction angle ε (= α ^ tr. {010}), as measured on six albite-twinned crystals, is -17°, while a Carlsbad twin yielded a maximum ε of +12° in the direction of [001]. These data indicate an average composition of Ab<sub>99.5</sub>An<sub>0.5</sub>.

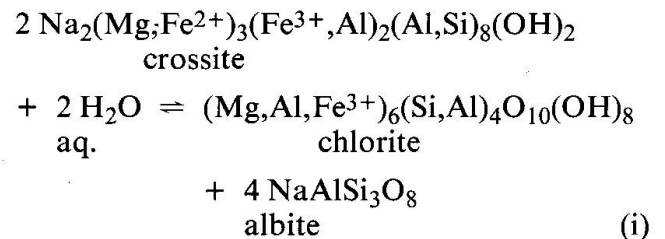
Chlorite flakes constitute the matrix in which albite and crossite are embedded.

It is predominantly an alteration product of crossite but lacks its rigorous preferred orienta-

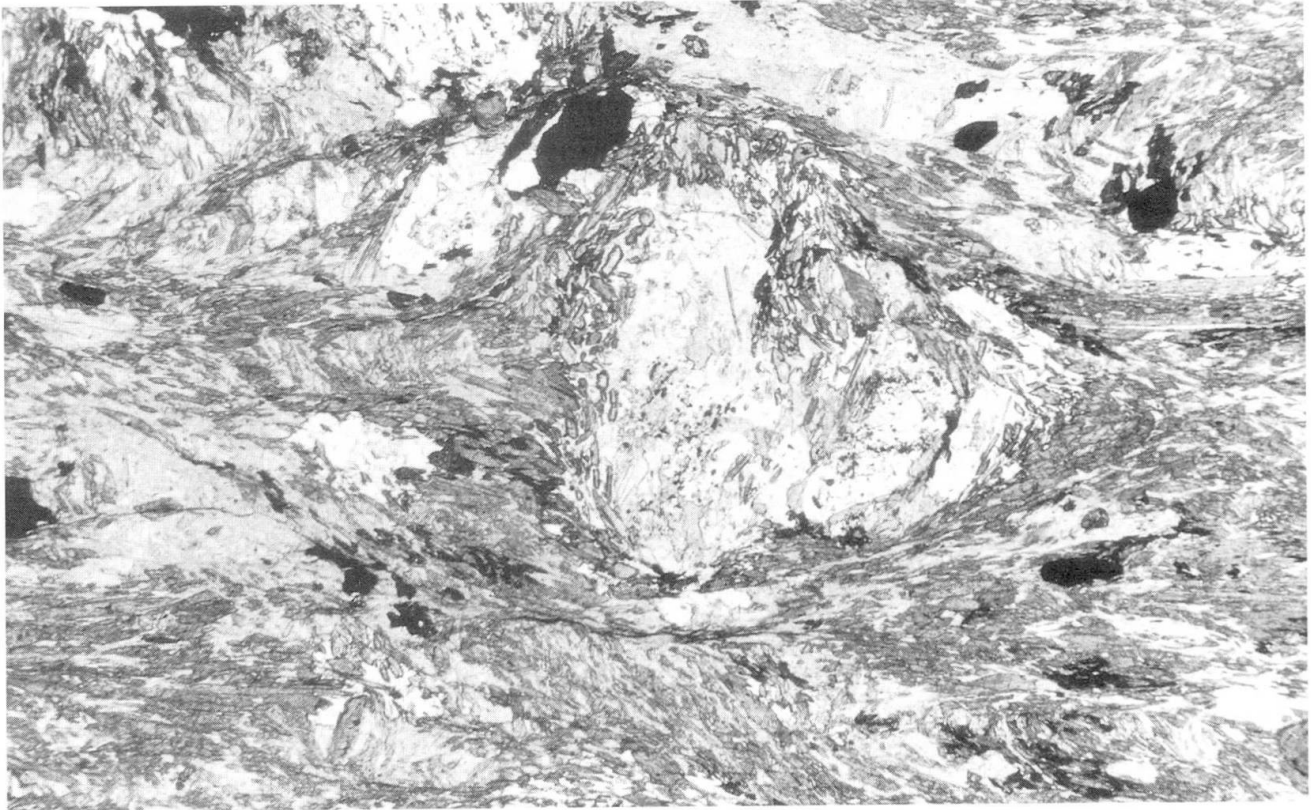
tion. Some chlorite has corroded phengite instead of crossite.

Apart from the principal constituents crossite, chlorite and albite, the two thin sections contain accessory quartz (locally arranged in laminae and showing preferred orientation), epidote/clinozoisite (corroded by titanite), phengite, tourmaline, pyrite and rutile (corroded by titanite).

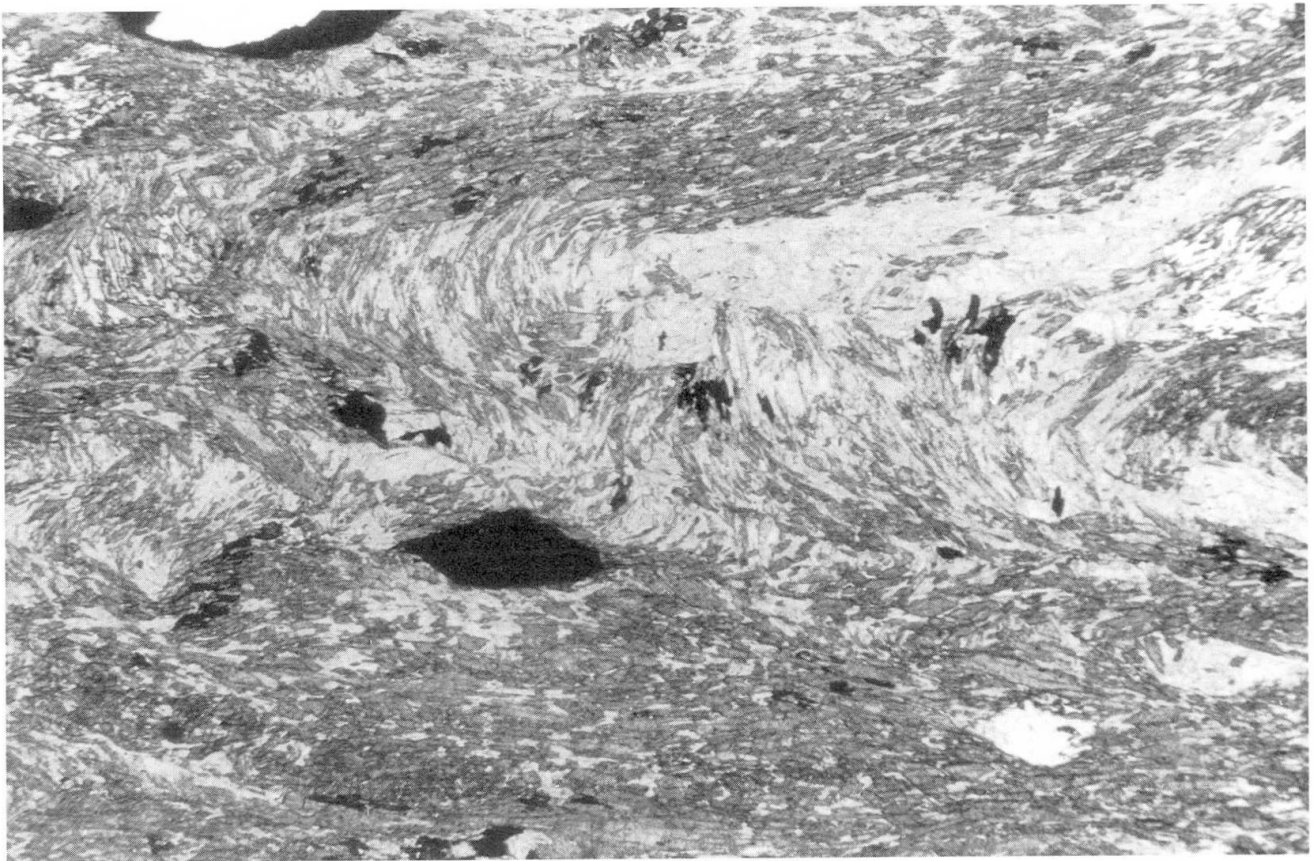
This association of crossite-schist and ovardite, together with their mutual gradations, has the advantage that the process of ovarditization may be tied down to a limited number of participating mineral phases. In its most simple form the process may be represented by the following reaction-equation:



For one thing we know that small amounts of the anorthite molecule may be present in the resulting albite. Therefore it is necessary to test the possible participation in the ovardite reaction of substances other than H<sub>2</sub>O in the fluid, and of minerals other than crossite, chlorite and albite in the solid phase. For this purpose electron-microprobe analyses have been per-



*Fig. 2* Partially ovarditized crossite-chlorite schist. The crenulation-foliation, marked by crossite needles, bends around an albite metablast. Thin sect. 4166. // pol., 25  $\times$ . From OTTEN, 1978, foto 39.



*Fig. 3* Same rock as photo 1. Crenulation-foliation enclosed in albite metablast. Thin sect. 4168, // pol., 25  $\times$ . From OTTEN, 1978, foto 38.

Tab. 3 Weight percentages of major oxides, numbers of cations per corresponding numbers of oxygen ions, structural formulae and charge balances of crossite, chlorite and albite from ovarditized crossite-schist near Usseaux. Pol. thin section T166B (= 4168 of Otten, 1978).

a Averaged values of core and rim of a crossite crystal with standard deviations.

b Values of a single chlorite crystal contiguous to the crossite crystal of a.

c Averaged values of 3 albite crystals nearly contiguous to chlorite and crossite of b and a.

Tab. 3a Crossite (CA) contiguous with chlorite (CHC) from section 4168.

weight % oxides		cations per 23 O		structural formula	
SiO <sub>2</sub>	57.1 ± .1	Si <sup>4+</sup>	7.97 ± .003	Si <sup>4+</sup>	7.97 } Z = 8.00
Al <sub>2</sub> O <sub>3</sub>	5.81 ± .05	Al <sup>3+</sup>	.956 ± 0.14	Al <sup>IV</sup>	.03 }
TiO <sub>2</sub>	—	Ti <sup>3+</sup>	—	Al <sup>VI</sup>	.926 } Y = 1.978
Fe <sub>2</sub> O <sub>3</sub>	n.d.	Fe <sup>3+</sup>	1.052 ± .008	Fe <sup>3+</sup>	1.052 }
FeO	14.4 ± .2	Fe <sup>2+</sup>	.633 ± .096	Fe <sup>2+</sup>	.633 } X = 3.021
MnO	.15 ± .00	Mn <sup>2+</sup>	.017 ± .001	Mn <sup>2+</sup>	.017 }
MgO	11.2 ± .2	Mg <sup>2+</sup>	2.33 ± .03	Mg <sup>2+</sup>	2.33 }
CaO	.47 ± .11	Ca <sup>2+</sup>	.071 ± .016	Ca <sup>VI</sup>	.041 }
Na <sub>2</sub> O	7.25 ± .05	Na <sup>+</sup>	1.97 ± .01	Ca <sup>VIII</sup>	.03 } W = 2.00
K <sub>2</sub> O	—	K <sup>+</sup>	—	Na <sup>+</sup>	1.97 }
Suppl. f. Fe <sup>3+</sup>	1.00				
96.38		14.999		charge balance: - .024	

Tab. 3b Chlorite (CHC) contiguous with crossite (CA) in section 4168.

weight % oxides		cations per 14 O		structural formula	
SiO <sub>2</sub>	28.4	Si <sup>4+</sup>	2.93	Si <sup>4+</sup>	2.93 } Z = 4.00
Al <sub>2</sub> O <sub>3</sub>	17.8	Al <sup>3+</sup>	2.16	Al <sup>IV</sup>	1.07 }
TiO <sub>2</sub>	—	Ti <sup>3+</sup>	—	Al <sup>VI</sup>	1.09 } WXY = 5.980
Fe <sub>2</sub> O <sub>3</sub>	n.d.	Fe <sup>3+</sup>	n.d.	Fe <sup>3+</sup>	— }
FeO	15.3	Fe <sup>2+</sup>	1.32	Fe <sup>2+</sup>	1.32 }
MnO	.28	Mn <sup>2+</sup>	.025	Mn <sup>2+</sup>	.025 }
MgO	23.0	Mg <sup>2+</sup>	3.54	Mg <sup>2+</sup>	3.54 }
CaO	—	Ca <sup>2+</sup>	—	Ca <sup>2+</sup>	— }
Na <sub>2</sub> O	—	Na <sup>+</sup>	—	Na <sup>2+</sup>	— }
K <sub>2</sub> O	.04	K <sup>+</sup>	.005	K <sup>+</sup>	.005 }
84.82		9.980		charge balance: - .015	

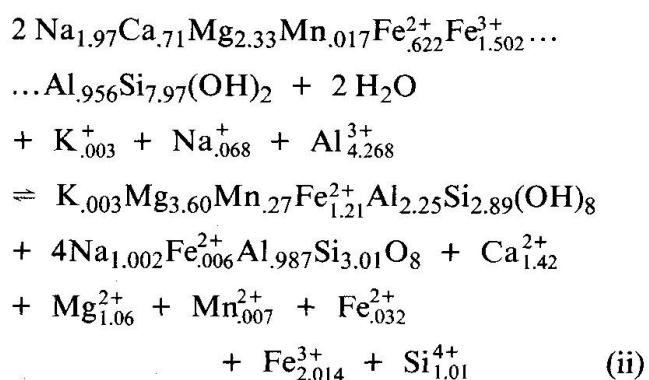
Tab. 3c Average of 3 albites (AA, AB & AC), nearly contig. with a & b from section 4168.

weight % oxides		cations per 8 O		structural formula	
SiO <sub>2</sub>	68.7 ± .3	Si <sup>4+</sup>	3.01 ± .00	Si <sup>4+</sup>	3.01 } Z = 3.997
Al <sub>2</sub> O <sub>3</sub>	19.1 ± .1	Al <sup>3+</sup>	.987 ± .002	Al <sup>IV</sup>	.987 }
FeO	.18 ± .06	Fe <sup>2+</sup>	.006 ± .002	Fe <sup>2+</sup>	.006 } XY = 1.008
CaO	— (det. lim. 3%)	Ca <sup>2+</sup>	—	Ca <sup>2+</sup>	— }
Na <sub>2</sub> O	11.8 ± .1	Na <sup>+</sup>	1.002 ± .006	Na <sup>+</sup>	1.002 }
K <sub>2</sub> O	—	K <sup>+</sup>	—	K <sup>+</sup>	— }
99.78		5.005		charge balance: +.015	

formed on 3 albites, 9 chlorites and 52 crossite cores, -rims and -intermediate zones from polished thin sections 4166 and 4168 by the research group for analytical chemistry of minerals and rocks, located at the Free University in Amsterdam. The full results are available on request from the author or the research group.

Apparently unsystematic variations between the compositions of core, rim and intermediate zones of individual crossite crystals, and between the bulk compositions of different crossite grains occur. For striking a chemical balance on the basis of equation (i) I have chosen between the average of core and rim of a single crossite grain on the one hand, and the sum of a contiguous chlorite- and the average of three nearly contiguous albite grains on the other hand.

In table 3 the weight percentages of oxides, the numbers of cations per corresponding number of structural O (each with its standard deviation if averaged) and the resulting structural formula and charge balance are listed. Deviation from the theoretical number of WXYZ sites does not exceed .021 and that from the zero charge balance is not more than -.024 and +.015. The cation numbers of crossite, chlorite and albite allow the simplified ovarditic reaction-equation to be specified as follows:



Of the additions to the ovardite system only  $\text{Al}^{3+}$  amounts to a quantity significantly exceeding the margin of error of the analytical results (approx. .01) and the same applies to  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{3+}$  and  $\text{Si}^{4+}$  among the subtractions. Of the latter  $\text{Ca}^{2+}$  is much too far in excess over what could be accommodated in an albite of composition  $\text{Ab}_{99.5} \text{An}_{.05}$  (as was determined on the universal stage) and allowing for a detection limit of .03 for Ca on the elec-

tron-microprobe. Since (partial) outer rims of actinolite are locally present around crossites, it is quite probable that actinolite was a by-product of the ovarditic reaction(s), even though an approximately stoichiometric actinolite composition cannot be formed from the available  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{\text{tot}}$  and  $\text{Si}^{4+}$  ions. A better stoichiometric approximation is achieved, when the transformation of epidote/clinozoisite into titanite is taken into account whereby not only  $\text{Fe}^{3+}$  and  $\text{Si}^{4+}$  are set free but also  $\text{Al}^{3+}$  that may fill the requirement on the left-hand side of the simplified ovardite reaction. The conversion of phengite to chlorite is another possible supplier of  $\text{Al}^{3+}$  and, concomitantly, of  $\text{K}^+$  and  $\text{Na}^+$  to the reactants. Thus, the mineral system that was subject to the process of ovarditization probably comprised epidote/clinozoisite and/or phengite, titanite and actinolite as well as crossite, chlorite and albite. Although indubitably open to water, the system was probably virtually closed to  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{\text{tot}}$ ,  $\text{Mn}^{2+}$ ,  $\text{Al}^{3+}$ , and  $\text{Si}^{4+}$ . In the complete absence of carbonates  $\text{X}_{\text{CO}_2}$  must have been very low during ovarditization of these crossite-schists (CHATTERJEE, 1971).

### Monomictic ovardite breccia

At another locality in the schistes lustrés near the village of Usseaux a breccia was found by OTTEN (op. cit.) consisting of foliated ovardite fragments set in a coarse-grained, randomly oriented albite-chlorite-quartz matrix (Fig. 5). Its structural relations imply an ovarditization process that occurred in two discrete phases, the most recent of which was connected with a brittle tectonic event ( $\text{D}_4$ ), whereas the earlier phase took place distinctly before  $\text{D}_4$  and probably during, or even before, the latest penetrative deformation event ( $\text{D}_3$ ) (Tab. 1). This conclusion is supported by the unstrained nature of the coarse-grained constituents of the ovarditic matrix, and by the features characteristic of plastic deformation, such as undulatory extinction, subgrain formation, grain-boundary migration and dynamic recrystallization, shown by albite metablasts in the foliated fragments.

Other occurrences of ovardite breccia have been described by BROUWER (1979). One is a brecciated lower margin of an ovardite layer E.



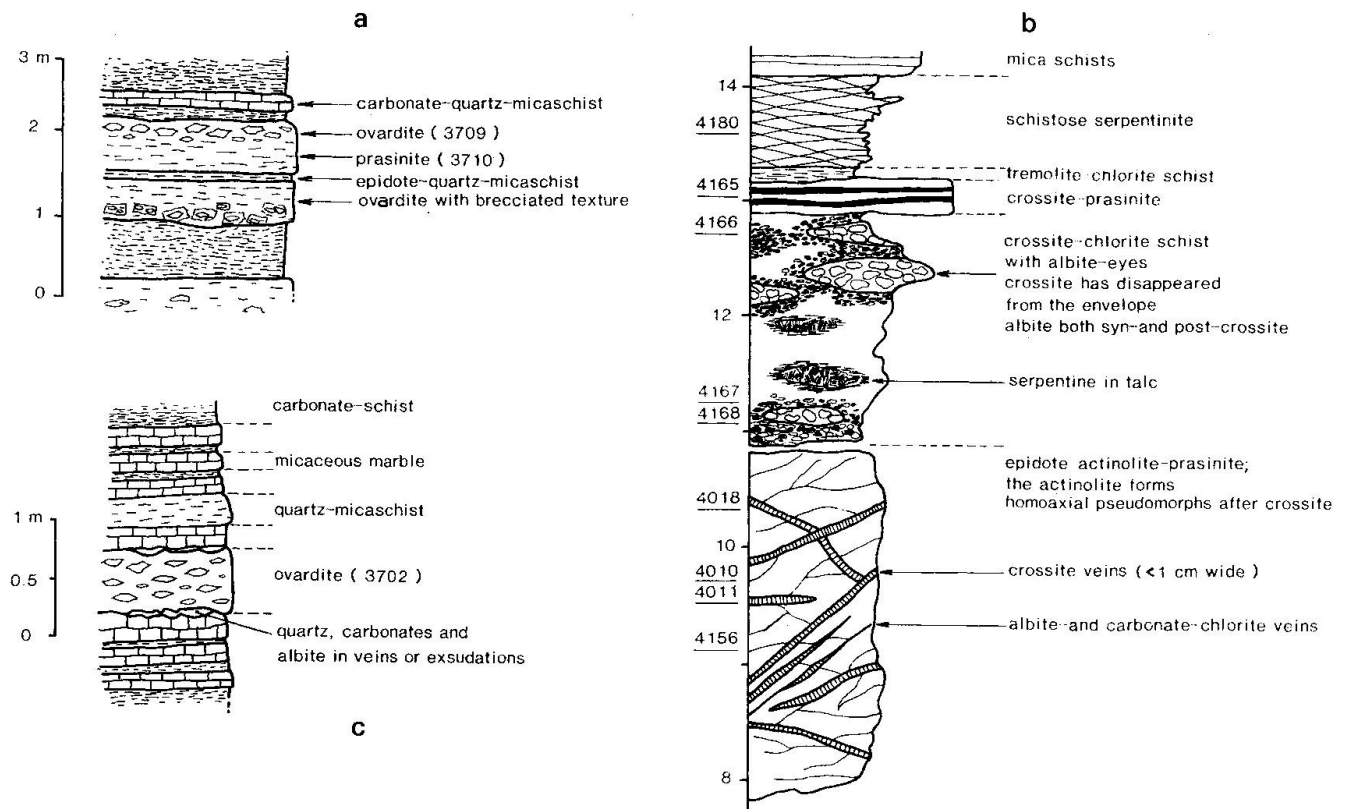


Fig. 4 Slightly idealized sections through the schistes lustrés suite between Val Chisone and Val Susa, showing three occurrences of ovardite, crossite-schist and prasinite treated in the text.

- a Brecciated lower margin of an ovardite layer E. of Monte Pelvo (from BROUWER, 1979), Fig. 13);  
 b Coarse-grained albite-chlorite-quartz veins in the margin of an ovardite layer N. of Monte François Pelouse. From BROUWER, 1979, Fig. 12.  
 c Section 300 m NW of Usseaux showing the relations between ovardite, partially ovarditized crossite-chlorite schist, crossite-schist, prasinite and serpentinite in a melange-type association. From OTTEN, 1978, Fig. 12.

of Monte Pelvo in Val Chisone (Fig. 4a). Another consists of margins of an ovardite layer in schistes lustrés N. of Monte François Pelouse in the same subarea. These margins are veined by conformable, coarse-grained albite-chlorite-quartz assemblages (Fig. 4b). The discovery of an ovardite-mylonite in Valle Tronca by HAZELHORST (1983) should not be passed over in this context.

### Conclusions

The melange-type association of crossite-schist and ovardite, located near Usseaux, has permitted the striking of a simplified chemical balance based on electron-microprobe analyses of (nearly) contiguous crossite-, chlorite-, and albite crystals. This was possible because the conversion of crossite into chlorite and albite is documented in a number of thin sections. The balance indicates that the system subject to ovarditization involves addition of

$Al^{3+}$  (and possibly small amounts of  $K^{+}$  and  $Na^{+}$ ), derived from the transformation of epidote/clinozoisite into titanite (and possibly of phengite into chlorite), and subtraction of  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Fe^{2+}$ ,  $Fe^{3+}$  and  $Si^{4+}$  (and possibly some  $Mn^{2+}$ ), absorbed by the formation of actinolite rims around crossite. In the presence of neighbouring calcareous schist and in the absence of carbonates in the ovardite system, the gradient of  $X_{CO_2}$  must have been steep and the mobility of  $CO_2$  low. Calcite-bearing albite-chlorite veins in the underlying epidote-actinolite prasinite support the latter conclusion. Thus the ovarditization of crossite-schist appears to be an essentially isochemical reaction and not a metasomatic process as assumed for the ovarditization of prasinites.

The monomictic breccia near Usseaux with foliated ovardite fragments set in a randomly oriented ovardite matrix demonstrates that two distinct events of ovarditization have occurred: one before or during the latest phase of pene-

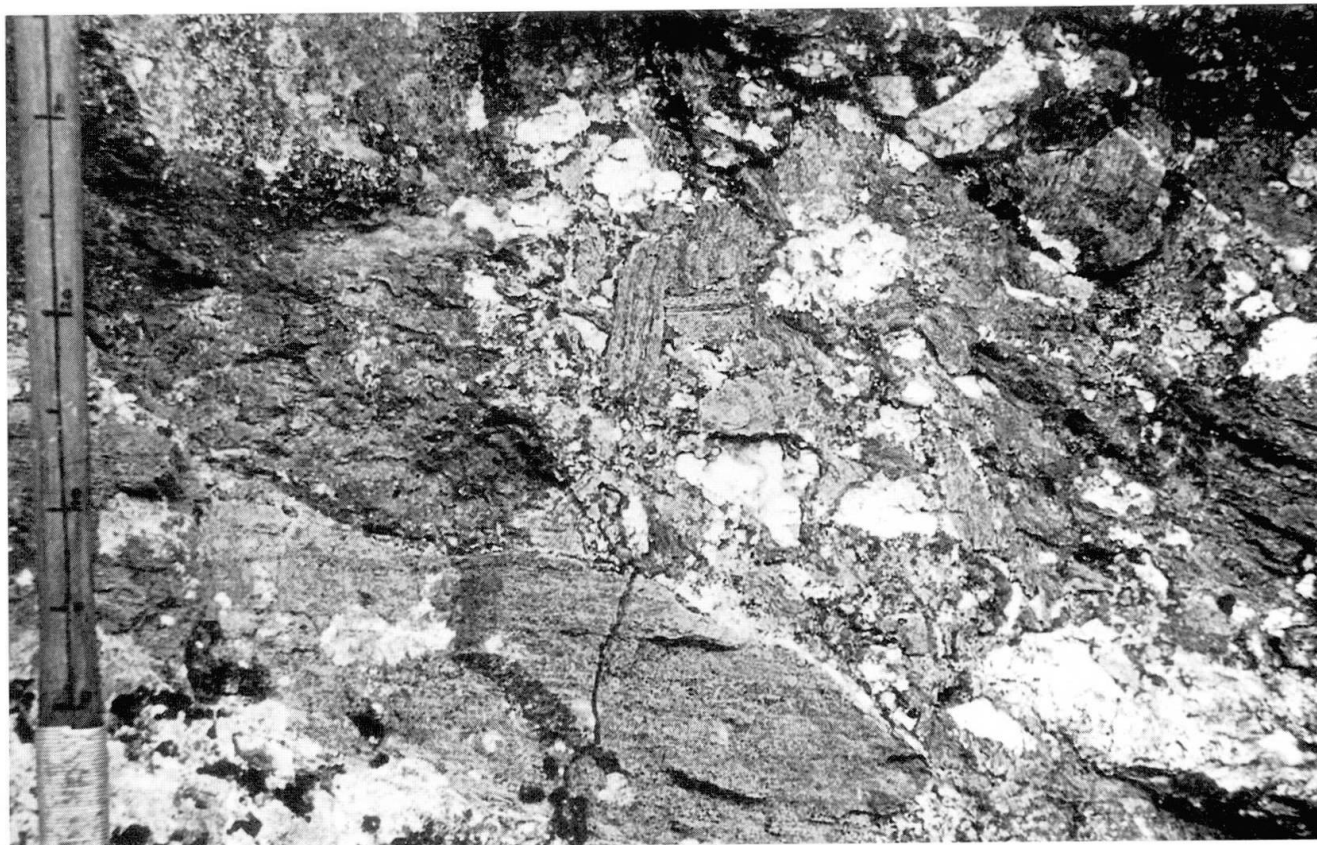


Fig. 5 Monomictic ovardite breccia in schistes lustrés near Usseaux in Val Chisone. Foliated ovardite fragments set in a coarse-grained, randomly oriented ovardite matrix. From OTTEN, 1978, foto 2.

trative deformation ( $D_3$ ) and one after the phase of brittle deformation that concluded the Alpine orogeny with the final uplift of the Dora Maira Massif ( $D_4$ ). Possibly the uplift occurred in stages, such that successively deeper levels of blueschist and prasinite arrived in a P/T domain where ovarditization reactions could proceed.

#### Acknowledgements

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The aid of Mr. B.F.M. Collet, draughtsman of the National Museum of Geology and Mineralogy at Leiden, in drawing the figures is gratefully acknowledged.

I am indebted to Professor M. Vuagnat for drawing my attention to the occurrence of ovardites in the Swiss canton Valais and to the work thereon by J.-M. Vallet.

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