MITT.ÖSTERR.MINER.GES. 149 (2004)

EXPLANATORY NOTES TO THE MAP:
METAMORPHIC STRUCTURE OF THE ALPS
WESTERN AND LIGURIAN ALPS

by

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1 - Generalities and choice for the representation

In the Western and Southwestern part of the Alps from Val d'Aoste in the North to Genova in the South, the Alpine Type Metamorphism, characterized by a high-pressure low-temperature regime (HP-LT), is particularly well expressed.
In this area, the retromorphic conditions influencing the rocks during their exhumation paths have never exceeded the temperatures attained at peak pressure. As a result, during decompression of the metamorphic rocks the PT-t trajectories always remained cooling paths. Therefore, our choice was to represent the metamorphic peak conditions, while the retromorphic evolutions are only indicated together with ages in the inset map and not on the main map. However, these retromorphic imprints exist and can be locally intense.

2 - The main metamorphic zones

In the area of the Western Alps the HP-LT conditions range from the very low-grade greenschist facies to the Ultra High Pressure (UHP) conditions crossing 8 of the 14 metamorphic facies encountered in the whole map.
Generally the contacts between the metamorphic units correspond to tectonic contacts (thrusts, normal faults, strike-slip faults). However, on the map, the boundaries between the metamorphic units frequently appear as crossing the tectonic contacts mainly when they correspond to the limits of paleogeographic domains.

Detailed examination of these contacts shows that this feature is the result of the late tectonic evolution bringing into contact units of equal metamorphic grade but different ages. Two main examples of this feature can be found in the blueschist and in the eclogite facies zones that overlap both oceanic (Schistes Lustrés nappe) and continental (Briançonnais and internal basements) domains: the high pressure metamorphic conditions prevailing in the Briançonnais domain and in the internal basements are Late Tertiary in age (Oligocene) while in the oceanic domain these conditions are Early Tertiary in age (early Eocene) (DUCHENE et al, 1987; AGARD et al. 2002).

Despite the simplistic choice of the metamorphic criteria, only oriented on the metamorphic peak conditions and thus related to early orogenic processes (subduction), the metamorphic imprint at the map scale is consistent with the geometry of the Western alpine arc, i.e. the PT metamorphic conditions increase from the external to the internal part of the arc with an inward movement of the subducting slab. However, more complex situations resulting from the initial structure of the European or Apulian margins or resulting of the late tectonic of the belt can be depicted. Two main examples of this situation are particularly interesting to be mentioned (see also the general cross section of the Western Alps shown in Figure 1):

1) The repetition of the metamorphic sequence (greenschist-blueschist-eclogite facies) observed in the Northwestern part of the Alps from the external to internal basements through the Valaisan, the Briançonnais and the Ligurian domains. This can be related to the prolongation of the southern realm of the Valaisan oceanic domain;
2) The decrease of the metamorphic grade in the deepest part of the belt, i.e. the easternmost side of the Dora Maira internal basement, with a reappearance of HT blueschists facies conditions in the Pinerolo unit below the overlying eclogitic units. This metamorphic structure can be interpreted as the result of the late tectonic evolution of the orogenic wedge.

The nature of some boundaries of the metamorphic facies is still not totally determined. Some boundaries run along isograds as for the appearance of the very low-grade metamorphism in the external part of the belt or as for the external limit of the HP greenschist facies in the Briançonnais domain, North-West of Briançon. Some could be undefined tectonic contacts as for the Blueschist - Upper Blueschist facies limits in the Schistes Lustrés nappe in the Cottian Alps, East and South-East of Briançon.

The HP-LT metamorphic conditions occur in all rocktypes encountered in the belt including continental basements, oceanic crust and an exceptional variety of metasediments. Generally, the PT conditions recorded by the different rocktypes are consistent. Only in two specific areas of the Schistes Lustrés domain, West of the Gran Paradiso and West of the Monviso, the metamorphic imprint of mafic blocks or slices contrasts with the surrounding pelitic lithologies. This is represented, on the map, by coloured dots superposed on the main metamorphic facies. These features suggest the possible existence of a melange of high grade metamorphic blocks in a matrix of lower metamorphic degree.

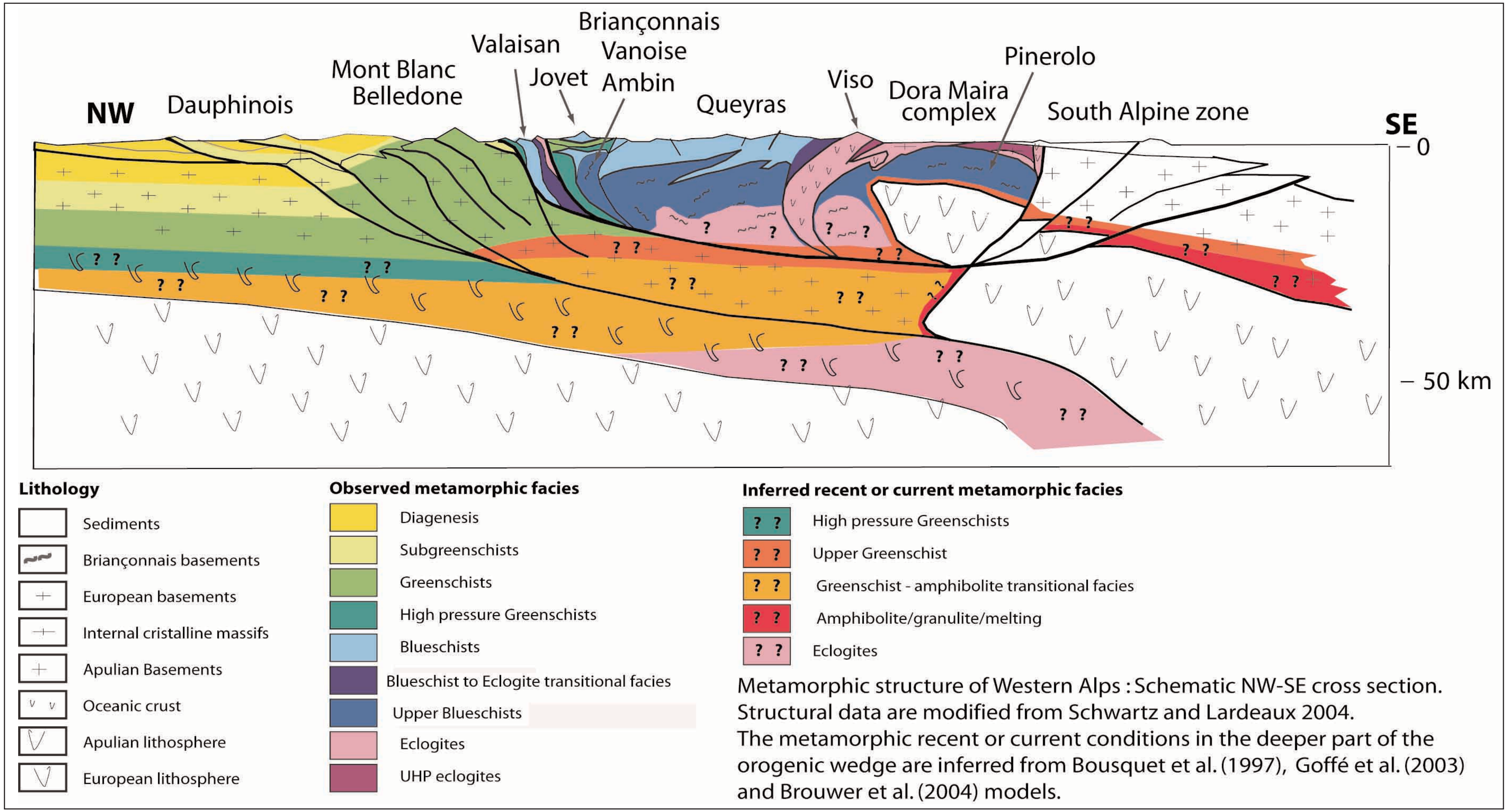

Figure 1

Schematic projected NW-SE cross section of the Western Alps showing the metamorphic structure. The upper part of the cross section is drawn using surface metamorphic data as drawn in the map. The deeper part of the cross section is hypothetically inferred from numerical modelling and data coming from Central Alps, considering this area as a possible further evolution for Western Alps. A moderated thermal imprint is also considered as a possible current deep metamorphic structure resulting from a slab breakoff event as modelled by BROUWER et al. (2004). This metamorphic thermal imprint around the mantel indenter could thus be compared to those observed around the peridotitic bodies of Beni Bousera and Ronda in the Rif and Betic Chain.

3 - The metamorphic facies in the Western Alps

The metamorphic facies used here are mainly based on B. EVANS (1990) metamorphic grid defined for metabasites. In the case of the Western and South-Western Alps, these facies definitions actually cover a large variety of other index minerals depending of the nature of the protoliths, particularly, the metasediments. In the following, the specific index minerals found in the belt are listed and discussed for each metamorphic facies in function of the lithology. In each facies the minerals regarded as defining the metamorphic index mineral assemblages are printed in bold, while additional index minerals, locally present, are added in italic. Localities where a specific mineralogy can be found are indicated in brackets.
For organic matter, only the appearance of graphite is considered to enhance the absence of diamond in the HP conditions. In the other case the organic matter is considered as disordered carbonaceous matter.

- **Sub greenschist facies (200–300°C; P < 4kbar)**
  Mafic system: albite – chlorite – pumpellyite (Chenaillet)
  Volcanoclastic metasediments: **laumontite – prehnite** (Champsaur)
  Pelitic system: **kaolinite – chlorite – illite - interlayered illite-smectite**,
  Rectorite (Nappe de Digne)
  Metabauxites (Prealpes, Devreneuse): **diaspore – kaolinite – berthierite**

- **Lower greenschist facies (300–400°C; P < 4kbar)**
  Mafic system and Volcanoclastic metasediments: **albite – chlorite – epidote – actinolite**
  Na rich metapelites: **albite – chlorite – phengite**
  Al rich metapelites: **pyrophyllite – chlorite – illite-phengite – paragonite** - *cookeite (Ultra-Dauphinois unit, La Grave and la Mure area) – chloritoid (Northern part of Ultra-Dauphinois North of the Maurienne valley) – paragonite*

- **Upper greenschist facies (300–400°C; 4 < P < 8kbar)**
  Mafic system and Volcanoclastic metasediments: **albite – lawsonite – chlorite** – *paragonite – phengites – riebeckite-crossite – pumpellyite – stilpnomelane*
  Pelitic system: **phengite – chlorite** – *chloritoid (Northern Vanoise, Ligurian Alps)*

- **Blueschist facies (300–400°C; 8 < P < 15kbar)**
  Mafic system: **glaucophane – lawsonite – jadeite-quartz** – *pumpellyite*
  Marble and calcschists: **aragonite** - *glaucophane*
  Evaporites (Maurienne Valley near Bramans): **jadeite + quartz – anhydrite** – *selaite – sulfur*
  Pelitic system: **ferro- magnesiocarpholite –phengite** – *chloritoid – pyrophyllite – lawsonite – aragonite – cookeite – paragonite*
  Na rich metapelites: jadeite + quartz – glaucophane – chlorite – *paragonite*
  Al rich metapelites and metabauxites: **ferro- magnesiocarpholite – pyrophyllite – diaspore – chloritoid** – *lawsonite – aragonite – cookeite – paragonite – sudoite (Antoroto metabauxite, Liguria) – gahnite – euclase (Western Vanoise)*

- **Upper Blueschist facies (400–500°C; 10 < P < 15kbar)**
  Mafic system: **glaucophane – epidote** - *garnet or omphacite (+ jadeite)-sphene*
  Granitic System: **phengite – jadeite**- *epidote (Southern Vanoise, Ambin, Acceglio)*
  Pelitic system: **chloritoid – glaucophane – phengite** – *graphite (Southern Vanoise, Ambin massif)*

- **Blueschist to eclogite transitional facies (400–480°C; 15 < P < 20kbar)**
  Mafic system: **glaucophane – epidote** (+ *garnet)* – **omphacite** *(+ jadeite)-sphene*
  Pelitic system: Mg rich **chloritoid – phengite** – *magnesiocarpholite – garnet – graphite*

- **Eclogite facies (500–600°C; 13 < P < 25kbar)**
  Mafic system: **garnet – omphacite – quartz** – *zoisite – phengite- rutile*
  Granitic system: garnet-jadeite-phengite- *zoisite-rutile (Sesia-Lanzo zone)*
  Pelitic system: **chloritoid – kyanite – phengite – garnet** – g*laucophane – paragonite-graphite (Sesia-Lanzo zone)*

- **Ultra high-pressure facies (600–800°C; 25 < P < 40kbar)**
  Mafic system: **garnet – omphacite – zoisite – coesite** – *kyanite – Mg-chloritoid – talc (Mon Viso)*
  Pelitic system: **Magnesiochloritoid – kyanite – phengite – pyrope – talc – coesite** – *Magnesiostaurolite – ellenbergerite– bearthite – magnesiodumortierite – graphite (Dora Maira massif)*

4 - Diversity of Alpine high-pressure mineralogy: an overview

The diversity of the Alpine metamorphic high-pressure assemblages reflects the contrasted bulk-rock chemistries of the metamorphosed protoliths. Hereafter, we present a review of the metamorphic assemblages recognized in different chemical systems.

a) Metasediments

Compared to the earlier published metamorphic maps FREY et al. (1999), and beside the different choice of the metamorphic representation, the main new data of this present map is the large and continuous expression of the high-pressure and low temperature metamorphic conditions in the metasediments as shown in Figure 2 and 3.
This new data mainly results from the consideration of the ferro- and magnesiocarpholite occurrences in the metapelites. The magnesiocarpholite first discovered in the metabauxites of Western Vanoise (GOFFÉ et al., 1973, GOFFÉ & SALIOT 1977) is now known in all the high-pressure metasedimentary lithologies having initially a low Na content (i.e. bauxite, aluminous pelites, common pelites, sandstones, conglomerates). They occur abundantly in the Briançonnais domain in Western and Southern Vanoise, Cottian and Ligurian Alps, both in the Paleozoic series (Stephanian and Permian schists and metaconglomerates) and in the Mesozoic cover (Triassic series, Dogger metabauxites, Eocene flysch).

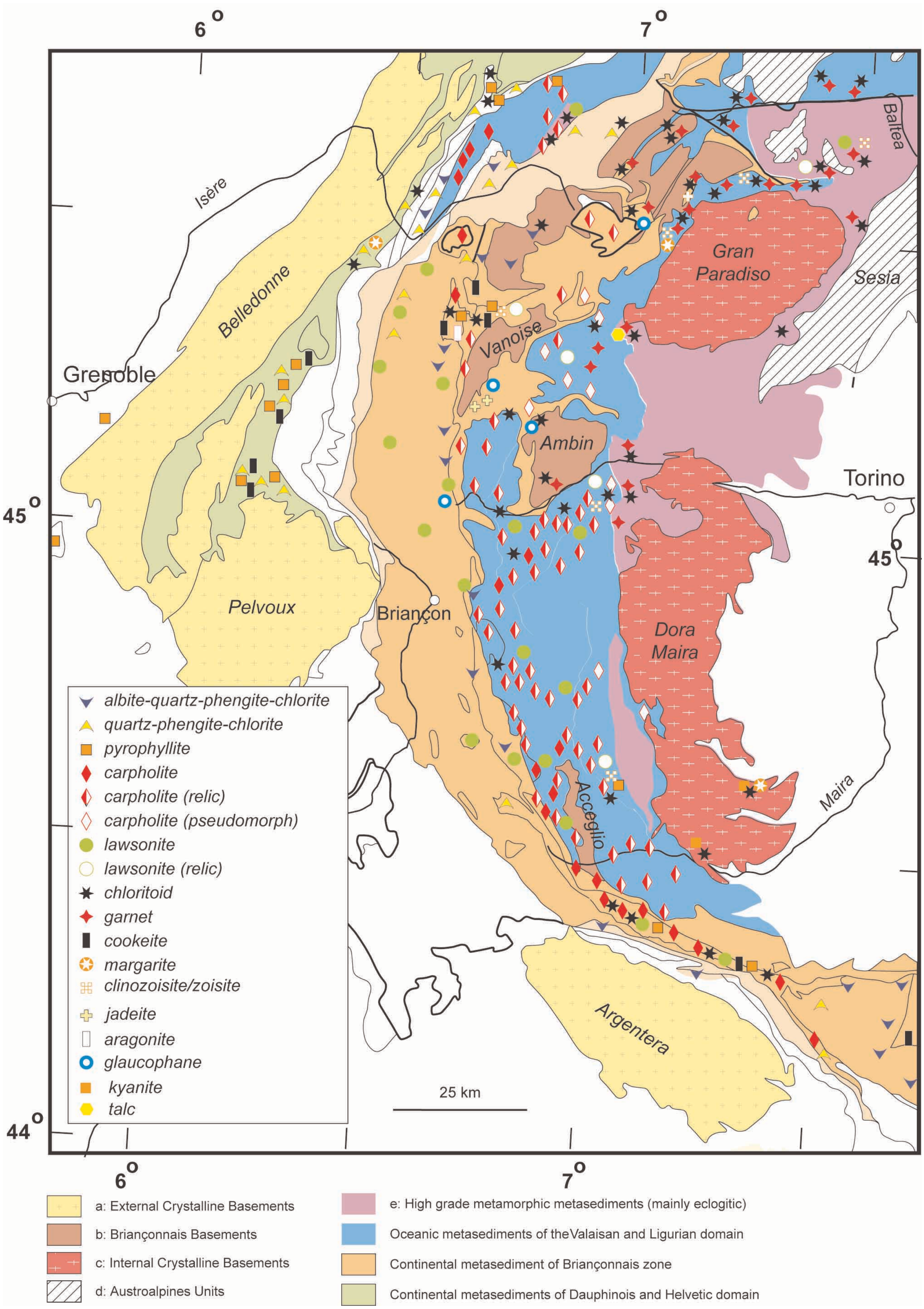
6°
7°
Isère
Belledonne
Grenoble
Pelvoux
Briançon
Vanoise
Ambin
Gran Paradiso
Sesia
Baltea
Torino
Dora Maira
Maira
Acceglio
Argentera
45°
44°
25 km
albite-quartz-phengite-chlorite
quartz-phengite-chlorite
pyrophyllite
carpholite
carpholite (relic)
carpholite (pseudomorph)
lawsonite
lawsonite (relic)
chloritoid
garnet
cookeite
margarite
clinozoisite/zoisite
jadeite
aragonite
glaucophane
kyanite
talc
a: External Crystalline Basements
b: Briançonnais Basements
c: Internal Crystalline Basements
d: Austroalpines Units
e: High grade metamorphic metasediments (mainly eclogitic)
Oceanic metasediments of theValaisan and Ligurian domain
Continental metasediment of Briançonnais zone
Continental metasediments of Dauphinois and Helvetic domain

Figure 2
Occurrences of metamorphic index mineral observed in Alpine metasediments of the Greenschist and Blueschist metamorphic zones of Western Alps used to draw the metamorphic map.
White: Sediments or very low grade metasediments.

They occurs also widely in blueschists facies metapelites of the Tethys oceanic domain in the Valaisan realm (Versoyen and Brêches de Tarentaise units) and in the Ligurian zone from the more external klippe of Mont Jovet (AGARD, 2001, pers. com.) to the more internal one in the Sestri-Voltaggio-Cravasco unit. Its stability domain in blueschists metamorphic facies and its progressive replacement during the prograde and retrograde metamorphic evolution by chloritoid, chlorite, phengite and generally numerous minerals of the KMASH reduced system can be used to describe and to quantify continuously the metamorphic evolution (GOFFÉ, 1982; CHOPIN 1983; GOFFÉ & CHOPIN 1986; VIDAL et al., 1992; GOFFÉ et al., 1997; JOLIVET et al. 1998; VIDAL & PARRA 2000; PARRA et al., 2002; AGARD et al., 2001; among others). In the Western Alps, ferro- and magnesiocarpholite ranges from 80% of the Fe end member to 85% of the Mg one. In the Briançonnais domain, Fe-Mg-carpholites are commonly associated to pyrophyllite and record pressures between 8 to 12 kbar for temperatures ranging from 330°C to 400°C. In the Schistes Lustrés domain, the Fe-Mg-carpholites are never associated to pyrophyllite and shown equilibrium with phengites through the reaction: Chlorite + muscovite + quartz ⇔ phengite + Fe-Mg-carpholite. The reported maximum pressures for this reaction are around 15-18 kbar for temperatures reaching 480°C (GOFFÉ et al., 1997; AGARD et al. 2001). These conditions are those of the upper blueschists facies reported on the map in the inner part of the Schistes Lustrés domain and the Valaisan, at the external limit of the eclogite domain.

Lawsonite occurrences are also very common in metapelites and calcschists of the Schistes Lustrés units (CARON & SALIOT, 1969; SICARD et al., 1986) and in meta-sandstones of the Briançonnais domain. Lawsonite is often associated to Fe-Mg-carpholite in continental and oceanic metasediments. Its distribution is wider than that of Fe-Mg-carpholite with occurrences in upper greenschist and eclogite facies units, where Fe-Mg carpholite is not stable and was never found. This widest distribution is in accordance with a largest stability field toward both low pressure and high temperature conditions.

Cookeite (lithium chlorite) is also an important metamorphic index mineral in the Briançonnais (Barrhorn, Vanoise, Cottian and Ligurian Alps) and Dauphinois (la Grave, La Mure) domains of the Western Alps. It occurs widely in metapelites, metaconglomerates and metabauxites in association with quartz or diaspore in a large variety of low to high-pressure metamorphic assemblages (GOFFÉ, 1977, 1980, 1984; SARTORI, 1988; JULLIEN & GOFFÉ, 1996). Cookeite records medium temperature conditions (300 to 450°C) of the greenschist to blueschist facies (VIDAL & GOFFÉ, 1991). Cookeite shows a pressure dependence of its polytypism with an increase of structural ordering with pressures from 100 to 1500 Mpa (JULLIEN et al., 1996).

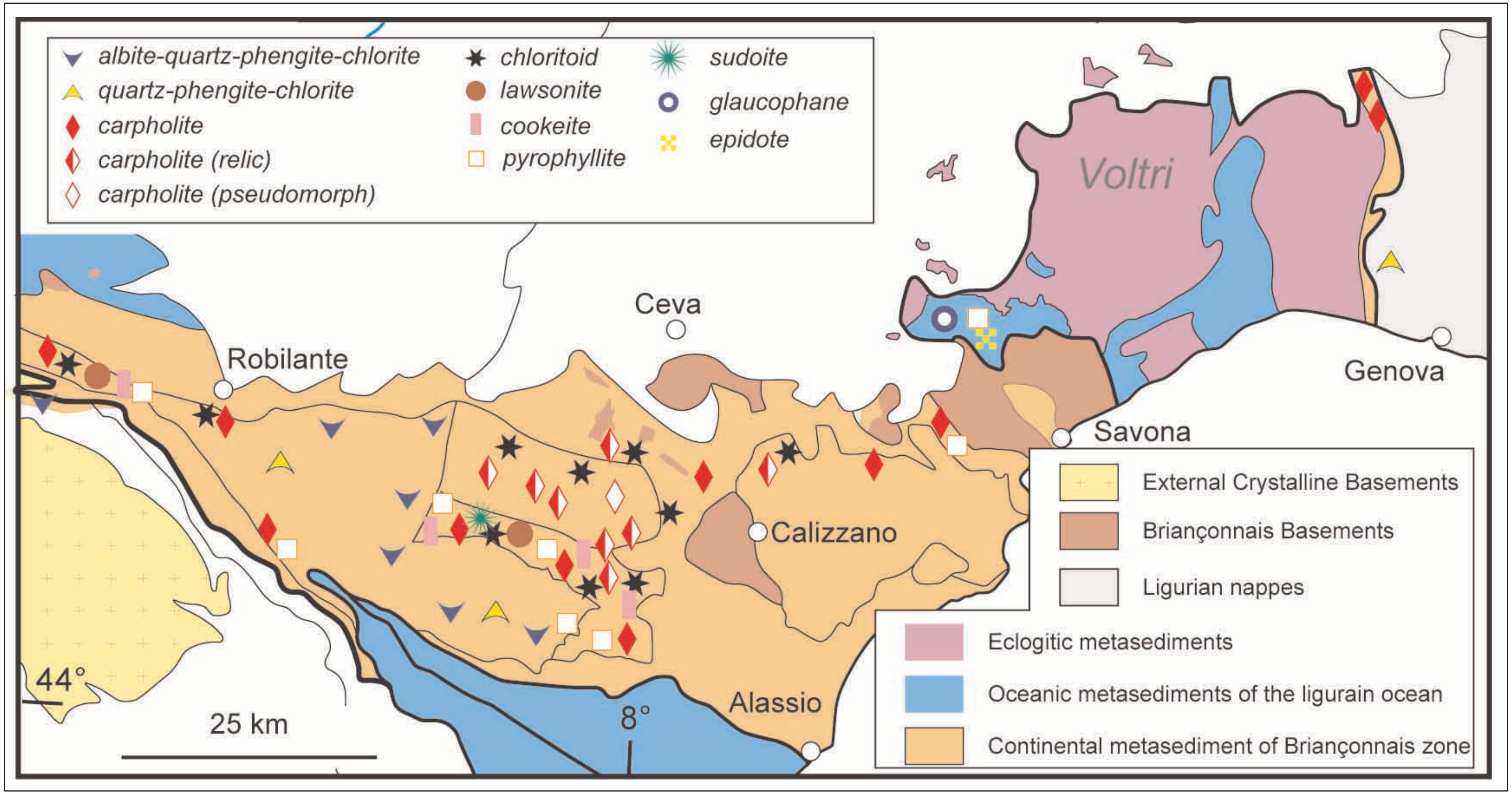

Figure 3

Occurrences of metamorphic index mineral observed in Alpine metasediments of the Greenschist and Blueschist metamorphic zones of Ligurian Alps used to draw the metamorphic map. The structural frame is from the general map.

Very high metamorphic conditions lead the metapelitic system to react continuously to give appearance to kyanite which is associated to a specific mineralogy showing a linear increase of Mg content with the metamorphic grade. This results in pure Mg-endmembers of FMASH system minerals in the coesite stability field such as: magnesiochloritoid, magnesiostaurolite, pyrope, talc, clinochlore in association with unique very high pressure minerals like ellenbergerite, magnesiodumortierite or bearthite (CHOPIN and CHOPIN et al., 1981-1995, SIMON et al., 1997).

Under quartz-eclogite facies conditions, metapelites have been described and analysed in details since their discovery in the Sesia-Lanzo zone (DAL PIAZ et al, 1972; COMPAGNONI et al., 1977; LARDEAUX et al., 1982; VUICHARD & BALLÈVRE, 1988), where the association of quartz, phengite, jadeite, chloritoid , garnet and glaucophane characterizes the so-called "eclogitic micaschists". Similar well preserved eclogitic metapelites occur in other Austro-Alpine units of the Western Alps for example the Monte Emilius massif (DAL PIAZ et al., 1983).

The organic carbonaceous matter of the metasediments is also an interesting way to follow the metamorphic evolution. The organic carbonaceous matter is particularly abundant in the Western Alps either as coal in the Briançonnais domain or as diffuse marine organic matter in the Schistes Lustrés series. With increasing metamorphic grade the organic matter evolvs continuously from disoriented structures (turbostratic) in the sub-greenschist facies to perfectly organized graphite in UHP facies in the Dora Maira massif through carbons having peculiar onion like shaped structures in the blueschist facies (BEYSSAC et al., 2002). This evolution can be linked to the temperature evolution without evidences of a pressure effect (BEYSSAC et al., 2002). Graphite appears in high temperature and high-pressure blueschist facies. Diamond was never found, neither characteristic carbonaceous structures resulting of its retromorphosis (BEYSSAC & CHOPIN, 2003). Anomalous well preserved organic matter (C_n gas, liquid hydrocarbons, low evolved solid carbonaceous matter) are reported in the blueschist facies of the Western Vanoise (GOFFÉ, 1982, GOFFÉ & VILLEY, 1984).

b) Mafic rocks

Mafic rocks from the Western Alps represent ophiolite suites mainly formed during the opening of the Piemont-Ligurian oceanic basin durin Jurassic times (LOMBARDO et al., 1978; POGNANTE, 1980; LOMBARDO & POGNANTE, 1982). However, a limited number of mafic rocks derive from metamorphosed continental crust as for example meta-amphibolites and meta-granulites from the Sesia-Lanzo zone (LARDEAUX & SPALLA, 1991).

Mineralogical and geochemical studies have demonstrated that the Western Alps ophiolites derive from partial melting of rather homogeneous peridotites which generated melts similar to normal – MORB. Consequently Alpine metabasalts represent differentiated (Fe-Ti rich) tholeiitic liquids. On the other hand, metagabbros display a wide spectrum of compositions ranging from Cr-Mg rich gabbros to Fe-Ti gabbros. Therefore, the so-called mafic metamorphic rocks in the Western Alps derive from the variuos protoliths following a tholeiitic differentiation trend:

- Mg (± Cr) rich gabbros: olivine-bearing cumulates,
- Intermediate gabbros: gabbro-norites,
- Fe-Ti rich gabbros: ilmenite and magnetite-bearing gabbros,
- Fe-Ti rich basalts

Moreover, some of these lithologies have been subjected to ocean-floor hydrothermal activity leading to the development of rodingitic alterations. When affected by high-pressure Alpine metamorphism, these rocks correspond to metarodingites with peculiar mineralogical associations (BEARTH, 1967; DAL PIAZ, 1967).
In our metamorphic map, we select Fe-Ti rich metabasalts and metagabbros for the definition of the metamorphic facies because, in comparison with other gabbro compositions, the ophiolitic Fe-Ti rocks show better developed high- pressure and low-temperature metamorphic assemblages. Metagabbros, in many cases, show incomplete metamorphic recristallization allowing to study reaction mechanisms at the boundaries between the magmatic mineral relics.

At quartz-bearing eclogite-facies conditions, the following mineralogical associations have been recognized (LOMBARDO et al, 1978; DAL PIAZ & ERNST, 1978; LARDEAUX et al., 1986, 1987; POGNANTE & KIENAST, 1987).
- Mg (± Cr) rich metagabbros: omphacite (± smaragdite), pale blue/colourless glaucophane, zoisite, ± chlorite, ± Mg-chloritoid, ± talc,± kyanite, ± scarce garnet, ± fuchsite
- Intermediate metagabbros: omphacite , garnet, zoisite, glaucophane, ± jadeite, ± talc, ± paragonite
- Fe-Ti rich metagabbros and metabasalts: omphacite (± jadeite), garnet, zoisite, rutile, glaucophane, ± paragonite, ± phengite, ± clinozoisite, ± Fe-talc
- Metarodingites: diopside and / or «omphacitic clinopyroxene», grandite and / or grossular rich garnet, epidote, chlorite, ± idocrase, ± amphibole, ± Ti-clinohumite

Under blueschist-facies conditions, the following associations have been described:
- Mg (± Cr) rich metagabbros: Amphibole, chlorite, clinozoisite, ± white micas
- Intermediate metagabbros: Na-amphibole, chlorite, ± clinozoisite, ± sphene, ± lawsonite
- Fe-Ti rich metagabbros and metabasalts: Acmite-rich clinopyroxene, «omphacitic» clinopyroxene, glaucophane, epidote (or lawsonite), sphene, ± garnet, ± white micas

In Fe-Ti matagabbros, at P-T blueschist facies conditions, the chemical evolution of the clinopyroxenes is controlled by the existence of non-omphacitic unmixing domains for temperatures lower than 350°C (CARPENTER, 1980). Fe-Ti metagabbros show different chemical evolution of their initial magmatic clinopyroxene (augitic-cpx). Indeed, under low-temperature blueschist facies conditions (i.e. lawsonite-glaucophane conditions), the increase of the P-T conditions during Alpine metamorphism is recorded by an increase of the Fe-content in clinopyroxene from the core to the rim of the initial magmatic clinopyroxene, with apparition of acmite-rich clinopyroxene on the crystal rims (POGNANTE & KIENAST, 1987). Whereas under high-temperature blueschist (i.e. zoisite-glaucophane conditions), the increase of the P-T conditions during Alpine metamorphism is characterized by an increase of the Na component in clinopyroxene leading to the crystallisation of omphacite (SCHWARTZ, 2001).

Spectacular metamorphic transformations can be observed in mafic rocks of continental origin. In eclogitized amphibolites and granulites, high-temperature calcic amphiboles are progressively replaced by calco-sodic (barroisite) and sodic amphiboles (glaucophane), sometimes in association with phengites. Associations of zoisite, garnet and omphacite are developed at the expense of plagioclase or at the plagioclase/amphibole, plagioclase/ilmenite or plagioclase/pyroxene boundaries, while coronas of rutile are frequently developed around ilmenite grains.

c) Meta-granitoids

In the Western Alps the following protoliths have been recognized for the meta-granitoids:

- Biotite- bearing granites and granodiorites,
- Two-micas granites,
- Fe-rich syenites,
- Trondhjemites, plagiogranites and quartz-keratophyres in ophiolites.

It should be underlined that eclogitized metagranites from the Sesia-Lanzo zone have been regarded as the first indication for the subduction of the continental crust (DAL PIAZ et al., 1972; COMPAGNONI & MAFFEO, 1976; COMPAGNONI et al., 1977; LARDEAUX et al., 1982; OBERHÄNSLI et al., 1982).

Under quartz-eclogite facies conditions, in mica-rich granites and granodiorites, the igneous mineralogy is replaced by an high-pressure metamorphic association composed of: jadeite, phengite, garnet, zoisite, rutile and quartz. K-feldspar is generally recristallised but remains stable sometimes with intergrowths of white micas and quartz. An association of jadeite and zoisite replaces plagioclase, while, close to the biotites/plagioclases boundaries, Ca-rich garnet develops as thin coronas. Biotites are replaced by coronitic garnets and an association of phengite, quartz and rutile. Magmatic muscovites are replaced by celadonites-rich white micas, while quartz recristallised (sometimes in coesite) and zircons, apatite and tourmalines remain as recital phases.

In Fe-rich syenites (LARDEAUX et al., 1983), the metamorphic high-pressure mineralogy is composed by ferro-omphacites, garnets and epidotes.

In leucocratic rocks from Alpine ophiolites (i.e. trondhjemites, quartz-keratophyres or plagiogranites), the Alpine eclogite facies metamorphism leads the development of: jadeite, quartz, phengite, ± garnet, ± epidote and rutile (LOMBARDO et al., 1978; POGNANTE et al., 1982).

Meta-granitoids reworked under blueschist facies conditions have been described in Vanoise, Ambin and Acceglio massifs (GAY, 1973; SALIOT, 1978; GANNE et al., 2003; ROLLAND et al., 2000; SCHWARTZ et al., 2000). In the Acceglio massif the metamorphic conditions reach the transition between high-temperature blueschist and eclogite facies conditions. The observed metamorphic assemblages consist of an association of quartz, jadeite, phengite, lawsonite or epidote, ± almandine-rich garnet. Secondary magmatic minerals like zircons, apatite and tourmaline are frequently well preserved.

5 - Conclusions

The metamorphic structure of the western part of the Alpine belt shows probably the best preserved example of the "Alpine-type" metamorphism with a continuous evolution of high pressure conditions from very low temperature conditions to the highest ones. These conditions can be observed in all lithologies with a near theoretical coherence between them.
As shown in the synthetic cross section through the Western Alps (Fig.1), these high-pressure and low-temperature conditions can be considered as relicts of the early (pre Oligocene) evolution of the belt related to the subduction processes. Three main geodynamic consequences can be emphasised after our metamorphic analysis:

- Even in a mature collisional belt like the Western Alps, the memory of subduction processes should be well preserved in a fossil accretionnary wedge like the western internal Alps.
- Both oceanic and continental crustal slices should be involved in the subduction zone during plate convergence. In Western Alps, numerous examples of subducted continental crust have been exhumed and are now preserved in Austro-Alpine (i.e. Sesia-Lanzo, Mt. Emilius klippe, etc.) and Penninic units (i.e. Internal Crystalline Massifs, Dora-Maira, Gran-Paradiso, Monte Rosa, etc.).
- The huge mass of weathered sediments issued from the erosion of the Hercynian belt and reworked during the Thethys opening along its passive margins, led to a peculiar metamorphic belt constituted by a large metasedimentary orogenic wedge characterized by prevalent high pressure-low temperature conditions (GOFFÉ et al. 2003). This could be considered as the definition of the so-called Alpine type metamorphism sensus stricto characterized by a high-pressure – low-temperature regime of 10°C/km or less. These metamorphic conditions contrast with those prevailing early in the Eastern Alps and lately in Central Alps where the pressure-temperature ratio is highest even at high pressure (see the map) and where mainly continental crust is involved in the orogenic process.

Now, the present-day ongoing continental collision process involves the European crust and the thermal regime is changing. Alpine metamorphism evolves from the early high-pressure and low-temperature conditions to present-day high-temperature and medium-pressure metamorphic conditions. These conditions, clearly expressed in the Central Alps, can be already observed in the external part of the Western Alps around the external crystalline massifs and probably prevail at depth in the orogenic root (Fig. 1).

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manuscript received: June 2004
manuscript accepted: July 2004