Correlation and evolution of the Alpine basement

Autor(en): **Frisch, Wolfgang / Ménot, René-Pierre / Neubauer, Franz**

Objekttyp: **Article**

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

Band (Jahr): **70 (1990)**

Heft 2

PDF erstellt am: **07.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-53618

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

http://www.e-periodica.ch

SCHWEIZ. MINERAL. PETROGR. MITT. 70, 265–285, 1990

Herrn Professor Dr. Christof Exner zu seinem 75. Geburtstag gewidmet

Correlation and evolution of the Alpine basement

by *Wolfgang Frisch*[1], *René-Pierre Ménot*[2], *Franz Neubauer*[3] *and Jürgen F. von Raumer*[4]

Abstract

The basement of the Alps constitutes part of the Variscan orogen. Helvetic and Penninic basement as well as a small portion of the Austroalpine basement belong to the internal zone of the Variscan orogen, i.e. the Ligerian-Moldanubian Zone. The major part of the Austroalpine-Southalpine basement belongs to the southern branch of the Variscides. Parts of the Penninic basement as exposed in the Eastern Alps are not correlatable with other zones of the Variscides.

Early Precambrian elements going back into the Archean exist in the Austroalpine basement which probably formed part of Africa. Recent publications and comparison with the extra-Alpine foreland lead to the conclusion that Archean elements occur also in the Helvetic basement. Crustal mobility characterizes the period from the Late Proterozoic to the Ordovician throughout the Alpine basement zones. This is demonstrated by the formation and subduction of ocean floor and the generation of large volumes of subduction-related magmatism. Crustal consolidation occurs from the Ordovician through the Carboniferous in various stages of collisional tectonics.

Keywords: Alpine basement, Variscan orogen, crustal evolution, Helvetic Zone, Penninic Zone, Austroalpine Zone, Southalpine Zone.

1. Introduction

Basement is incorporated in all Alpine mega-units of the Alps. Basement complexes with contrasting lithologies may have been formed in distant places and brought together during the Alpine or older orogenies. Therefore it is of interest to show differences and similarities between distinct tectonometamorphic units. Basement occurs in the following Alpine units (Fig. 1):

(1) the Helvetic Zone which is correlated with the European foreland of the Alps and is part of the Alpine lower plate;

(2) the Penninic Zone which is also a continuation of the European foreland but separated from it by crustal thinning and the formation of microplates;

(3) the Austroalpine and Southalpine Zones represent the upper plate of the Alpine edifice, both being separated by the Periadriatic Lineament which was active in the Tertiary.

The aim of this paper is to give a comprehensive review of data and interpretations concerning the basement evolution and to discuss correlations and differences between various units. Polyphase deformation and metamorphism including the Alpine events veil the earlier history and the nature of the protoliths. However, the increase of stratigraphical, petrological, geochemical, and geochronological data in the near past demonstrate the complex histories of the rocks and allow models for both the geotectonic environments in which the protoliths were formed and the pre-Alpine evolution of the units to be proposed. Immense uncertainties still exist with the reconstruction of the pre-Alpine spatial relationships of the basement zones.

---

[1] Institut für Geologie und Paläontologie der Universität, Sigwartstrasse 10, D-7400 Tübingen/Deutschland.

[2] Université Jean Monnet, Lab. de géologie-pétrologie, U.R. associé C.N.R.S no 10, F-42023 Saint-Etienne, Cédex, France.

[3] Institut für Geologie und Paläontologie der Universität, Heinrichstrasse 26, A-8010 Graz/Österreich.

[4] Institut für Mineralogie und Petrographie, Universität Fribourg, Bd de Pérolles, CH-1700 Fribourg/Schweiz.

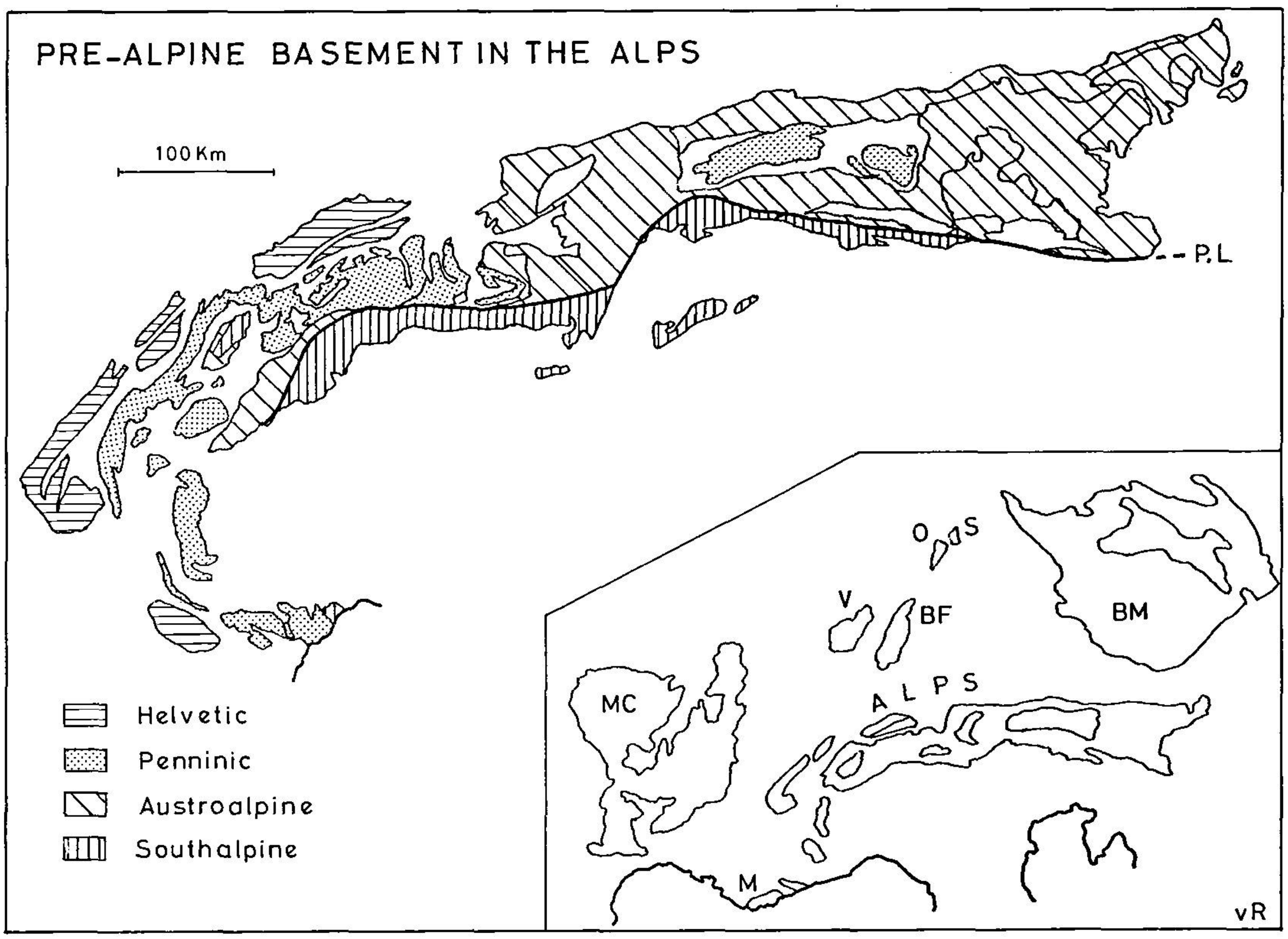

Fig. 1 Sketch map of pre-Alpine basement units in the Alps and their affiliation to the Alpine tectonostratigraphic zones. P.L.: Periadriatic Lineament.
Inset: the pre-Alpine basement areas in the European framework.
Legend: BF – Black Forest; BM – Bohemian Massif; M – Massif des Maures; MC – Massif Central; O – Odenwald; S – Spessart; V – Vosges.

2. Basement of the Helvetic Zone

The Helvetic Zone contains a number of basement complexes (the so-called External Massifs), from S to N (Fig. 2): Argentera Massif, Haut Dauphiné-Grandes Rousses Massif, Belledonne Massif, Mont Blanc-Aiguilles Rouges Massif, and Aar-Gotthard Massif. Erosion and first deposition of overstep sequences occurred in the Late Carboniferous. The northern parts of this basement were part of the "Vindelizische Schwelle" in the Triassic.

The Helvetic basement comprises three different types of rock assemblages: (1) The major part is occupied by polymetamorphic series which suffered high-grade metamorphism and include relics of an eclogitic and a granulitic event. (2) Monometamorphic series with a contrasting evolution appear in the Belledonne Massif and consist of low- to medium-grade metamorphic rocks. (3) Throughout the basement massifs, small inliers of low-grade metamorphic sedimentary and volcanic rocks exist, which probably are of Late Devonian and Early Carboniferous age.

2.1. POLYMETAMORPHIC AREAS

Age interpretations are based on both lithostratigraphic comparison with the extra-Alpine foreland (Arnold, 1970; Pecher, 1970; Le Fort, 1973; Le Fort et al., 1971; Bogdanoff, 1980, 1986; Schenker, 1986; Ménot, 1987 a,b, 1988; von Raumer, 1984a,b, 1987, 1988; Vittoz et al., 1987; Vivier et al., 1987) and radiometric data. The oldest basement relics are difficult to define and may include Cadomian and Early Precambrian structures. They are composed mainly of granitic gneisses and migmatites with lenses of amphibolites, ultramafic rocks, quartzites, and calcsilicate rocks. The latter preserved sedimen-

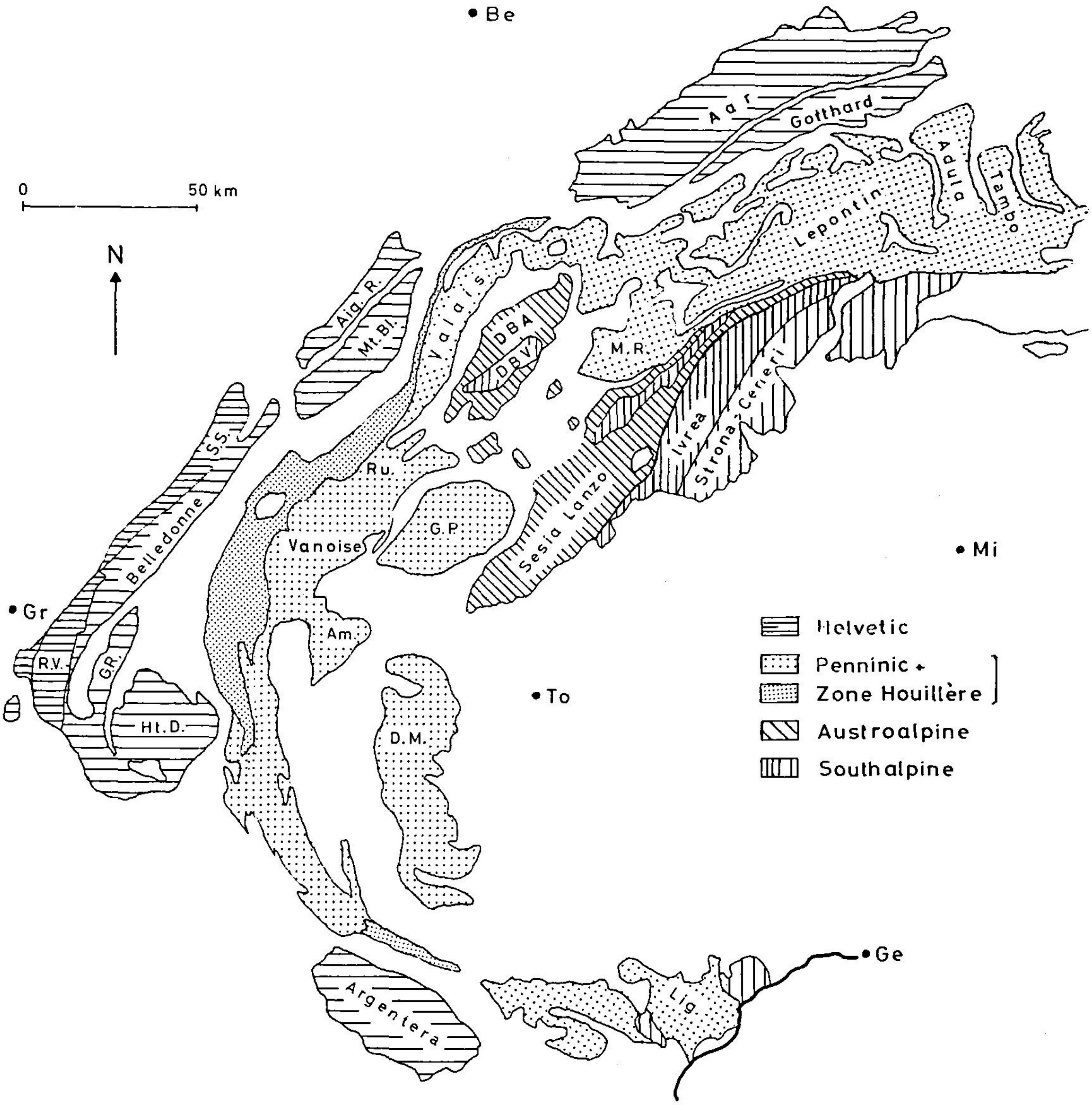

Fig. 2 Simplified map of basement units in the Central and Western Alps.
Abbreviations: Be – Bern; Ge – Genova; Gr – Grenoble; Mi – Milano; To – Torino.
Helvetic basement: Aig.R. – Aiguilles Rouges Massif; G.R. – Grandes Rousses; Ht.D. – Haut Dauphiné; Mt.Bl. – Mont Blanc Massif; R.V. – Romanche valley area; S.S. – Série satinée unit.
Penninic basement: Am. – Ambin Massif; DM – Dora Maira Massif; GP – Gran Paradiso Massif; Lig – Ligurian Alps; MR – Monte Rosa Nappe; Ru – Ruitor zone.
Austroalpine-Southalpine basement: DBA – Dent Blanche Nappe, Arolla series; DBV – Dent Blanche Nappe, Valpelline series.

tary structures as observed in the Gotthard Massif (ARNOLD, 1970). Radiometric data from the Gotthard Massif, Aiguilles Rouges, Belledonne and Argentera Massifs (PAQUETTE et al., 1989) provide evidence of Proterozoic and Archean elements with upper intercept zircon ages between > 2.1 – > 2.6 b.y. (GRÜNENFELDER et al., 1964; NUNES and STEIGER, 1974; GEBAUER and GRÜNENFELDER, 1983; GEBAUER et al., 1988; PAQUETTE et al., 1989). Precambrian sequences in the Schwarzwald show a comparable lithostratigraphy and are therefore correlated with the Helvetic basement (HIRSCHMANN, 1987; VON RAUMER, 1988).

The Precambrian basement is covered by Late Proterozoic to Early Paleozoic detrital metasediments. They are interlayered with very few carbonate horizons and contain acidic and basic volcanogenic rocks in many places. The metabasic rocks are prominent in the Aar and Argentera Massifs. The geochemistry of eclogites and amphibolites from the Aiguilles Rouges Massif is interpreted in terms of a continental rift environment (LIÉGOIS and DUCHESNE, 1981; PAQUETTE, 1987; PAQUETTE et al., 1989; VON RAUMER et al., 1990).

An important orogenic event in the Ordovician and Silurian causes a major break in the geotectonic evolution. It comprises subduction and eclogite formation, collision, and obduction of ophiolites. Radiometric data for the eclogitization are Ordovician in the Gotthard Massif (GEBAUER et al., 1988), Early Ordovician to Silurian in the Argentera Massif, and Ordovician to Early Devonian in the Belledonne and Aiguilles Rouges Massifs (PAQUETTE, 1987; PAQUETTE et al., 1989). The eclogites were formerly interpreted as tectonic lenses incorporated into higher structural levels. Recent oberservation pleads for in-situ formation, the eclogitic mineral assemblages being preserved only in the metabasic rocks (Aiguilles Rouges Massif: VON RAUMER, 1988). Relics of granulites are recorded from the Gotthard and Argentera Massifs (ARNOLD, 1970; LATOUCHE and BOGDANOFF, 1987). Precambrian or Early Paleozoic rock series suffered amphibolite facies metamorphism and anatexis before they were transformed under granulite facies conditions 450 Ma ago and intruded by granitoids of Ordovician to Silurian age (GRAUERT and ARNOLD, 1968; ARNOLD, 1970). The granitoids are widespread and especially abundant in the Argentera Massif.

These events were followed by a Devonian to Carboniferous metamorphic cycle. Its prograde path is of the Barrovian type with the successive formation of kyanite and sillimanite and correlates with early Variscan nappe formation in the Devonian (VON RAUMER, 1983, 1984a,b, 1987; BOGDANOFF, 1986; JOYE, 1989). Sillimanite bearing parageneses predominate in most areas, whereas kyanite bearing parageneses are only preserved as relics. The thermal peak is documented by the formation of eutectic and cordierite bearing incongruent melts. Andalusite formed during the consecutive updoming. Large strike slip faults facilitated the post-metamorphic intrusion of Late Carboniferous granites throughout the Helvetic Zone (e.g., Mont Blanc granite: 316 Ma; BUSSY et al., 1989; Aar granites: 290–265 Ma; SCHALTEGGER, 1986). Thrusting and granite intrusion accompanied by volcanic activity continued until the Permian (MERCOLLI and OBERHÄNSLI, 1988; OBERHÄNSLI et al., 1988).

2.2. MONOMETAMORPHIC AREAS

In contrast to the long, polymetamorphic evolution of the great part of the Helvetic basement, two areas in the Belledonne Massif are worthy of attention because of their monometamorphic evolution of generally lower grade: the "Série satinée" unit in the northwestern part and the Romanche valley in the southwestern part.

"Série satinée" unit

The "Série satinée" consists of pelitic schists and metapsammites with some scarce volcanogenic layers of basaltic composition (BORDET, 1961; SIMEON, 1979). The sequence forms kilometer-sized folds with vertical cleavage and fold axes (CARME, 1970b). The mineral parageneses report an evolution from medium- to low-grade metamorphism. Post-metamorphic strike slip faults are of Early to Middle Carboniferous age (KALSBEEK, 1961; CARME, 1970b, 1971; GASQUET et al., 1981). The depositional age of the metasediments is inferred to be Late Precambrian to Early Paleozoic when compared with the series in the Cevennes and the northern Vosges.

Romanche valley area

The Romanche valley area includes three lithostratigraphic units with distinct metamorphic evolutions before nappe formation in the Early Carboniferous:

(1) The Allemont-Rochetaillée Formation of Late Proterozoic to Early Paleozoic age (CARME and PIN, 1987) is composed of gneisses and amphibolites comparable in lithology and amphibolite chemistry to the polymetamorphic basement. A high-pressure event could not be recognized. Intermediate-pressure metamorphism is locally followed by the formation of anatectic melts (CARME, 1974). A greenschist facies overprint is related to thrusting and strike slip faulting (MÉNOT, 1987b).

(2) The ophiolite of Chamrousse-Séchilienne, the most prominent unit of the area, yielded for-

mation ages of 496 ± 6 Ma (U/Pb, zircon; MÉNOT et al., 1984a, 1988) and 497 ± 24 Ma (Sm/Nd; PIN and CARME, 1987). The ophiolite body is in an inverted position and shows a continuous gradation from the plutonic sequence (Chamrousse Formation) into the volcanic and volcano-sedimentary sequences (Séchilienne Formation) (CARME, 1973; MÉNOT, 1987a, 1988). The geochemical pattern suggests that the ophiolite was formed in a transitional environment between attenuated continental crust and oceanic crust (BODINIER et al., 1981; MÉNOT, 1987). PIN and CARME (1987) pointed out a supra-subduction zone influence. Metamorphic recrystallizations are related to early intra-oceanic tectonics and to Late Devonian to Early Carboniferous orogenic events (MÉNOT, 1987a; MÉNOT et al., 1987). The ophiolite neither suffered the Early Paleozoic high-pressure event nor the Devonian intermediate-pressure metamorphism and anatexis.

(3) The Devonian Rioupéroux-Livet plutonic and volcanic complex includes a leptynitic and amphibolitic series and meta-trondhjemitic plutons associated with mainly meta-acidic volcanic rocks, meta-volcaniclastic rocks, and meta-greywackes (CARME, 1965; MÉNOT et al., 1984b; MÉNOT, 1986). Two sills of meta-trondhjemites were dated 352 ± 56 and 365 ± 17 Ma, data respectively corresponding to lower and upper intercepts of discordia lines (U/Pb, zircon; MÉNOT, 1987a). The tectogenesis is younger than about 360 Ma (after the meta-trondhjemite intrusion) and older than the 324 ± 12 Ma cooling age (K/Ar; MÉNOT et al., 1987). It leads to low- to medium-grade mineral assemblages.

2.3. FOSSILIFEROUS SEDIMENTARY SEQUENCES

The Taillefer unit is a sedimentary sequence deposited in troughs on top of the crystalline basement. Accompanying igneous activity is considered a late expression of the Devonian orogenic events. The age of the Taillefer unit is Late Devonian (?) and Early Carboniferous. GIBERGY (1968) discussed the occurrence of fossil relics of probably Viséan age. Palynological data from the western part of the Aiguilles Rouges Massif confirm a Late Viséan age for a part of the detrital series (BELLIÈRE and STREEL, 1980). It seems reasonable to relate the Early Carboniferous sedimentation to strike-slip fault systems. Late Carboniferous molasse-type sediments are limited to well defined tetctonic structures (probably pull-apart basins) and represent the detritus of the eroding mountain chain.

2.4. CONCLUSIONS

The polymetamorphic parts of the Helvetic basement are correlated with the European foreland of the Alps (VON RAUMER and MÉNOT, 1989). Comparable rock units appear in the boreholes of northern Switzerland and in the Variscan basement of the French Massif Central, the Vosges, and the Schwarzwald. The origin of most units is still a matter of debate. The "Série satinée" and the Chamrousse ophiolite were interpreted as subautochthonous (MÉNOT, 1987a) or as "klippen" (VON RAUMER and MÉNOT, 1989). A southward polarity of Variscan structures as observed in the Helvetic basement in its present position is considered the result of late Variscan tectonics. The present day situation supports overthrusting of lower basement units (e.g., the Chamrousse ophiolite) over the parautochthonous Late Devonian and Early Carboniferous formations.

3. Basement of the Penninic Zone

Penninic basement appears in a broad zone in the Central and Western Alps and extends into the Tauern Window of the Eastern Alps. It is generally strongly deformed together with its Mesozoic cover and shows Alpine metamorphic overprint in greenschist and amphibolite facies grade obliterating most pre-Alpine structures. Most information about the Penninic basement stems from the Tauern Window.

3.1. PENNINIC BASEMENT OF THE TAUERN WINDOW

The Tauern Window is composed of two Penninic mega-units. Only the lower one, referred to as the Venediger Nappe (FRISCH, 1974), contains a pre-Alpine basement.

The main lithologies of the Penninic basement of the Tauern Window are amphibolites and plagioclase gneisses intruded by large volumes of Variscan granitoids. The pre-granitoid sequence is dominated by metavolcanic rocks interlayered with metasedimentary rocks and is referred to as the Habach Group in the central part of the window (FRASL, 1958) and the Storz Group in its eastern part (EXNER, 1971). The metavolcanic rocks form a typical island arc sequence (VON QUADT, 1984; STEYRER and HÖCK, 1985; FRISCH and RAAB, 1987; VAVRA and FRISCH, 1989). The protoliths are basalts, andesites, and more acidic calc-alkalic rocks. The widespread amphibolites derive from low-K tholeiites and low- to medium-K calc-alkalic basalts and andesites. The tholeiites are inferred as having formed in a geotectonic setting transitional between ocean floor and a primitive island arc. Mesocratic to leucocratic plagioclase gneisses are the most prominent lithology and represent dacitic (mainly pyroclastic) and reworked volcanic rocks (FRISCH and RAAB, 1987). Metapelitic rocks, which are generally graphite bearing, are prominent in some areas and show graded bedding in a few places (LAMMERER, 1986). Metachert occurs in different places, whereas carbonate rocks are almost lacking.

Ophiolite slices referred to as the Stubach Group are associated with the island arc sequence and interpreted as part of the oceanic basement on which the island arc evolved (FRISCH and RAAB, 1987; NEUBAUER et al., 1989; VAVRA and FRISCH, 1989). From the trace element pattern of the basic rocks, the Stubach ophiolite is interpreted as former back arc oceanic crust. The lack of a high-pressure metamorphic event and the predominance of deep crustal rocks favour an emplacement by obduction.

Gabbroic amphibolite from the Stubach ophiolite yielded U/Pb zircon ages and Sm/Nd mineral isochron ages in the range of 660–640 Ma interpreted as formation ages (VON QUADT, 1989). The volcanic arc sequence was active since at least the Cambrian. An end-Precambrian to Cambrian age is documented by the upper discordia intercept of U/Pb data from zircons of a metadacite (VAVRA and HANSEN, in prep.) representing an already advanced stage of the island arc evolution. Late Proterozoic is documented by acritarchs in metapelites of the Habach Group (REITZ and HÖLL, 1988a; GILG et al., 1989). Upper intercepts ages from U/Pb zircon dating in amphibolites derived from gabbro and cumulate pyroxenite are 498 ± 12 and 492 ± 2 Ma and are interpreted as intrusion ages (VON QUADT, 1984, 1987, 1989). A Sm/Nd mineral isochron age indicates a metamorphic event shortly after this magmatic event (VON QUADT, 1987). VAVRA (1989) argued that also the zircon ages may indicate an Early Paleozoic metamorphic event with partial anatexis.

Variscan metamorphism had its climax around 320 Ma before present. This is shown by K/Ar dating of amphibole (PESTAL, 1983) and by zircon dating of amphibolitic rocks (VON QUADT, 1987) and in anatectic gneisses (VAVRA, 1989). At the same time anatectic granitoids formed, now transformed into the "Central Gneiss". They are surrounded by migmatitic halos sometimes of considerable width (CLIFF, 1971; EXNER, 1971; MORTEANI, 1971). Geochemistry and morphological evolution of zircons indicate that the Storz and Habach Groups were involved in the anatectic process which furnished the granitoids (VAVRA, 1989). High-pressure metamorphic assemblages in the basement are suggested by DROOP (1983) to be pre-Alpine. ZIMMERMANN et al. (1989) brought radiometric evidence for the existence of early Paleozoic eclogites. This age, however, is debatable since the localities are situated close to the Alpine eclogite zone.

The mid-Carboniferous granitoids form batholiths ranging from quartzdiorite to leucogranite (LAMMERER et al., 1976). FINGER and STEYRER (1988) identified both I- and S-type granitoids. Rb/Sr whole rock and U/Pb zircon ages of the granitoids cluster around 325–315 Ma (CLIFF, 1981) and are interpreted as intrusion ages and the climax of anatexis. High level porphyric metagranite intruding the Storz Group and displaying chemical characteristics transitional between calc-alkalic and alkalic suites yielded a Permian intrusion age (VAVRA and HANSEN, in prep.). This magmatism is probably genetically related to the intrusion of lamprophyres which also display an intraplate component (EXNER, 1971; VAVRA 1989). A number of Permian Rb/Sr ages from Zentralgneisses are probably slightly disequilibrated Carboniferous ages (FRANK et al., 1987).

The post-Variscan overstep sequence (Wustkogel Formation; FRASL, 1958) consists of terrestrial psephites and psammites intercalated with acidic volcanic rocks. The sediments contain much detritus from these volcanic rocks and the Variscan granitoids. Their age is inferred to be Permian.

3.2. PENNINIC BASEMENT OF THE CENTRAL AND WESTERN ALPS

Cross sections through the Penninic Zone of the Central and Western Alps (e.g., ESCHER et al., 1988) show the intense deformation of basement nappes due to Alpine metamorphism. The basement suffered Early Carboniferous medium- to high-grade metamorphism and anatexis which was followed by the intrusion of granitoids (BEARTH, 1961; HUNZIKER, 1970; DAL PIAZ et al., 1972). The main pre-granitic lithologies are metasediments (paragneisses and micaschists), K-feldspar augengneisses, and amphibolites (e.g. THÉLIN and AYRTON, 1983; FABRE et al., 1987). Bodies of ultramafic rock occur sporadically (e.g., Ligurian Alps: VANOSSI et al., 1984). A banded sequence of amphibolites and plagioclase gneisses with ultramafic lenses occurs in the Berisal complex (western Lepontin area) and is interpreted as the product of island-arc volcanic rocks (tholeiites and dacites; STILLE, 1980).

U/Th/Pb age determinations on zircon plead for two episodes of events, one about 500–400 Ma ago and one about 300 Ma ago (KÖPPEL et al., 1981). STILLE (1980) yielded radiometric evidence for Late Cambrian formation ages for the banded sequence of the Berisal complex, whereas STILLE and TATSUMOTO (1985), based on Sm/Nd dating, propose a Proterozoic age for basic volcanic rocks (1071 ± 59 Ma) and a bad defined Paleozoic age for ultramafic intrusive rocks (475 ± 81 Ma). This is in contrast to Rb/Sr data which indicate an age of ca. 500 Ma for all ultramafic, mafic, and intermediate rocks. Crustal contamination of the Sm/Nd system may be the explanation for the discrepancy between the Rb/Sr and Sm/Nd whole rock ages (PIN, pers. commun.). Partly based on the data of STILLE and TATSUMOTO (1985) ZINGG (1989) discusses a Proterozoic protolith age of amphibolites from the Siviez-Mischabel series in the Bernhard Nappe and a Cambrian Sm/Nd age for komatiitic metabasalts. U/Pb determinations on zircon from orthogneisses yield Ordovician and Silurian ages ranging between 484 and 406 Ma which are interpreted as minimum intrusion ages. Augengneisses representing Ordovician granitoids are frequent in the whole domain (THÉLIN, 1983).

The post-Variscan overstep sequence is dominated by metasedimentary and metavolcanic rocks of Late Carboniferous to Permian age. The terrestrial sequence is well documented in the Ligurian Alps and the "Zone Houllière" (CABELLA et al., 1988; CORTESOGNO et al., 1988a,b; FABRE et al., 1987). It is confined to graben and pull-apart structures. The sedimentary rocks are mainly clastic but also include coal seams. Most of the volcanic rocks show calc-alkaline affinities. Ignimbrites become predominant in the Late Permian. Some bodies of augengneiss in the basement (e.g., Randa gneiss) are interpreted as Permian alkalic granites (THÉLIN, 1987). Occurrences of Permian gabbro and pillow basalt were also reported (THÉLIN and AYRTON, 1983; ESCHER, 1988).

3.3. CONCLUSIONS

Besides Early Proterozoic components the pre-granitic sequences of the Penninic basement in the Tauern Window represent an ensimatic island arc deposited on oceanic basement that reveals back-arc (supra subduction zone) characteristics (FRISCH and RAAB, 1987; NEUBAUER and FRISCH, 1989; VAVRA and FRISCH, 1989). An ensialic nature of the basement was discussed by PESTAL (1983), STEYRER and HÖCK (1985), and KRAIGER (1989). The evolution of the island arc lasted from the Late Proterozoic (ca. 700 Ma b.p.) to the Early Paleozoic. The production of crust not older than Late Precambrian is also indicated by lead isotope data (KÖPPEL, 1983) although the presence of an older crust component is indicated by T_{DM} data. Much of the more evolved, acidic island arc volcanic rocks were transformed by anatexis into the Variscan granitoids. A widespread I-type component in the granitoids is inherited from the island arc rocks (VAVRA, 1989). The association of greenstones and granitic rocks closely resembles Archean granite-greenstone belts. A common mode of origin was proposed by FRISCH and RAAB (1987). ZINGG (1989) described Cambrian komatiitic metabasalts in the Penninic Zone of the Central Alps.

Lithologies representing ocean floor, island arc, and back-arc environments of Late Proterozoic to Early Paleozoic age are also present in the Central and Western Alps. A crustal component, however, is more pronounced. Like in the Helvetic and Austroalpine-Southalpine basement, Ordovician to Silurian granitoids are widespread. This is in marked contrast to the basement of the Tauern Window.

4. Basement of the Austroalpine-Southalpine Zone

4.1. AUSTROALPINE BASEMENT OF THE EASTERN ALPS

The Austroalpine basement is composed of a variety of complexes. They show differences in age, environment of formation, and degree of pre-Alpine metamorphism and were interpreted in terms of tectonostratigraphic terranes by FRISCH and NEUBAUER (1989). Fossiliferous sedimentary sequences ranging in age from Late Ordovician to Namurian A constitute the weakly metamorphosed areas (for a review, see SCHÖNLAUB, 1979). Geochronologic work revealed that the crystalline areas with a higher degree of pre-Alpine metamorphism encompass all Ordovician and Devonian basement complexes with a Precambrian history as well as the equivalents of the fossil-bearing sequences (for reviews, see BECKER et al., 1987; FRISCH et al., 1984; FRISCH and NEUBAUER, 1989). The different basement units

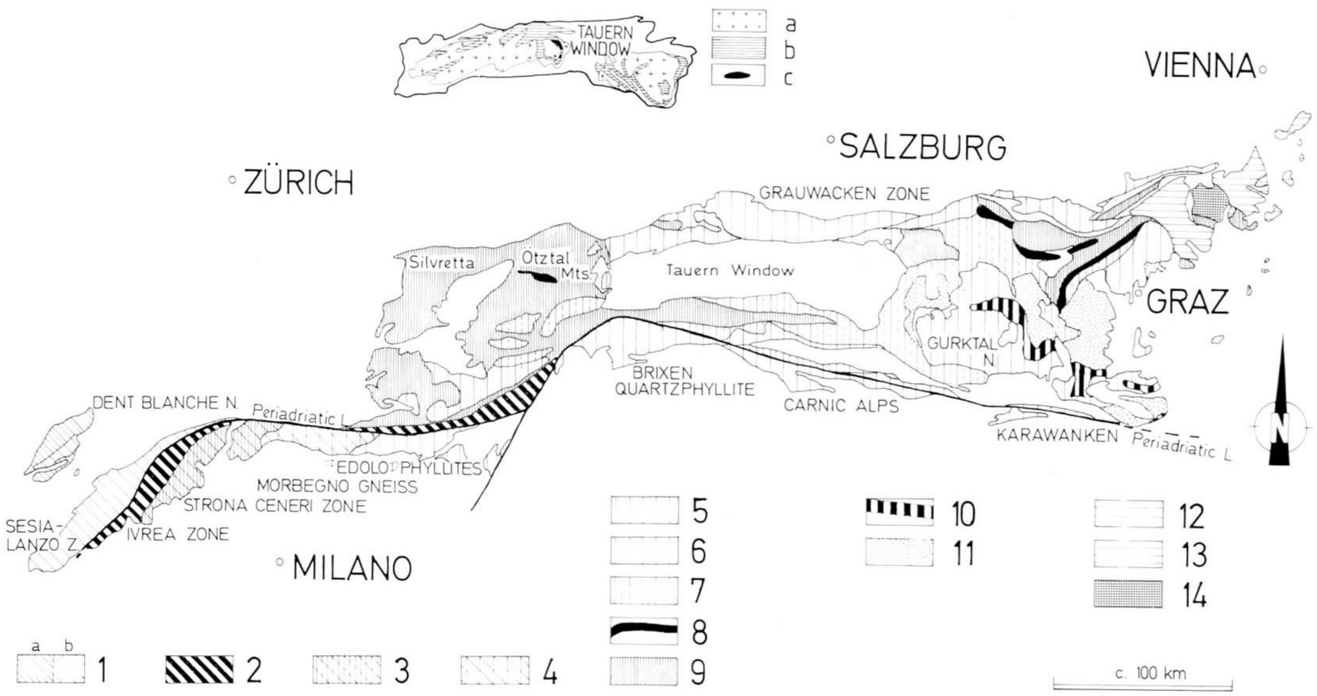

Fig. 3 Simplified map of lithostratigraphic units of the Austroalpine-Southalpine basement. The Austroalpine basement is north of the Periadriatic lineament, the Southalpine basement to the south of it. Both units contain a number of comparable lithotectonic basement units.
Legend: 1a – DB.N, Arolla Zone; 1b – DB.N, Valpelline Zone and Sesia-Lanzo Zone; 3 – Ivrea-Verbano Zone; 4 – Morbegno gneiss-Val Colla zone and related units; 5 – weakly metamorphosed, fossiliferous Paleozoic units; 6 – Quartzphyllite units; 7 – Micaschist-marble complexes; 8 – Speik complex and related units; 9 – gneiss-amphibolite associations; 10 – Plankogel complex and related micaschist units; 11 – Koriden (gneiss group) and Bundschuh complex; 12 – Noetsch-Veitsch-North Gemeric zone; 13 – Pannonic unit; 14 – Wechsel unit.

occur in different levels of the Alpine nappe edifice (Fig. 3, 4). Most of their boundaries correspond to Alpine tectonic lines partly marked by Permomesozoic rocks.

Based on field relationships and geochronologic and biostratigraphic data we propose a multi-stage geotectonic evolution:

(1) Radiometric dating of zircon reveals Early Precambrian crust-forming processes in three tectonostratigraphic units. The significance of these events remains unclear.

(2) A Late Precambrian to Early Paleozoic cycle ends in the Ordovician with orogenic movements, metamorphism, magmatism, and uplift.

(3) A subsequent cycle is characterized by rifting and subsidence recorded in a Late Ordovician to Early Carboniferous shelf and slope sequence deposited on top of the consolidated crust. Orogenic compression occurred in the Carboniferous.

(4) Some tectonostratigraphic units show evidence for a contrasting Paleozoic evolution with metamorphism and magmatism in the Devonian.

Precambrian to Early Paleozoic evolution

Tectonometamorphic units with a Precambrian to Early Paleozoic history and involved in the Early Paleozoic (Ordovician) orogeny form a pre-Variscan basement. An Early Paleozoic orogeny was claimed by SASSI et al. (1974) and discussed controversely since then (HEINISCH and SCHMIDT, 1976). Findings of Ordovician basement-cover contacts (NEUBAUER, 1985), geochronological and geochemical data, and Ordovician metamorphism and magmatism confirm the existence of such an orogenic event. The following units are discerned:

(1) Evidence for the existence of Late Archean crust material was given by U/Pb zircon dating in the crystalline Frauenberg slice forming the base of the fossiliferous Late Ordovician to Early Carboniferous sedimentary sequence of the Grauwacken Zone (NEUBAUER et al., 1989). The lower intercept of the discordia (ca. 512 Ma) indicates Early Paleozoic metamorphism.

(2) The "gneiss-amphibolite association" (FRISCH et al., 1984) comprises large areas in the

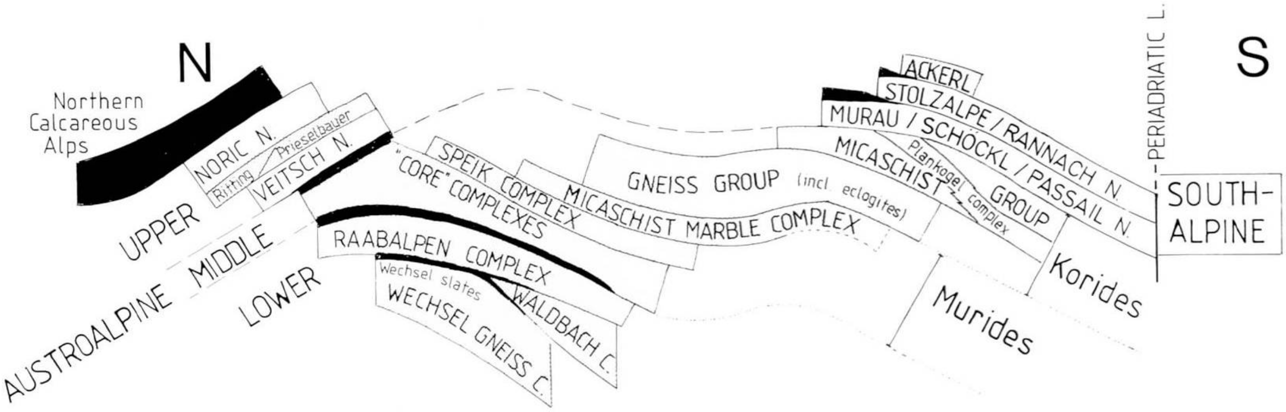

Fig. 4 Schematic section of Austroalpine basement units east of the Tauern Window (modified after NEUBAUER, 1988): Black – Permo-Mesozoic metasediments; unornamented – very low grade to low grade metamorphosed Paleozoic tectonostratigraphic units; dotted – medium to high grade metamorphosed tectonostratigraphic basement units.

Austroalpine basement. Monotonous biotite-plagioclase gneisses derived from sedimentary series. Plagioclase gneisses of plutonic and volcanic origin and sheet-like amphibolites including banded sequences are widespread. Petrographical and geochemical data suggest a supra-subduction zone or a mid-ocean ridge origin for most of the amphibolites (MAGGETTI et al., 1984, 1987, 1988; FRISCH et al., 1987; NEUBAUER, 1988b). Geochronologic work shows a wide range of protolith ages. Zircons from a calc-alkalic plutonic rock east of the Tauern Window contain an Archean component (3.0 ± 0.1 Ga: NEUBAUER et al., 1987). Protolith ages of the Late Proterozoic to Early Paleozoic cycle range from 950 to 440 Ma west of the Tauern Window (SÖLLNER and HANSEN, 1987; FLISCH, pers. comm.) and from Cambrian to Ordovician east of the Tauern Window (e.g., FRANK et al., 1976). Paragneisses show a parallel shift in their record: whereas a prominent Early Proterozoic component (2.4–2.1 Ga) is present in zircons from rocks west of the Tauern Window (GRAUERT et al., 1973, 1974; SÖLLNER and HANSEN, 1987), the paragneiss zircons do not contain memories older than 700 Ma east of the Tauern Window. Model ages show a complex metamorphic history with three events in the Ötztal region (SÖLLNER and HANSEN, 1987): one around 670 Ma, an eclogite-forming event close to 500 Ma, and a low-pressure/high-temperature event near 460–450 Ma. The latter is accompanied and followed by large scale intrusions of granites (450–430 Ma) later transformed to augengneisses. Geochemical data (THÖNI, 1986) favour a syncollisional origin of the granitic melts.

(3) Metamorphosed and dismembered ophiolites form a third type of tectono-metamorphic units in the pre-Variscan basement. Some "serpentinite-amphibolite associations" (FRISCH et al., 1984) within the gneiss-amphibolite association are of obscure origin. The Ritting and Speik complexes, however, form two distinct ophiolite zones (Figs. 3, 4; NEUBAUER et al., 1989). The Ritting complex encompasses serpentinites and metabasalts which suffered high-pressure metamorphism followed by pre-Late Ordovician regional metamorphism. The Speik complex contains nearly all members of the ophiolite sequence including cumulate rocks. Geochemical and metallogenic data of both complexes confirm their ophiolitic origin (NEUBAUER et al., 1989). Field relationships suggest a pre-Late Ordovician protolith age for both complexes.

Late Ordovician to Carboniferous evolution

The following sedimentary sequences with different grades of pre-Alpine metamorphism have a proved or inferred Ordovician to Carboniferous age and are supposed to represent equivalent stratigraphic piles:

(1) The weakly metamorphosed fossiliferous sequences of the highest Alpine nappes within the Alpine edifice (e.g., Noric Nappe of Grauwacken Zone, Stolzalpe Nappe of Gurktal Paleozoic, Rannach-Hochlantsch-Laufnitzdorf nappe system of Paleozoic of Graz; Fig. 4) are biostratigraphically dated as latest Middle Ordovician (Berounian; HALVICEK et al., 1987) to earlymost Late Carboniferous (Namurian A). Recently, early Ordovician acritarchs have been found in the western Grauwacken zone (REITZ and HÖLL, 1989).

(2) The weakly metamorphosed quartzphyllite areas (Murau Nappe of Gurktal Paleozoic,

Schöckel Nappe of Paleozoic of Graz, Innsbruck and corresponding quartzphyllite areas) furnished conodonts in few localities indicating a stratigraphic range between Late Ordovician and Late Devonian.

(3) The widespread micaschist-marble complexes in lower tectonic levels of the Austroalpine stack suffered amphibolite facies grade metamorphism in the Variscan era. They show a very comparable lithostratigraphic succession to the less intensely metamorphosed Late Ordovician to Carboniferous sequences.

The fossiliferous sequence of the highest Alpine tectonic level serves as a reference for the quartzphyllite and micaschist-marble areas. Clastic sedimentary rocks dominate in the Ordovician and Early Silurian. A basal conglomerate and some pebble-bearing horizons near the base are preserved in the Noric Nappe (SCHÖNLAUB, 1979). Volcanic rocks intercalated in the clastic rocks show an evolution from basic subalkalic in the Caradocian and acidic calc-alkalic (HEINISCH, 1981) around the Caradocian/Ashgillian boundary to basic alkalic in the Silurian (GIESE, 1988; FRITZ and NEUBAUER, 1988; LOESCHKE, 1989). The sedimentary facies differentiates in the Late Silurian to Middle Devonian due to rifting. A shallow water carbonate platform with reef buildups contrasts with pelagic limestones and a clastic, shale-dominated facies in basins (FLÜGEL, 1977; HEINISCH et al., 1988; NEUBAUER and PISTOTNIK, 1984; NIEVOLL, 1987). The basin sequence comprises intraplate basalts transitional between tholeiitic and alkalic. Lead isotope patterns of stratiform Pb/Zn ores of probably Early Devonian age and clastic components argue in favour of a continental provenance. Model calculations of ore lead isotopes suggest a 2–3 Ga old source (KÖPPEL, 1983). The Early Precambrian basement relics in the Austroalpine Zone may have been part of this old continent. The carbonate platform subsided into pelagic environments in the Late Devonian. Both flysch-like sediments and shallow-water clastic sediments were deposited in the Early Carboniferous. Orogenic movements occurred throughout the Carboniferous and migrated from internal parts (NW) to external parts (SE) of the orogen. Local terrestrial conglomerates of Westphalian B/C to Stephanian age overstep tilted, thrusted, and internally deformed rocks (for a review, see NEUBAUER, 1988a). The clastic sequence comprising fanglomerates, arkoses, sandstones, and shales continues into the Permian and is intercalated with intermediate to acidic volcanic rocks.

The quartzpyhllite areas of the Austroalpine-Southalpine Zone very much resemble those parts of this sequence dominated by clastic sedimentation.

The micaschist-marble complexes, together with their substratum, the gneiss-amphibolite association and the Speik complex, suffered Carboniferous medium- to high-grade metamorphism accompanied by few granitoid intrusions and large-scale thrusting (NEUBAUER, 1988b). Partial anatexis was widespread and also affected intermediate to mafic rocks. It is dated in the region east of the Tauern Window with concordant U/Pb zircon ages from trondhjemite gneisses (353 ± 1 Ma; NEUBAUER, FRISCH and HANSEN, in prep.), a lower intercept U/Pb zircon age (355 Ma; NEUBAUER et al., 1987), and Rb/Sr mineral ages (e.g. FRANK et al., 1983). THÖNI (1986) reported Rb/Sr mineral ages and Rb/Sr thin slab isochron ages between 310 and 280 Ma due to cooling and deformation along mylonitic shear zones in the Ötztal region. Late Variscan mineral ages are also known from other areas (SASSI et al., 1987; FRANK et al., 1987). Metamorphism affected the more internal parts whereas the external parts remained almost unmetamorphosed.

Contrasting histories are known from certain basement complexes east of the Tauern Window, summarized as the Pannonian terrane by FRISCH and NEUBAUER. A U/Pb zircon study from the crystalline Prieselbauer slice encompassed in a high Alpidic tectonic level yielded evidence for Devonian anatectic metamorphism and magmatism (NEUBAUER et al., 1987). This slice is associated with clastic to carbonatic marine shallow-water sedimentary rocks of the Veitsch Nappe (Grauwacken Zone) which are interpreted as the sedimentary response to a pre-Carboniferous orogenic event (RATSCHBACHER, 1987). Devonian metamorphism is also known from the Bundschuh area (FRIMMEL, 1986, 1988) and the Wechsel complex, and was suggested for the Raabalpen complex (FRISCH and NEUBAUER, 1989).

Lithostratigraphic units, whose ages are still being discussed, are the eclogite bearing gneiss group of the Korides and, on top of it, the Plankogel Zone which is associated with a micaschist complex.

The eclogites of the Korides gneiss group derive from mid-ocean ridge basalts and ferro-gabbros according to their geochemical pattern (MILLER et al., 1988). The enclosing gneisses are interpreted as former flysch deposited in a trench system and mixed with oceanic basement during offscraping in an accretionary wedge setting (FRISCH et al., 1984; NEUBAUER and FRISCH, 1989). The preliminary Sm–Nd whole rock errorchrone from the Saualpe eclogites (MANBY and

Thiedig, 1988) has now become meaningless due to erroneous use of garnet data. Rittmann (1984) reports a wide scatter of ^{40}Ar/^{39}Ar amphibole ages possibly related to retrograde disequilibration. A geologically meaningful age of amphibole formation may be around 400 Ma (Rittmann, 1984). A comparable Rb/Sr garnet whole rock age was found by Kunze and Deutsch (1989). Miller and Frank (1983) report K/Ar amphibole model ages from the eclogites ranging between the Variscan and eo-Alpine orogenic periods.

The Plankogel Zone represents a metamorphosed ocean-floor and seamount complex containing dismembered ophiolite slices and alkalic basalts in a tectonic melange setting (Schmerold, 1988; Neubauer et al., 1989; Frisch et al., 1989). Blocks and slices of harzburgitic serpentinites, amphibolites (derived from mid-ocean ridge and alkalic basalts), marbles, and quartzites float in a micaschist matrix. Part of the micaschist matrix shows the chemical fingerprint of lateritic weathering products of the alkalic seamount basalts. Manganese quartzites associated with the seamount assemblage are interpreted as exhalative manganese concentrations. An early high-pressure metamorphism was followed by pre-Alpine medium-grade metamorphism. A garnet-whole rock Sm/Nd pair suggests eclogitization at 693 Ma (Manby et al., 1988, 1989). Rb/Sr geochronologic data give younger ages (Frank et al., 1983; Morauf, 1981). Pegmatite muscovites and thin slab errorchrons yield Permian ages which are interpreted as the time of uplift of the Korides and the Plankogel Zone (Neubauer, 1988a; Frisch and Neubauer, 1989).

Another complex with a badly constrained history is the Tonale-Ulten Valley Zone in the southwestern part and an analogous zone (Hinterlechner-Ravnik, 1988) in the southeastern part of the Austroalpine basement (Fig. 3). This zone is correlated with the Ivrea Zone of the Southalpine basement. Sillimanite bearing migmatitic gneisses and granulites contain inclusions of ultramafic magmatic rocks (e.g., garnet peridotite). Protolith ages are unknown but a Variscan age of metamorphism is constrained by U/Pb zircon data (336 Ma, garnet-rich pyroxenite, resp. 332 Ma, garnet-pyroxenite; Gebauer and Grünenfelder, 1978).

4.2. AUSTROALPINE BASEMENT OF THE SESIA-LANZO ZONE

The Sesia-Lanzo Zone appears as a crystalline basement nappe south of the Penninic Zone of the Central Alps and as klippen (Arolla-Mt. Emilius Nappe in the Dent Blanche nappe system) on top of the Penninic nappes. It encompasses large bodies of granitoid gneiss (gneiss d'Arolla, "gneiss minuti"), basic magmatic rocks, and a great number of basic dikes (Dal Piaz et al., 1972). The Arolla-Mt. Emilius Nappe comprises a detrital sequence of probably Late Carboniferous to Permian age representing the post-Variscan overstep sequence (Ayrton et al., 1982). This sedimentation is contemporaneous with the intrusion of granites (Oberhänsli et al., 1985; Paquette, 1987).

4.3. BASEMENT OF THE SOUTHALPINE ZONE

The Southalpine Zone is separated from the Austroalpine Zone by a prominent Alpine fault, the Periadriatic Lineament. The Austroalpine and Southalpine basements formed a coherent unit prior to the activation of the lineament. The correlation across the Periadriatic Lineament is facilitated by a distinct zonation of the Southalpine basement in such a way that the units with the highest Variscan metamorphism appear in the west, the unmetamorphosed units in the east (Flügel, 1975; Vai and Cocozza, 1986). The general strike direction of the lithologic zoning is NE–SW.

The tectonostratigraphic units of the Southalpine basement (see Fig. 3) are:

- the Ivrea Zone
- the Strona-Ceneri Zone
- the Morbegno gneiss-Val Colla Zone and related units
- the Edolo schists/phyllites and Brixen quartzphyllites

"Cristallino dei Laghi"

- the fossiliferous Paleozoic sequence of the Carnic Alps and Karawanken

The Ivrea Zone

The Ivrea Zone forms the westernmost part of the Southalpine basement and also appears in klippen on top of the Sesia-Lanzo Zone ("seconda zona diorito-kinzigitica") and in the upper part of the Dent Blanche nappe system (Valpelline series). The main rocks are sillimanite bearing paragneisses (granulites, "kinzigites") intruded by large bodies of mafic and intermediate layered plutonic rocks and minor ultramafic rocks. As the whole zone is subject of recent papers (Hunziker and Zingg, 1980; Pin and Sills, 1986; VOSHAGE et al., 1988; ZINGG, 1983 and ZINGG et al., 1989, with many references) we prefer to give only the headlines of evolution than to repeat the corresponding authors. Precambrian and Ordovician stages of evolution are preserved as relics, and the corresponding polyphase metamorphic evolution ended during the Variscan. Late Carboniferous and Permian data are widespread, being the expression of the Late Variscan high temperature transformations and the intrusion of magmatic rocks, before the whole region underwent late crustal thinning.

The Strona-Ceneri Zone

The Strona-Ceneri Zone comprises orthogneisses, paragneisses, and micaschists with concordant granite to tonalite (SCHMID, 1967; ZINGG, 1980). Paragneiss and micaschist are separated by lenses of MORB-type garnet amphibolites and ultramafic rocks, especially garnet peridotites (BULETTI, 1983). According to BORGHI (1989), a lower unit (Scisti dei Laghi) comprises polymetamorphic metapelitic series of probably Precambrian age with metabasic intercalations, whereas an upper unit (Strona Ceneri Zone sensu stricto) is composed of monometamorphic detrital series ("gneiss minuti") and coarse grained gneiss (Ceneri gneiss). He describes an early eclogitic event in the Ordovician (HUNZIKER and ZINGG, 1980) for the lower unit. Metamorphism of the upper unit is related to the emplacement of granitoids supposedly Ordovician in age. ZINGG (1983) discusses radiometric age determinations of metamorphism and proposes a continuous high temperature evolution from the Ordovician to the Variscan events. Late Variscan granitoids and volcanic rocks yielding Permian ages around 280–270 Ma (KÖPPEL and GRÜNENFELDER, 1978; HUNZIKER and ZINGG, 1980; STILLE and BULETTI, 1987) are of regional importance.

The Morbegno gneiss-Val Colla Zone and related units

Southeast of a regional Alpine fault zone, the Morbegno gneiss-Val Colla Zone and related lithotectonic units border the Strona-Ceneri Zone. The separation from the Strona-Ceneri Zone is questionable in some areas. Little is known about protolith ages and conditions of metamorphism. K/Ar white mica and biotite data (white micas: 331–218 Ma, biotites: 330–170 Ma) suggest a two stage cooling history in the Late Carboniferous, Permian, and Triassic (BOCCHIO et al., 1981; MOTTANA et al., 1985). Early deformation occurred under amphibolite facies conditions followed by a pre-Permian retrograde overprint under greenschist facies conditions (MILANO et al., 1988).

The Edolo schists/phyllites and Brixen quartzphyllite

The Edolo schists and phyllites are exposed west of the Judicare line, an Alpine fault, whereas the Brixen quartzphyllite appears to the east of it. The Edolo schists are monotonous quartz-rich phyllites including quartzites, greenschists, and marble lenses. Microfloras indicate Silurian and probably Ordovician sediments from a marine environment (GANSSER and PANTIC, 1988). The Brixen quartzphyllite and equivalent sequences in some inliers under the Mesozoic cover are inferred to be of Early Ordovician to Devonian age. Microfloras from some few localities indicate the presence of Early Ordovician strata (SASSI et al., 1984).

Like in the Austroalpine equivalents (the quartzphyllite areas) no evidence exists for pre-Variscan metamorphism and deformation in the Edolo and Brixen schists and phyllites. Rb/Sr and $^{40}Ar/^{39}Ar$ data indicate a two stage metamorphism of Early and Late Carboniferous age (DEL MORO et al., 1980; HAMMERSCHMIDT and STÖCKHERT, 1987).

Carnic Alps and Karawanken

The unmetamorphosed to very low-grade metamorphic, fossiliferous Paleozoic area of the Carnic Alps and its continuation in the southern Karawanken contain continuous Late Ordovician to Early Carboniferous sedimentary sections (for a review, see SCHÖNLAUB, 1979). The sequence is comparable with the fossiliferous Paleozoic areas in the Austroalpine highest tectonic levels. It is sheared off from an unknown basement during the Carboniferous orogeny. The differences in facies are due to subsidence of a passive continental margin. An Early to Middle Devonian carbonate platform with reefs may represent an outer, Pacific-type shelf (VAI and SPALLETTA, 1982). Some Early Devonian bivalves as well as trilobites show affinities to the Uralo-Tienshanian faunal province (RAU and TONGIORGI, 1981). The Viséan Hochwipfel flysch (VAI and SPALLETTA, 1982; CASTELLARIN and VAI, 1981) is interpreted as the response to loading of the passive continental margin by advancing thrust sheets including another plate.

The overstep sequence above a regional unconformity starts with clastic and continues with cyclic, clastic-carbonatic molasse-type sediments of Late Carboniferous age. Faunas show relationships to areas in the east as far as southeastern Asia (KAHLER and KAHLER, 1982). Numerous Late Carboniferous to Permian calc-alkalic granitoids intruded the area between the Strona-Ceneri Zone and the Brixen quartzphyllite (e.g., D'AMICO et al., 1979; GIOBBI ORIGONI, 1987). The plutonism is accompanied by andesitic to rhyolitic, mainly ignimbritic volcanism. The sedimentary record reflects basins and swells which largely follow the Variscan structures (CASTELLARIN and VAI, 1981).

4.4. CONCLUSIONS

The Austroalpine basement consists of a variety of lithostratigraphic units. A distant place of origin for some of these units is apparent due to fundamental differences in their history or oceanic realms which separated them. Therefore, they were interpreted in terms of allochthonous tectonostratigraphic terranes by FRISCH and NEUBAUER (1989). The Pannonian terrane shows a consistent history with the internal zone of the European Variscides (Ligerian Cordillera, Moldanubian Zone, Helvetic Zone). The Korides and the Plankogel Zone represent an oceanic realm (Korides: trench-accretionary wedge system; Plankogel Zone: sea floor with seamount) which separated the Pannonian terrane in the NW from the Noric terrane in the SE. The Noric terrane is composite, comprises pre-Variscan ophiolite zones and a pre-Variscan basement consolidated during the Ordovician orogeny. This basement carries the Late Ordovician to Carboniferous sedimentary sequence of a passive continental margin. Both the Pannonian and the Noric terrane contain Archean to Early Proterozoic isotopic signatures. The Sesia-Lanzo Zone in the Central Alps is not directly comparable with the Austroalpine basement units of the Eastern Alps.

Apparently the Southalpine basement exposes a nearly complete section through the Variscan crust from basal granulitic to unmetamorphosed supra-crustal rocks (FLÜGEL, 1975; VAI and COCOZZA, 1986). However, there is an important hiatus in this section. The western units (Ivrea and Strona-Ceneri Zones) suffered Ordovician high- to medium-grade metamorphism and subsequently remained in deep crustal levels. The eastern units (Edolo schists to Carnic Alps and Karawanken) are the product of Late Ordovician to Devonian/Early Carboniferous sedimentation in a passive continental margin environment. It is still unclear whether major Variscan detachment between both occurred or not. Variscan metamorphism and deformation are younger in the eastern than in the western units (FLÜGEL, 1975). The overstep sequences show that part of the deep levels were already exposed in the Permian. Tilting of the crustal segment commenced as an immediate response to the Variscan orogeny but continued into the Mesozoic.

5. Comparative discussion and summary

Comparing the geologic evolution of the Helvetic, Penninic, and Austroalpine-Southalpine basement zones, certain resemblances but also striking differences become evident and help to reconstruct the pre-Alpine puzzle of lithostratigraphic units which is a delicate exercise.

5.1. EARLY PRECAMBRIAN ELEMENTS

It is extremely difficult to develop models for the Precambrian evolution of Alpine basement units and their spatial relationships. Proof for Early Precambrian (Archean and Early Proterozoic) elements comes primarily from the Austroalpine Zone. Lead isotope patterns indicate the existence of such old rock series acting as source material for lead in the Austroalpine and Southalpine basement (KÖPPEL, 1983) as well as for the External Massifs (PAQUETTE et al., 1989). Radiometric age determinations provide evidence for the existence of Early Precambrian elements in the Noric and Pannonian terranes. Although belonging to different zones in the Variscan orogen, they are inferred to have had a paleogeographic position as a part of, or close to, what evolved to form the Gondwana continent.

Early Precambrian crust is unknown from the Penninic basement. Comparative studies with the northern foreland of the Alps lead to the conclusion that Early Proterozoic elements exist in the Helvetic basement. This is confirmed by radiometric data from the Gotthard Massif (GEBAUER et al., 1988). The polymetamorphic areas of the Helvetic basement correlate well with the French Massif Central, the Vosges, the Schwarzwald, and the Bohemian Massif (HIRSCHMANN, 1987, 1988). Lead isotope patterns suggest that the Early Precambrian influence is less important in the Helvetic than in the Austroalpine basement (KÖPPEL, 1983).

5.2. LATE PROTEROZOIC TO ORDOVICIAN EVOLUTION

A striking similarity of the Alpine basement domains is the crustal mobility in the Late Proterozoic to Ordovician period as expressed by the formation of ocean floor (partly in back-arc settings), subduction and high-pressure metamorphism, and the formation of magmatic arcs above subduction zones. Ophiolites of proved or inferred Late Proterozoic to earlymost Paleozoic age are known from all Alpine basement domains. Subduction-related magmatism is widespread in the Penninic and Austroalpine basement domains. In the Austroalpine basement this magmatism evolved on top of continental crust and is dominated by acidic melts. In contrast to the Austroalpine-Southalpine basement, the Penninic basement contains only Phanerozoic crustal lead in addition to a clear component of oceanic mantle lead (KÖPPEL, 1983).

We assume an extension of the Cadomian orogen, discussed by ZWART and DORNSIEPEN (1978) and COGNÉ and WRIGHT (1980) for Northern Europe, into the Alpine region. Late Proterozoic radiometric ages are rare (e.g., 650 Ma, VON QUADT, 1989). A group of ages clusters around 500 Ma (Cambrian/Ordovician boundary) and indicates magmatic and metamorphic processes. A great number of radiometric ages around 450 Ma indicate high-grade metamorphism with the formation of granulites or anatectic melts, and granitoid magmatism.

Ordovician paleomagnetic data yield high latitudes for central and southern Europe and thus show a position close to Gondwana (NEUGEBAUER, 1988, 1989). Parts of the Alpine basement may have been in connection with Africa. There is no indication that basement zones of the Alps can be correlated with Fennoscandia in northern Europe.

5.3. LATE ORDOVICIAN TO CARBONIFEROUS EVOLUTION

The Variscan era starts after the Ordovician orogenic episode including consolidation, uplift, and erosion of the crust. Distension is indicated by rift-related magmatism and subsidence, partly in a passive continental margin setting. Some domains remained buried at depth like parts of the Helvetic and Southalpine basements.

The Alpine basement includes parts of the internal zone and of the southern branch of the Variscides. The internal zone represented by the Moldanubian and Ligerian Zones in the extra-Alpine Variscides included the Helvetic basement of the Alps which have a consistent history. The Helvetic basement is characterized by Devonian thrusting and crustal thickening and subsequent uplift resulting in a pressure-temperature path leading to lower P/T ratios with time. This is demonstrated by the successive appearance of kyanite, sillimanite, and andalusite. Large volumes of anatectic melts formed at the thermal peak (Late Devonian to Carboniferous).

The Pannonian terrane in the Austroalpine basement reveals a comparable history as the Helvetic basement. It is characterized by Devonian deformation, high-temperature metamorphism, and abundant granitoid intrusions. It is therefore considered as a part of the internal zone of the Variscides (FRISCH and NEUBAUER, 1989).

The Devonian thrusting and metamorphism, the temperature emphasized type of metamorphism with widespread sillimanite and andalusite, and the numerous granites are in marked contrast to the main part of the Austroalpine-Southalpine basement. Together with the Ligerian Zone, the Helvetic basement and the Pannonian terrane are considered to have formed an active continental margin (FRISCH and NEUBAUER, 1989) referred to as the Ligerian Cordillera (MATTE, 1986).

According to FRISCH and NEUBAUER (1989), the Noric terrane of the Austroalpine basement together with the Southalpine basement was temporarily attached to Africa in the Early Paleozoic. It was part of the southern (southeastern) branch of the Variscan orogen and continuous with the Montagne Noir and the Cantabrian Zone in southwestern Europe. It experienced distension and subsidence until orogenic movements started in the Early Carboniferous. Thrusting prograded from internal to external parts. Although anatectic temperatures were reached in the Early Carboniferous, granite intrusions are much less abundant than in the Helvetic basement and the Pannonian terrane. This is due to the lower-plate position during Variscan collision.

The evolution of the Penninic basement during the Late Ordovician to Carboniferous period remains rather obscure. VAVRA (1989) proposed that the island arc in the Tauern Window attained maturity with the production of large volumes of rhyodacitic melts which were transformed into antectic granitoids in the Carboniferous. A comparable evolution may be true for the Central and Western Alps.

5.4. LATE VARISCAN EVOLUTION

The Late Variscan period (Late Carboniferous to Permian) is dominated by a major strike-slip fault system which was active since the Late Devonian in some parts (ARTHAUD and MATTE, 1977; NEUGEBAUER, 1988, 1989). The strike-slip faults facilitated the formation and ascent of granitoid melts. They evolve from calc-alkalic rocks in the Late Carboniferous to intraplate granites with an increasing alkalic component in the Permian (MERCOLLI and OBERHÄNSLI, 1988).

Sedimentation during this period was generally terrestrial and occurred in graben and pull-apart structures in a similar way as described by ZIEGLER (1980) for northwestern Europe. Narrow but laterally extended zones filled with Late Carboniferous molasse-type sediments separated distinct basement zones. They imply that the sedimentary troughs formed along zones of crustal weakness. The Zone Houillère separates the Penninic and the Helvetic basement domains. The Nötsch-Veitsch-Ochtina Zone separates the weakly metamorphosed parts of the Austroalpine basement from the highly metamorphosed ones. Both sedimentary troughs follow the same trend and indicate a Late Carboniferous extensional or transtensional regime.

The position of the Penninic basement relative to the Helvetic and Austroalpine basement zones during the Variscan orogeny is not well constrained. Major late Variscan strike slip faulting may have severely changed the paleogeographic positions. Restoration of the Alpine history implies that in post-Variscan times the Penninic basement was directly attached to the Helvetic basement and that the Austroalpine-Southalpine Zone was positioned to the east of them (e.g., RATSCHBACHER et al., 1989). Intense syn- to late-orogenic magmatic activity in the Penninic basement underlines the spatial neighbourhood of the Helvetic and Penninic basement domains in the Carboniferous and Permian.

Acknowledgments

Susanne Borchert corrected the English text. This is gratefully acknowledged. The work of J. v. R. was facilitated by the financial help of the Swiss Science Foundation (project. No. 2.610-0.85). We thank for the critical remarks and helpful suggestions of A. von Quadt (Zürich).

References

ARNOLD, A. (1970): Die Gesteine der Region Nalps-Curnera im nordöstlichen Gotthardmassiv, ihre Metamorphose und ihre Kalksilikateinschlüsse. Beitr. geol. K. Schweiz N.F. 138, 1–128.

ARTHAUD, F. and MATTE, P. (1977): Late Paleozoic strike-slip faulting in Southern Europe and northern Africa: Result of a right-lateral shear zone between Appalachians and the Urals. Bull. Geol. Soc. Amer. 88, 1305–1320.

AYRTON, ST., BUGNON, C., HAARPAINTNER, T., WEIDMANN, M. and FRANK, E. (1982): Géologie du front de la nappe de la Dent-Blanche dans la région des Monts-Dolins, Valais. Eclogae geol. Helv. 75, 269–286.

BEARTH, P. (1961): Contribution à la subdivision tectonique et stratigraphique du cristallin de la nappe du Grand-St-Bernard dans le Valais (Suisse). In: Livre à la mémoire du Prof. P. Fallot. (Mém. h.s. 1960–1963), Soc. géol. France, Paris, p. 407–418.

BECKER, L.P., FRANK, W., HOECK, V., KLEINSCHMIDT, G., NEUBAUER, F., SASSI, F.P. and SCHRAMM, S.M. (1987): Pre-alpine metamorphic event in the Austrian Alps. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts, FLÜGEL, H.W., SASSI, F.P. and GRECULA, P. (eds.), Alfa Publishers, Bratislava, p. 69–106.

BELLIERE, J. and STREEL, M. (1980): Roches d'âge viséen supérieur dans le massif des Aiguilles Rouges (Haute Savoie). C.R. Acad. Sci. Paris 290, D, 1341–1343.

BOCCHIO, R., DE CAPITANO, L., LIBORIO, G., MOTTANA, A., NICOLETTI, M. and PETRUCCIANI, C. (1981): K–Ar radiometric age determinations of the south-Alpine metamorphic complex, western Orobic Alps (Italy). N. Jb. Mineral. Monatsh. 289–307.

BODINIER, J.L., DUPUY, C., DOSTAL, J. and CARME, F. (1981): Geochemistry of ophiolites from the Chamrousse complex (Belledonne massif, Alps). Contr. Min. Petr. 78, 379–388.

BOGDANOFF, S. (1980): Analyse structurale dans la partie occidentale de l'Argentera-Mercantour (Alpes Maritimes). Thèse, Orsay, pp. 1–316.

BOGDANOFF, S. (1986): Evolution de la partie occidentale du massif cristallin externe de l'Argentera. Place dans l'arc alpin. Bull. B.R.G.M. sér. géol. France 4, 433–453.

BORDET, C. (1961): Recherches géologiques sur la partie septentrionale du Massif de Belledonne (Alpes françaises). Mém. Serv. Carte géol. France, 1–218.

BORGHI, A. (1989): L'evoluzione metamorfico-strutturale del settore nord-orientale della Serie dei Laghi (Alpi Meridionali). Univercittà, Genova, pp. 1–187.

BULETTI, M. (1983): Zur Geochemie und Entstehungsgeschichte der Granat-Amphibolite des Gambarognogebiets, Ticino. Schweiz. Mineral. Petrogr. Mitt. 63, 233–247.

BUSSY, F., SCHALTEGGER, U. and MARRO, Ch. (1989): The age of the Mont-Blanc granite (Western Alps): a heterogeneous isotopic system dated by Rb–Sr whole rock determination on its microgranular enclaves. Schweiz. Mineral. Petrogr. Mitt. 69, 3–13.

CABELLA, R., CORTESOGNO, L., DALLAGIOVANNA, G., VANUCCI, R. and VANOSSI, M. (1988): Vulcanismo, sedimentazione e tettonica nel Brianzonese Ligure esterno durante il Permo-Carbonifero. Atti Ticinense di Scienze della Terra 31, 269–326.

CARME, F. (1965): Sur deux formations, d'origine volcanique, des schistes cristallins anté-houillers de la chaîne de Belledonne (Alpes françaises). C.R. Acad. Sci. Paris 260, 6401–6404.

Carme, F. (1970a): Tectoniques superposées et granitisations successives dans les massifs cristallins externes des Alpes; arguments nouveaux en faveur du rôle majeur d'une orogenèse anté-hercynienne dans la formation des terrains cristallins de Belledonne et des Aiguilles Rouges. C.R. Acad. Sci. Paris 271, 1733–1736.

Carme, F. (1970b): Caractères fondamentaux de l'architecture d'ensemble des chaînes de Belledonne et des Aiguilles Rouges. Rôle des décrochements. C.R. Acad. Sci. Paris 271, 2232–2235.

Carme, F. (1971): Les phases successives de déformation continue dans l'ensemble Belledonne-Aiguilles Rouges (Massifs cristallins externes, Alpes françaises). C.R. Acad. Sci. Paris 273, 1771–1774.

Carme, F. (1973): Précisions sur le métamorphisme majeur des schistes C.R. Acad. Sci. Paris 277, D, 2133–2136.

Carme, F. (1974): Sur une paragenèse tardive à disthène, sillimanite prismatique et zoïsite dans les anatexites à pinite des environs d'Allemont (Chaîne de Belledonne); essai d'interprétation pétrogénétique. C.R. Acad. Sci. Paris 278 D, 565–567.

Carme, F. and Pin, Ch. (1987): Vue d'ensemble sur le magmatisme pré-orogénique et l'évolution métamorphique et tectonique varisques dans le sud de la chaîne de Belledonne (Massifs cristallins externes, Alpes françaises) C.R. Acad. Sci. Paris, 304, II, 19, 1177–1181.

Castellarin, A. and Vai, G.B. (1981): Importance of Hercynian tectonics within the framework of the Southern Alps. J. Struct. Geol. 3, 477–486.

Cliff, R.A. (1971): Strontium isotope distribution in a regionally metamorphosed granite from the Zentralgneiss, south-east Tauernfenster, Austria. Contr. Min. Petr. 32, 274–288.

Cliff, R.A. (1981): Pre-alpine history of the Pennine zone in the Tauern window, Austria: U–Pb and Rb–Sr geochronology. Contr. Min. Petr. 77, 262–266.

Cogné, J. and Wright, A.E. (1980): L'orogène cadomien. Int. Geol. Congr. 26. Sess., Paris C6, 29–54.

Cortesogno, L., Dallagiovanna, G. and Vanossi, M. (1988): Paléogéographie du Briançonnais ligure d'après les lithoclastes des formations Permo–Carbonifères. Geol. Alpine Mem. h.s. no 14, 9–28.

Cortesogno, L., Dallagiovanna, G., Vanucci, R. and Vanossi, M. (1988): Volcanisme, sédimentation et tectonique pendant le Permo–Carbonifère en Briançonnais ligure: une revue. Eclogae geol. Helv. 81, 487–510.

D'Amico, C. (1974): Hercynian Plutonism in the Alps – a report 1973–74. Mem. Soc. Geol. Ital. XIII, 49–118.

Dal Piaz, G.V., Hunziker, J.C. and Martinotti, G. (1972): La zona Sesia-Lanzo e l'evoluzione tettonico-metamorfica delle alpi nordoccidentali interne. Mem. Soc. Geol. Ital. XI, 433–466.

Droop, G.T.R. (1983): Pre-alpine eclogites in the Pennine basement complex of the Eastern Alps. J. metam. Geol. 1, 3–12.

Escher, A. 1988: Structure de la nappe du Grand Saint-Bernard entre le Val de Bagnes et les Mischabel. Rapp. géol. Serv. hydr. géol. nat. 7, 1–26.

Escher, A., Masson, H. and Steck, A. (1988): Coupes géologiques des Alpes Occidentales Suisses. Rapp. géol. Serv. hydr. géol. nat. 2, 1–11.

Exner, Ch. (1971): Geologie der peripheren Hafnergruppe (Hohe Tauern). Jahrb. geol. B.A. 114, 1–119.

Fabre, J., Schade, J., Baudin, T., Desmons, J., Mercier, D. and Perruccio-Parison, M.D. (1987): Relics of pre-Mesozoic events in the Briançon zone (Northern French Alps). In: Pre-Variscan and variscan events in the Alpine-Mediterranean mountain belts, Flügel, H.W., Sassi, F.P. and Grecula, P. (eds.). Alfa Publishers, Bratislava, p. 183–208.

Finger, F. and Steyrer, H.P. (1988): Granite types in the Hohe Tauern (Eastern Alps, Austria): Some aspects on their correlation to Variscan plate tectonic processes. Geodinamica Acta 2, 75–117.

Flügel, H.W. (1975): Einige Probleme des Variszikums von Neo-Europa. Geol. Rdsch. 64, 1–62.

Flügel, H.W. (1977): Paläogeographie und Tektonik des alpinen Variszikums. N. Jahrb. Geol. Pal. Monatsh. 11, 659–674.

Frank, W., Esterlus, M., Frey, I., Krohe, G. and Weber, J. (1983): Die Entwicklungsgeschichte von Stub- und Koralpenkristallin und die Beziehung zum Grazer Paläozoikum. Die frühalpine Geschichte der Ostalpen, 3, 263–293, Leoben.

Frank, W., Klein, P., Nowy, W. and Scharbert, S. (1976): Die Datierung geologischer Ereignisse im Altkristallin der Gleinalpe (Steiermark) mit der Rb/Sr-Methode. Tscherm. Mineral. Petrogr. Mitt. 23, 191–203.

Frank, W., Kralik, M., Scharbert, S. and Thöni, M. (1987): Geochronological data from the Eastern Alps. In: Geodynamics of the Eastern Alps, Flügel, H.W. and Faupl, P. (eds.), Deuticke, Wien, p. 272–281.

Frasl, G. (1958): Zur Seriengliederung der Schieferhülle in den mittleren Hohen Tauern. Jahrb. geol. B.A. 101, 323–472.

Frimmel, H. (1986): Isotopengeologische Hinweise für die paläogeographische Nachbarschaft von Gurktaler Decke (Oberostalpin) und Altkristallin östlich der Hohen Tauern (Österreich). Schweiz. Mineral. Petrogr. Mitt. 66, 193–208.

Frimmel, H. (1988): Metagranitoide am Westrand der Gurktaler Decke (Oberostalpin) – Genese und paläotektonische Implikationen. Jahrb. geol. B.A. 131, 575–592.

Frisch, W. (1974): Die stratigraphisch-tektonische Gliederung der Schieferhülle und die Entwicklung des penninischen Raumes im westlichen Tauernfenster. Mitt. Geol. Ges. Wien 66–67, 9–20.

Frisch, W. and Neubauer, F. (1989): Pre-Alpine terranes and tectonic zoning in the Eastern Alps. Geol. Soc. Amer. Spec. Paper 230, 91–99.

Frisch, W. and Neubauer, F. (in press): Map of the circum-Atlantic Paleozoic terranes. Geol. Soc. Amer.

Frisch, W., Neubauer, F., Bröcker, M., Brückmann, W. and Haiss, N. (1987): Interpretation of geochemical data from the Caledonian basement within the Austroalpine basement complex. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts. Flügel, H.W., Sassi, F.P. and Grecula, P. (eds.), Alfa Publishers, Bratislava, p. 209–226.

Frisch, W., Neubauer, F. and Satir, M. (1984): Concepts of the evolution of the Austroalpine basement complex (Eastern Alps) during the Caledonian-Variscan cycle. Geol. Rdsch. 73, 47–68.

Frisch, W. and Raab, D. (1987): Early paleozoic back arc and island arc settings in greenstone sequences of the Central Tauern Window (Eastern Alps). Jahrb. geol. B.A. 129, 545–566.

Frisch, W., Schmerold, R. and Neubauer, F. (1989): Die Plankogelserie – eine voralpidische ophiolithische Sutur. Arbeitstagung Geol. Bundesanst. 1989, 34–41.

Fritz, H. and Neubauer, F. (1988): Geodynamic aspects of the Silurian and Early Devonian sedimentation in the Paleozoic of Graz (Eastern Alps). Schweiz. Mineral. Petrogr. Mitt. 68, 359–367.

Gansser, A. and Pantic, N. (1988): Prealpine events along the eastern Insubric Line (Tonale Line, northern Italy). Eclogae geol. Helv. 81, 567–577.

Gasquet, D., Giraud, P., Ploquin, A. and Vivier, G. (1981): Géochimie des mylonites et relations entre les Rameaux interne et externe du massif de Belledonne (Alpes françaises). C.R. Acad. Sci. Paris 292, II, 607–610.

Gebauer, D. and Grünenfelder, M. (1978): U–Pb Zircon dating of alpine-type garnet-peridotites example: Val Ultimo (Eastern Alps, Northern Italy). Geological Survey Open-File Report 78–701, 135–137

Gebauer, D. and Grünenfelder, M. (1983): The oldest rocks of the central European Hercynides – rock chemistry, REE, Sm–Nd- and U–Pb zircon data. Terra Cognita 3, 198.

Gebauer, D., von Quadt, A., Compston, W., Williams, I. and Grünenfelder, M. (1988): Archaean zircons in a retrograded, caledonian eclogite of the Gotthard Massif (Central Alps, Switzerland). Schweiz. Mineral. Petrogr. Mitt. 68, 485–490.

Gibergy, P. (1968): Découverte de «grès à trous» renfermant des débris d'organismes dans les schistes noirs du Valbonnais (série cristallophyllienne des massifs cristallins externes des Alpes françaises). C.R. Acad. Sci. Paris 267, D, 1251–1254.

Giese, U. (1988): Lower Paleozoic volcanic evolution at the northwestern border of the Gurktal nappe, Upper Austroalpine, Eastern Alps. Schweiz. Mineral. Petrogr. Mitt. 68, 381–396.

Gilg, H.A., Höll, R., Kupferschmid, M.P., Reitz, E., Stärk, H. and Weber-Diefenbach, K. (1989): Die Basisschieferfolge in der Habachformation im Felber- und Amertal (Tauernfenster, Salzburg). Mitt. Österr. Geol. Ges. 81, 65–91.

Giobbi Origoni, E. (1987): Hercynian plutonism in the Western Southern Alps. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts, Flügel, H.W., Sassi, F.P. and Grecula, P. (eds.), Alfa Publishers, Bratislava, p. 227–236.

Grauert, B. and Arnold, A. (1968): Deutung diskordanter Zirkonalter der Silvrettadecke und des Gotthardmassivs. Contr. Mineral. Petrogr. 20, 34–56.

Grauert, B., Hänny, R. and Sobtrajanova, B. (1973): Age and origin of detrital zircons from the pre-Permian basements of the Bohemian Massif and the Alps. Contr. Min. Petr. 40, 195–230.

Grauert, B., Seitz, M.G. and Soptrajanova, G. (1974): Uranium and lead gain of detrital zircon studied by isotopic analyses and fission-track mapping. Earth. Planet. Sci. Lett. 21, 389–399.

Grünenfelder, M., Hofmänner, F. and Grögler, N. (1964): Heterogenität akzessorischer Zirkone und die petrographische Beurteilung ihrer Uran/Blei-Zerfallsalter. II. Präkambrische Zirkonbildung im Gotthardmassiv. Schweiz. Mineral. Petrogr. Mitt. 44, 543–558.

Grundmann, G. (1988): Metamorphic evolution of the Habach formation. A review. Mitt. Österr. Geol. Ges. 81, 133–149.

Hammerschmidt, K. and Stöckhert, B. (1987): A K–Ar and ^{40}Ar/^{39}Ar study on white micas from the Brixen quartzphyllite, Southern Alps. Contr. Min. Petr. 95, 393–406.

Havlicek, V., Kriz, J. and Serpagli, E. (1987): Upper Ordovician brachiopod assemblages of the Carnic Alps, Middle Carinthia and Sardinia. Boll. Soc. Paleont. Ital. 25, 277–311.

Heinisch, H. (1981): Zum ordovizischen «Porphyroid»-Vulkanismus der Ost- und Südalpen – Stratigraphie, Petrographie, Geochemie. Jahrb. geol. B.A. 124, 1–109.

Heinisch, H. (1988): Hinweise auf die Existenz eines passiven Kontinentalrandes im Altpaläozoikum der nördlichen Grauwackenzone – Ostalpen. Schweiz. Mineral. Petrogr. Mitt. 68, 407–418.

Heinisch, H. and Schmidt, K. (1976): Zur kaledonischen Orogenese in den Ostalpen. Geol. Rdsch. 65, 459–482.

Hinterlechner-Ravnik, A. (1987): Garnet peridotite from the Pohorje Mountains. Geologija 30, 149–181.

Hirschmann, G. (1987): Some remarks on the position of the Rhenisch Massif between the Variscides and the Caledonides. In: The Rhenisch Massif – structure, evolution, mineral deposits and present geodynamics, Vogel, A., Miller, H. and Greiling, R. (eds.), Vieweg and Sohn, Braunschweig, p. 103–112.

Hunziker, J.C. (1970): Polymetamorphism in the Monte Rosa, Western Alps. Eclogae geol. Helv. 63, 151–161.

Hunziker, J.C., Desmons, J. and Martinotti, G. 1989): Alpine thermal evolution in the Central and the Western Alps. In: Coward, M.P. and Park, R.G. (eds.), Alpine Tectonics, Geol. Soc. Spec. Publ. 45, 353–367.

Hunziker, J.C. and Zingg, A. (1980): Lower Paleozoic Amphibolite to Granulite Facies Metamorphism in the Ivrea Zone (Southern Alps, Northern Italy). Schweiz. Mineral. Petrogr. Mitt. 60, 181–213.

Joye, J.B. (1989): L'évolution pression – température – déformation dans le massif des Aiguilles Rouges, massif externe alpin. Thèse Université Fribourg, 1–135.

Kahler, F. and Kahler, G. (1982): Oberkarbonische Fusuliniden der Karnischen Alpen. Palaeontographica 177, 89–128.

Kalsbeek, F. (1961): Petrology and structural geology of the Berlanche–Valloire area (Belledone massif, France). Pub. Dept. Petrogr. Crist. Univ. Leyden 2, 5, 1–136.

Kober, B. and Lippold, H.J. (1985): Pre-Hercynian mantle lead transfer to basement rocks as indicated by lead isotopes of the Schwarzwald crystalline, SW-Germany. II: Lead isotope evolution of the European Hercynides. Contr. Min. Petr. 90, 172–178.

Köppel, V. (1983): Summary of lead isotope data from ore deposits of the Eastern and Southern Alps: some metallogenetic and geotectonic implications. In: Mineral deposits of the Alps and of the Alpine epoch in Europe, Schneider, H.J. (ed.), Springer Verlag, Berlin, p. 162–168.

Köppel, V., Günthert, A. and Grünenfelder, M. (1981): Patterns U–Pb zircon and monazite ages in polymetamorphic units of the Swiss Central Alps. Schweiz. Mineral. Petrogr. Mitt. 61, 97–119.

Köppel, V. and Schroll, E. (1983): Lead isotopes of Paleozoic, strata-bound to stratiform galena bearing sulfide deposits of the Eastern Alps (Austria); implications for their geotectonic setting. Schweiz. Mineral. Petrogr. Mitt. 63, 347–460.

Kraiger, H. (1989): Die Habachformation – ein Produkt ozeanischer und kontinentaler Kruste. Mitt. Österr. Geol. Ges. 81, 47–64.

Kunze, P. and Deutsch, A. (1989): Rb-Sr-Datierungen an einem Staurolith-Granat-Glimmerschiefer aus der Plankogelserie (Saualpe). Arbeitstagung Geol. Bundesamst. 31–33.

Lammerer, B. (1986): Das Autochthon im westlichen Tauernfenster. Jb. Geol. Bundesanst. 129, 51–67.

Lammerer, B., Fruth, I., Klemm, D.D., Prosser, E. and Weber-Diefenbach, K. (1976): Geologische und geochemische Untersuchungen im Zentralgneis und in der Greiner-Schiefer-Serie (Zillertaler Alpen, Tirol). Geol. Rdsch. 65, 436–459.

Latouche, L. and Bogdanoff, S. (1987): Evolution précoce du massif de l'Argentera: apport des eclogites et des granulites. Geologie Alpine 63, 151–164.

Lefort, J.P. (1989): Basement correlation across the North Atlantic. Springer Verlag (ed.), 1–148.

Lefort, J.P. (1990): Cinématique de la collision Gondwana-Laurentia entre la Bretagne et la Floride d'après les données du socle submergé. Schweiz. Mineral. Petrogr. Mitt. 8 (in press).

Le Fort, P. (1973): Geologie du Haut Dauphiné cristallin (Alpes françaises). Etude pétrologique et structurale de la partie occidentale. Sc. de la Terre 25, 1–373.

Le Fort, P. and Pecher, A. (1971): Présentation d'un schéma structural du Haut Dauphiné cristallin. C.R. Acad. Sci. Paris 273, D, 3–5.

Liégois, J.P. and Duchesne, J.C. (1981): The Lac Cornu retrograded eclogites (Aiguilles Rouges Massif, Western Alps, France): evidence of crustal origine and metasomatic alteration. Lithos 14, 35–48.

Loeschke, J. (1989): Lower Paleozoic volcanism of the Eastern Alps and its geodynamic implications. Geol. Rdsch. 78, 599–616.

Maggetti, M. and Galetti, G. (1984): Chemie und geotektonische Position von Metabasiten aus dem Südosten der Silvretta (Schweiz). Schweiz. Mineral. Petrogr. Mitt. 64, 423–450.

Maggetti, M. and Galetti, G. (1988): Evolution of the Silvretta eclogites: metamorphic and magmatic events. Schweiz. Mineral. Petrogr. Mitt. 68, 467–484.

Maggetti, M., Galetti, G. and Stosch, H.G. (1987): Eclogites from the Silvretta nappe (Switzerland): Geochemical constraints on the nature and geotectonic setting of their protoliths. Chem. Geol. 64, 319–334.

Manby, G.M. and Thiedig, F. (1988): Petrology of eclogites from the Saualpe, Austria. Schweiz. Mineral. Petrogr. Mitt. 68, 441–466.

Manby, G.M., Thiedig, F. and Millar, I. (1989): Textural, chemical and isotopic constraints on the age of the Saualpe eclogites (Carinthia/Austria). In: Sassi, F.P. and Bourrouilh, R.; IGCP Project No. 5, Newletter 7 (1987), 195–202.

Ménot, R.P. (1984): Cambro-Ordovician age for the ophiolitic complex of Chamrousse-Tabor (Belledonne massif, French external domain). Ofioliti 10, 2/3, 527.

Ménot, R.P. (1986): Les formations plutono-volcaniques dévoniennes de Rioupéroux-Livet (Massifs cristallins externes des alpes françaises): nouvelles définitions lithostratigraphiques et pétrographiques. Schweiz. Mineral. Petrogr. Mitt. 66, 227–256.

Ménot, R.P. (1987a): Magmatismes paléozoïques et structuration carbonifère du Massif de Belledonne (Alpes françaises). Thèse, Université de Lyon, pp. 1–363.

Ménot, R.P. (1987b): Magmatismes et structuration paléozoïques de la chaîne de Belledonne (Massifs cristallins externes alpins). Geol. Alpine 63, 55–93.

Ménot, R.P. (1988): The geology of the Belledonne massif: an overview / External crystalline massifs of the Western Alps). Schweiz. Mineral. Petrogr. Mitt. 68, 531–542.

Ménot, R.P., Bonhomme, M.G. and Vivier, G. (1987): Structuration tectono-métamorphique carbonifère dans le massif de Belledonne (Alpes occidentales françaises). Apport de la géochronologie K/Ar des amphiboles. Schweiz. Mineral. Petrogr. Mitt. 67, 273–284.

Ménot, R.P., Peucat, J.J., Piboule, M. and Scarenzi, D. (1984a): Cambro-ordovician age for the ophiolitic complex of Chamrousse-Tabor (Belledonne massif, French external alpine domain). Ofioliti, 10, 2–3, 527.

Ménot, R.P., Peucat, J.J., Scarenzi, D. and Piboule, M. (1984b): A continental (?) volcanic arc of devono-carboniferous age in the french alpine external massifs: the Rioupéroux and Livet formations (Romanche valley, Belledonne massif). Ofioliti, 10, 2–3, 528.

Ménot, R.P., Peucat, J.J., Scarenzi, D. and Piboule, M. (1988): 496 My age of plagiogranites in the Chamrousse ophiolite complex (external crystalline massifs in the French Alps): evidence of a lower Paleozoic oceanization. Earth. Planet. Sci. Lett. 88, 82–92.

Mercolli, I. and Oberhänsli, R. (1988): Variscan tectonic evolution in the Central Alps. Schweiz. Mineral. Petrogr. Mitt. 68, 491–500.

Milano, P.F., Pennacchioni, G. and Spalla, M.I. (1988): Alpine and pre-Alpine tectonics in the Central Orobic Alps. Eclogae geol. Helv. 81, 273–293.

Miller, C. and Frank, W. (1983): Das Alter der Metamorphose von Metabasiten und Eklogiten in Kor- und Saualpe. Die frühalpine Geschichte der Ostalpen 3, 229–236, Leoben.

Miller, C., Stosch, H.B. and Hoernes, S. (1988): Geochemistry and origin of eclogites from the type locality Koralpe and Saualpe, Eastern Alps, Austria. Chemical Geology 67, 103–118.

Morauf, W. (1981): Rb-Sr- und K-Ar-Isotopenalter an Pegmatiten aus Kor- und Saualpe, SE-Ostalpen, österreich. Tschermaks Miner. Petr. Mitt. 28, 113–129.

Moro del, A., Sassi, F.P. and Zirpoli, G. (1980): Preliminary results on the radiometric age of the Hercynian metamorphism in the South-Alpine basement of the Eastern Alps. N. Jahrb. Geol. Pal. Monatsh. 707–718.

Morteani, G. (1971): Gliederung und Metamorphose der Serie zwischen Stilluptal und Schlegeistal (Zillertaler Alpen, Nordtirol). Verh. Geol. B.A. 287–314.

Mottana, A., Nicoletti, M., Petrucciani, O., Liborio, G., De Capitani, L. and Bocchio, R. (1985): Pre-Alpine and Alpine evolution of the Southalpine basement of the Orobic Alps. Geol. Rdsch. 74, 353–366.

Neubauer, F. (1985): Eine präoberordovizische Transgression in der Grauwackenzone (Ostalpen) und ihre Bedeutung für paläozoische Geodynamik und alpidischen Deckenbau. N. Jahrb. Geol. Paläontol. Monatsh. 1985, 46–64.

Neubauer, F. (1988a): Bau und Entwicklungsgeschichte des Rennfeld-Mugel- und des Gleinalm-Kristallins (Ostalpen). Abh. Geol. B.A. 42, 1–137.

Neubauer, F. (1988b): The Variscan orogeny in the Austroalpine and Southalpine domains of the Eastern Alps. Schweiz. Mineral. Petrogr. Mitt. 68, 339–349.

Neubauer, F. and Frisch, W. (1988): Ordovician-Silurian geodynamic evolution of the Alps – the orogeny – back-arc basin model. Schweiz. Mineral. Petrogr. Mitt. 68, 351–357.

Neubauer, F., Frisch, W. and Hansen, B.T. (1987): New data on the evolution of the Austroalpine basement: A U/Pb zircon study. Terra Cognita 7, 96.

Neubauer, F., Frisch, W. and Hansen, B.T. (1989): A late Archean rock in the Eastern Alps? Terra abstracts (EUG V Strasbourg, 20.–23.3.1989), 1, 1 p. 5, Oxford.

Neubauer, F., Frisch, W., Schmerold, R. and Schlöser, H. (1989): Metamorphosed and dismembered ophiolite suites in the basement units of the Eastern Alps. Tectonophysics 164, 49–62.

Neubauer, F. and Pistotnik, J. (1984): Das Altpaläozoikum und Unterkarbon des Gurktaler Deckensystems (Ostalpen) und ihre paläogeographischen Beziehungen. Geol. Rdsch. 73, 149–174.

Neugebauer, J. (1988): The Variscan plate tectonic evolution: an improved "Iapetus model". Schweiz. Mineral. Petrogr. Mitt. 68, 313–333.

Neugebauer, J. (1989): The Iapetus model: a plate tectonic concept for the Variscan belt of Europe. Tectonophysics 169, 229–256.

Nievoll, J. (1987): The lower Paleozoic of the Noric nappe at Veitsch (Eastern Alps, Austria). In: Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts, Flügel, H.W., Sassi, F.P. and Grecula, P. (eds.), Alfa Publishers, Bratislava, p. 379–386.

Nunes, P.D. and Steiger, R.H. (1974): A U–Pb zircon and Rb–Sr and U–Th–Pb whole rock study of a polymetamorphic terrane. Contr. Min. Petr. 47, 255–280.

Oberhänsli, R., Hunziker, J.C., Martinotti, G. and Stern, W.B. (1985): Geochemistry, geochronology and petrology of Monte Mucrone: an example of eo-alpine eclogitization of Permian granitoids in the Sesia-Lanzo zone, Western Alps, Italy. Chemical Geology 52, 165–184.

Oberhänsli, R., Schenker, F. and Mercolli, I. (1988): Indications of Variscan nappe tectonics in the Aar massif. Schweiz. Mineral. Petrogr. Mitt. 68, 509–520.

Paquette, J.L. (1987): Comportement des systèmes isotopiques U–Pb et Sm–Nd dans le métamorphisme éclogitique. Chaîne hercynienne et chaîne alpine. Mém. doc. Centre Arm. et struct. socle 14, 1–190.

Paquette, L., Ménot, R.P. and Peucat, J.J. (1989): REE, Sm–Nd and U–Pb zircon study of eclogites from the Alpine External massifs (Western Alps): Evidence for crustal contamination. Earth. Planet. Sci. Letters 96, 181–198.

Pecher, A. (1970): Etude pétrographique de la partie orientale du massif des Ecrins–Pelvoux. Le socle ancien. Thèse 3e cycle, Grenoble, pp. 1–122.

Pestal, G. (1983): Beitrag zur Kenntnis der Geologie in den mittleren Hohen Tauern im Bereich des Amer- und des Felbertales. Diss. Universität, Wien, pp. 1–117.

Pin, Chr. (1986): Datation U/Pb sur zircons à 285 Ma du complexe gabbro-dioritique du Val Sesia–Val Mastallone et âge tardi-hercynien du métamorphisme granulitique de la zone Ivrea-Verbano. C.R. Acad. Sci., Paris, 303, II, 9, 827–830.

Pin, C. and Carme, Chr. (1987): A Sm–Nd isotopic study of 500 Ma old oceanic crust in the Variscan belt of Western Europe: the Chamrousse ophiolite complex, Western Alps (France). Contr. Min. Petr. 96, 406–413.

Pin, C. and Sills, J.D. (1986): Petrogenesis of layered gabbros and ultramafic rocks from Val Sesia, the Ivrea zone, NW Italy: trace element and isotope geochemistry. Geol. Soc. Spec. Publ. 24, 231–249.

von Quadt, A. (1984): Geochemische und U-Pb-Untersuchungen der unteren Schieferhülle (Ostalpen). Fortschr. Mineral. 62, 191–193.

von Quadt, A. (1987): U-Pb- und Sm-Nd-Datierungen der Habach-Formation und des Basisamphibolits im Bereich der mittleren Hohen Tauern. Uni-Aktuell (Salzburg) 10, 28.

von Quadt, A. (1989): Sm–Nd and U–Pb systematics of zircon fractions, garnet and whole rock amphibolitic rocks of the Tauern Window (Eastern Alps). Terra abstracts 1, 349.

Ratschbacher, L. (1987): Stratigraphy, tectonics and paleogeography of the Veitsch nappe (Graywacke zone, Estern Alps, Austria): a rearrangement. In: Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts, Flügel, H.W., Sassi, F.P. and Grecula, P. (eds.), Alfa Publishers, Bratislava, p. 407–414.

Ratschbacher, L., Frisch, W., Neubauer, F., Schmidt, S.M. and Neugebauer, J. (1989): Extension in compressional orogenic belts: The eastern Alps. Geology 17, 404–407.

Rau, A. and Tongiorgi, M. (1981): Some problems regarding the Paleozoic paleogeography in Mediterranean western Europe. J. Geol. 89, 663–673.

von Raumer, J.F. (1984a): The Hercynian basement in the Helvetic Realm. Western and Central Alps. Mem. Soc. Geol. Ital. 29, 57–69.

von Raumer, J.F. (1984b): The External Massifs, relics of Variscan Basement in the Alps. Geol. Rdsch. 73, 1–31.

von Raumer, J.F. (1987): Les massifs du Mont Blanc et des Aiguilles Rouges: témoins de la formation de croûte varisque dans les Alpes Occidentales. Géologie Alpine 63, 7–24.

von Raumer, J.F. (1988): Caledonian-Variscan structures in the Alps: an introduction. Schweiz. Mineral. Petrogr. Mitt. 68, 291–299.

von Raumer, J.F. and Ménot, R.P. (1989): Evolution paléozoïque du socle ouest-alpin et place des Massifs Cristallins Externes dans l'orogène Varisque. C.R. Acad. Sci. Paris 309, II, 397–402.

von Raumer, J.F., Galetti, G., Pfeifer, H.R. and Oberhänsli, R. (1990): Amphibolites from Lake Emosson/Aiguilles Rouges, Switzerland: Tholeiitic basalts of a Paleozoic continental rift zone. Schweiz. Mineral. Petrogr. Mitt. 70/3 (in press).

Reitz, E. and Höll, R. (1988): Jungproterozoische Mikrofossilien aus der Habachformation in den mittleren Hohen Tauern und dem nordostbayerischen Grundgebirge. Jahrb. geol. B.A. 131, 329–340.

Reitz, K. and Höll, R. (1989): Unterordovizische Akritarchen aus der Nördlichen Grauwackenzone (Ostalpen). Jahrb. Geol. Bundesanst. 132, 761–774

Rittmann, K.L. (1984): Argon in Hornblende, Biotit und Muskovit bei der geologischen Abkühlung – ^{40}Ar/^{39}Ar-Untersuchungen. Diss., Heidelberg, pp. 1.

Sassi, F.P., Kalvacheva, R. and Zanferrari, A. (1984): New data on the age of deposition of the Southalpine phyllitic basement in the Eastern Alps. N. Jahrb. Geol. Pal. Monatsh. 741-751.

Sassi, F.P., Visona, D. and Zirpoli, G. (1987): Similarities among the lithostratigraphic sequences in different parts of the Austrides (Eastern Alps). In: Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts, Flügel, H.W., Sassi, F.P. and Grecula, P. (eds.), Alfa Publishers, Bratislava, p. 427–430.

Sassi, F.P., Zanferrari, A. and Zirpoli, G. (1974): Some considerations on the South Alpine basement of the Eastern Alps. N. Jahrb. Geol. Paläontol. Monatsh. 1974, 609–624.

Schaltegger, U. (1986): Geochemische und Rb-Sr-Systematik der Aarmassiv-Granite zwischen Grimsel und Reusstal. Schweiz. Mineral. Petrogr. Mitt. 66, 462–466.

Schenker, F. (1986): Spätpaläozoischer saurer Magmatismus und Beckenbildung im Aarmassiv unter kompressiver Tektonik. Unveröffentl. Dr.-Arbeit, Bern, pp. 1-116.

Schmerold, R. (1988): Die Plankogelserie im ostalpinen Kristallin von Kor- und Saualpe (Kärnten, Steiermark-Österreich) als ophiliothische Sutur. Diss. Univ. Tübingen, 1–161.

Schmid, R. (1967): Zur Petrographie und Struktur der Zone Ivrea-Verbano zwischen Valle d'Ossola und Val Grande (Prov. Novara, Italien). Schweiz. Mineral. Petrogr. Mitt. 47, 935–1118.

Schönlaub, H.P. (1979): Das Paläozoikum in Österreich. Abh. Geol. B. A. 33, 1–124.

Schulz, B. (1988): Deformation und Metamorphose im ostalpinen Altkristallin südlich des Tauernfensters (südliche Deferegger Alpen, Österreich). Schweiz. Mineral. Petrogr. Mitt. 68, 397–406.

Simeon, Y. (1979): Etude pétrologique, géochimique et structurale des terrains cristallins de Belledonne entre l'Arc et l'Isère (Alpes françaises). Thèse Université de Grenoble, 1–224.

Söllner, F. and Hansen, B.T. (1987): «Pan-afrikanisches» und «kaledonisches» Ereignis im Ötztalkristallin der Ostalpen. Jahrb. geol. B.A. 130, 4, 529–569.

Steyrer, H.P. and Höck, V. (1985): Geochemistry of the metabasites in the Habach formation (Salzburg, Hohe Tauern, Austria). A preliminary report. Ofioliti 10, 441–456.

Stille, P. (1980): On the genesis of the amphibolites and the hornblendefelses in the Berisal complex. Mem. Sc. geologiche XXXIV, 205–246.

Stille, P. and Buletti, M. (1987): Nd–Sr isotopic characteristics of the Lugano volcanic rocks and constraints on the continental crust formation in the South Alpine domain (N. Italy, Switzerland). Contr. Miner. Petrol. 96, 140–150.

Stille, P. and Tatsumoto, M. (1985): Precambrian tholeiitic-dacitic rock-suites and Cambrian ultramafic rocks in the Pennine nappe system of the Alps: Evidence from Sm–Nd isotopes and rare earth elements. Contr. Min. Petr. 89, 184–192.

Thélin, Ph. (1983): Les gneiss œillés de la nappe du Grand-Saint-Bernard: essai d'évaluation des critères susceptibles d'en préciser l'hérédité prémétamorphique (Alpes valaisannes, Suisse). Thèse, Lausanne, pp. 1–485.

Thélin, Ph. (1987): Nature originelle des gneiss œillés de Randa (Nappe de Siviez–Mischabel, Valais). Mém. Soc. vaud. Sci. nat. 18/1 (104), 1–75.

Thélin, Ph. and Ayrton, St. (1983): Cadre évolutif des événements magmatico-métamorphiques du socle anté-triasique dans le domaine pennique (Valais). Schweiz. Mineral. Petrogr. Mitt. 63, 393–420.

Thöni, M. (1986): The Rb–Sr thin slab isochron method – an unreliable geochronologic method for dating geologic events in polymetamorphic terrains? Mem. Sc. geologiche XXXVIII, 283–352.

Vai, G.B. and Cocozza, T. (1986): Tentative schematic zonation of the Hercynian chain in Italy. Bull. Soc. geol. France (8), II, 95–114.

Vai, G.B. and Spalletta, C. (1982): Devonian Paleo–Tethyan carbonate platform-basin system of the Southern Alps: evolutionary trend and comparative analysis. Terra Cognita 2, 109–115.

Vanossi, M., Cortesogno, L., Galbiati, B., Messiga, B., Piccardo, G. and Vanucci, R. (1984): Geologia delle Alpi Liguri: dati, problemi, ipotesi. Mem. Soc. Geol. Ital. 28, 5–75.

Vavra, G. (1989): Die Entwicklung des penninischen Grundgebirges im östlichen und zentralen Tauernfenster der Ostalpen. Geochemie, Zirkonmorphologie, U/Pb-Radiometrie. Diss. Univ. Tübingen, 1–170.

Vavra, G. and Frisch, W. (1989): Pre-Variscan backarc and island-arc magmatism in the Tauern Window (Eastern Alps). Tectonophysics 169, 271–280.

Vavra, G. and Hansen, B.T. (in prep.): Cathodoluminescence and U/Pb dating of zircons in pre-Mesozoic gneisses of the Tauern window: Implications for the Penninic basement evolution.

Vittoz, P., Costarella, R., Vivier, G. and Oliver, R.A. (1987): Typologie des granitoïdes hercyniens du Haut Dauphiné par l'étude des terres rares et de la morphologie des cristaux de zircon: mise en évidence d'une zonation magmatique dans ce massif. Géol. Alpine 63, 119–163.

Vivier, G., Ménot, R.P. and Giraud, P. (1987): Magmatismes et structuration orogénique paléozoïques de la chaîne de Belledonne (massifs cristallins externes). Le domaine Sud-occidental. Géol. Alpine 63, 25–53.

Voshage, H., Hunziker, J.C., Hofmann, A.W. and Zingg, A. (1987): A Nd and Sr isotopic study of the Ivrea zone, Southern Alps, N-Italy. Contr. Mineral. Petrol. 97, 31–42.

Zeman, J. (1980): Die Krustenentwicklung im präkambrisch und paläozoisch mobilen Europa ausserhalb der Osteuropäischen Tafel. Z. geol. Wissensch. 8, 393–404.

Ziegler, P.A. (1980): Northwestern Europe: Subsidence patterns of post-Variscan basins. Int. Geol. Congr. 26. Sess., Paris C6, 249–280.

Ziegler, P.A. (1984): Caledonian and Hercynian Crustal consolidation of Western and Central Europe – a working hypothesis. Geologie en Mijnbouw 63, 93–108.

Ziegler, P.A. (1988): Laurussia – the old red continent. In: Devonian of the World, vol. 1, McMillan, N.J., Embry, A.F. and Glass, D.J. (eds.), Can. Soc. Petr. Geol., 15–48.

Ziegler, P.A. (1989): Post-Hercynian plate reorganization in the Tethys and Arctic–North Atlantic. AAPG 234, 1-27.

Zingg, A. (1980): Regional metamorphism in the Ivrea zone (Southern Alps): Field and microscopic investigations. Schweiz. Mineral. Petrogr. Mitt. 60, 153–179.

ZINGG, A. (1983): The Ivrea and Strona–Ceneri zones (Southern Alps, Ticino and N-Italy) – A review. Schweiz. Mineral. Petrogr. Mitt. 63, 361–392.

ZINGG, A., HANDY, M.R., HUNZIKER, J.C. and SCHMID, S.M. (1989): Tectonometamorphic history of the Ivrea Zone and its relationship to the crustal evolution of the Southern Alps. Tectonophysics (in press).

ZINGG, M.A. (1989): Die Siviez-Mischabel-Decke: Entstehung und Entwicklung eines Altkristallins. Schweiz. Mineral. Petrogr. Mitt. 69, 130.

ZWART, H.J. and DORNSIEPEN, U.F. (1978): The tectonic framework of Central and Western Europe. Geologie en Mijnbouw 57, 627–654.

Manuscript received February 8, 1990; revised manuscript accepted May 15, 1990.