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

Band: 79 (1999)

Heft: 1: The new metamorphic map of the Alps

Artikel: Pre-Alpine metamorphism of the Internal zones of the Western Alps

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DOI: https://doi.org/10.5169/seals-60196

SCHWEIZ. MINERAL. PETROGR. MITT. 79, 23–39, 1999

Pre-Alpine metamorphism of the Internal zones of the Western Alps

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Abstract

Two types of basement are distinguished in the Internal Western Alps. (i) The ancient basement is characterized by the following metamorphic facies sequence: eclogite (in the Ligurian Alps, followed by granulite ± migmatite) → M-P, then lower-P amphibolite → greenschist. On the basis of geological and radiometric data from the Briançon zone the amphibolite facies is considered as Pan-African in age. However, it is also assigned a Variscan age in the Internal Penninic massifs, the Sesia zone and the Ligurian Alps. In the Briançon zone the amphibolite-facies imprint predates Ordovician granitoid intrusions and, in the Internal Penninic massifs (Gran Paradiso, Monte Rosa), it predates Variscan granitoid intrusions, which produced a contact metamorphism. Permian felsic and mafic intrusions, also with a contact aureole, and Permian ages repeatedly found in micas are evidence of a widespread thermal event of that age. This event ended with the Permian-Triassic intermediate and felsic volcanism commonly found in the Ligurian Alps. (ii) The second type of pre-Alpine sequence, the so-called younger basement, which occurs in part of the Briançon zone, possibly also in the Dora-Maira massif, is assigned a lower Palaeozoic age and is lacking any identifiable pre-Alpine metamorphic imprint. The basement units of the Western Alps are considered to have originated from Gondwana and accreted to Eurasia during the Alpine orogeny. However, according to some authors, they already accreted during the Variscan orogeny.

Keywords: Western Alps, Internal zones, basement, pre-Alpine metamorphism.

1. Introduction

In the Internal Western Alps, basement rocks are exposed in the Briançon-Gd St-Bernard zone, the Internal Penninic massifs, the Sesia zone, the Dent Blanche nappe, the Austro-Alpine klippen of Val d'Aosta, and the Canavese zone. Small outcrops are found in the Valais-Versoyen zone (the Pointe Rousse slice) and in the Subbriançon zone near Moûtiers. There are other isolated occurrences related to, and south of, the Dora-Maira massif. Olistoliths of unclear origin occur in the Combin zone. The subdivision into structural zones is Alpine, but it may have been predetermined by pre-Alpine structural and magmatic events. (General statements on the structure of the Western Alps are given in DESMONS et al., 1999, this volume.)

There are two contrasting opinions as concerns the paleogeographic origin of these units. According to the first, the Briançon zone and the Internal Penninic massifs were accreted to Laurentia during the Variscan orogeny and since that time evolved with Eurasia, as did the External Alpine zones (for these see VON RAUMER et al., 1999, this volume). According to the second, the Variscan accretion only involved the External Alpine zones, and both the Penninic and Austro-Alpine zones were located on the Gondwanian margin until their Alpine accretion to Eurasia in Mesozoic and Cainozoic times. This may explain

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the lack of Variscan tectonic-metamorphic-magmatic imprint in parts of the Internal basements. The present authors are divided on this problem, owing to varying observational data from the various fields. In particular, the Ligurian Alps are interpreted on the basis of a Variscan accretion, whereas in the northern and central Internal Western Alps the second interpretation is, at least, seriously taken into consideration (e.g. DESMONS, 1992, and ref. therein). Evidence supporting both options will be mentioned below.

In this paper and in accordance with common practice among Alpine geologists, all rocks older than the latest Variscan magmatic and sedimentary rocks are collectively called basement rocks, even if they have not been metamorphosed before Alpine times. Most are siliceous or silicate-rich, in contrast to the Mesozoic cover sequence. A main regional unconformity separates the folded and metamorphosed basement from the Permo-Carboniferous cover.

Data up to 1992 on the Alpine basement have been collected in the book edited by VON RAUMER and NEUBAUER (1993), in particular in the papers by BONIN et al., CORTESOGNO et al., DESMONS and MERCIER, THÉLIN et al., SANDRONE et al., and DAL PIAZ. Many of the references included in these papers will not be repeated here.

2. Protoliths and occurrences

In the northern and central Western Alps, two main types of basement sequences have been distinguished on the basis of their metamorphisms. Remnants of pre-Alpine medium- and lower-grade metamorphism are present in the first type, which thus was polymetamorphic already before Alpine times, but none are seen in the second (DESMONS and FABRE, 1988). For the following, they will be called ancient and younger basement respectively in accordance with DESMONS and PLOQUIN (1989) who first used the terms in the northern and central Briançon zone. The younger basement is often designated as monometamorphic, because it apparently experienced only Alpine metamorphism. However this in itself was polymetamorphic (see DESMONS et al., 1999, this volume). The lack of any identifiable pre-Alpine metamorphism does not mean that the protoliths were post-Variscan, i.e. Upper Carboniferous-Permian, as the interpretation in the Briançon zone has been for decades. Although a Devonian-Visean age has also been suggested, the favoured protolith age for the younger basement is Cambrian to Silurian. This age is based on lithological comparisons and limited radiometric results. In the Ligurian Alps, all basement rocks record a polyphase pre-Alpine metamorphic evolution, with one exception: clasts from the Westphalian-Stephanian conglomerates include metasedimentary rocks displaying only one pre-Alpine foliation and granitoids devoid of any pre-Alpine metamorphic imprint.

2.1. NORTHERN AND CENTRAL WESTERN ALPS: ANCIENT BASEMENT

The ancient basement includes (Fig. 1)

(i) in the Briançon-Gd St-Bernard zone:
- the Mischabel-Siviez zone (+ Leverogne),
- the Ruitor (called Pontis zone in the Gd St-Bernard area and further east),
- the Berisal and Upper Stalden zones in the Gd St-Bernard,
- the Sapey zone,
- small slices at the bottom of the Pourri-Bellecôte massif (also called northern Vanoise),
- the Chasseforêt massif (also called southern Vanoise),
- the Clarea series in the Ambin massif,
- various slices near Briançon,
- the Sagnères and Pelvo d'Elva slices in the Acceglio zone;

(ii) in the Internal Penninic massifs:
- the host rocks of the Gran Paradiso and Monte Rosa granitoids;
- in the Dora-Maira massif the units consisting of polymetamorphic rocks, including the Brossasco-Isasca unit;

(iii) in the Austro-Alpine basement:
- the Eclogitic Micaschist complex of the internal Sesia zone,
- scarce remnants of the host rocks in both the Gneiss Minuti complex of the external Sesia zone and in the Arolla series of the Dent Blanche nappe,
- the Valpelline zone in the Dent Blanche nappe,
- the Second Diorito-Kinzigitic zone,
- parts of the klippen in the Aosta valley.

The *sedimentary* protoliths are mostly shales and locally Na-rich greywackes, with some sandstones and conglomerates (Ambin massif, Pontis nappe), and very minor marbles (reported from the Ruitor massif, Dora-Maira, Valpelline series, Second Diorito-Kinzigitic zone, the Perrière Austroalpine outlier in Val d'Aosta, and the Sesia zone where they appear to define a stratigraphic horizon). In the Siviez-Mischabel nappe an upper and a lower zone have been distinguished. The Ergischhorn zone, composed of micaceous sandstones, arkoses and conglomerates, lies below the

Barneuza zone. The rock types of this upper zone were more diverse, essentially being composed of pelites in association with basic and felsic igneous rocks.

These sedimentary rocks are associated with abundant *mafic rocks* and a few *ultramafic rocks*. The basic rocks are frequently interlayered with leucocratic rocks, and both now form banded amphibolites. Gabbroic, or ophitic, textures are locally preserved, e.g. in the Turtmann valley (Siviez-Mischabel nappe), the Berisal unit, the Ruitor, Chasseforêt, Ambin and Gran Paradiso massifs and in the Sesia Eclogitic Micaschist complex in the lower Aosta valley where the gabbro is layered. A few ultramafic rocks have been found, deriving from cumulus pyroxenite (Ruitor), basaltic komatiite (Berisal) and cumulus peridotite (Eclogitic Micaschist complex). The majority of the occurrences, which lack any relict magmatic textures or minerals, are considered to be former sills, lava flows or volcaniclastics. Chemically the extrusive rocks are tholeiitic basalts, either Ti-rich (Chasseforêt) or Ti-low (Ambin-Clarea), with MORB (Ruitor; T-MORB in Siviez-Mischabel) or within-plate affinities (Ruitor, Siviez-Mischabel, Gran Paradiso). A gabbro from the Gran Paradiso massif displays subalkaline characters and a continental affinity. A spilitic chemical trend is frequently noted. There is clear evidence of more than one basic magmatic event. In the Berisal unit Precambrian to Cambrian ages have been obtained from mafic and ultramafic rocks respectively.

The leucocratic rocks in the banded amphibolites have sometimes been interpreted as plagiogranitic dykes, but an origin in bimodal volcanism is most commonly attributed. An interpretation as metasedimentary rocks seems less likely.

At least two generations of *intrusive felsic magmatic rocks* occur within the ancient basement. One generation is Ordovician in age, the age of the other is still to be conclusively determined (see the radiometric data below). Only the largest occurrences are shown on the map. These metagranitoids are subalkaline in the Ruitor, calc-alkaline (granodiorite or monzogranite) in the Pontis nappe and alkaline peraluminous to metaluminous in the Sapey unit, in Thyon in the Gd St-

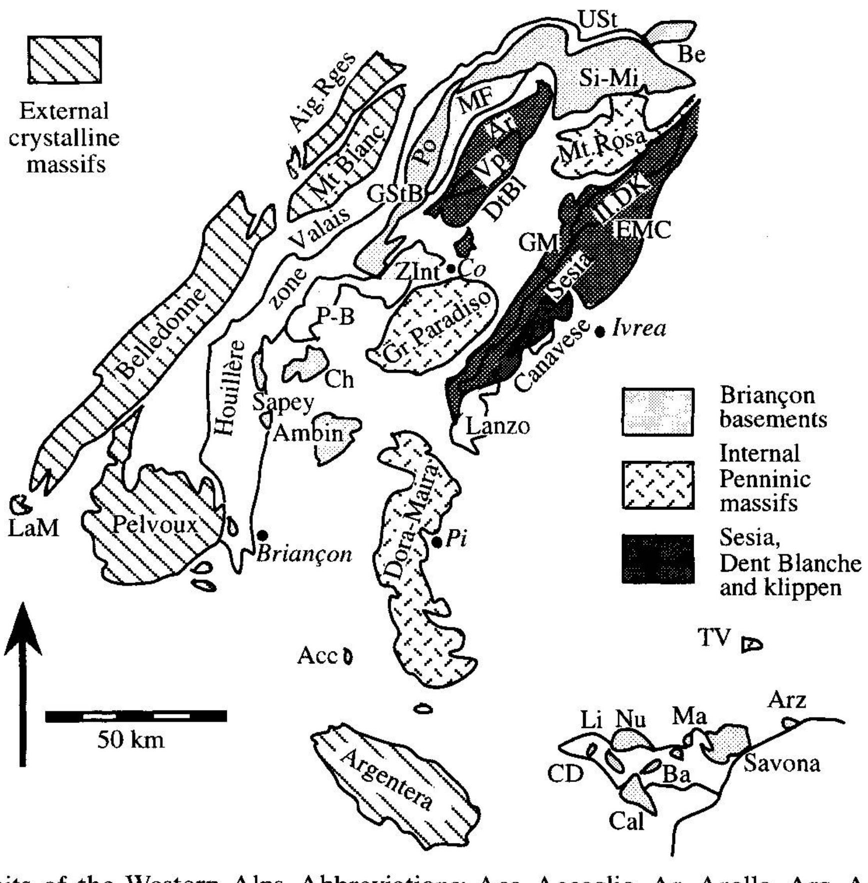

Fig. 1 Basement units of the Western Alps. Abbreviations: Acc. Acceglio, Ar. Arolla, Arz. Arenzano, Ba. Bagnaschino, Be. Berisal, Cal. Calizzano, CD. Costa Dardella, Ch. Chasseforêt, Co. Cogne, EMC. Eclogitic Micaschist complex, GStB. Gd St-Bernard, GM. Gneiss Minuti, II.DK. Second Diorito-Kinzigitic zone, LaM. La Mure, Li. Lisio, Ma. Mallare, MF-M. Mt Fort-Métailler, Nu. Nucetto, *Pi.* Pinerolo, Po. Pontis, SV. Sestri-Voltaggio, TV. Torrente-Visone, USt. Upper Stalden, VP. Valpelline, ZInt. Zona Interna.

Bernard and at Pta Muret in northern Dora-Maira (all dated more or less accurately as Ordovician, and mainly thought to be anatectic in origin). Granitoid is lacking in the Ambin-Clarea massif. Pegmatite, keratophyre, and diorite are minor rock types in the Ruitor. A few aplites and pegmatites considered to be Ordovician in age are found in the Siviez-Mischabel.

Huge granitic bodies dated as Variscan, or considered as Variscan on geological or petrological grounds, occur in the Internal Penninic massifs and the Siviez-Mischabel unit, but not in the central Briançon massifs.

2.2. NORTHERN AND CENTRAL WESTERN ALPS: YOUNGER BASEMENT

The younger basement includes

(i) in the Briançon-Gd St-Bernard zone:

- the Bellecôte-Pourri massif (also called northern Vanoise),
- the Zona Interna,
- the Mont Fort-Métailler nappe,
- and possibly also the Ambin Formation in the Ambin massif;

(ii) in the Internal Penninic massifs:

- possibly the Pinerolo nappe, which is the lower sheet in the Dora-Maira massif.

In the Bellecôte-Pourri massif, interlayered bimodal basic (spilitized low-Ti tholeiites) and felsic rocks (quartz-albite-white mica rocks, perhaps ignimbritic rhyolites, Na- and Si-keratophyres) are intruded by a cumulus gabbroic body. It has been assumed that late magmatic alteration affected this body. The upper part of the sequence consists of marine pelites intruded by Ti-rich tholeiitic sills. Layers rich in organic matter are present. The Zona Interna also contains metasedimentary rocks interlayered with metabasic rocks.

Bodies of anorogenic alkaline granophyre occur in the Bellecôte-Pourri massif, the Zona Interna and the Ambin series of the Ambin massif. The Zona Interna includes a tonalitic intrusive body known as the Cogne-Valsavarenche "diorite". Many of these felsic bodies, as well as some of the ancient basement, may have a lower Palaeozoic age and recent radiometric data support such an age for several cases (see below).

The Mt Fort-Métailler zone contains pelites, greywackes and abundant, mostly interlayered, basic rocks. The Ambin Formation in the Ambin massif consists of a transgressive sequence including a basal conglomerate with basement blocks up to 1 m across, acidic extrusive rocks, mainly granophyres, minor pelitic and rare basic rocks. The Pinerolo zone of the Dora-Maira massif, drawn on the map as Carboniferous in age, also consists of pelitic, arenitic, felsic and basic igneous protoliths, intruded by large felsic bodies.

2.3. LIGURIAN ALPS BASEMENT

In the *Ligurian Briançon zone*, the basement bodies display some features unknown – or so far undiscovered – in the northern and central zones, thus, the interpretation differs. Future work will establish whether the different data reveal different evolutions or not. The following lithological groups are distinguished:

(i) Polyphasic metamorphic rocks showing two main schistosities, S_1 and S_2, and comprising three complexes: a) a migmatite-eclogite complex, b) a gneiss-amphibolite complex, and c) a granitoid orthogneiss complex (orthogneiss$_I$).

(ii) Metamorphosed intrusive rocks, including dykes, emplaced in all three polyphasic complexes before, or during, the D_2 event (orthogneiss$_{II}$).

(iii) Post-orogenic intrusive rocks (CORTESOGNO et al., 1996).

The Bagnaschino and Arenzano units are formed by the polyphase metamorphic rocks of lithological group (i). The largest Savona and Calizzano massifs contain rocks of all three lithological groups. The basement of the Mallare, Nucetto, Costa Dardella and Lisio units consist of orthogneiss of lithological group (ii). The post-orogenic acidic intrusive rocks, ranging in composition from tonalite to aplite, intruded rocks of lithologic groups (i) and (ii), as well as the Permian-Carboniferous cover.

In the *migmatite-eclogite complex*, the migmatites represent the products of anatectic processes affecting metasedimentary protoliths, probably pelites and arenites; the eclogites preserve an overall tholeiitic-basalt composition.

The *gneiss-amphibolite complex* originates from a sequence of arenitic and pelitic sedimentary protoliths associated with tholeiitic basalts and calc-alkaline rhyolites. Serpentinized ultramafic rocks are rare. It has been envisaged that the rocks of both the migmatite-eclogite and gneiss-amphibolite complexes derive from the same protoliths. The granitoid orthogneisses$_I$ originate from an intrusive sequence consisting of granodiorite, granite, leucogranite and aplite. The common occurrence within the gneiss-amphibolite complex of minor metagranitoid lenses (probably transposed dykes), showing compositional affinity with the granitoid orthogneisses, suggests that the latter were emplaced within the gneiss-amphibolite complex during an early orogenic (pre-S_1) event.

Intrusive rocks, emplaced between the D_1 and

D_2 events, are: (i) gabbroic lenses emplaced in the migmatite-eclogite complex during the decompression phase; (ii) subalkaline basic and intermediate dykes intruded in the migmatite-eclogite and gneiss-amphibolite complexes; and (iii) peraluminous monzogranites, intruded as large masses and dykes in the migmatite-eclogite, the gneiss-amphibolite and the granitoid orthogneiss complexes. Locally, orthogneisses$_{II}$ also intruded fine-grained gneisses alternating with metapelites. An andalusite-bearing contact aureole suggests a shallow crustal level for their emplacement.

The upper levels in the Variscan metamorphic pile are recorded by *clasts* of *anchimetamorphic* metapelites and radiolarites reworked in the Upper Carboniferous conglomerates.

The *Torrente Visone* unit is built up by two superimposed lithostratigraphic complexes. The geometrically lower complex consists of siliciclastic arenite, rudite and quartzite with rare calcareous and dolomitic layers, intercalated with large rhyolite lenses bearing K-feldspar megacrysts. Metre-sized lenses of basaltic composition are interpreted as having derived from dykes cutting the volcano-sedimentary sequence. (ii) The upper complex consists of a sequence of arenaceous and pelitic layers with minor carbonate beds, and serpentinitic and basaltic lenses interpreted as olistoliths. It is debatable whether the upper complex represents pre-Alpine basement rocks or Mesozoic sequences. The former interpretation is supported by the rare occurrence of biotite and muscovite deformed during the Alpine H-P event.

2.4. LATE VARISCAN SEDIMENTARY AND MAGMATIC ROCKS

In the Ligurian Alps the *Permian-Carboniferous* layers overlie the basement as an unconformable *cover* and the contacts survived, on a local scale, the Alpine transposition, such as in the Calizzano, Mallare, Nucetto and Costa Dardella units. In the northern and central Internal Western Alps, Upper Carboniferous layers exist only in the Houillère zone where they grade into Permian layers, and the contact with basement rocks (the Sapey zone) is tectonic, often mylonitic. In the basement massifs the rocks are directly overlain by Permian rocks, the contact being either depositional or tectonic depending on the place under consideration.

On the map, the continental deposits of the Houillère zone – sandstones, conglomerates, shales and organic-matter-rich rocks – are shown as molasse, although the term is not entirely correct for these formations. The Pinerolo rocks of the Dora-Maira massif and the Money rocks of northern Gran Paradiso have received the same signature, in accordance with the generally assumed Upper Carboniferous to Permian age. However, as mentioned above, a lower Palaeozoic age is also envisaged for the Pinerolo complex (DESMONS and PLOQUIN, 1989; DESMONS and MERCIER, 1993).

In the Ligurian Alps, the Permian-Carboniferous sequence begins with Lower Westphalian arkoses interlayered with quartzite and conglomeratic sandy-pelitic fluvial lacustrine sequences probably corresponding to the "Houiller productif". Overlying these are quartz-micaceous sediments interbedded with acidic pyroclastites. The Upper Carboniferous-Lower Permian sediments are associated with rhyolites and andesites, and covered by thick acidic pyroclastites of dacitic, rhyodacitic and rhyolitic composition. At the top, lacustrine deposits are intercalated, and the sequence ends with Upper Permian Verrucano deposits.

The latest Paleozoic *magmatic* activity also includes *felsic* intrusions, felsic volcanism (andesite and calc-alkaline rhyolite) and basic intrusions. In the northern and central Western Alps, large felsic, mostly calc-alkaline, intrusions (now mainly augengneiss) are known in the Sesia zone (e.g. the Mucrone metagranitoid and the widespread metamorphic leucogranitic dykes), in the Siviez-Mischabel zone (the Randa body, aluminous subalkaline in composition), in the Dora-Maira massif (subalkaline to peraluminous Freydour and Sangone diorites, metagranite and orthogneiss of the Brossasco-Isasca unit), and, according to recent age data, in the western Gran Paradiso massif. These intrusions have been dated from Late Carboniferous to Permian.

The Canavese basement has been intruded by leucogranite, granite to granodiorite and minor diorite and gabbro.

In the Austro-Alpine zones a Late Variscan intrusion age is suggested for the protoliths of most Alpine orthogneisses (including the Gneiss Minuti of the external Sesia zone and the Arolla series of the Dent Blanche nappe) on the basis of the intrusion relationships, the local occurrence of a relict contact metamorphism and a few radiometric dates.

In the Ligurian Alps, granophyric (Mallare) and granitic (Savona) dykes which intrude the metamorphic basement and lack evidence of Variscan metamorphism, are considered to be cogenetic with the widespread calc-alkaline tonalites, granodiorites and granites (such as in Borda and Noli) which intruded into Upper Carboniferous-Lower Permian cover rocks. It seems likely that the intrusive activity is genetically related to the huge acidic Permian volcanism, and associated with a transpressional tectonic event.

Basic magmatism has been intense in Permian times in the Southern Alps (the Ivrea complex, see COLOMBO and TUNESI, 1999, this volume), layered gabbro occurs in the Dent Blanche nappe (Cervino-Matterhorn gabbro, and Arolla-Mt Collon), a minor occurrence is located in southern Sesia, and, according to recent zircon dating, more basic intrusions of Carboniferous-Permian age may exist in Sesia (not shown on the map). Small gabbro bodies and dykes intruding the Siviez-Mischabel sequences and their upper Palaeozoic cover have also been suggested to be Permian in age.

3. Metamorphic assemblages and facies

3.1. IN THE NORTHERN AND CENTRAL WESTERN ALPS

The main pre-Alpine metamorphic imprint in the *ancient Penninic* basement is amphibolite facies. Relics predating this amphibolite facies are rare. *Eclogites* affected by retrograde metamorphism occur in the Ruitor massif (the mineral sequence shows that they cannot be of Alpine age as once claimed by some authors), well preserved and symplectite eclogites are found at various levels of the Siviez-Mischabel unit, in the Turtmann and Matter valleys (THÉLIN et al., 1990, 1993; RAHN, 1991). In Turtmann eclogite, the garnet core is grossular-rich and the rim pyrope-rich (which demonstrates that a high pyrope content in garnet does not necessarily imply an Alpine age). Phengite is present both in the core of garnet and in symplectite after clinopyroxene. Possible eclogite relics older than the amphibolite association have been reported from the Aosta valley (GOUFFON, 1993; GOUFFON and BURRI, 1997). No structures are known to be related to this facies. In the Sesia zone and the Internal Penninic massifs, no relics of any pre-Alpine eclogite have been identified so far.

In the Ruitor massif a polyphase evolution under *amphibolite*-facies conditions was recognized: an S_1 foliation, defined by Hbl + Grt in basic rocks and by Ky + St + Grt in pelitic rocks, was succeeded by a new foliation, S_2, marked by Bt + Ms + Grt (mineral abbreviations according to BUCHER and FREY, 1994). The garnet is predominantly almandine (DESMONS et al., 1977; DESMONS, 1992), the white mica mainly ferrimuscovite. Plagioclase has been mentioned in Gd St-Bernard and Ruitor ($An_{\leq 20}$, BURRI, 1983). Locally, Alpine garnets have pre-Alpine cores, such as in the Brossasco-Isasca unit of southern Dora-Maira (MATSUMOTO et al., 1997) and in the Austroalpine Châtillon outlier of the middle Val d'Aosta (CONTE et al., 1997). In the Ruitor massif the last pre-Alpine assemblage (Ms + Bt ± Chl), associated with an S_3 foliation, denotes a *greenschist* facies. In the Gd St-Bernard area Sil + And postdate Ky + Bt (BURRI, 1983, and ref. therein). In the Ambin massif the Clarea series contains relics of Ms, Bt, Grt and pseudomorphs of St and Ky in metapelites, Ms, Bt and possibly Grt in orthogneiss, and brown Am, Ep and Grt in amphibolite. A widespread relictic pervasive foliation, defined by Ms and Bt, is considered to be pre-Alpine; it is characteristically absent from the monometamorphic Ambin series (BORGHI and GATTIGLIO, 1997; BORGHI et al., 1997).

In the northern Dora-Maira massif Grt + Ms are pre-Alpine relics which, together with, but now replaced, Bt + St + Ky, characterize an amphibolite facies (CADOPPI, 1990). The occurrence in the same locality of relictic fibrolitic sillimanite and biotite armoured in a porphyroclastic garnet has been interpreted by BOUFFETTE et al. (1993) as the evidence of pre-Alpine metamorphic conditions at the boundary between the amphibolite and the granulite facies. In the Brossasco-Isasca unit of southern Dora-Maira the following pre-Alpine amphibolite-facies assemblage has been described: Grt + Ms + Kfs + Bt + pseudomorphs of Sil, Pl and Ilm (COMPAGNONI et al., 1995). Relict or transformed staurolite has been mentioned by HENRY (1990) from other thrust sheets of southern Dora-Maira.

In the Gran Paradiso massif a pre-granitic foliation is observed. Relics of Bt, Ms, Kfs, Grt and Pl are found, as well as pseudomorphs after possible contact-metamorphic andalusite and cordierite. Sillimanite from both regional and contact metamorphism is widespread (COMPAGNONI et al., 1974).

In both Eclogitic Micaschist and Gneiss Minuti complexes of the Sesia zone, a relictic pre-Alpine amphibolite-facies garnet is common in metapelitic paraschists. Older *granulite*-facies assemblages, including Opx, Grt, Pl, brown Am, Bt, Qtz and prismatic Sil, have been reported from Monte Emilius (DAL PIAZ et al., 1983), the Eclogitic Micaschist complex of the Sesia zone (LARDEAUX and SPALLA, 1991; SPALLA et al., 1991; REBAY, 1997) and the Austro-Alpine slices of Perrière and Grun of middle Val d'Aosta (CONTE et al., 1997); these slices are not shown on the map owing to their small size.

In the Second Diorito-Kinzigitic zone and in the Valpelline series of the Dent Blanche nappe the amphibolite facies is largely prevalent, the

Alpine recrystallizations not having been penetrative. Granulite relics (Sil, Opx, brown Am, Kfs, Grt) are numerous in the Valpelline series, but are less common in the Second Diorito-Kinzigitic zone (+ plagioclase $An_{>50}$ as inclusions in garnet cores, VUICHARD, 1987). In the Valpelline series, two generations of garnet, the first associated with M-P granulite facies, the second with amphibolite facies, have been distinguished on the basis of armoured inclusions (GARDIEN, 1994; GARDIEN et al., 1994).

In the Canavese zone, the basement is different from both the Sesia and Ivrea zones, but similar to the South-Alpine Lake Schist Formation or the Orobic Alps basement (see COLOMBO and TUNESI, 1999, this volume). A low-grade amphibolite facies (associated with an S_2) has been followed by an andalusite-bearing greenschist facies, possibly of Variscan age (BIINO et al., 1988; BIINO and COMPAGNONI, 1989; BORGHI et al., 1996).

In the core of the Lanzo peridotite massif, which lacks penetrative Alpine deformation, the high-T mantle associations are perfectly preserved, apart from a still visible pre-Alpine (oceanic?) chrysotile serpentinization (BOUDIER, 1971), which is in agreement with the development of rodingites (RÖSLI et al., 1991).

In the *younger basement*, there is no trace of pre-Alpine metamorphism. It has thus been inferred that the possible range of the pre-Alpine grade is between *diagenetic* and *very-low,* or at a maximum the beginning of low.

Most pre-Alpine minerals present in the northern and central parts of the Internal Western Alps are listed in figure 2.

3.2. IN THE LIGURIAN ALPS

Within the migmatite-eclogite complex, eclogites are characterized by rotated (pre-kinematic) poikiloblastic garnet including Omp_I (Jd_{26-36} Aeg_{7-16}), subcalcic Am_I, Qtz, Zo, Rt and Phe. Garnet is overgrown by post-kinematic garnet coexisting with Omp_{II} (Jd_{30-47} Aeg_{0-15}), subcalcic Am_{II}, Zo_{II}, white $mica_{II}$ and Qtz. The garnet shows abrupt chemical differences between pre- and post-kinematic compositions (Alm_{30-56} Prp_{2-37} Grs_{14-50} Sps_{0-7} Adr_{0-10}) with a large pyrope increase coupled to a grossular decrease, and a minor almandine decrease (CORTESOGNO et al., 1997).

A decompressional evolution lacking evidence of deformation is found in the eclogites, characterized by omphacite breakdown to Di + Pl (An_{10-35}) ± Hbl and locally by the growth of Opx (Mg/Mg + Fe = 0.6–0.7, CaO 0.6–0.7 wt%, Al_2O_3 = 2.3–3.0 wt%). Following a D_2 deformation phase,

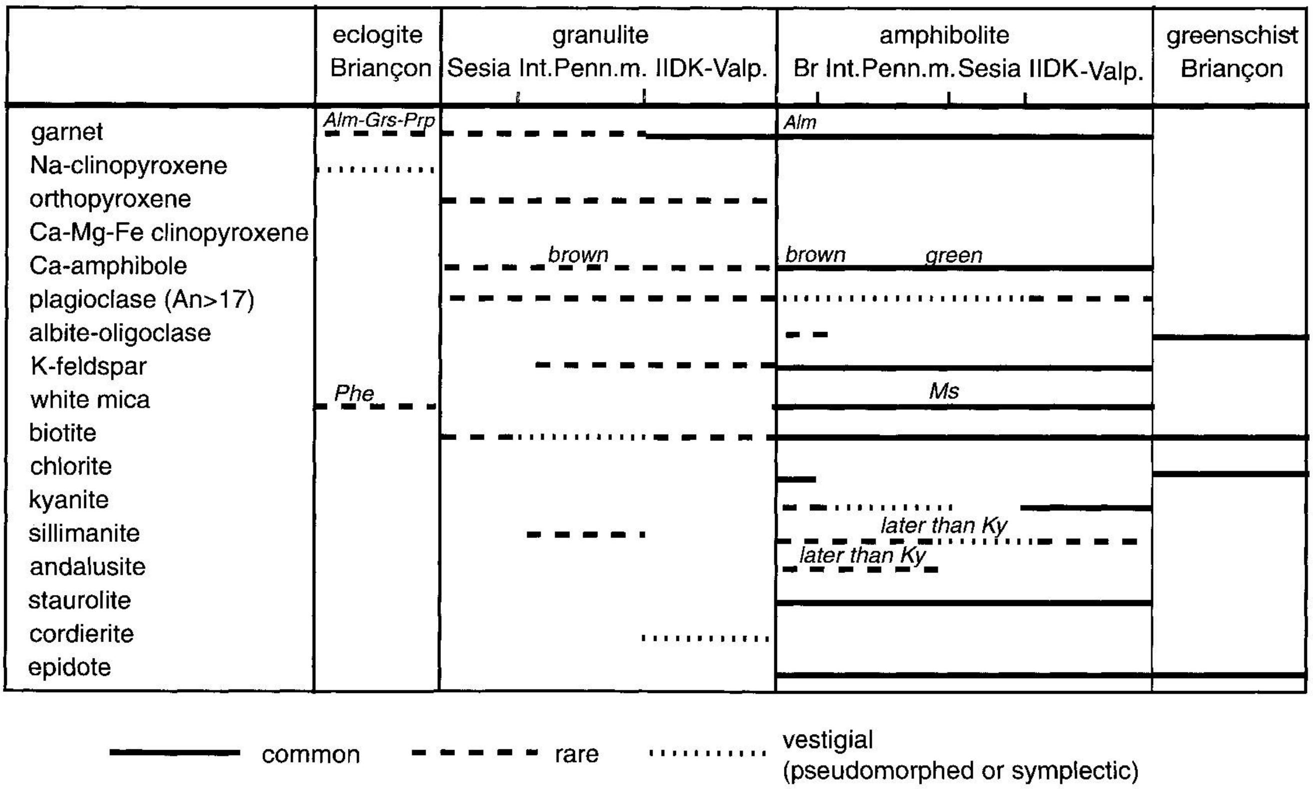

Fig. 2 Pre-Alpine mineral assemblages in the basement units of the northern and central Western Alps according to metamorphic facies. The metamorphic evolution is summarized in figure 5.

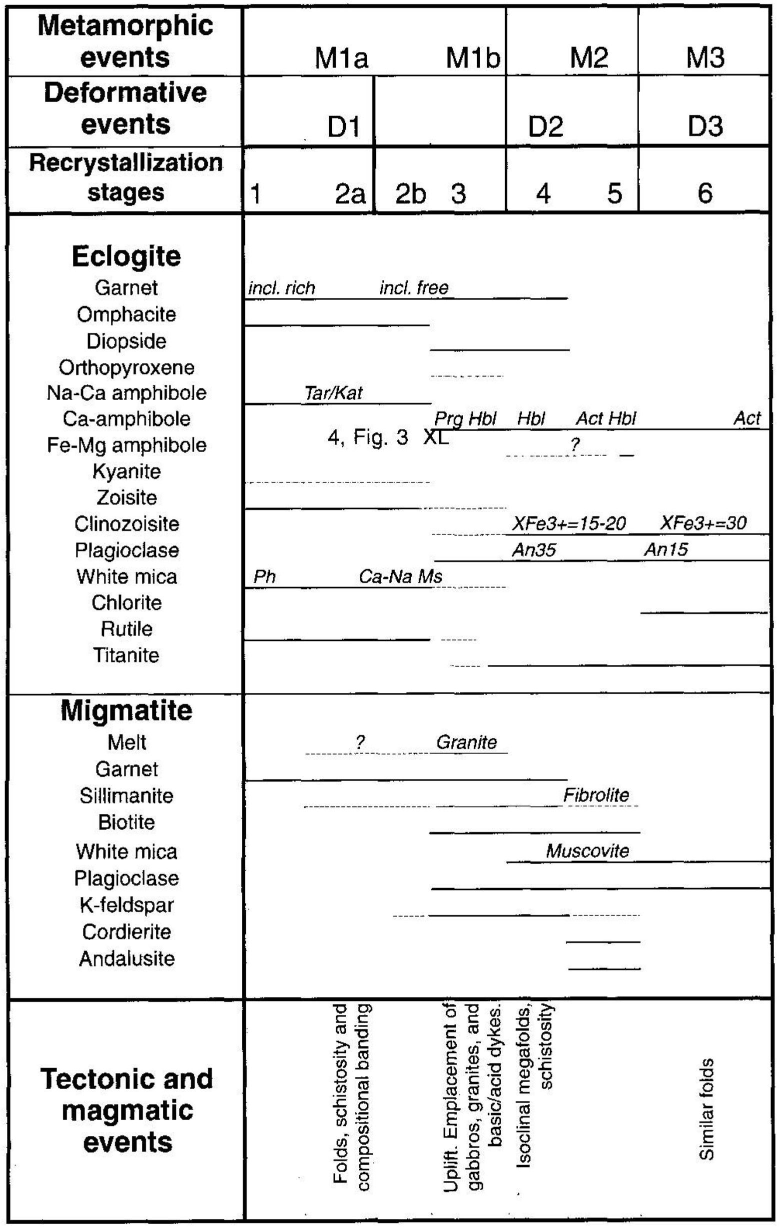

Fig. 3 Pre-Alpine assemblages in the *eclogite-migmatite complex* of the Ligurian Briançon zone with respect to deformation phases.

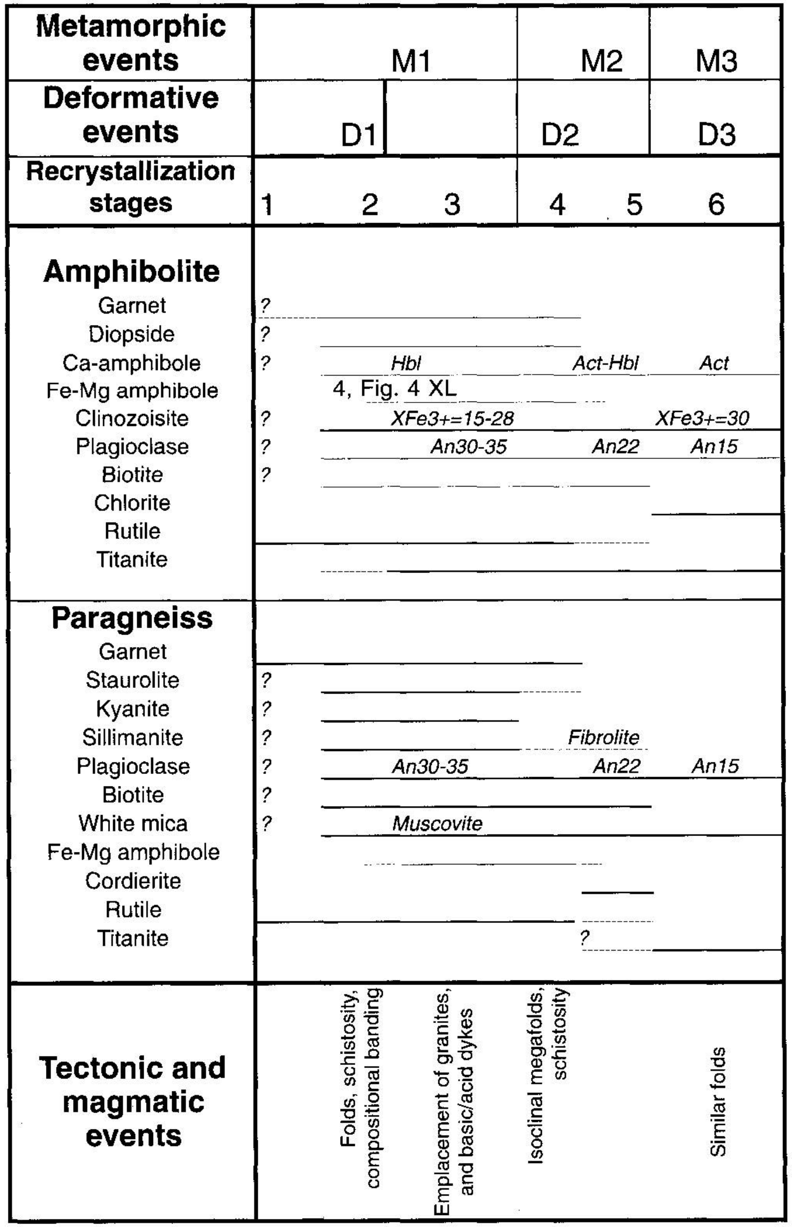

Fig. 4 Pre-Alpine assemblages in the *gneiss-amphibolite complex* of the Ligurian Briançon zone with respect to deformation phases.

a widespread re-equilibration under amphibolite-facies conditions is characterized by the post-kinematic growth of Pl, Hbl, Bt and Mag.

In migmatites, the melanosomes are characterized by the polyphase growth of Bt + Sil ± Pl ± Kfs ± Grt (Alm_{43-50} Prp_{37-44} Grs_{0-4} Sps_{2-5} Adr_{19-22}), and by a post-D_2 growth of Bt, Ms and And megablasts. Leucosomes occur as granitic veins, dykelets and impregnations, folded during the D_2 event. The melanosome assemblages developed during the decompressional event, possibly coeval with the emplacement of gabbroic bodies and basaltic to intermediate dykes.

In the gneiss-amphibolite complex, amphibolites preserve evidence of Hbl_I + Pl + Rt ± Grt (Alm_{47-68} Prp_{0-15} Grs_{17-37} Sps_{2-14} Adr_{0-8}) ± Di ± Czo assemblages developed along an S_1 schistosity and are commonly seen as bands. Garnet, hornblende, plagioclase and diopside usually show syn-kinematic growth with respect to the S_2 schistosity, whereas rutile is largely overgrown by titanite. Garnet zoning is characterized by Alm decrease and Grs increase toward the rim, and by an important decrease of spessartine from core to rim. Under post-kinematic conditions, Grt and Di were destabilized, Pl + Bt + Hbl + Mag (+ Crd ?) pseudomorphs formed after Grt, and actinolitic Hbl replaced Di.

Symplectitic Hbl and Pl locally occur in the Savona Massif. They have been interpreted as replacing omphacite (MESSIGA, 1981), thus indicating that eclogite-facies conditions were attained in part of the gneiss-amphibolite complex.

In paragneisses a Pl (An_{25}) + Qtz + Bt + Ms + Rt assemblage is widespread; it may coexist with garnet (Alm_{62-83} Prp_{4-11} Grs_{5-27} Sps_{1-4} $Adr_{0-1.5}$) and, in Al-rich bulk-rock compositions, with Sil + Ky + St. The assemblage which developed together with the S_1 schistosity has in part been re-equilibrated during the D_2 event. The uneven distribution of Al-silicate minerals in the basement units of the Ligurian Alps (e.g. Ky + Sil + St are widespread in the Savona massif, Ky + St occur in the Arenzano massif and Sil occurs sporadically in the Calizzano massif) suggests a metamorphic zonation during the eo-Variscan event.

In the orthogneisses Kfs and Ms recrystallized along the S_1 schistosity. The post-S_2 re-equilibration was characterized by the breakdown of Ky, Sil, St and Grt. Fibrolitic sillimanite grew locally around biotite and garnet.

The intrusive rocks emplaced between D_1 and D_2 were affected by amphibolite-facies re-equilibration. Assemblages of Pl + Bt + Ms without significant Kfs re-crystallization characterize the metagranites, whereas Pl and Hbl are the metamorphic phases in metagabbros and garnet is found occasionally in metabasalt dykes. The stability of mineral phases during the metamorphic evolution of both the migmatite-eclogite and gneiss-amphibolite complexes of the Ligurian Alps is represented in figures 3 and 4.

In the Torrente Visone basement only scarce relics of biotite and traces of an older schistosity survived the pervasive Alpine deformation and re-equilibration in eclogite facies. Preserved primary textures in metarhyolites and metaconglomerates are evidence of a moderate pre-Variscan metamorphic imprint.

4. Geochronological data

4.1. GEOLOGICAL

No fossil older than Upper Carboniferous has ever been found in the Internal basement units, even in the younger basement where the search for identifiable organisms within the organic matter has so far been unsuccessful.

The upper age limit of the pre-Alpine metamorphisms is lowermost Namurian, the oldest fossils in the Houillère zone being Namurian B-C to Westphalian A depending on the locality (MERCIER and BEAUDOUIN, 1987; BROUSMICHE-DELCAMBRE et al., 1995). The Namurian-lower Westphalian deposition of basal breccias and conglomerates, marks the end of the Variscan compressional event and the beginning of post-orogenic transtensional tectonics.

On geological grounds only, the younger basement sequences, free of any pre-Alpine metamorphism, have been assumed to be lower Palaeozoic or older in age (Pourri-Bellecôte: e.g. GUILLOT et al., 1993, and ref. therein), though other authors still consider Devonian-Lower Carboniferous as likely ages (Mt Fort: CHESSEX, 1995; Zona Interna: CIGOLINI, 1995).

For the middle- to high-grade metamorphism of the ancient basement, which is assumed to be older than the protolith age of the younger basement, a Pan-African age has been proposed (e.g. DESMONS, 1992, with previous ref.). On the other hand, THÉLIN and AYRTON (1983) and THÉLIN et al. (1990, 1993) proposed for the Briançon-Gd St-Bernard basement a chronological sequence of metamorphic events ranging from upper Proterozoic to Permian and including: (i) upper Proterozoic to lower Palaeozoic sedimentation, mafic and felsic magmatism; (ii) eclogite and amphibolite metamorphic imprints of uncertain age, possibly Variscan; and (iii) Permian gabbroic and subalkaline granitoidal magmatism in both types of basement.

Within the basement rocks of the Ligurian Alps a relative timing is inferred from the occurrence and textural relationships of three main deformative events. The D_1 event, characterized by important textural and paragenetic re-organization, is considered to have occurred under high-grade eclogite and amphibolite-facies conditions depending on the level in the crust. Localized fine-grained Bt-Ms-Qtz-Pl schists and gneisses commonly preserving blastopsammitic textures, possibly represent the lower-grade overprint during D_1. Intrusive rocks emplaced within basement rocks previously metamorphosed in association with D_1 at different P and T conditions, and later involved with these host rocks in the D_2 event, represent episodes of synorogenic magmatism. Post-D_1 and pre-D_2 andalusite developed in contact aureoles around the granitic intrusions. A coeval or nearly coeval development of D_1 throughout the basement is only hypothesized and, if it proves to be correct, the age can be assumed to be eo-Variscan. As a consequence, the protoliths can be considered as Ordovician, by comparison with palaeontologically dated basement units in the Alps which are lithologically similar. Clasts from the Westphalian-Stephanian Ollano conglomerates show only one pre-Alpine foliation, considered to be post-D_1. Their age is tentatively assumed to be Silurian to Lower Visean.

The D_2 event is characterized by isoclinal, kilometre-scale, megafolds involving the migmatite-eclogite, gneiss-amphibolite and granitoid orthogneiss complexes, as well as the associated intrusive bodies. Amphibolite-facies assemblages developed in association with the S_2 schistosity. The post-kinematic recrystallization is characterized by widespread destabilization of garnet, replaced by Hbl + Pl + Bt in metabasite and by Bt + possible Crd in gneissic rocks, and by the localized growth of fibrolite on biotite and muscovite.

D_3 similar folds on a metre to tens of metres scale are associated with Chl-Tr-Ep-Ab assemblages along cracks and cleavages. These folds preceded the exposure of the basement and its Upper Carboniferous erosion.

4.2. RADIOMETRIC DATA

All radiometric data available for the Western Alps up to 1992 are found in a review by HUNZIKER et al. (1992) (see also GEBAUER, 1993). Most radiometric results relevant to pre-Alpine metamorphism are derived from *magmatic bodies*, whose ages constrain the timing of the metamorphisms. As said above, the younger basement sequence includes *Late Cambrian* intrusions (Mt Pourri granophyre in the Pourri-Bellecôte massif, GUILLOT et al., 1991; Thyon gneiss in the Siviez-Mischabel unit, BUSSY et al., 1996a). This confirms the lower Palaeozoic age proposed for the younger basement sequence and thus the (Lower Cambrian to) Precambrian age of the main metamorphism in the ancient basement. Such an old age is also supported by Sm–Nd Cambrian and Precambrian dates from mafic and ultramafic protoliths of the Berisal unit (STILLE and TATSUMOTO, 1985; ZINGG, 1989). The same age is given by the upper intercept of the U–Pb discordia of zircons of the Permian Randa intrusion (BUSSY et al., 1996b), and a Proterozoic heritage is also discerned in zircons from the Sapey and the Houillère zones (BERTRAND et al., 1998). Such old ages in zircon cores from Alpine basement rocks are not rare and probably indicate a long history of magmatic and sedimentary re-working of the grains.

Ordovician U–Pb zircon ages have been yielded by granitoids intruded in amphibolite-facies basement rocks, e.g. in the Siviez-Mischabel nappe (ZINGG, 1989), in the Sapey zone, in the Chasseforêt and Ambin massifs (BERTRAND and LETERRIER, 1997; GUILLOT et al., 1998), and in augengneisses from the Dora-Maira massif (BUSSY and CADOPPI, 1996). On the map, most of these granitoids have been marked as having an unknown age. The Gran Paradiso granitoid is so far radiometrically undated, but has been marked on the map as Late Variscan, similar in age to the dated Mte Rosa and most Dora-Maira granitoids. In the northern Sesia zone monazite from porphyritic veins has been dated as Ordovician (448 Ma: ROMER et al., 1996). Since the Ordovician granitoids in the Briançon zone are intruded into amphibolite-facies basement rocks, Ordovician or Cambrian is the upper age limit of the amphibolite metamorphism and this is another piece of evidence supporting the assumed Pan-African age. This conclusion may be valid for all Internal basements; however, not all authors of the present paper agree. Some of them do not accept this interpretation, taking into account that in the Internal Penninic massifs and the Austro-Alpine basement, only Variscan and/or Late Variscan granitoids are identified and, therefore, the amphibolite facies of the intruded metamorphic rocks could, conceivably, be Variscan in age. As concerns the Sesia cover, which has not been metamorphosed before Alpine times, an Early Carboniferous magmatic age has been yielded by zircon dating of a gabbro. This gives evidence that at least the Sesia cover has not been affected by any metamorphism older than Early Carboniferous.

In the Ligurian Alps, Rb–Sr and K–Ar radiometric ages of 327 Ma (DEL MORO et al., 1982) were obtained from biotites of the Calizzano massif, which were re-equilibrated during D_2.

Pre-Alpine radiometric data of *metamorphic minerals* are scarce in the pre-Alpine Internal basement units. A few Rb–Sr and ^{40}Ar–^{39}Ar measurements on micas (MONIÉ, 1990, from Ambin and Acceglio; COSCA et al., 1992, from the Briançon-Gd St-Bernard supernappe) yielded apparent Variscan ages (no plateaus). Neoformed monazite from the Pontis-Ruitor zone has been dated at 330 Ma (BUSSY et al., 1996b), which can be interpreted either as a magmatic or a hydrothermal Variscan event.

5. P-T-t evolution

Details on the P-T-t evolution of the ancient pre-Alpine basement are best obtained from the units which have been least affected by Alpine metamorphic overprinting, that is, the Briançon-Gd St-Bernard zone and, more particularly, from the Ligurian Alps (THÉLIN et al., 1990, 1993; DESMONS, 1992; CORTESOGNO et al., 1993; DESMONS and MERCIER, 1993; and ref. therein), and from both the Dent Blanche and Second Diorito-Kinzigitic zones.

For the northern and central Briançon zone, i.e. from Siviez-Mischabel down to Acceglio, the P-T path starts from H-T eclogite facies (Fig. 5) estimated at ≥ 15 kbar / ~ 650 °C, then goes through amphibolite-facies values of approximately 6 ± 1 kbar / ~600 °C, based on the presence of kyanite (for this facies a Pan-African age has been proposed), down to probably high-grade greenschist facies at 3 to 5 kbar and 450–500 °C. There is, so far, no dating of the latter event, but it may be suggested as contemporary with the Variscan granitoidal intrusions of the Internal Penninic massifs.

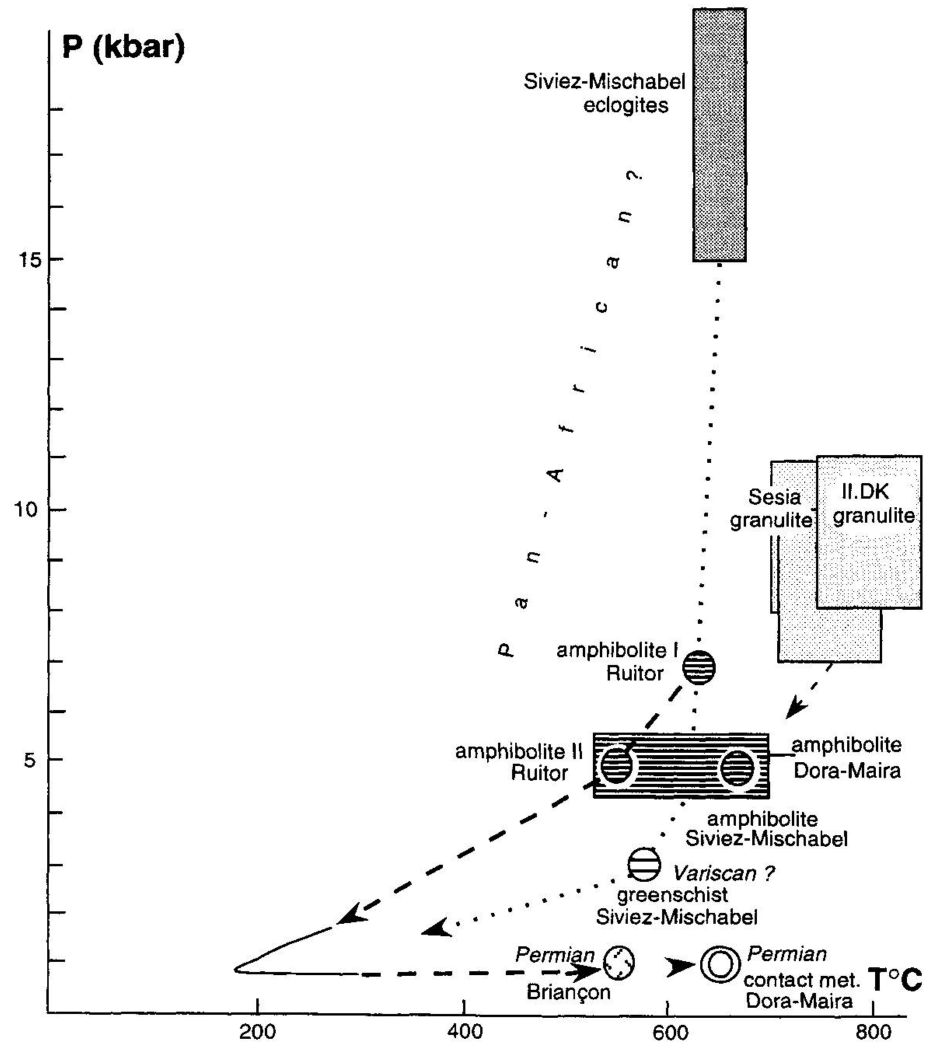

Fig. 5 P-T estimates and P-T-t paths for the northern and central Western Alps. Source of data: Siviez-Mischabel, THÉLIN et al. (1993); Ruitor and Briançon, BAUDIN (1987) and DESMONS (1992); Sesia and Second Diorito-Kinzigitic zone (II.DK), LARDEAUX and SPALLA (1991), POGNANTE et al. (1987); Dora-Maira, COMPAGNONI et al. (1995).

These implied a high heat flow at the time of their emplacement, most likely produced by a magmatic underplating process, i.e. the intrusion of basaltic magmas at the crust-mantle boundary. The main, amphibolite-facies, metamorphism in the Internal Penninic massifs, which on the map has been indicated as Pan-African, could be Variscan in age according to some of the present authors, as explained above.

Field and petrologic data from the *Internal Penninic massifs* and the *Sesia zone* indicate that granitoids dated as Late Variscan (Permo-Carboniferous) intruded an amphibolite-facies metamorphic basement. Since there are no other geological or radiometric constraints which conflict with this age as there are in the Briançon zone, some authors consider the age of the amphibolite facies as Variscan. Furthermore, a Variscan age is also assumed by some authors for the amphibolite-facies imprint in the Southern Alps (see COLOMBO and TUNESI, 1999, this volume), from which the Sesia zone derived; however, another interpretation of the Variscan radiometric ages could be that of a Variscan re-opening in relation with the Variscan magmatism and high heat flow. In the Sesia zone, the Valpelline series and the Second Diorito-Kinzigitic zone, the granulite facies could be Pan-African in age, even though a Permian age related to crustal thinning has also been suggested (GARDIEN et al., 1994).

In the Ligurian Alps, the metamorphic evolution (Fig. 6) in the migmatite-eclogite complex is characterized by the polyphase re-equilibration

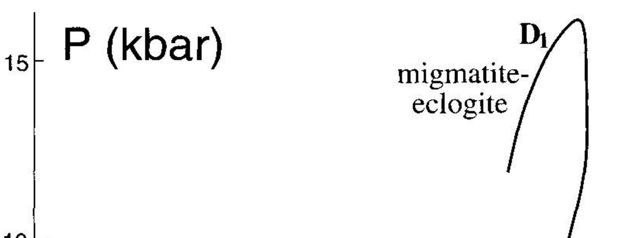

Fig. 6 P-T-t path for the migmatite-eclogite and gneiss-amphibolite complexes of the Ligurian Briançon zone.

of metabasites to eclogite assemblages during the D_1 deformation; geothermobarometric evaluations yielded temperature values in the range of 700–760 °C and minimum pressures of about 17 kbar for the Grt-Omp pairs equilibrated in S_1. Pre-kinematic Grt-Omp and Grt-Phe pairs suggest slightly lower P and T. During a multistage decompressional path the eclogitic assemblages were partially transformed to Di + Pl or Hbl + Pl symplectite and local Opx + Grt + Pl assemblages. During such evolution, the metasedimentary rocks, associated with eclogites, underwent partial melting; Sil, Grt, Kfs and Bt are restitic phases.

In the gneiss-amphibolite complex the amphibolite-facies metamorphism attained a minimum temperature of about 600 °C and pressures in the range of 6–8 kbar as suggested by Pl-Hbl and Grt-Hbl exchange thermometry in amphibolite, and by Ky, Sil, St, Alm, Bt, Pl equilibria in paragneiss. The lowest pressures for the D_1 event are probably recorded by the fine-grained gneisses and micaschists showing the Bt + Ms + Qtz assemblage.

Although a metamorphic zonation in the gneiss-amphibolite complex is at present poorly constrained, it cannot be excluded that part of the complex has been affected by eclogite-facies metamorphism. The evolution of the gneiss-amphibolite complex could be eo-Variscan in age, or older, with respect to D_1 and Variscan with respect to D_2.

The migmatite-eclogite complex may represent either (i) rocks genetically equivalent to the gneiss-amphibolite complex, evolved in more extreme metamorphic conditions during the eo-Variscan event, or (ii) slices originating from an older orogenic basement (MATTE, 1998; VON RAUMER et al., 1999, this volume; HANDY et al., in press) and tectonically incorporated during the Variscan event.

6. Permian metamorphism

The existence of a Permian metamorphism in the Western Alps has been detected radiometrically: Permian ages were recurrently obtained from both K–Ar and Rb–Sr measurements of micas, especially large flakes, from metamorphic basement. This intriguing feature was noticed in the Eastern Alps (FRANK et al., 1987; see NEUBAUER et al., this volume) and in the Carpathians as well.

The Permian sequence in the Western Alps exhibits an unconformity, but no evidence of tangential tectonics has been found so far. On the contrary, the widespread acidic and mafic magmatic activity points to an extensional setting for the Internal zones which, within the frame of arcrelated magmatism, belonged to the upper plate. It must be noted that Permian beds stratigraphically overlie at least the younger basement, thus indicating that in Permian times part of the basement was either exposed or at shallow depth.

Contact metamorphism is observed around many Permian igneous bodies (see chapter 7 of this paper), but the distribution of the Permian mica ages is regional. Since, in the Western Alps, the Permian micas are unrelated to a new foliation, it has been concluded that the Permian metamorphism was thermal.

It was during the Permian period that the magma underplating responsible for the intrusion of the Ivrea mafic-ultramafic complex occurred, together with the development of H-T regional metamorphism and the emplacement of widespread pegmatite dykes into what was to become during Alpine times the Southern Alps (see COLOMBO and TUNESI, 1999, this volume). Many gabbroic intrusions and felsic magmatic bodies in the Internal Western Alps have also been radiometrically or geologically dated from Permian to Triassic times. The hypothesis by DESMONS and HUNZIKER (1988) that the detected Permian thermal metamorphism may be related to the Ivrea mantle upwelling is thus well-founded and supports the idea that these future Internal zones were not far from the Ivrea zone at that time.

The pressure was low, but it is still unclear whether the temperature was low, medium or high in the various zones. The minerals apparently affected by this thermal metamorphism, as far as the Briançon-Bernard zone, the Internal Penninic massifs and the Dent Blanche nappe are concerned, are mainly white micas. The Permian granulite-facies recrystallization suggested by GARDIEN et al. (1994) to have occurred in the Valpelline series of the Dent Blanche nappe has been mentioned above. Moreover, many vein minerals have been partly re-equilibrated at the same time, such as tourmaline, allanite and uranium-bearing minerals (EIKENBERG et al., 1989, in Siviez-Mischabel, ~ 255 Ma; FERRARA et al., 1958, in Dora-Maira, ≥ 215 Ma; RUBATTO, 1998, in the Sesia zone, 266–260 and Triassic: 221 Ma). Widespread U-mineralization in the Permian-Carboniferous sequences of the Ligurian Alps also reflects thermal activity.

The Permian metamorphism has probably been much more widespread than the relatively small dataset would suggest. For this reason, and also in order not to further complicate the display of polymetamorphic areas, this Permian metamorphism has not been shown on the map as concerns the Western Alps.

7. Contact metamorphism

Remnants of biotite, sillimanite, andalusite and cordierite (now completely pseudomorphed by Alpine minerals) which developed during contact metamorphism were found around the Variscan Gran Paradiso and southern Dora-Maira (Brossasco-Isasca unit) granitoids, and a smaller assemblage of biotite and garnet was found around the Variscan Cogne body.

In the Ligurian Alps the shallow granitic intrusion in the fine-grained gneisses and micaschists developed an andalusite-bearing contact aureole, which may be measured over tens of metres. This was overprinted by the muscovite-bearing S_2 foliation.

Thermal metamorphic minerals also occur around some of the Late Variscan magmatic rocks, such as: andalusite, now pseudomorphed by white mica, albite and uncommon chloritoid in the lower sheet of the Dora-Maira massif (Pinerolo complex); graphite (FEYS, 1963 in FABRE et al., 1987) and anthracite (FABRE, 1961) at the contact with microdiorite sills in the Houillère zone.

However, the Alpine metamorphisms have erased most contact aureoles generated by the Palaeozoic and older intrusive bodies, even those of large bodies such as Randa in the Siviez-Mischabel nappe.

8. Conclusions

The lithological and metamorphic features of the pre-Alpine rocks in the Internal Western Alps at first produce a coherent general picture, in which each zone, or part of it, contributes its own complementary information. There is a main body of amphibolite-facies rocks derived from clastic and magmatic rocks. Local variations lie in the presence of greywackes and in the nature of the plutonic rocks. Relics of eclogites testify to early high P and T conditions. The amphibolite-facies imprint was followed by an evolution leading to greenschist-facies conditions through either low-grade amphibolite or greenschist conditions. This picture is valid for the northern and central Briançon zones and Internal Penninic massifs, i.e. for the rocks of the Monte Rosa, Gran Paradiso and the upper sheet of Dora-Maira, which contains granitoids. In the Sesia zone, the Valpelline series and the II.DK, somewhat deeper crustal levels are now displayed.

Additional information is given by the existence of sequences of the younger basement, which are lithologically unlike the sequences of the ancient basement and could be lower Palaeozoic in protolith age. These sequences, in the Ligurian Alps also possibly identifiable in clasts from Upper Carboniferous conglomerates, have not, or have only been slightly metamorphosed during the Palaeozoic.

The pre-Alpine metamorphic evolution of the Ligurian Alps is summarized as follows. High-T eclogites in the Savona and Calizzano units were re-equilibrated under granulite facies during a nearly adiabatic decompression which also, most probably, produced the associated migmatites; during uplift, the eclogite-migmatite complex was intruded by basic melts. At the same time and at shallower crustal levels, the gneiss-amphibolite complex acquired an early D_1 foliation and, in pelitic rocks, assemblages developed that include kyanite (Arenzano) or coexisting kyanite and sillimanite (Savona massif); gneiss and amphibolite were later intruded by granite and occasionally basalt. During the main Variscan event both eclogite-migmatite and gneiss-amphibolite complexes, together with the acidic and basic intrusive rocks, were involved in megafolds and re-equilibrated under amphibolite-facies conditions, with a decreasing P, as shown by the post-kinematic breakdown of Grt, Di, Ky and Sil, and by local And growth. The late pre-Alpine evolution is marked by open folds associated with mild greenschist-facies re-equilibration.

There are differences in the ages ascribed to the pre-Upper Carboniferous basement in the various parts of the Internal Western Alps. In the north and central Briançon zone and, according to some of the present authors, in all Internal Western Alps, the protoliths, consisting of sedimentary, mafic-ultramafic and few felsic rocks, as well as the eclogite and the main amphibolite-facies imprints, are all considered as pre-Upper Cambrian, most probably Precambrian, i.e. Pan-African. No regional foliation remains from such a metamorphic evolution, only relictic microtructures, at grain scale. The younger basement sequence formed during lower Palaeozoic. Both ancient and younger basement were intruded by Ordovician granitoids, which generated contact aureoles and possibly even local regional H-T metamorphism, but in neither case were anatectic conditions reached. Two biotite-bearing metamorphic events associated with foliations overprint the main amphibolite-facies event. There is as yet no evidence concerning the chronological relationships of these last imprints, in particular, with respect to the Ordovician and the Variscan granitoids. In the Internal Penninic massifs the pre-Alpine metamorphic imprint, possibly Variscan according to some authors, seems to be polyphase and, most likely, prograde up to the peak amphibolite-facies conditions.

In contrast, in the Ligurian Briançon zone, the volcano-sedimentary protoliths of the gneiss-amphibolite complex are considered as Ordovician, and the first amphibolite facies as eo-Variscan in age (Silurian ? to Lower Devonian). Eclogites are considered to have been formed under higher pressure during the same metamorphic event but, in view of lacking radiometric measurements, it cannot be excluded that they originated during an older event. Nevertheless, it is clear that migmatites, as well as basic magmas, were associated with the uplift of the eclogites. Granitoids and mafic intrusions preceded, or were coeval with, the high T/P amphibolite-facies conditions associated with D_2, which characterized the Variscan phase (Upper Devonian to Lower Carboniferous). This time period corresponds to the melting of deep crustal material, exhumation of crustal material from various lithospheric levels and collision. The collisional metamorphic conditions are dated as 327 Ma (late Visean).

Additional evidence is awaited to decide whether the above chronological differences are real or due to lack of data. If it is proved that such differences are real, it will follow that the north-central Briançon and the Ligurian Briançon zones were separate during the pre-Alpine evolution and perhaps belonged, during Alpine times, to different plates. The features of the Ligurian basement allow strong comparisons with areas such as Sardinia as concerns the pre-Alpine history. In the northern and central Western Alps the Gondwanian character of the basement is an established fact. The pre-Permian evolution of the External zones was Gondwanian only until Variscan times, thereafter their evolution was European. As previously formulated (Desmons, 1993; Desmons and Mercier, 1993), the basement of both External and Internal zones is of Gondwanian origin, but the basement of the former was accreted to Eurasia one orogeny earlier than the basement of the latter. This accretion occurred rather early in the Variscan evolution since the External zones were involved in the magmatic and metamorphic Variscan events. It is thus fruitless to try and extrapolate European Variscan data to the Internal basement of the Alps.

The Upper Carboniferous and Permian evolution, characterized by basement erosion, sedimentation, followed by intermediate and acidic volcanism which was particularly well developed in the Ligurian Alps, felsic and mafic intrusions, thermal metamorphism and finally quartz-rich sediment deposition, shows only minor local variations across the whole Internal Western Alps.

Acknowledgements

The paper has been reviewed by R.P. Ménot and V. Gardien; the authors are thankful for the constructive comments. Thanks are due to C. Hetherington who carefully revised the English. Financial support from the Italian C.N.R, Centro di Studio sulla Geodinamica delle Catene Collisionali, Turin, is acknowledged by R.C.

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Manuscript received July 6, 1998; revision accepted December 16, 1998.