Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 66 (1986)

Heft: 1-2

Artikel: High-pressure metamorphism in the Western Alps : zoneography of metapelites, chronology and consequences

Autor: Goffé, Bruno / Chopin, Christian

DOI: https://doi.org/10.5169/seals-50880

Schweiz. mineral. petrogr. Mitt. 66, 41–52, 1986

High-pressure metamorphism in the Western Alps: zoneography of metapelites, chronology and consequences

by *Bruno Goffé*[1] and *Christian Chopin*[1]

Abstract

Recent developments in the petrology of high-pressure metapelites from the Western Alps are reviewed. They reveal considerable variations in metamorphic grade, from a Fe–Mg-carpholite domain with or without chloritoid extending along the contact between Briançon and Piemont zones, through an intermediate domain with Mg-rich chloritoid–talc–phengite with or without kyanite covering the Zermatt zone s.l. and the Monte Rosa and Gran Paradiso massifs, to a unit of the Dora Maira massif in which coesite, pyrope and ellenbergerite, a new mineral of the pelitic system, are of regional occurrence.

The most remarkable feature of this pattern is the discontinuous increase both in age and grade of the metamorphism toward the Ivrea gravimetric anomaly, from 4–6 kbar, 300 °C, 35–40 Ma, to about 30 kbar, 750 °C, 110 Ma.

The preservation of carpholite in the westernmost units and of coesite in the innermost one requires peculiar tectonic mechanisms, which allow the underthrusting of cold external units below warmer internal zones. This may be achieved by the progressive migration within plate of intracontinental overthrusts after the blocking of an initial subduction in which continental crust was buried to over 100 km depth.

Keywords: high-pressure metamorphism, metapelites, subduction, carpholite, coesite, ellenbergerite, Western Alps.

Introduction

Since BEARTH'S 1962 pioneering work, the improvements successively brought to the zoneography of high-pressure metamorphism in the Western Alps by BOCQUET (1971), SALIOT (1973), FREY et al. (1974), and CABY et al.

[1] E.R. 224 du C.N.R.S., Laboratoire de Géologie, Ecole normale supérieure, 46, rue d'Ulm, 75005 Paris, France.

(1978) essentially relied on the index minerals prehnite, pumpellyite, lawsonite, glaucophane and jadeite, i.e. essentially on the mineralogy of metabasites. Recent field-petrologic studies have led to considerable new developments, most of which concern the metamorphic transformation of pelitic protoliths. The purpose of this paper is to present a short review of our results in the Western Alps, showing how the combination of petrologic, chronologic and structural data may improve our understanding of mountain-building processes.

An outline of the phase relations in high-pressure metapelites

A pelitic protolith consisting of quartz, chlorite, illite and possibly kaolinite may be adequately considered in the sytem FeO–MgO–Al_2O_3–SiO_2–H_2O, taking into account that a phengitic white mica is the only K-bearing phase throughout the metamorphic evolution (CHOPIN, 1981, 1985). The phases of interest are shown in the projection of Figure 1. Less common minerals are the single-chain silicate Fe-Mg-carpholite, $(Fe,Mg)Al_2Si_2O_6(OH)_4$, the di-trioctahedral chlorite sudoite $Mg_2Al_3AlSi_3O_{10}(OH)_8$, and the new mineral ellenbergerite, $(Mg,Ti,\square)_2Mg_6Al_6Si_8O_{28}(OH)_{10}$ (CHOPIN et al., 1986; CHOPIN, 1986a), which involves the additional component TiO_2.

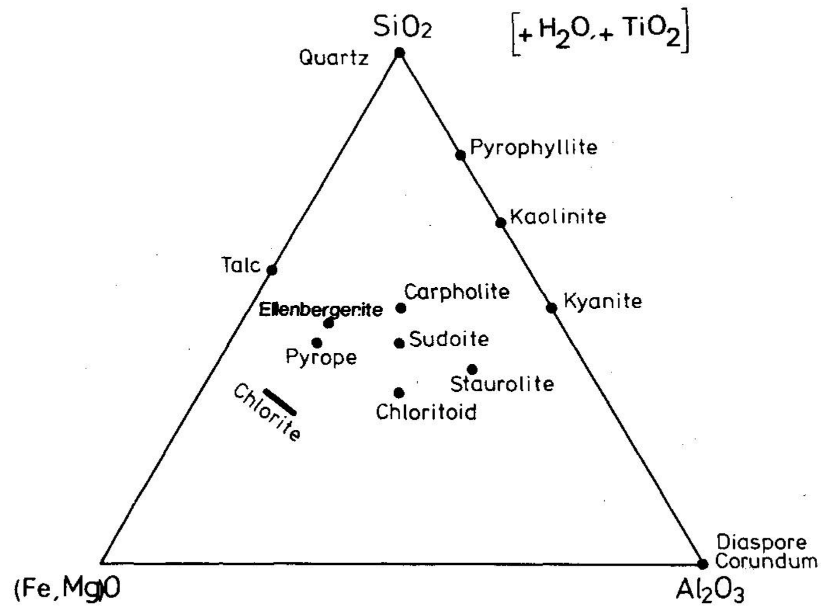

Fig. 1 Phases of interest in high-pressure metapelites considered in the sytem $(Fe,Mg)O$–Al_2O_3–SiO_2–TiO_2–H_2O.

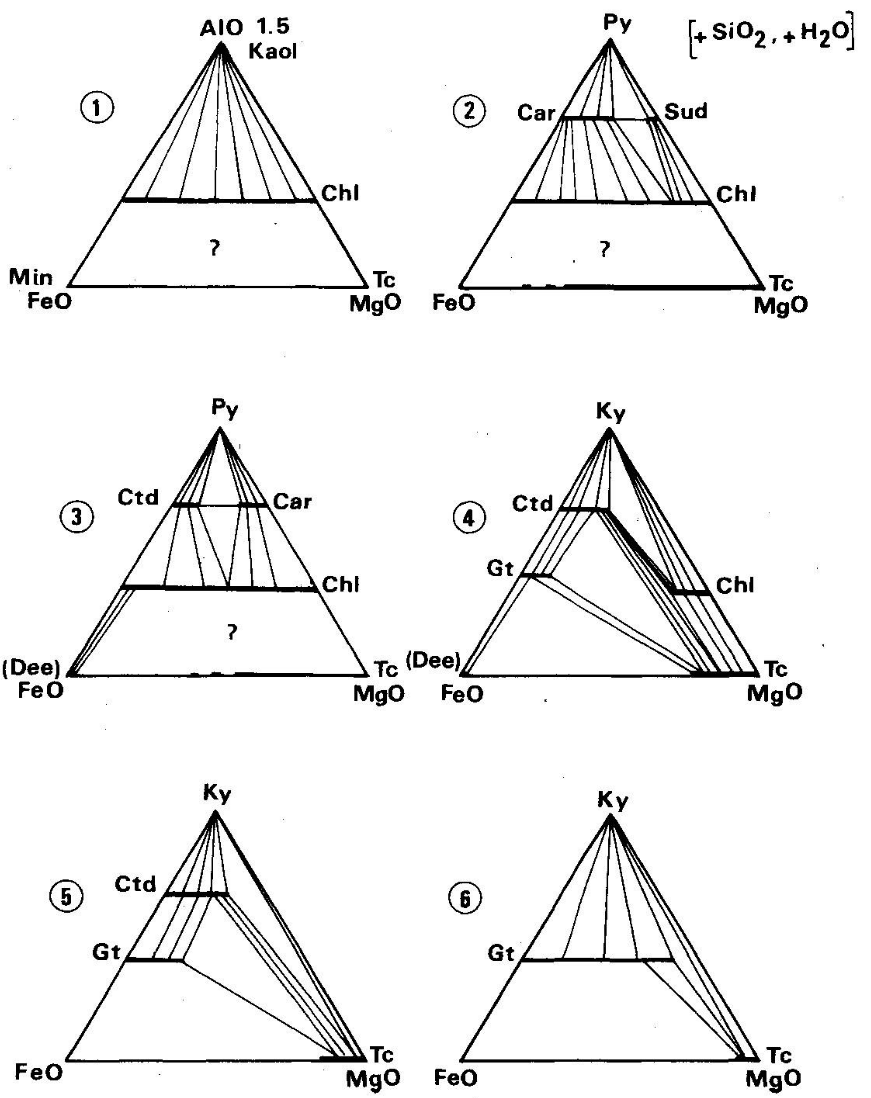

Fig. 2 Phase relations in high-pressure metapelites. Metamorphic grade increases from 1 to 6. Additional solid phases are quartz and phengite in 1 to 5, coesite and phengite in 6. Abbreviations: Kaol: kaolinite, Py: pyrophyllite, Ky: kyanite, Car: carpholite, Sud: sudoite, Ctd: chloritoid (Chlor in Fig. 7), Chl: chlorite, Gt: garnet, Min: minnesotaite, Tc: talc, Dee: deerite (which involves the additional component Fe_2O_3).

The mineral evolution with increasing grade along a high-pressure, low-temperature gradient is represented in Figure 2, from a quartz-chlorite ± kaolinite protolith (Fig. 2-1) to the uncommon coesite-garnet-kyanite rocks of the Dora Maira massif (Fig. 2-6) described by CHOPIN (1984, 1985, 1986b). Intermediate stages are typified by the critical assemblages carpholite-kaolinite (not found in the Alps but widespread in Oman: GOFFÉ, unpub. data), carpholite-sudoite-pyrophyllite (Fig. 2-2, known in Crete and Oman: SEIDEL, pers. comm. 1985, and GOFFÉ, unpub. data, respectively), carpholite - chloritoid (Fig. 2-3), Mg-rich chloritoid-talc-chlorite (Fig. 2-4), and Mg-chloritoid-talc-kyanite (Fig. 2-5). The main stages are the appearance of carpholite, the formation of

Fe-chloritoid and then garnet while carpholite disappears, the progressive breakdown of chlorite + quartz to Mg-rich chloritoid + talc (ultimately + kyanite), and the disappearance of chloritoid + quartz in favour of garnet + kyanite (± talc).

The significance of these assemblages in terms of pressure and temperature is outlined in Figure 3, after CHOPIN (1985). In this figure three domains have been distinguished with hachures, corresponding to P–T conditions deduced from natural assemblages: (i) an undifferentiated carpholite domain for pressures between 4 and 8 kbar, near 300 °C (GOFFÉ and VELDE, 1984; GOFFÉ, 1984); (ii) a talc-chloritoid domain near 15 kbar, 500–600 °C, subdivided into two subareas depending whether chlorite is stable or not in the presence of quartz (CHOPIN and MONIÉ, 1984); (iii) a pyrope-talc-coesite field at 700–800 °C for pressures in excess of 27 kbar (CHOPIN, 1984). The three metamorphic grades define clearly different P–T conditions and have therefore been used to establish the metamorphic patterns represented in Figure 4 and 5.

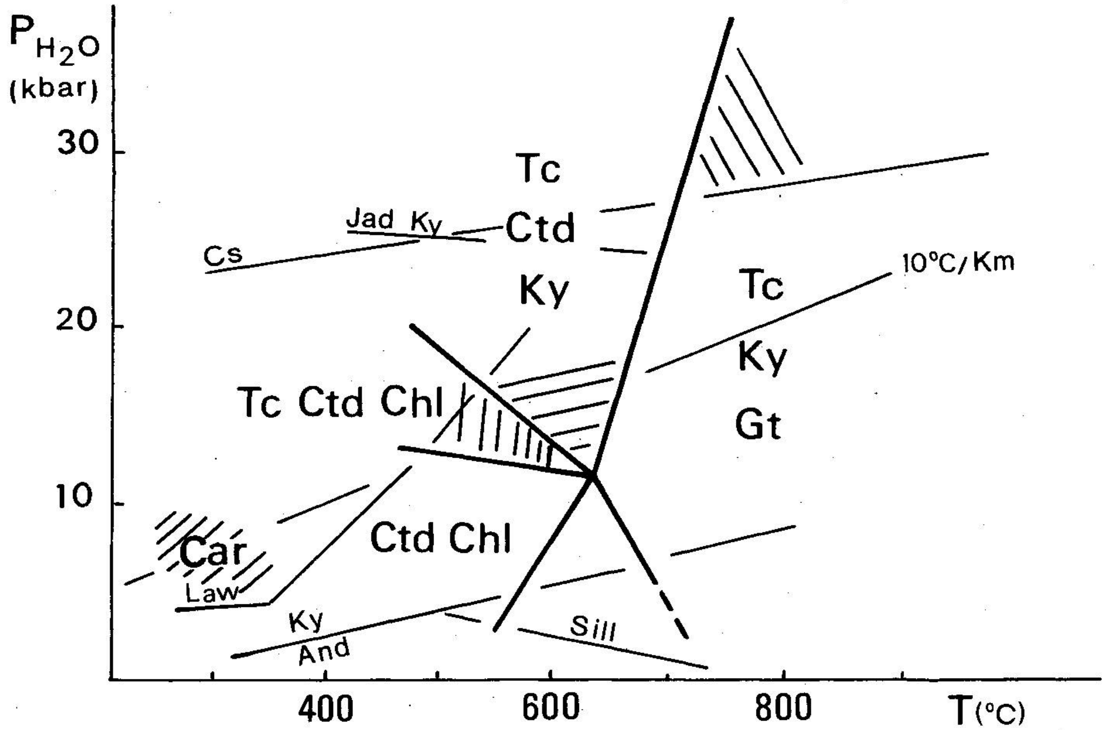

Fig. 3 Stability fields of some critical mineral assemblages with excess quartz (or coesite) and H_2O (after CHOPIN, 1985). The ruled areas correspond to the natural carpholite-bearing assemblages and natural talc-chloritoid-chlorite, talc-chloritoid-kyanite and talc-pyrope-coesite assemblages discussed in the text. Additional abbreviations: Law: lawsonite, Cs: coesite, Jad: jadeite.

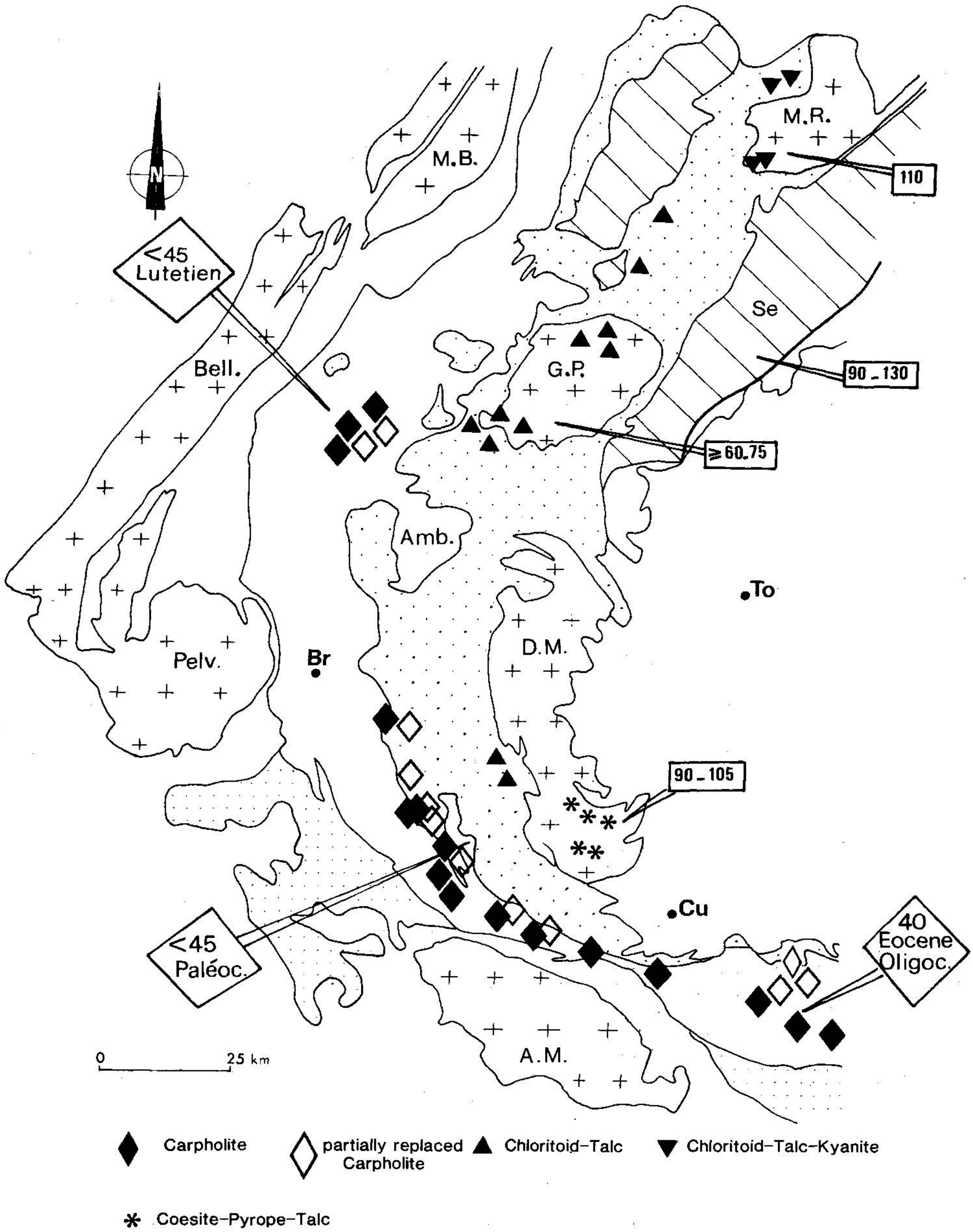

Fig. 4 Occurrence map of critical minerals and mineral assemblages in metapelites of the Western Alps; boxes are constraints on the age of high-pressure metamorphism. The structural sketch map shows the external crystalline massifs Mont-Blanc (M.B.), Belledonne (Bell.), Pelvoux (Pelv.) and Argentera-Mercantour (A.M.), the Penninic front limiting the Briançon zone, the Schistes lustrés nappe dotted, the internal crystalline massifs Monte Rosa (M.R.), Gran Paradiso (G.P.), and Dora Maira (D.M.), the Austro-alpine Sesia unit (Se) and its Dent-Blanche outlier ruled. Amb.: Ambin massif, Br: Briançon, To: Torino, Cu: Cuneo. Source of data: see text.

Occurrence and age of the high-pressure assemblages

The occurrences of the critical assemblages mentioned above have been reported on the structural sketch map of Figure 4. References for carpholite will be available in GOFFÉ and CHOPIN (in prep.); talc–chloritoid occurrences are taken from BEARTH (1963), SALIOT et al. (1980), CHOPIN (1981), and CHOPIN and MONIÉ (1984); coesite occurrences are from CHOPIN (1986b). The areal arrangement of these occurences makes it possible to define a series of successive zones (Fig. 5).

- Carpholite is stable (and abundant!) in the most external, western zone (A in Fig. 5) which nicely follows the contours of the Alpine chain, in the very front of the Schistes lustrés nappe. Carpholite occurs indeed both in the nappe itself and in its substratum, the Briançon zone, along a 0.5 to 5 km narrow band. The external limit of this zone is defined by the prograde appearance of carpholite, which nearly coincide with that of lawsonite in various lithologies (Fig. 5). The internal limit of this zone represents the incipient breakdown of carpholite, which goes to completion further east. The parallelism of both boundaries is a remarkable feature. The age of metamorphism is paleontologically constrained to be younger than 45 Ma in Vanoise and in the Acceglio area (cf. ELLENBERGER and RAOULT, 1979, and LEFÈVRE and MICHARD, 1976, respectively), and stratigraphically closely bracketed near 40 Ma in Liguria (cf. MESSIGA et al., 1983).
- The overprinting of high-pressure assemblages is rather general in the zone extending further east (B in Fig. 5). The presence of chloritoid and relics of glaucophane, lawsonite and jadeite (cf. CARON, 1977) point to high-pressure conditions which were probably intermediate between those of the carpholite zone and of the next, talc-chloritoid zone.
- The talc-chloritoid zone (C in Fig. 5) is well-developed in the central and northern part of the chain, both in the internal crystalline massifs Monte Rosa and Gran Paradiso and in Mesozoic ophiolite-bearing units like the Zermatt-Saas unit, or Monviso in the South. Metamorphic grade is somewhat higher in and around the Monte Rosa massif. This zone nearly coincides with the eclogite zone as defined, for example, by CABY et al. (1978) whose limits have been largely used in Fig. 5 (excepting the Dora Maira massif). In contrast to the carpholite zone, this one seems to be everywhere tectonically bounded with sharp metamorphic discontinuities, as documented in Val d'Aoste (CABY et al., 1978), in Maurienne (CHOPIN, 1979) and in Val Susa (POGNANTE, 1984).
- The highest-grade, coesite zone is limited to part of the Dora Maira massif; it has been represented in Fig. 5 (D) as its *maximum possible extension,* i.e. over the whole polymetamorphic basement unit as defined by VIALON (1966). In fact coesite has so far been found only in its southern part (compare Figs. 4 and 5). Constraints on the age of high-pressure metamorphism in this zone and in the former one are only radiometric. In spite of the different techniques applied

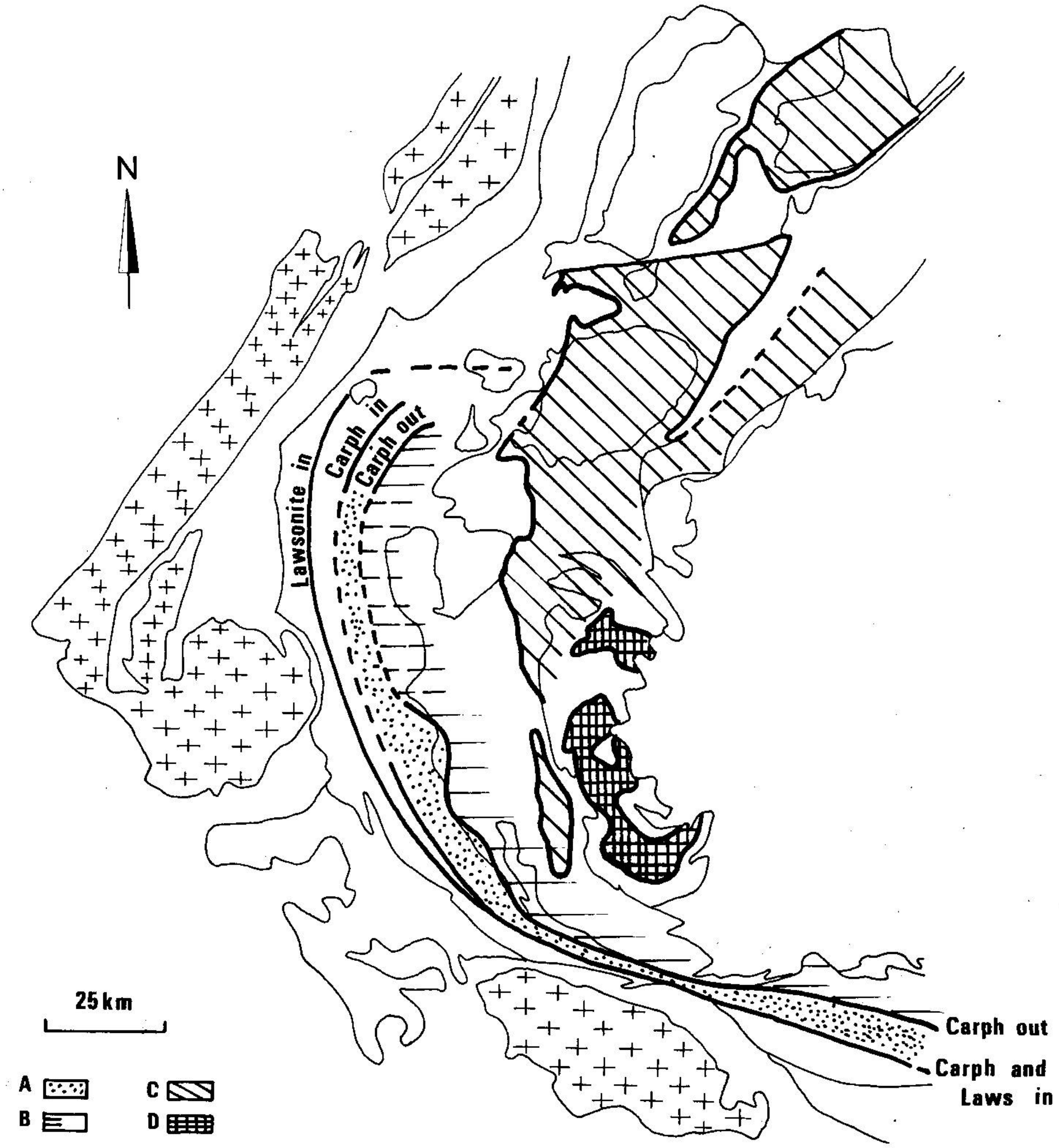

Fig. 5 Metamorphic map of Western Alps showing the main metamorphic zones defined in high-pressure metapelites. A is the carpholite zone; in B, the ruling indicates that pseudomorphs after carpholite may still be found. C is the talc-chloritoid and eclogite zone, D the maximum possible extent of the coesite zone. The external boundary of the lawsonite zone is traced using data of SALIOT (1973) and BOCQUET (1974) for the north of the Briançon zone, LEFÈVRE (1982) for the Cottian Alps, GOFFÉ (1979) for the Ligurian Alps, and GOFFÉ (unpub.) for the Zone Houillère and the Cottian Alps.

in different areas, the results definitely suggest a common Late to mid-Cretaceous age in both units (Fig. 4). References are CHOPIN and MONIÉ (1984) for Monte Rosa, OBERHÄNSLI et al. (1985) for the Sesia zone, CHOPIN and MALUSKI (1980) for Gran Paradiso, and MONIÉ (unpub. data) for phengite from the coesite-pyrope-rock in Dora Maira.

The fact that three distinct metamorphic grades (tc–ctd–chl, tc–ctd–ky, and coesite-pyrope-talc) can be distinguished on the basis of metapelite mineralogy within a uniform eclogite zone shows how a much more sensitive recorder metapelites are. The same holds true at lower grade, within the lawsonite zone, for which the considerable variety of critical carpholite-bearing assemblages allows very precise comparisons between different areas, in spite of the rather narrow P–T range concerned. In fact most of the improvements brought by the new maps presented here over the former ones are essentially due to our recent progress in recognizing the so far unsuspected mineral variety in metapelites.

Interpretation and discussion

A tentative reconstruction of the evolution of the European continental margin during the collision with the African plate s. l. is proposed in Fig. 6. This reconstruction is intended to account for the following remarkable features.

- The regional occurrence of coesite and other uncommon or new minerals in part of the Dora Maira massif implies that continental crust may be buried to depths of about 100 km along a rather low temperature gradient, which is best accounted for by the deep subduction of continental lithosphere. A more difficult problem is that these rocks must then reach the surface without complete overprinting (CHOPIN, 1986b).
- Considered across the chain, the metamorphic evolution proceeds discontinuously, both in age and in grade. The gaps in temperature may be of about 200 °C, in pressure from 6 to at least 12 kbar (compare Figs. 3 and 4). The highest pressures were reached about 40 Ma ago in the carpholite zone, 90 to 120 Ma ago in the most internal zones. The overprinting itself is variable in age and grade: unconspicuous in the carpholite zone, well-developed, probably 38 to 40 Ma ago, immediately eastward of it, again much less developed in the eastern Sesia zone in which it should be 60 Ma or older (HUNZIKER, 1974; OBERHÄNSLI et al., 1985). This characteristic pattern of the metamorphic evolution is best accounted for by the existence of large intra-crustal thrusts migrating "in-plate", i.e. toward the external zones, with time once the subduction was blocked (cf. also GILLET et al., 1986). The present-day uplift of the external crystalline massifs is the vertical component of such an overthrust (see PERRIER, 1980). A metamorphic gap of 200 °C, 6 kbar would correspond to about 20 km thick units. This seems reasonable, but one may then wonder why so few continental lower crustal rocks are presently exposed.
- A characteristic structure along the chain is the underthrusting of lower, mostly basement units along westward dipping accidents, while overlying units are thrusted westward upon flat-lying shear planes, as shown in Fig. 7 for the Vanoise–Gran Paradiso traverse. In Vanoise, this tectonic mechanism has been shown to be responsible for the selective preservation of carpholite in the upper units thrusted onto relatively cold, more external terrains, while the temperature rise in the underthrusted units led to a general overprinting of high-pressure assemblages there (Fig. 7 and GOFFÉ and VELDE, 1984).

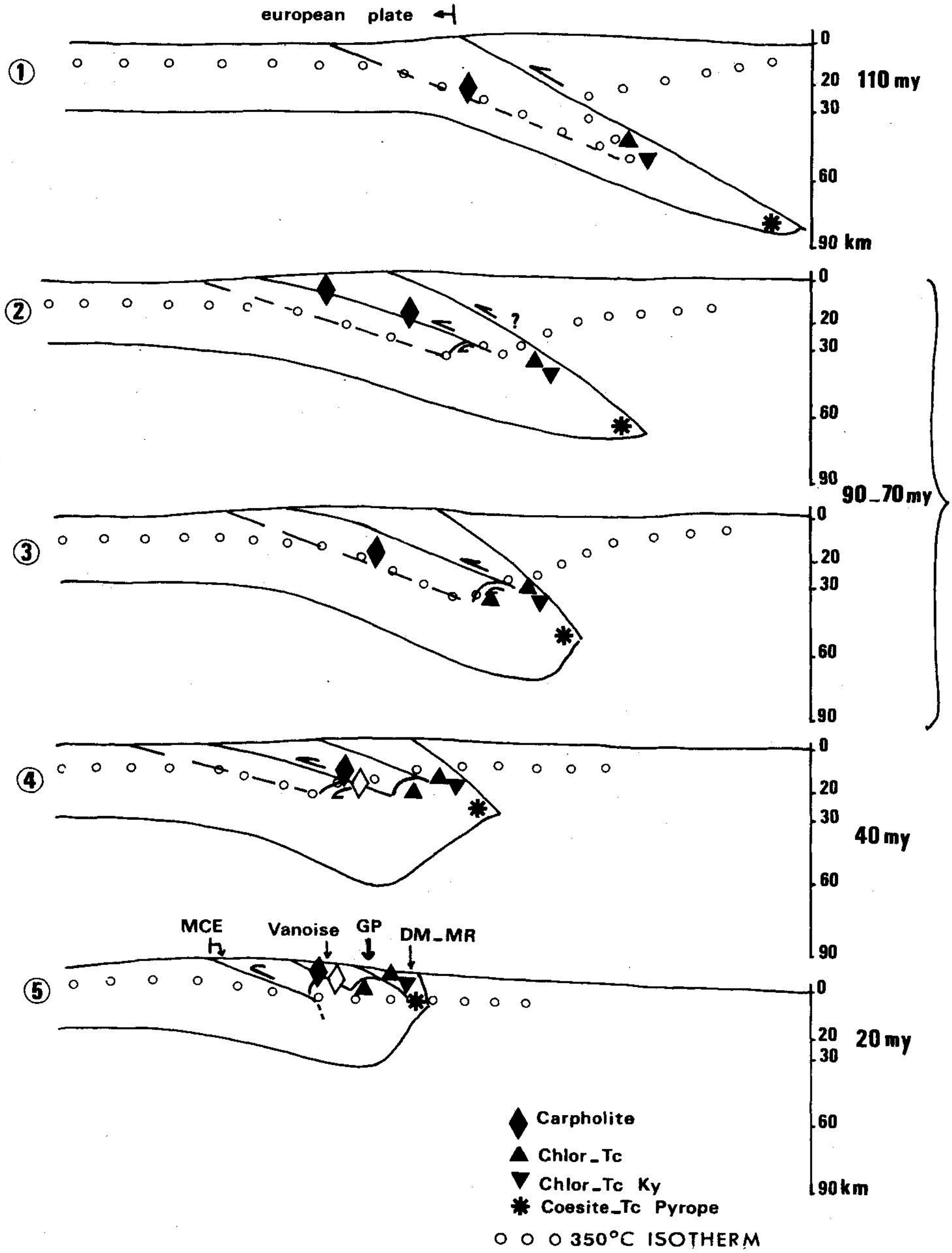

Fig. 6 Tentative reconstruction of the tectono-metamorphic evolution of the Western Alps emphasising the deep subduction of continental crust, the migration in-plate of intracrustal thrusts, the ductile thickening of the crust, and the role of the 350 °C isotherm (open circles) for tectonic decoupling and carpholite preservation or breakdown by coeval over- and underthrusting movements. Abbreviations: MCE: external crystalline massifs, GP: Gran Paradiso, DM: Dora-Maira, MR: Monte Rosa. Symbols used are the same as in Fig. 4; the solid ones indicate the appearance and later preservation of the relevant high-pressure assemblage.

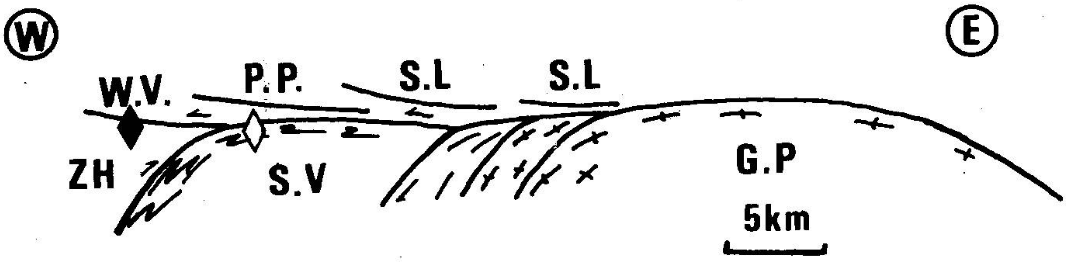

Fig. 7 Schematic cross-section along the Vanoise-Gran Paradiso traverse after CABY et al. (1978) and GOFFÉ and VELDE (1984). ZH: Zone Houillère, SV: southern Vanoise, GP: Gran Paradiso, WV: western Vanoise, PP: Prépiémontais nappe, SL: Schistes lustrés nappes. Solid lozenge: stable carpholite, open lozenge: partial breakdown of carpholite.

Interestingly, the boundary marking the incipient breakdown of carpholite (Fig. 5) seems to coincide with such a structure all along the chain: Chavière lineament in Vanoise, Preit lineament in the Cottian Alps, Fontane lineament in Liguria (GOFFÉ 1984). The thermal mechanism evidenced in Vanoise may then be tentatively extended to the rest of the carpholite zone.

- Furthermore, this process characterised by coeval over- and underthrusting implies a slicing of the crust under conditions close to the breakdown of carpholite, about 330–350 °C at 20 km depth. Noteworthily, these conditions are close to those under which the transition from brittle to ductile deformation may be expected for crustal material. The resulting possibility of a mechanical decoupling within the crust close to the 350 °C isotherm has just been envisaged for the Alps (LE PICHON et al., 1986) and seems very appealing in the present context. Upper units would be stacked to form the mountain chain and be early eroded (cf. GRACIANSKY et al., 1971; BONHOMME et al., 1980; MANGE-RAJETSKY and OBERHÄNSLI, 1983), while lower units would initially remain at depth, at least in the more external zones. In our reconstruction, we assumed that this decoupling mechanism with coeval over- and underthrusting repeatedly acted during the continental collision even if, admittedly, it has still to be demonstrated in the internal zones. In intermediate zones, the rise of the depressed isotherms in the rear part of the overthrusted units leads to rather general overprinting of the high-pressure assemblages (cf. Fig. 6–4 and zone B in Fig. 5).
- The uplift of the most internal and highest-grade units is achieved by the combination of erosion, ductile shortening and thickening of the crust, and upward thrusting onto cooler units, which prevents a too rapid thermal equilibration.

Conclusion

In the present study, we tried to show that the petrologic investigation of high-pressure metapelites is not of purely mineralogic interest but also provides us with fine tools for dissecting the thermal and tectonic evolution of a chain. Interesting results have just been obtained at low and extremely high grade, the presence of carpholite being a direct record of intracrustal thrusting while coesite and ellenbergerite demonstrate that subduction of continental crust is possible. However, these new tools have now to be extensively used in order to better constrain the tectonic models.

References

BEARTH, P. (1962): Versuch einer Gliederung alpinmetamorpher Serien der Westalpen. Bull. suisse Mineral. Pétrogr., 42. 127–137.

BEARTH, P. (1963): Chloritoid und Paragonit aus der Ophiolith-Zone von Zermatt-Saas Fee. Bull. suisse Minéral. Pétrogr., 43: 269–286.

BOCQUET, J. (1971): Cartes de répartition de quelques minéraux du métamorphisme alpin dans les alpes franco-italiennes. Eclogae geol. Helv. 64, 71–103.

BOCQUET, J. (1974): Etudes minéralogiques et pétrologiques sur les métamorphismes d'âge alpin dans les Alpes françaises. Thèse d'état, Univ. Grenoble, 476 p.

BONHOMME M.G., SALIOT, P., PINAULT, Y. (1980): Interpretation of K–Ar isotopic data related to metamorphic events in South-Western Alps. Bull. suisse Minéral. Pétrogr., 60, 81–98.

CABY R., KIENAST J.R. and SALIOT, P. (1978): Structure, métamorphisme et modèle d'évolution tectonique des Alpes occidentales. Revue Géographie physique et Géologie dynamique (2), vol. 20, 307–322.

CARON, J.M. (1977): Lithostratigraphie et tectonique des schistes lustrés dans les Alpes cottiennes septentrionales et en Corse orientale. Thèse d'état, Univ. Strasbourg, Sci. Géol. Mém. 48, 326 p.

CHOPIN, C. (1979): De la Vanoise au Massif du Grand Paradis: une approche pétrographique et radiochronologique de la signification géodynamique du métamorphisme de haute pression. Thèse 3e cycle, Univ. P. et M. Curie-Paris 6, 245 p.

CHOPIN, C. (1981): Talc-phengite, a widespread assemblage in high-grade pelitic blueschists of the Western Alps. J. Petrol. 22, 628–650.

CHOPIN, C. (1984): Coesite and pure pyrope in high-grade pelitic blueschists of the Western Alps: a first record and some consequences. Contrib. Mineral. Petrol. 86, 107–118.

CHOPIN, C. (1985): Les relations de phases dans les métapelites de haute pression: approches expérimentale et naturaliste, conséquences géodynamiques pour les Alpes occidentales. Thèse d'état, Univ. Paris 6, 80 p.

CHOPIN, C. (1986a): Phase relationships of ellenbergerite, a new high-pressure Mg-Al–Ti-silicate in coesite-pyrope-quartzite from the Western Alps. Geol. Soc. America Memoir 164 "Blueschists and related eclogites", 31–42.

CHOPIN, C. (1986b): Very-high-pressure metamorphism in the Western Alps: implications for subduction of continental crust. Phil. Trans. Royal Soc. London (in press).

CHOPIN, C. and MALUSKI, H. (1980): ^{40}Ar–^{39}Ar dating of high-pressure metamorphic micas from the Gran Paradiso area (Western Alps): evidence against the blocking temperature concept. Contrib. Mineral. Petrol. 74, 109–122.

CHOPIN, C. and MONIÉ, P. (1984): A unique magnesiochloritoid-bearing, high-pressure assemblage from the Monte Rosa: a petrologic and ^{40}Ar-^{39}Ar study. Contrib. Mineral. Petrol. 87, 388–398.

CHOPIN, C., KLASKA, R., MEDENBACH, O. and DRON, D. (1986): Ellenbergerite, a new high-pressure Mg–Al–(Ti,Zr)-silicate with a novel structure based on face-sharing octahedra. Contrib. Mineral. Petrol. 92, 316–321.

ELLENBERGER, F. and RAOULT, J. F. (1979): Les enseignements géologiques des roches de la Loze à Pralognan. Travaux scientifiques du Parc National de la Vanoise, 10, 37–63.

FREY, M., HUNZIKER, J.C., FRANK, W., BOCQUET, J., DAL PIAZ, G.V., JÄGER, E. and NIGGLI, E. (1974): Alpine Metamorphism of the Alps - a review. Bull. suisse Minéral. Pétrogr. 54, 247–290.

GILLET, P., CHOUKROUNE, P., BALLÈVRE, M. and DAVY, P. (1986): Thickening history of the Western Alps. Earth Planet. Sci. Lett. (in press).

GOFFÉ, B. (1979): La lawsonite et les associations à pyrophyllite-calcite dans les sédiments alumineux du Briançonnais. Premières occurrences. C.R. Acad. Sci. Paris, D, 289, 813–816.

GOFFÉ, B. (1984): Le faciès à carpholite-chloritoïde dans la couverture briançonnaise des Alpes ligures: un témoin de l'histoire tectono-métamorphique régionale. Mem. Soc. Geol. It., 28 (in press).

GOFFÉ, B. and VELDE, B. (1984): Contrasted metamorphic evolutions in thrusted cover units of the Briançonnais zone (French Alps): a model for the conservation of HP-LT-metamorphic mineral assemblages. Earth. Planet. Sci. Lett. 68, 351–360.

GRACIANSKY, P.C. DE, LEMOINE, M., SALIOT, P. (1971): Remarques sur la présence de minéraux et de paragenèses du métamorphisme alpin dans les galets des conglomérats oligocènes du synclinal de Barrême (Alpes de Haute Provence). C.R. Acad. Paris, D 272, 3243–3245.

HUNZIKER, J.C. (1974): Rb–Sr and K–Ar age determinations and the Alpine tectonic history of the Western Alps. Mem. Ist. Geol. Miner. Univ. Padova 31, 55 p.

LEFÈVRE, R. (1982): Les nappes briançonnaises internes et ultrabriançonnaises dans les Alpes cottiennes méridionales. Thèse d'état, Univ. Paris sud - Orsay, 435 p.

LEFÈVRE, R. and MICHARD, A. (1976): Les nappes briançonnaises internes et ultrabriançonnaises de la bande d'Acceglio (Alpes franco-italiennes); une étude structurale et pétrographique dans le faciès des schistes bleus à jadéite. Sci. Géol. Bull. 29, 183–222.

LE PICHON, X., BERGERAT, F. and ROULET, M.J. (1986): Plate kinematics and tectonics leading to the alpine belt formation: a new analysis. G.S.A. special book in honor of John Rodgers (in press).

MANGE-RAJETSKY, M., OBERHÄNSLI, R. (1982): Detrital lawsonite and blue sodic amphibole in the Molasse of Savoie, France, and their significance in assessing Alpine evolution. Bull. suisse Mineral. Petrogr., 62, 415–422.

MESSIGA, B., OXILIA, M., PICCARDO, G.B., VANOSSI, M. (1983): Fasi metamorfiche e deformazioni alpine nel Brianzonese e nel Pre-Piemontese - Piemontese esterno delle Alpi Liguri: un possibile modello evolutivo. Rend. Soc. It. Mineral. Petrol., 38 (1), 261–280.

OBERHÄNSLI, R., HUNZIKER, J.C., MARTINOTTI, G. and STERN, G. (1985): Geochemistry, geochronology and petrology of Monte Mucrone: an example of Eo-Alpine eclogitization of Permian granitoids in the Sesia-Lanzo zone, Western Alps, Italy. Chemical Geol. (Isotope Geosci. Sect.) 52, 165–184.

PERRIER, G. (1980): La structure des Alpes occidentales déduite des données géophysiques. Eclogae geol. Helv., 73, 407–424.

POGNANTE, U. (1984): Eclogitic versus blueschist metamorphism in the internal western Alps along the Susa valley traverse. Sci. Géol. Bull., 37, 29–36.

SALIOT, P. (1973): Les principales zones de métamorphisme dans les Alpes françaises. Répartition et signification. C.R. Acad. Sci. Paris, D, 276, 3081–3084.

SALIOT, P., DAL PIAZ, G.V. and FREY, M. (1980): Métamorphisme de haute pression dans les Alpes franco-italo-suisses. Géologie alpine, 56, 203–235.

VIALON, P. (1966): Etude géologique du massif cristallin Dora Maira, Alpes cottiennes internes, Italie. Thèse d'état, Univ. Grenoble, 293 p.

Manuscript received July 16, 1986; revised manuscript accepted August 15, 1986.