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Metabasites in the Basement Units of the Western Alps

By JACQUELINE DESMONS*)

With 4 Text-Figures and 2 Tables

Westalpen
Ostalpen
Metabasite
Paläozoikum
Oberes Proterozoikum
Gondwana
Variszisches Europa

Contents

Metabasite in den Grundgebirgseinheiten der Westalpen

Zusammenfassung

Der vorliegende Artikel gibt einen kurzen Überblick über die Metabasite der voralpinen kristallinen Folge der Westalpen, um sie mit denen der Ostalpen vergleichen zu können.

In den internen Einheiten bestehen die gebänderten Amphibolite und boudinierten Lagen der „alten" Kruste im wesentlichen aus ehemaligen Ti-reichen Tholeiiten. Ihre amphibolitfazielle Metamorphose, jünger als ein Eklogitereignis, ist vermutlich oberproterozoischen Alters. Ein „jüngeres" Grundgebirge, vermutlich oberkambrischen Alters, enthält Ti-reiche tholeiitische Sills und einen basischen Körper mit geringen Ti-Gehalten. Die Stärke der vorpermischen variszischen Metamorphose reicht von unmetamorph bis gering metamorph.

Die externen kristallinen Massive enthalten gebänderte Amphibolite, eine Ophiolithabfolge, einen plutonisch-vulkanischen Komplex und verschiedene andere Metabasitkörper. Eklogitische Relikte kommen vor. Die Protolithalter reichen vom oberen Proterozoikum bis zum Devon. Die ursprünglichen tektonischen Bereiche sind heterogen: Back-arc und intrakontinentaler Magmatismus kommen vor.

*) Author's address: JACQUELINE DESMONS, C.N.R.S.; C.R.P.G., B.P. 20, F-54501 Vandoeuvre-lès-Nancy Cedex.

Auf die Schwierigkeiten, geotektonische Daten zu interpretieren, in denen Perioden mit hohem Wärmefluß (z.B. das Perm) und tektonische Ereignisse (Abspaltung und Aufstieg von Fragmenten der Unterkruste in Eklogit- oder Granulitfazies) eine entscheidende Rolle spielen, wird hingewiesen.

Vergleiche werden
1) sowohl zwischen den externen Kristallinmassiven, besonders den Sub-Penninischen Einheiten, d.h. dem Simplon-Ticino in den Zentralalpen einerseits und den kristallinen Abfolgen der Hohen Tauern (alle wurden während des Variszikums an Europa angegliedert) andererseits und
2) einerseits zwischen den mittel- und unterpenninischen und auch den Ostalpinen Einheiten der Westalpen und andererseits den Mittel- und Oberostalpinen Einheiten der Ostalpen (die alle bis zur Alpinen Orogenese zu Gondwana gehörten)

angestellt.

Abstract

Metabasites found in the pre-Alpine crystalline sequences of the Western Alps are briefly reviewed in order to provide comparisons for the Eastern Alps.

In the internal units, banded amphibolites and boudinaged layers of the "ancient" basement are mostly Ti-rich tholeiites. Their amphibolite facies metamorphism, which post-dated an eclogite phase, is considered as probably late Proterozoic in age. A "younger" basement type, likely Late Cambrian in age, contains high-Ti tholeiitic basic sills and a low-Ti basic body. The grade of the pre-Permian Variscan metamorphism in these internal units ranges from nil to low.

The external crystalline massifs contain banded amphibolites, an ophiolite sequence, a plutonic-volcanic complex and various other metabasic bodies. Eclogite relics are found. The protolith ages range from late Proterozoic to Devonian. The original tectonic environments are heterogeneous. Both back-arc and intracontinental magmatisms are probably present.

Attention is drawn to difficulties in interpreting geochronological data, in which the leading part is played by high heat flow periods (e.g. Permian) and tectonic events (e.g. decoupling and upheaval of slabs of lower crust in eclogite or granulite facies).

Comparisons are suggested
1) between, on one hand, the external crystalline and more particularly, in the Central Alps, the Simplon-Ticino Sub-Pennine units and, on the other hand, the Tauern crystalline sequences (all accreted to Europe in Variscan times), and
2) between, on one hand, the middle and lower Pennine and the Austro-Alpine units of the Western Alps and, on the other hand, the Middle and Upper Austro-Alpine of the Eastern Alps (all belonging to Gondwana up to Alpine times).

Les Métabasites dans les Unités de Socle des Alpes Occidentales

Résumé

Les métabasites des séries cristallines pré-alpines des Alpes occidentales sont brièvement passées en revue afin de fournir des termes de comparaison avec les Alpes orientales. Dans les unités internes des amphibolites rubanées et des niveaux boudinés du socle dit ancien sont principalement des tholéites riches en Ti. Le métamorphisme de faciès amphibolite qui les affecte est postérieur à une phase éclogitique et est considéré comme d'âge probablement protérozoïque supérieur. Un type de socle dit récent, dont l'âge est vraisemblablement cambrien supérieur, renferme des sills basiques tholéitiques riches en Ti et une masse basique pauvre en Ti. Le degré du métamorphisme varisque anté-permien de ces unités internes est nul à faible.

Les massifs cristallins externes contiennent des amphibolites rubanées, une série ophiolitique, un complexe plutono-volcanique et diverses autres masses métabasiques. Il s'y trouve des reliques d'éclogites. Les âges des protolites vont du Protérozoïque supérieur au Dévonien. Les milieux tectoniques originels sont hétérogènes; un magmatisme d'arrière-arc et un magmatisme intra-continental sont tous deux présents.

Les difficultés rencontrées dans l'interprétation des résultats géochronologiques sont soulignées. Le rôle principal y est joué par les périodes de flux thermique élevé (par exemple le Permien) et par les événements tectoniques (par exemple le détachement et la surrection d'écailles de croûte inférieure de faciès métamorphique éclogitique ou granulitique).

Les rapprochements suivants sont proposés:
1) entre, d'une part, les séries cristallines externes et plus particulièrement, dans les Alpes centrales, le Subpennique et, d'autre part, celles des Tauern (toutes unités ajoutées à l'Europe au cours de l'orogenèse varisque) et
2) entre, d'une part, le Pennique moyen et inférieur et l'Austro-Alpin des Alpes occidentales et, d'autre part, l'Austro-alpin moyen et supérieur des Alpes orientales (toutes unités qui ont appartenu à Gondwana jusqu'aux orogenèses alpines).

1. Introduction

In the Western Alps, crystalline sequences, Proterozoic and Palaeozoic in protolith age, constitute the basement of

1) the external (Dauphiné-Helvetic) crystalline massifs,
2) the Pennine Briançon-Bernhard units,
3) the internal Pennine massifs,
4) the so-called Austro-Alpine units and
5) the Southern Alps (Fig. 1; Table 1).

According to the current picture of their evolution, the external crystalline massifs, like central Europe, have been strongly affected by the Variscan orogeny, whereas the predominant metamorphic and tectonic imprints in the Pennine and Austro-Alpine units are lower Palaeozoic and older in age. From this, and owing to similarities in the lithology and in the Alpine sedimentary facies, the Pennine and Austro-Alpine crystalline units of the Western Alps are now regarded as detached from Gondwana not earlier than the Alpine cycle (DESMONS, 1986; RADELLI & DESMONS, 1987). It follows that fruitful comparisons can be made of the crystalline basement of both Western ans Eastern Alps.

The pre-Alpine sequences belong to three age groups (Table 1):

1) Upper Carboniferous and Permian sequences consisting of clastic rocks and intermediate to acid magmatic rocks in the external and in the Pennine cover, including the zone Houillère of the Briançon zone; acid and intermediate igneous and volcaniclastic rocks of the internal Pennine and Austro-Alpine units; layered gabbroic complexes in the Dent Blanche unit;

Table 1.
Pre-Upper Carboniferous metabasites in the Western Alps.
* = synthetic paper containing previous references.

Massif / unit	Metabasic exposure	Chemistry of the metabasites	Measured/assumed age of protolith	Type and age of pre-Alpine metam.	References (*=synthetic paper)
External crystalline massifs					
Aiguilles Rouges	interlayered lenses	tholeiite + K-basalt ; N-MORB	453 ± 3 (U/Pb zr)	eclogite, U. Silurian-L. Devonian ; amphib., Devonian	Liégeois & Duchesne 1981 ; Paquette et al., 1989b
Belledonne	NE part and Allemont/ Rochetaillée form. : banded amphibolites, lenses	T- and N-MORB ; low-Ti tholeiite	≈ 600-500 ; early Palaeozoic	idem, ± Lower Carboniferous greenschist	Bodinier et al., 1981 *Ménot, 1988 Ménot et al., 1988a Carme & Pin, 1987
	Chamrousse : ophiolite sequence	E-, T- and N-MORB + arc tholeiite	496 ± 6 (U-Pb zr) 497 ± 24 (Sm/Nd) ;	amphibolite, Lower Carboniferous	Paquette et al., 1989b
	Riouperoux-Livet : banded metabasites, (plutonic and volcanic)	crust-contaminated T-MORB and calc-alkaline	352±55, 365±17 (U-Pb zr)	amphibolite and greenschist, Variscan	
Pelvoux	W = Chaillol : banded amphibolites, lenses core = E part : idem	low-Ti tholeiite + calc-alkaline, splitic idem		eclogite ; amphib., Variscan	Lefort, 1973 *Barféty & Pêcher, 1984
Argentera	banded amphib., lenses	intermediate-Ti tholeiite, N- and E- MORB, crust-contaminated	471 +40 -29 (U-Pb zr)	idem	Latouche & Bogdanoff, 1987 Paquette et al., 1989b
Briançon-Bernhard (Middle Pennine) units :					
ancient basement :					
Siviez-Mischabel	banded amphibolites, boudins	low-Ti tholeiite, spilite + alkaline ?		eclogite, amphib., late Pan-African ?	*Desmons & Ploquin, 1989
Stalden sup. + Ruitor + + Pontis	banded amphibolites, boudins	high-Ti tholeiite (MORB), spilite + alkaline ?	Late Proterozoic ?	idem	
Chasseforêt = S Vanoise	banded amphibolites	Ti-rich tholeiite, spilite	idem	amphibolite	
Clarea formation	idem	tholeiite, spilite	idem	amphibolite	
Calizzano-Savona	idem	Ti-rich thol. (MORB) ; spilite + alkaline	idem	eclogite, amphib., greenschist, Variscan	Messiga, 1981 ; *Cortesogno, 1984-86 ; Cortesogno et al., 1982
younger basement :					
Métailler	layers in metasedim.	Ti-rich tholeiite	Cambrian ?	none or very low	*Desmons & Ploquin, 1989
N Vanoise=Bellecôte-Pourri	sills igneous body	Ti-rich tholeiite Ti-poor tholeiite			Guillot et al., 1991
Zona interna	layers, banded meta-tuffs and -tuffites	basalt to andesite, tholeiite			
Ambin F.	idem	basalt to andesite, Ti-rich tholeiite			
Acceglio p.p.	idem	tholeiite (+calc-alkaline?)			
Internal Pennine massifs :					
Mt. Rose	banded amphibolites, lenses	high-Ti tholeiite ?	Late Proterozoic ?	eclogite, amphibolite, Late Pan-African ?	Bearth, 1952
Gran Paradiso	idem				Michel, 1953 ; Compagnoni & Prato, 1969
Dora-Maira	idem				*Desmons & Ploquin, 1989
? Valosio=T.Visone (Ligury)	idem				Forcella et al., 1973
Austro-Alpine :					
internal Sesia-Lanzo	banded metabasites, boudins	low-Ti tholeiite, calc-alk. + high-Ti tholeiite ?	Late Proterozoic ?	eclogite, amphibolite, late Pan-African ?	Viterbo-Bassani & Blackburn, 1968 ; Liébeaux, 1974 ; Reinsch, 1977, 1979 ; Desmons & Ghent, 1977

2) "Younger" basement (pre-Upper Carboniferous and post-Proterozoic) sequences which are constituted by metasedimentary and meta-igneous rocks forming some Pennine massifs (northern Vanoise, or Pourri-Bellecôte, massif, Ambin formation, etc.); a similar age is assigned to parts of the external crystalline massifs;
3) "Ancient" basement sequences (Proterozoic ?), comprised of metasedimentary and meta-igneous rocks of parts of the external crystalline massifs, most of Briançon, internal Pennine and internal Sesia units, and the Southern Alps.

The present paper reviews the available petrological data concerning the metabasites found in the "younger" and "ancient" basement units of the Western Alps. The Upper Carboniferous to Permian sequences and the metabasites of the Southern Alps will not be discussed. The chemical and geochronological coverage of these rocks is far from complete and the synthesis will remain provisional in many aspects.

2. Petrography

2.1. Pennine Ancient Basement

The Alpine metamorphism and deformation, which have been strong and commonly pervasive, make it difficult to characterize the pre-Alpine sequences in the Pennine basement. Pre-Alpine metamorphic mineral associations have often been destroyed and the grain size strongly reduced; pre-Alpine structural planes have been transposed into Alpine planes.

The ancient basement sequences of the Pennine units comprise: metasedimentary schist and gneiss, very rare marble; acid orthogneiss (augen-gneiss, minor granophyre); and metabasite showing amphibolite and subordinate eclogite facies pre-Alpine associations. There is an insignificant amount of ultrabasic rocks, of cumulate origin. The metabasites most commonly consist of banded amphibolites, with alternating melanocratic and leucocratic layers. (These leucocratic layers are often ill-named

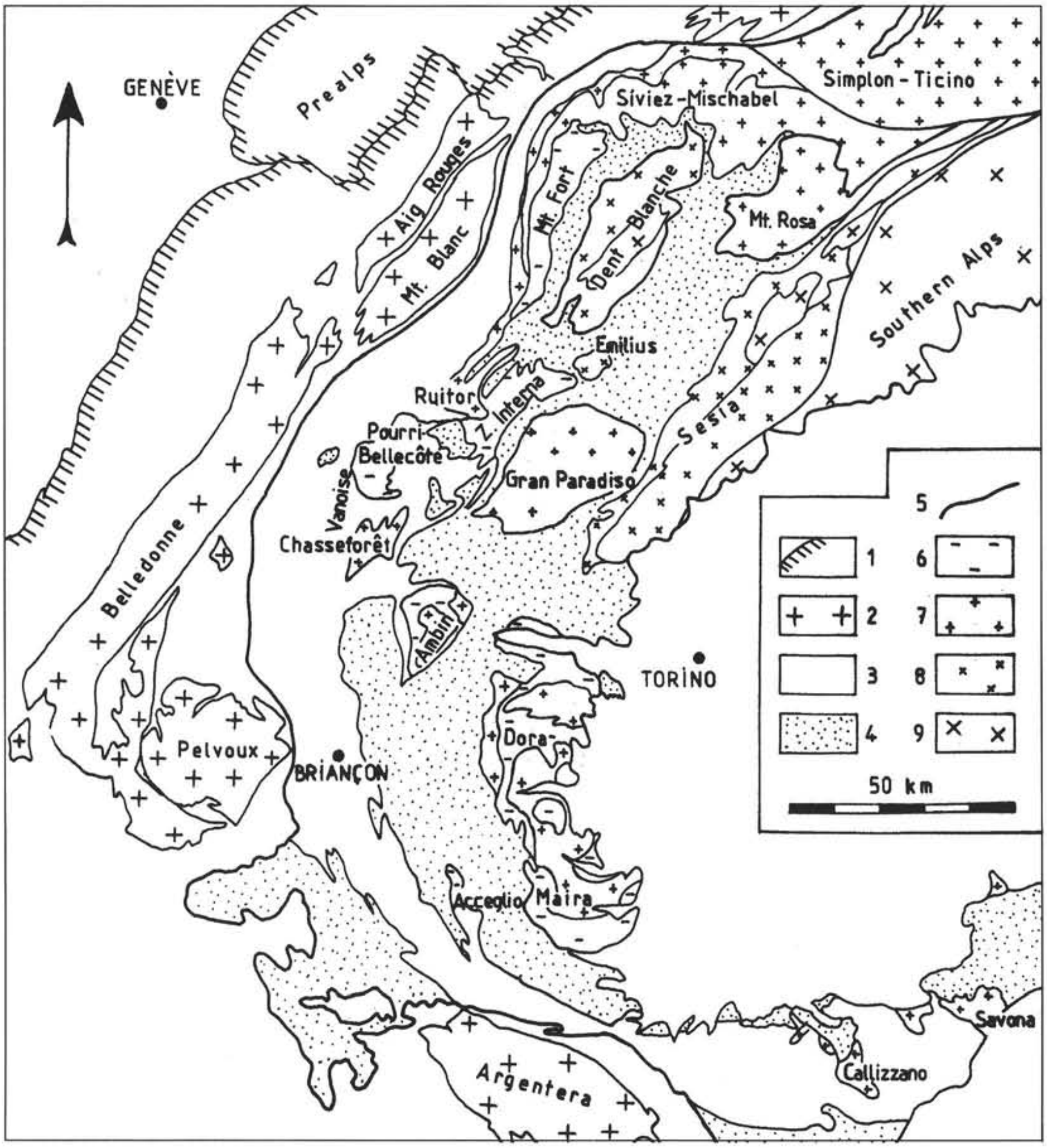
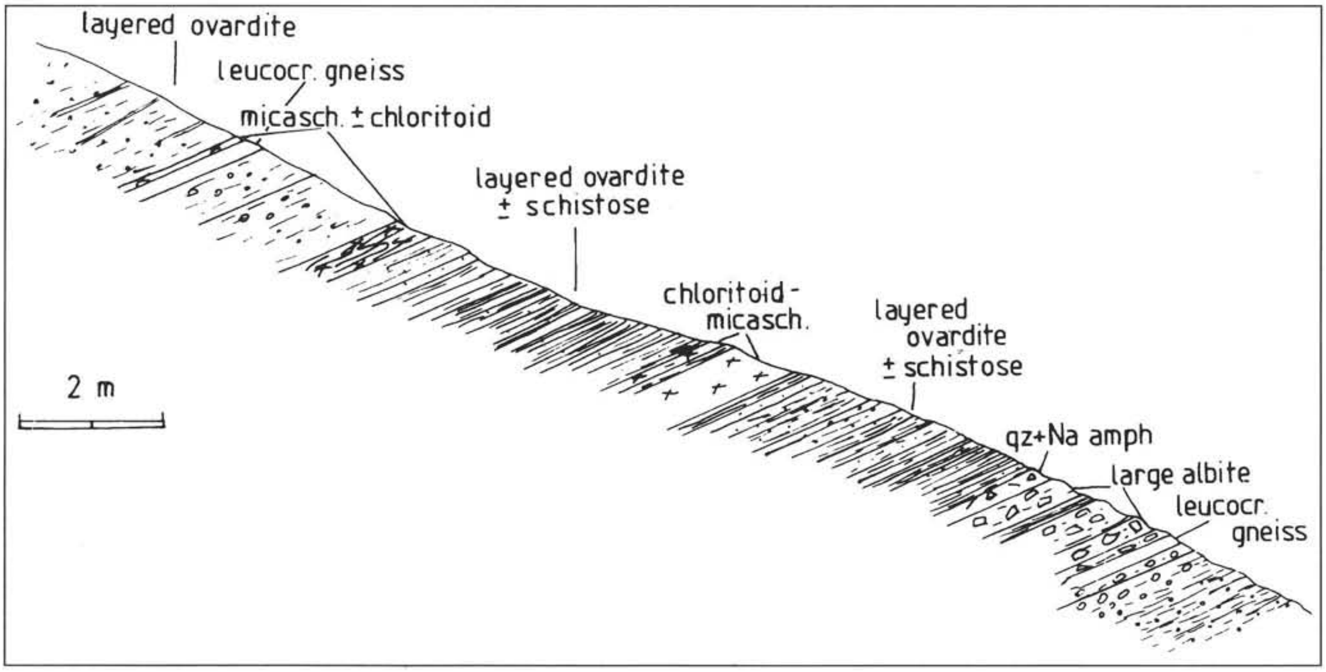


Fig. 1.
Tectonic map of the Western Alps.
1 = Cover of the external zones; Prealps; 2 = External crystalline massifs; 3 = Pennine cover; Valais zone; 4 = Combin and Zermatt zones, undifferentiated; 5 = Pennine front (boundary between Alpine Europe and Alpine Gondwana); 6 = Pennine younger basement; 7 = Pennine ancient basement; Simplon-Ticino nappes (central Alps); 8 = Sesia and Dent Blanche (Arolla) zones and related klippen; 9 = Southern Alps; "Second diorito-kinzigitic" zone; Valpelline unit.

Fig. 2.
Example of lithostratigraphic section through a banded metabasic outcrop (chlorite-epidote-albite-actinolite rock, possible meta-pyroclastite) in the Briançon zone, Ruitor massif, Valgrisanche (NW Italy).
Note the interlayered mica-schists ± chloritoid.



leptynites by French authors.) In addition, there are a few metre-sized, lenticular or boudinaged, bodies. Relics of gabbroic or ophitic structure are scarce.

In the banded amphibolites (DESMONS & HUNZIKER, 1988) the relative proportions of basic, intermediate and acid parts, the thickness of the individual layers and thus the number of alternations, vary strongly. These alternating rocks of contrasting compositions (Fig. 2) are most frequently interpreted, in the Alps and Variscan Europe, as bimodal volcanics and/or volcaniclastics (e.g. FRANK et al., 1976; FRISCH et al., 1984; WIMMENAUER & LIM, 1988; SANTALLIER et al., 1988), but this explanation is far from being entirely satisfying, owing to the high number of these repeated, often thin, layers. An origin in a layered plutonic complex can not be contemplated but in a few cases: most leucocratic layers are sodic, thus not corresponding to anorthosite, but rather to plagiogranite composition.

Evidence from the Chamrousse ophiolite in the Belledonne massif (MÉNOT, 1988c) shows that a metamorphosed tilted dyke complex, with a foliation parallel to the intrusive contacts, can mimic a banded sequence. In addition, thinning of the layers and part of the alternations may have been generated by folding, as shown by the presence of host-rock layers in the sequence (Fig. 2).

2.2. Pennine Younger Basement

The younger basement type comprises sequences that have not been, or only slightly, metamorphosed in pre-Alpine time (DESMONS & FABRE, 1988; DESMONS & PLOQUIN, 1989; DESMONS, 1990). These sequences are found in the Briançon zone (so far not in Ligury), where their stratigraphical or structural position is intermediate between crystalline sequences of ancient basement type at the footwall and Lower Permian layers at the hanging wall. In the internal Pennine massifs(especially the Dora-Maira massif), evidence supporting younger basement type remains so far ambiguous.

It appears that only the younger basement units possess a Permian tegument, which directly overlies the basement (the Permian layers exposed west of the Chasseforêt, or southern Vanoise, massif do not constitute its cover, but a probable trace of the Pourri-Bellecôte unit, squeezed in the Chavière fault zone).

Although for a long time regarded as Upper Carboniferous to Permian in age, the younger basement sedimentary sequences in fact are no lithological equivalents of the palaeontologically dated clastic rocks of the zone Houillère and both belong to different structural units (BOCQUET [DESMONS], 1974a; GUILLOT et al., 1987).

The younger basement sequences include metamorphic shales and graywackes, felsic tuffs, granophyre bodies and metabasites which, in the western part of the Pourri-Bellecôte massif, or northern Vanoise, are of two different types: a lower tectonic slice containing an igneous body with gabbro, leucogabbro, basalt and a few rhyolitic rocks, and an overlying upper slice comprising basic layers interpreted as sills and sedimentary rocks.

2.3. Austro-Alpine Basement

In the eastern (internal) part of the Sesia-Lanzo zone and in the Mt. Emilius klippe, the so-called "eclogitic mica-schists" consist of centimetre to metre-thick basic boudins and layers, with eclogite and amphibolite metamorphic associations, enclosed within garnet mica-schists. Minor gabbro with some preserved magmatic features, marbles and quartzites are also found. These rocks belong to the ancient basement type.

The acid plutonic and volcaniclastic protoliths of the "gneiss minuti" and meta-diorites of the western (external) part of the Sesia-Lanzo zone, of the Arolla sequence in the Dent Blanche nappe and related klippen have been considered, but without radiometric evidence, as possibly Permian in age.

Associated metabasites are uncommon. The gabbro bodies of the Matterhorn-Arolla have yielded Permian radiometric ages (DAL PIAZ et al., 1977).

The Valpelline zone in the Dent Blanche nappe, and the "Second diorito-kinzigitic" klippen overlying the Sesia zone contain granulite facies metasedimentary and metabasic rocks which are similar to South-Alpine rocks.

These rocks of the external Sesia, the Dent Blanche and the "Second diorito-kinzigitic" units will not be taken into consideration in this paper.

2.4. External Crystalline Massifs

Metabasites are unevenly distributed in the different subunits making up the external crystalline massifs. Taking the Belledonne massif as an example (VIVIER et al., 1987; MÉNOT, 1988a and b), we see different types of basic associations related to separate structural units.

In the SW part of the massif an almost complete ophiolite sequence, the Chamrousse overturned sequence, is exposed over an area of 32×2 to 5 km. It includes ultrabasic and basic cumulates, isotropic gabbro, and various basalts. It lies in tectonic contact with a gneiss-amphibolite formation (the Allemont-Rochetaillée formation), and with an underlying plutonic-volcanic complex, the Riouperoux-Livet complex. The latter complex comprises banded metabasites intruded by acid magmatic rocks, and associated with some clastic sedimentary rocks.

The NE part of the Belledonne massif includes banded metabasites and metabasic lenses, interlayered with metasedimentary rocks. There are a few eclogite relics. This type of exposure is also found in the other external crystalline massifs: Aiguilles Rouges, western (Chaillol) and core parts of Pelvoux, and Argentera. In the Aiguilles Rouges and the Argentera massifs the amount of metabasites is trivial.

Unlike the Pennine and Austro-Alpine basement, the external crystalline massifs show the effects of a strong metamorphic imprint of Variscan age, predominantly of amphibolite facies, secundarily of greenschist facies, which has been only slightly disturbed by the Alpine events. In particular, the different domains making up each massif have been juxtaposed in late Variscan times (Lower Carboniferous).

3. Chemistry and Affinities

3.1. Pennine Ancient Basement

In the ancient Pennine basement units (DESMONS & PLOQUIN, 1989), in addition to a few cumulate samples

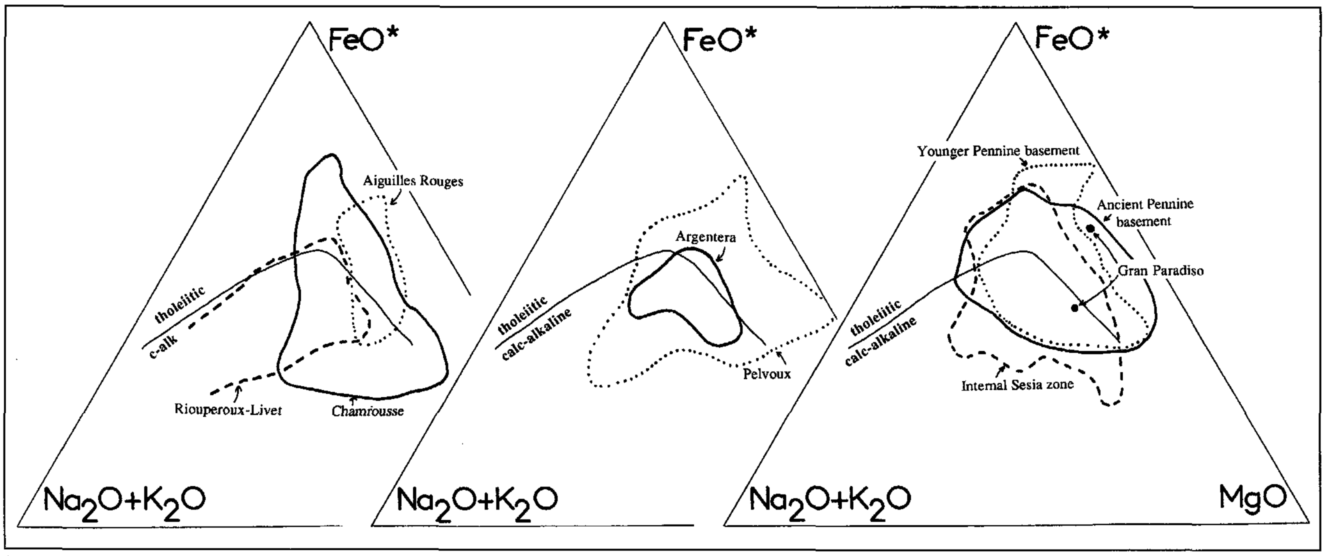


Fig. 3.
AFM diagram for West-Alpine metabasites.
Data from: MICHEL, 1953; VITERBO-BASSANI & BLACKBURN (1968); PÊCHER (1970); LEFORT (1973); LIÉBEAUX (1975); REINSCH (1977); LIÉGEOIS & DUCHESNE (1981); BODINIER et al. (1986); MÉNOT (1987); BIINO & POGNANTE (1989); DESMONS & PLOQUIN (1989); PAQUETTE et al. (1989b).
Boundary curve between tholeiitic and calc-alkaline trends according to IRVINE & BARAGAR (1971).

from the lenticular bodies, of alkaline composition, the analysed metabasites show a Ti-rich, less frequently a Ti-poor tholeiitic trend and are often spilitic (Table 1; Fig. 3 and 4D; only major element data are presented in diagrams, as only few trace element analyses are available). Those rocks that on the basis of their TiO_2 and Al_2O_3 contents can be safely considered as deriving from basalts (PEARCE, 1983) have a MORB affinity.

3.2. Pennine Younger Basement

In the younger Pennine basement units the metabasite composition is tholeiitic (Fig. 3 and 4C): high-Ti in the Bellecôte sills, low-Ti in the cumulates and basalts of the Bellecôte igneous body and in most Ambin and Acceglio metabasites. The additional presence of calc-alkaline (in pyroclastic rocks ?) and within-plate characteristics is not ascertained owing to the small number of the corresponding analyses. For igneous bodies such as that in the Pourri-Bellecôte massif, an arc tholeiite affinity and an immature arc setting have been inferred (GUILLOT, 1987), which should be corroborated by appropriate diagrams using trace elements.

3.3. Internal Sesia Zone

According to their TiO_2 and Al_2O_3 contents (PEARCE, 1983) only a small part of the analyzed metabasites can represent possible basaltic melts. These metabasites are described as plagioclase to olivine tholeiites, similar to MORB, but the TiO_2 – FeO*/MgO diagram (Fig. 4D) clearly indicates three trends: low-Ti tholeiitic, calc-alkaline and high-Ti tholeiitic. Trace element data should be used to discuss their possible tectonic environments.

3.4. External Crystalline Massifs

In the Belledonne external crystalline massif, the Chamrousse ophiolite contains olivine tholeiitic basalts, rich in Ti (Fig. 3 and 4B), with complex and evolving MORB affinities: E-, T-, N- and P-types have all been mentioned. It has been suggested that the magma was derived from a heterogeneous mantle influenced by a subduction zone (PIN & CARME, 1987), or from the mantle underlying an attenuated continental crust, transitional to oceanic crust (MÉNOT et al., 1988b). BODINIER et al. (1981) proposed a mid-ocean ridge and its flanks. On the basis of the chemical characteristics, of the olivine → clinopyroxene → plagioclase crystallization sequence and of the remark (DESMONS & RADELLI, 1989a and b) that the lithosphere of large oceans gets entirely subducted and has no chance to be accreted as ophiolites, a back-arc basin with an associated ensimatic arc seems to be a more likely original setting.

In the Riouperoux-Livet complex the basalts are described as T-MORB tholeiites, enriched in light REE and lithophile elements, typical of a contaminated mantle and an ensialic rift (MÉNOT, 1987). Another interpretation of the same complex, based on the low ϵNd value (CARME & PIN, 1987), is that of a calc-alkaline affinity and an active-margin magmatism. This interpretation, however, does not agree with the current picture of the Variscan orogenic evolution. In fact, the TiO_2 – FeO*/MgO diagram (Fig. 4B) shows that both low-Ti tholeiitic and calc-alkaline trends are present.

In the amphibolites of the Allemont-Rochetaillée formation both N- to T-MORB and supra-subduction-zone affinities are found.

The banded amphibolites of NE Belledonne, as well as the eclogites and amphibolites of the Aiguilles Rouges, Pelvoux and Argentera massif, include tholeiites with intermediate to low Ti-contents (Fig. 3 and 4A), which REE patterns show to be typical of N-MORB (Aiguilles Rouges, Belledonne and Argentera) and E-MORB (Argentera). In the last case, strongly enriched LIL-elements and the relatively high Nb/Zr ratio point to a subcontinental mantle source. Calc-alkaline metabasites are also present in the Pelvoux and Belledonne massifs (Fig. 4A). Field evidence (the insignificant amount of the basic rock relative to the host sedimentary rocks) and chemical comparisons, however, led LIÉGEOIS & DUCHESNE (1981) to suggest dyke

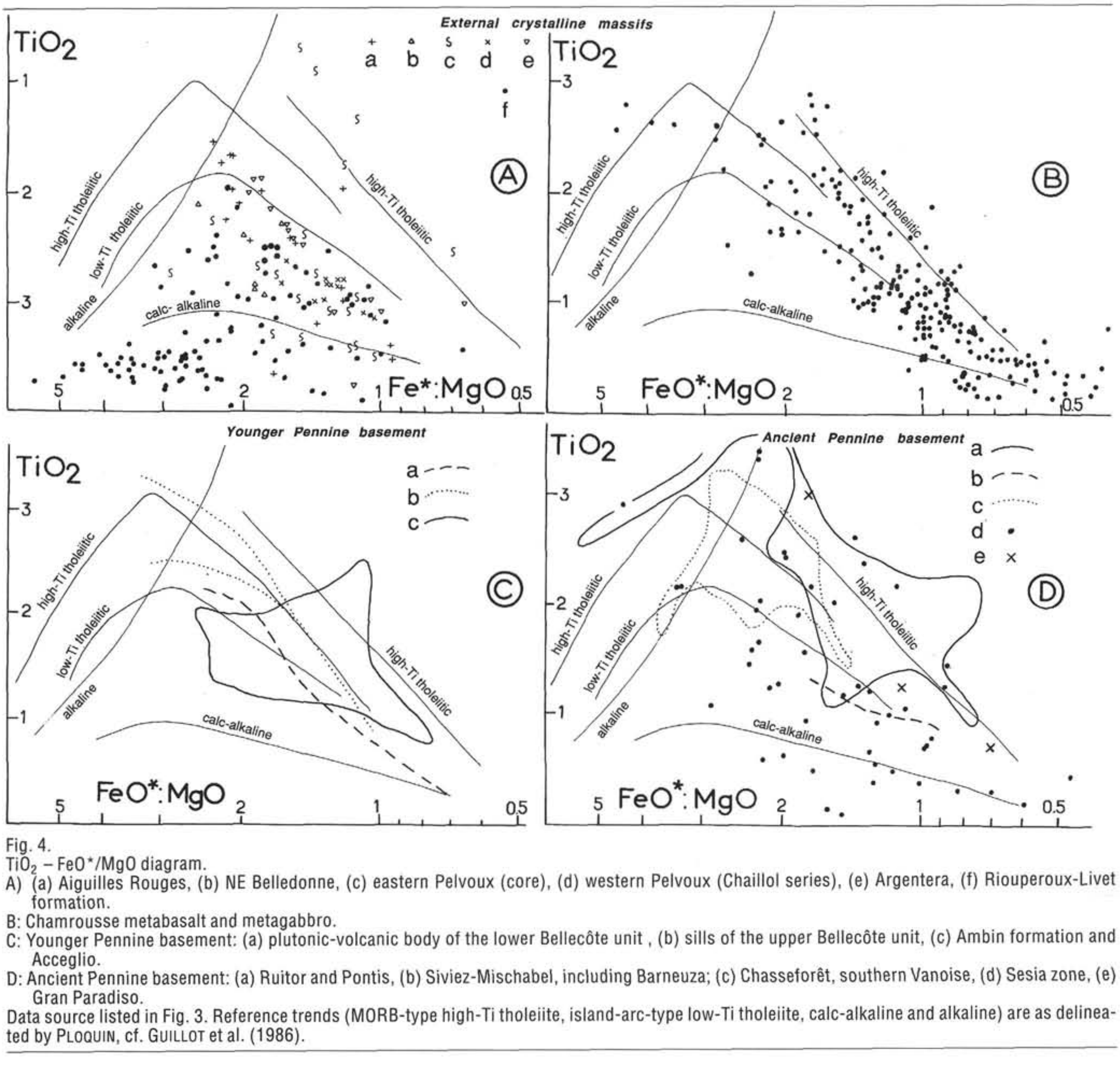


Fig. 4.
TiO_2 – FeO*/MgO diagram.
A) (a) Aiguilles Rouges, (b) NE Belledonne, (c) eastern Pelvoux (core), (d) western Pelvoux (Chaillol series), (e) Argentera, (f) Riouperoux-Livet formation.
B: Chamrousse metabasalt and metagabbro.
C: Younger Pennine basement: (a) plutonic-volcanic body of the lower Bellecôte unit , (b) sills of the upper Bellecôte unit, (c) Ambin formation and Acceglio.
D: Ancient Pennine basement: (a) Ruitor and Pontis, (b) Siviez-Mischabel, including Barneuza; (c) Chasseforêt, southern Vanoise, (d) Sesia zone, (e) Gran Paradiso.
Data source listed in Fig. 3. Reference trends (MORB-type high-Ti tholeiite, island-arc-type low-Ti tholeiite, calc-alkaline and alkaline) are as delineated by PLOQUIN, cf. GUILLOT et al. (1986).

or sill intrusions for some amphibolites and eclogites of the Aiguilles Rouges massif. Some eclogites of the Argentera appear to be derived from cumulates.

4. Metamorphism and Age Data

4.1. Protolith Ages

In the external crystalline massifs radiometric and isotopic data (Sm-Nd, U-Pb on zircon and Rb-Sr; references given in Table 1) indicate:

1) a late Proterozoic to early Palaeozoic age of the gneiss-amphibolite Allemont-Rochetaillée formation (500-600 Ma);
2) a Cambrian-Ordovician age (497 ± 24 and 496 ± 6 Ma) for the Chamrousse ophiolite body in the Belledonne external crystalline massif;
3) an early Palaeozoic age for the metabasites in the NE part of the Belledonne massif, in the Aiguilles Rouges ($453 \pm ^{3}_{2}$ Ma) and Argentera massifs ($471 \pm ^{40}_{29}$ Ma); and
4) a Devonian age (352 ± 55 and 365 ± 17 Ma) for the trondhjemite intruding the banded metabasites of the Riouperoux-Livet plutonic-volcanic complex in the same massif.

No direct chronological evidence is available for the West-Alpine Pennine and Austro-Alpine metabasites. Cambrian Rb-Sr and middle Proterozoic Sm-Nd ages have been obtained from similar amphibolites in the Central Alps (STILLE, 1980; STILLE & TATSUMOTO, 1985). Allowing for time for the subsequent metamorphic and magmatic events, which are to be placed at likely orogenic periods, late Proterozoic is considered to be a likely time for the main basic magmatism in the ancient Pennine units. In the Dora-Maira massif Sm-Nd and isotopic Pb ages (PAQUETTE et al., 1989a; TILTON et al., 1991) point to lower and middle Proterozoic for the granitic source of the metasedimentary rocks and two (674 and 667 Ma) data may be related to late Proterozoic granitic intrusions in the pre-existing sequence.

In the younger basement units the youngest possible age of the basic magmatism is Cambrian on the basis of the Late Cambrian zircon age of a granophyre sill (GUILLOT et al., 1991).

Traces of late magmatic alterations and ocean-type metamorphism and deformation have been described from the Ca-amphibole-bearing gabbros of the younger basement and from the Chamrousse ophiolite.

4.2. Metamorphic Evolution

4.2.1. Internal Zones

In the internal zones (Pennine and Austro-Alpine) the pre-Alpine metamorphic evolution includes the following stages recorded by mineral relics and/or radiometric ages: eclogite, amphibolite locally associated with anatexis, and local greenschist (DESMONS, 1992, with previous references).

4.2.1.1. Eclogites

Early eclogites are found in the Bernhard-Briançon zone (THÉLIN et al., 1989; DESMONS in DEBELMAS et al.; 1989; MESSIGA, 1981), in the internal Pennine massifs and in the internal Austro-Alpine units. They may have been much more widespread than currently found, as shown by the common presence of rutile, by the ≈10–30 % pyrope content of garnet cores and by symplectitic remnants.

Granulite relics older than eclogitic minerals have been mentioned in the Sesia Zone and considered as possibly present in the Gran Paradiso (BATTISTON et al., 1984–87).

The pre-Alpine age of the eclogites in the Briançon-Bernhard zone is beyond doubt (in spite of CABY & KIENAST's, 1989, contention of a Meso-Alpine age, i.e. Upper Eocene-Lower Oligocene), as the succeeding associations are observed : omphacite + garnet → (pre-Alpine) hornblende + plagioclase + clinozoisite + garnet → (Alpine) glaucophane + epidote + chlorite and chlorite ± actinolite + albite + epidote. Eclogites in more internal units could actually belong to two age groups, one earlier than the amphibolite metamorphic facies and one Eo-Alpine in age. In the Monte Rosa massif BEARTH (1952) suspected early eclogites, older than the amphibolite association. COMPAGNONI & LOMBARDO (1974), arguing that eclogite associations could not have survived at close contact with intrusive granite, as well as DAL PIAZ & LOMBARDO (1986) sustained an Alpine age for all Gran Paradiso and Mte Rosa eclogites. However, the argument can be reversed and one can wonder, in the hypothesis of Eo-Alpine eclogites, how would come that the granite adjoining the eclogite has not been eclogitized as the Sesia granitoids have been. Moreover, some pre-Alpine minerals such as kyanite do subsist as relics in spite of the granite intrusion.

For two decades the eclogites of the Dora-Maira massif and of the Sesia zone have been interpreted as only Eo-Alpine (Mid-Cretaceous) (DAL PIAZ et al., 1972; COMPAGNONI et al., 1977; CHOPIN, 1984; LARDEAUX et al., 1982) and radiometric data have been supplied as supporting evidence. However, it seems questionable whether the Eo-Alpine metamorphic event was ever able to pervasively recrystallize amphibolite-facies rocks, producing eclogite associations with centimetre and up to decimetre grain sizes. Ascertained pre-Alpine rocks similar in their mineralogical content and structure to the Western Alpine eclogite and amphibolite are present in the Middle Austro-Alpine. In the Dora-Maira case, grain size and structural relationships show that pyrope crystallized during a phase older than phengite: the question is how much older.

4.2.1.2. Remarks on the Radiometric Data

The interpretation of radiometric ages is a delicate task and the weak point in geochronological work. Minerals (such as the Dora-Maira phengite dated as Alpine, SCAILLET et al., 1990), may have first crystallized as members of a pre-Alpine paragenesis and have been rejuvenated during the late Eo-Alpine or the Meso-Alpine metamorphic event. In this case, they would not belong to an early Eo-Alpine, eclogitic, phase. Alpine apparent ages of zircon may correspond to a healing event after a period of alteration, which has actually been identified. The available Dora-Maira data yield, not Eo-Alpine, but Meso-Alpine and Permian ages, which correspond exactly to the two main thermal events since late Palaeozoic.

Generally speaking, Rb-Sr and K-Ar methods date thermal events: the thermal peak or the closure of the isotopic system. In many cases of polymetamorphism the apparent ages date neither the primary crystallization time, nor the foliation plane where the dated mineral is lying, nor even the associated minerals. When a same group of ages is found all over a large area (e.g. Permian ages in the Alps), a period of high heat flow, thus an extensional regime, must be suspected, which can be directly dated through the primary minerals of the related magmatics. Likewise, when similar ages are repeatedly obtained from one tectonic zone, the possibility must be considered that the dated event is not the crystallization but an isotopic closure due to an abrupt tectonic event.

Examples can be the tectonic detachment of slabs of eclogitic-cratonic and granulitic-tectonically active lower crust (sensu GRIFFIN & O'REILLY, 1987), or a shearing event catalyzing a reaction that in spite of appropriate P-T conditions had been prevented to occur earlier owing to nucleation or fluid circulation problems (e.g., AUSTHREIM & GRIFFIN, 1985). In many cases eclogites point not to a high--pressure type of metamorphism and ultra-deep subduction of sialic crust, but to the tectonic incorporation of slabs of cratonic deep crust, reflecting a shield, i.e. a high-pressure-barrovian, geotherm.

4.2.1.3. Amphibolite Facies

Amphibolite facies associations post-date the eclogite facies. Kyanite, staurolite, biotite, garnet, hornblende are known in all ancient Pennine and Austro-Alpine basement units, sillimanite (relic or pseudomorphed) has been found in the Monte Rosa and Gran Paradiso massifs (BEARTH, 1952; COMPAGNONI & PRATO, 1969), in the Bernhard zone near the Great St.-Bernhard pass and in Ligury where an anatexis grade has been reached (MESSIGA, 1981; CORTESOGNO et al., 1982; CORTESOGNO, 1984–86). An evolution of the amphibolite facies can be recognized in particular areas: a kyanite-bearing, middle-pressure phase has been followed by a higher-temperature, sillimanite-bearing, phase, then by a lower-pressure and temperature, biotite-bearing, phase during which kyanite was no longer stable (BOCQUET [DESMONS], 1974a; DESMONS, 1992; DESMONS & MERCIER, 1993). A late greenschist phase has been distinguished in the Ligurian Alps.

So far, the amphibolite facies phase or phases remain undated in the internal Western Alps. Variscan K-Ar ages obtained from biotite and white mica (BOCQUET [DESMONS], et al., 1974; MONIÉ, 1990) may date the greenschist phase, or have no geological significance. Most muscovite ages, if not Alpine-rejuvenated, point to the Permian thermal event. A late Proterozoic, i.e. late Pan-

African age is possible for this amphibolite facies phase in the internal basement units.

4.2.1.4. Variscan

In these internal units the Variscan (Devonian-Lower Carboniferous) metamorphic imprint has been absent or of very-low grade (in the younger basement and most of the ancient basement) to low-grade (in part of ancient basement units: the later greenschist facies mentioned in Ligury). This is of utmost importance in differentiating the basement of the external units from the internal units.

4.2.1.5. Late Variscan

As shown by the Upper Carboniferous rocks of the zone Houillère, the late Variscan events did not leave any noticeable metamorphic imprint in this part of the Briançon zone. However, the radiometric ages that are commonly obtained in the Pennine basement point to a Permian high heat flow regime. This can be connected with the widespread acid magmatism of that period and of Lower Triassic time, and with the likely existence of an underlying extensional and granulitized deep crust.

Most contact effects around the Variscan granitoids did not survive the Alpine metamorphic phases. Andalusite-bearing veins have been locally mentioned, however (BEARTH, 1960-63).

4.2.2. External Basement Units

In the external basement units a number of chronological data (summarized by von RAUMER, 1984; von RAUMER et al., 1990) point to:

1) poorly defined Proterozoic metamorphic events (amphibolite facies, migmatite);
2) Ordovician-Silurian eclogite (PAQUETTE et al., 1989b) (time of the crystallization of the eclogite minerals or of the detachment from the cratonic lower crust?);
3) Devonian to Carboniferous amphibolite metamorphic associations, evolving from kyanite through sillimanite to andalusite associations, with migmatite and Late Carboniferous granitoid intrusion.

5. Concluding remarks: Comparison with the Eastern Alps

Some close similarities can be recognized in protolith lithology and in pre-Alpine metamorphic evolution of Western and Eastern Alpine units (Table 2). It must be noted that these similarities may be related to common histories up to a certain time, but do not imply identical Alpine structural positions. The similarities are:

1) Between the ancient Pennine plus Austro-Alpine basement units of the Western Alps and Middle Austro-Alpine crystalline units of the Eastern Alps (Celtic and, in part, Noric terranes of FRISCH & NEUBAUER, 1989);
2) Between the younger Pennine basement units and the Upper Austro-Alpine in the Eastern Alps (e.g. most part of the Noric terrane; compare the Bellecôte sills and plutonites with the metabasites from the Greywacke Zone and Upper Austro-Alpine; NEUBAUER & FRISCH, 1988; LOESCHKE, 1989; NEUBAUER et al., 1989);
3) Between the external crystalline massifs (and the Sub-Pennine – i.e. lower than Pennine – units in the Central Alps) and both Untere Schieferhülle and Gneisskerne of the Tauern window (following a proposal of DESMONS & RADELLI, 1990, based on lithological similarities of both crystalline and Mesozoic sequences, on the Varis-

Table 2.
Summarized data and proposed correlations concerning the pre-Upper Carboniferous crystalline sequences.

Zone/Sequence	Lithology	Tectonic environment	Protolith ages (esp. basic rocks)	Comparable lithologies in the Eastern Alps
Upper Palaeozoic	clastic; veins and sills; acid magmatic rocks	intracrontinental basins; distension; desert climate	Upper Carboniferous-Permian	~ Veitsch ?; Verrucano, etc.
External crystalline massifs	greywackes, shales banded metabasites ophiolite body plutonic-volc. complex	intra-continental rift ? back-arc or ensialic basin on attenuated margin	early Palaeozoic late Proter./Cambrian Devonian	Tauern Unt. Schieferh. Stubach complex Untere Schieferhülle
ancient basement **Briançon and Internal Penninic massifs**	greywackes, shales banded metabasites, few boudinaged bodies	?	late Proterozoic ?	Middle AA : Ötztal, etc.
younger basement	shales, greywackes plutonic complex, basic sills, felsic tuffs (Pourri)	marginal basin ?	Cambrian	Upper Austro-Alpine ?: Graz, Gurk, Grauwackenzone Upper Ordov. in Upper AA
Eastern Sesia	greywackes, minor marbles and quartzites boudins and banded amphibolites	?	late Proterozoic ?	Middle AA : Ötztal, etc.

can age of the granitoid intrusives and on the Alpine structural position below Wallis-type ophiolites and schists). In particular, the Cambrian-Ordovician Chamrousse ophiolite, generated in a back-arc basin, partly above a subduction zone, should be compared with the ensimatic arc-derived Stubach ophiolite (FRISCH & NEUBAUER, 1989 with previous references). The late Proterozoic-early Palaeozoic banded amphibolites of the external crystalline massifs should be compared with the metabasites of the (upper Proterozoic or Palaeozoic?) Habach formation (HÖCK et al., 1982; FRISCH et al., 1987; REITZ & HÖLL, 1988). Thus, the Tauern crystalline basement and cover should best be compared, not to Briançon basement, but to Simplon-Ticino basement units and Wallis/Valais cover sequences.

At the onset of the Alpine orogenic cycle, all Pennine and Austro-Alpine units belonged to Gondwana, more precisely to that part of the Tethys s.l. formed by the Gondwanan margin, from which fragments will detach arc-fashion, creating back-arc basins behind them (RADELLI & DESMONS, 1987, 1988). These units are derived from a large Gondwanan province characterized by a same gneiss-amphibolite "ancient" association.

During Variscan times, while the future external crystalline massifs and Sub-Pennine units, already detached from Gondwana, together with other parts of Variscan Europe were progressively accreted to Laurentia-Baltica, extensional processes were resulting in some magmatism and intracontinental basin subsidence within the margin of Gondwana (the future younger basement and Upper Austro-Alpine). Localized high heat flow produced granitoid intrusions and rejuvenated isotopic systems. It is worth noting that the two basement types, younger and ancient, are also found in Calabria (DI PISA et al., 1988), in the Tuscan basement (e.g., MORETTI et al., 1990) and other places of the Alpine belt.

The importance of the Variscan thermal events in the Eastern Alps is still debated: regarded as minor by BECKER et al. (1987, p. 178, in the Ötztal), it is also considered as high (MORAUF, 1982, in the Koralm, and others). As mentioned above, one has to be careful in distinguishing a thermal re-setting from a regional metamorphic and deformational phase.

Much work has still to be done on the internal crystalline units of the Western Alps, especially as concerns the chemical composition, the magmatic sources and the ages of the metabasites. The ancient basement still conceals much of its complexity. The metabasites appear as polygenic. The Chamrousse ophiolite bears evidence of ocean-type crust in lower Palaeozoic times. Many of the other ancient metabasites have the composition of high Ti-tholeiites. As they do not form ophiolite sequences but are associated with leucocratic rocks, they perhaps are to be interpreted as ensialic magmatics or volcaniclastics, a hypothesis that should be confirmed by additional trace element data. A similar ensialic origin has been inferred for the metabasites of the Middle Austro-Alpine of the Eastern Alps (FRISCH & NEUBAUER, 1989). In the present state of knowledge any attempt at an Early Palaeozoic palaeogeographic reconstruction seems to be a premature and delusive attempt.

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