

Review of radiometric dating in the Western Italian Alps

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ABSTRACT. — This review of radiometric dating is limited to the Italian sector of the Western Alps and also disregards the Southalpine Ivrea-Verbano Zone, discussed in another article in this volume. Moreover we will mainly discuss the most significant data published between 1970 and 1984 because, for preceding years, substantial reviews of radiometric data and some articles with exhaustive bibliographies exist.

Recent Rb-Sr and K-Ar whole-rock and mineral age determinations on Penninic units in western Liguria give an early Hercynian or older intrusion age for the Calizzano-Savona metagranites, with a Hercynian thermal peak at 333 Ma and mica cooling ages between 327 and 311 Ma. In the Austroalpine continental crust megascopic relics of high-grade parashists are widespread and very similar to those occurring in the Southalpine Ivrea-Verbano Zone. Accordingly, their metamorphism probably goes back to the Ordovician cycle. Available age determinations are limited to some Rb-Sr cooling ages on biotites (180-240 Ma) agreeing with those recorded in the Ivrea-Verbano Zone.

Rb-Sr whole-rock isochrons attribute the intrusion of the Penninic Monte Rosa, Barbasiria and Orselina-Moncucco metagranites and the Helvetic Argentera and Mt. Blanc granites to the Upper Carboniferous and Permian.

An age of about 248 Ma (Permian/Triassic boundary) has been defined by Rb-Sr and K-Ar measurements on the magmatic phlogopite of the Matterhorn and Mt. Collon gabbros which are tectonically inserted in the Austroalpine continental crust. These mafic bodies have been interpreted as ensialic or subcrustal intrusions which took place during the pre-rift extensional process of tearing and thinning of the continental crust leading to the Upper Jurassic opening of the Tethyan ocean. Similar significance may be given to the Triassic-Lower Jurassic fission-track ages on zircons from acid differentiates associated with blueschist gabbros of the Piedmont ophiolitic nappes in the Cottian Alps.

The early Alpine HP/LT tectonometamorphic event has been dated on fragments of the oceanic lithosphere and on both Austroalpine and Penninic continental crust. It developed in the Northwestern Alps eclogite mineral associations with ages from 128 Ma (Rb-Sr whole-rock isochron) to 80 Ma (climax) and to 60 Ma (cooling during decompressional evolution). Early Alpine ages have also been obtained for the low-grade metamorphism of the sedimentary cover of the Canavese Unit.

K/Ar ages ranging from approximately 70 to 40 Ma have been obtained on phengites from metasediments of the blueschist Piedmont ophiolitic Units of the Cottian Alps. These ages may record a HP/LT event younger than the Early Alpine metamorphism of the Northwestern Alps or, alternatively, cooling ages of the latter event.

The Lepontine (mid-Tertiary) tectonometamorphic event is pervasively recorded in the whole Penninic area, over large sectors of the Piedmont ophiolitic nappes, and on the external sector of the Lower Austroalpine Unit. The climax of the Lepontine metamorphism occurred 38-40 Ma ago. The set of Rb-Sr and K-Ar data on micas shows that the younger the cooling ages, the higher the temperature of the Lepontine thermal peak. Ages are thus progressively younger going downwards through the nappe pile, from the capping Austroalpine nappes towards the lowest basement units of the Ossola-Tessin window, where Neogene ages are common. The Lepontine regional metamorphism is followed by the ultrapotassic to calcalkalic magmatic activity developed along the Periadriatic lineament and in the surrounding units 29-31 Ma ago.

Key words: radiometric review, Western Alps, Italy.

RIASSUNTO. — Il settore italiano delle Alpi occidentali dispone di una copertura di datazioni radiometriche molto eterogenea. La massima concentrazione di dati moderni (isocroni Rb-Sr roccia tot., età Rb-Sr e K-Ar su minerali) si registra nel tratto

di Alpi Pennine compreso tra la Valle d'Aosta e la Val d'Ossola. In questa regione i fondamentali contributi di J.C. HUNZIKER (1970-74) hanno consentito di attribuire ad un evento orogenico di età coalpina (Cretaceo sup.) le associazioni eclogitiche presenti nella crosta continentale Austroalpina (Sesia-Lanzo) e nelle metaofioliti piemontesi. Lo stesso autore ha inoltre definito l'età del picco termico del ciclo tettonico-metamorfico Lepontino (38 Ma) e precisata la cronologia della sua evoluzione termica nel settore in facies scisti verdi a SW del duomo Ossola-Ticino. Tali risultati sono stati recentemente confermati in Val d'Ossola da DEL MORO et al.

Età coalpine e leptonine si registrano anche nella crosta continentale paleoeuropea delle Unità Penniniche superiori del Monte Rosa (HUNZIKER) e del Gran Paradiso (CHOPIN & MALUSKI).

La sovrainflessione tettonico-metamorfica alpina, a carattere fortemente penetrativo, crea notevoli difficoltà alla possibilità di datare gli eventi prealpini in buona parte delle Alpi Occidentali italiane. Le miche metamorfiche prealpine presenti nei parascisti di alto grado della Serie di Valpelline e della II Zona diorito-kinzigitica (Austroalpina) denotano età di raffreddamento coerenti con il quadro cronologico definito nella Zona Ivrea-Verbano, unità di cui non si tratta in questa rassegna. Per gli ortogneiss Penninici di Calizzano-Savona sono state definite generiche età eociniche o più antiche per l'evento intrusivo ed una età ercinica del metamorfismo regionale, con picco termico a 333 Ma e raffreddamento delle miche tra 327 e 311 Ma (DEL MORO et al.). Isocroni Rb-Sr roccia totale hanno fornito età carbonifere superiori o permiane per l'intrusione dei protoliti granitici da cui derivano gli ortogneiss del Monte Rosa (HUNZIKER), di Moncucco-Orselina (BIGOGGERO et al.) e del Savonese (DEL MORO et al.), valori concordanti con le precedenti datazioni eseguite da FERRARA & MALARODA e da BAGGIO et al. sui graniti Elvetici dell'Argentera e del Monte Bianco.

Rimangono tuttora praticamente scoperte da sistematiche datazioni radiometriche le Unità Penniniche e Piemontesi che si estendono in territorio italiano tra Argentera e Gran Paradiso. Tra i più pressanti problemi cronologici pendenti si segnalano: a) la datazione del metamorfismo di alto grado, verosimilmente caledoniano, dell'Argentera; esso precede l'intrusione dei granitoidi paleozoico-inferiori successivamente trasformati in ortogneiss dal ciclo ercinico (Argentera); b) la datazione dell'evento granulitico nell'Austroalpina su cui si attendono risultati coerenti con quelli della Zona Ivrea-Verbano; c) la datazione dei granitoidi (ortogneiss alpini del Gran Paradiso e del Dora Maira); d) la conferma radiometrica degli eventi coalpino e leptonino supposti, sulla base di associazioni metamorfiche peculiari, nell'Unità Penninica superiore del Dora Maira e nelle metaofioliti eclogitiche del Gruppo di Voltri; e) la datazione delle associazioni di alta pressione nelle coperture brianzoni interne, nel basamento del Gran San Bernardo, e nelle metaofioliti in facies scisti blu delle Alpi Cozie e Marittime.

Parole chiave: geocronologia radiometrica, rassegna, Alpi occidentali italiane.

Introduction

The first radiometric age determinations on Alpine rocks were carried out by JÄGER & FAUL in 1959. Until the end of the 1960s, the production of isotopic data was relatively scarce and results were sometimes questioned or accepted with some perplexity. Between 1969 and 1974, the radiometric researches of J.C. HUNZIKER allowed the dating of the two main Alpine tectono-metamorphic events in the Swiss-Italian Penninic Alps. These events had previously been considered together a single polyphase cycle of mid-Tertiary age. The second half of the 1970s saw great development in the production of data in the fields of radiometric geochronology and isotopic geochemistry. The production of approximately one thousand data, on the Western Alps alone, was favoured by more refined analytical methods, massive investments, and the great increase in the number of laboratories and workers concentrating on Alpine problems.

It is not feasible here to review all these contributions completely. This report is limited to the Italian sector of the Western Alps and also disregards the well-known Ivrea-Verbano Zone and the associated sequences of the South-Alpine basement outcropping between Lake Maggiore and Ivrea (HUNZIKER & ZINGG, 1980, and references therein), discussed in another article in this volume. With a few exceptions, we will limit ourselves here to recalling the most significant data published between 1970 and 1984, bearing in mind that, for preceding years, substantial reviews of radiometric data and some monographs with exhaustive bibliographies exist (BUCHS et al., 1962, 1971; CHESSEX, 1964; CHESSEX et al., 1964; BERTRAND et al., 1965; JÄGER et al., 1967, 1969; DELALOYE & VUAGNAT, 1970; JÄGER, 1970, 1973; KÖPPEL & GRÜNENFELDER, 1975; KÖPPEL et al., 1980).

The Italian Western Alps essentially comprise the axial zone and the continental suture of the Alpine belt. From top to bottom, the pile of nappes is composed of: a) the Austroalpine system of paleo-African provenance (Dent Blanche and Sesia-Lanzo composite units); b) the Piedmont ophiolite nappe system, including segments of oceanic lithosphere and ocean-facing continental edges; c) the Paleo-European system. The

latter is composed of the Upper Penninic Monte Rosa, Gran Paradiso and Dora Maira basement nappes, the Middle Penninic Gran San Bernardo basement and cover nappes, including the Berisal and Moncucco-Orselina sheets, the Lower Penninic nappes of the Ossola Valley, and the Valais décollement nappes. The Helvetian domain outcrops mainly in France and Switzerland, and only parts of the Argentera and Mont Blanc crystalline massifs with some cover sequences outcrop in Italy.

With the exception of the Helvetian basement and of small Austroalpine sectors, all these units show a pervasive tectono-metamorphic imprint of Alpine age, characterized by high pressure-low temperature and/or greenschist mineral assemblages. This situation is shown on one hand by the excellent results obtained by radiometric geochronology in dating Alpine events and, on the other, it justifies the relative scarcity of data on pre-Alpine events. It should be remembered here that the pre-Alpine rock-forming minerals which are locally preserved as metastable metamorphic assemblages in the Penninic basement often show rejuvenated Rb-Sr and K-Ar ages. Instead, radiometric research on pre-Alpine magmatic events is more fortunate, in that Rb-Sr whole-rock isochrons have allowed definition of the pre-Alpine intrusion age in numerous significant orthogneiss bodies.

A review of radiometric data from the Italian Western Alps only, however, does not supply a complete picture of the pre-Alpine and Alpine history in the whole Western Alps, and a brief picture of the overall tectono-metamorphic evolution, inspired to a great extent by a communication by HUNZIKER (1984) on Western Alpine geochronology, will be given in the following section to fill the gap.

Geologic and radiometric framework

The oldest events which may be traced in the Alpine rocks are recorded in zircons occurring in the paragneisses of the main paleogeographic and structural domains, of Precambrian age (2500 Ma). Since the host rocks do not show radiometric evidence of such old events, these zircons are believed to be detrital and of extra-Alpine origin.

The existence of Proterozoic orogenic tectonometamorphic events also seems to be excluded from recent research on the Ivrea-Verbano Zone. The classic granulites, metamorphosed in the Lower Paleozoic, probably derived directly from sediments deposited 500-700 Ma ago (Rb-Sr), fed by a protolithic source which separated from the mantle between 1200 and 1800 Ma ago (Sm-Nd). Instead, the associated femic and ultra-femic rocks probably derived from magmas emplaced about 600 Ma ago (Sm-Nd).

The first tectono-metamorphic and magmatic cycle radiometrically documented on a regional scale in the whole Alpine chain goes back to the Ordovician (« Caledonian event » *Auct.*).

It is well preserved and dated in the Ivrea-Verbano Zone, in the Austroalpine and Helvetian, and locally in the Penninic Units too (Rb-Sr whole-rock isochrons and concordant U-Pb data on zircons). It is characterized by high-grade metamorphism with granulitic (local *HT* eclogites) and amphibolitic associations, and was followed by widespread anatectic processes and large-scale intrusion of granitoids.

Passing to the Hercynian, very numerous dating (Rb-Sr whole-rock isochrons and U-Pb, Rb-Sr and K-Ar data on minerals) reveal traces of a Eo-Hercynian episode (350-360 Ma) and a main tectonometamorphic event with a thermal peak at 320-330 Ma, characterized by metamorphic associations in amphibolite to greenschist facies. In sectors lacking radiometric age determinations, this event in any case predates the Hercynian unconformity of mainly Westphalian age (GB. DAL PIAZ, 1939). The Hercynian cycle ends with the widespread intrusion of Upper Carboniferous granitic plutons, followed by a Permian tectonic/magmatic phase showing local traces of a thermic event.

Until the beginning of the 1970s, the *HP-LT* metamorphic associations and later associations with features varying from the amphibolite (Ossola-Ticino) to the greenschist facies (Western Alps) were referred to a single tectono-metamorphic cycle, admittedly polyphase, and believed to be of Tertiary age. As will be shown in the following sections, systematic radiometric age determinations (Rb-Sr whole-rock isochrons and Rb-Sr and K-Ar ages from white micas and

sodic amphiboles) have shown the existence of an Eoalpine event, of Upper Cretaceous age, chronologically clearly separated from the later, middle Tertiary, Lepontine event. The latter predates the development of the Periadriatic magmatism, of mainly Oligocene age. The history of the Alps ends with the Neogene tectonic phases essentially developed at opposite margins of the chain. Only local traces of these phases are recorded in the available age determinations in the Italian sector of the Western Alps.

Radiometric dating in the Italian Western Alps

Pre-Alpine events

We have already mentioned that the Alpine tectonometamorphic overprint causes serious difficulties in the application of radiometric methods in dating the pre-Alpine metamorphic events locally recorded in the basement units of the Italian Western Alps.

Recent Rb-Sr and K-Ar whole-rock and mineral age determinations on Penninic units in Western Liguria (DEL MORO et al., 1982-83) give an early Hercynian or older intrusion age for the Calizzano-Savona metagranites, with Hercynian overprinting under amphibolite-facies conditions, with a thermal peak at 333 Ma and mica cooling ages between 327 and 311 Ma. It is therefore probable that at least part of the Gran San Bernardo paraschists underwent a Lower Paleozoic metamorphic event. The same hypothesis may possibly be extended to the high-grade associations locally preserved in the Monte Rosa and Gran Paradiso nappes, which certainly predate the intrusion of the Upper Carboniferous granitoids. In the Austroalpine units megascopic relics of high-grade paraschists are widespread and very similar to those of the Ivrea-Verbano Zone. Accordingly, their metamorphism probably goes back to the Ordovician cycle. Available age determinations are limited to some Rb-Sr cooling ages on biotites (180-240 Ma: DAL PIAZ et al., 1972; HUNZIKER, 1974) agreeing with those obtained from the Ivrea-Verbano Zone.

The high-grade paraschists and rare eclogites of the Argentera massif very probably record a pre-Hercynian metamor-

phic event, as deduced from their association with Hercynian orthogneisses deriving from granitoids of probable Lower Paleozoic age.

As regards magmatic events, a Rb-Sr whole-rock isochron attributes the intrusion of the Monte Rosa granitoids, transformed into orthogneisses by the Alpine metamorphism, to the Upper Carboniferous (HUNZIKER, 1970). The same age may probably be attributed to the metagranitoids and augen-gneisses of Gran Paradiso and part of Dora Maira — a stimulating topic for forthcoming geochronologic research.

In the Italian parts of the Helvetic domain, Rb-Sr whole-rock isochrons have been obtained both on the Mont Blanc granite (313 Ma: BAGGIO et al., 1967) and on the Argentera central granite (285-293 Ma: FERRARA & MALARODA, 1969). The ages refer to the intrusion of granitic batholiths and not, as proposed by the Authors, to an anatexis-metasomatic event. Other Permian plutons have recently been documented in the Austroalpine Sesia-Lanzo unit (OBERHÄNSLI et al., 1982) and in the middle Penninic units of the Val d'Ossola and western Liguria (BIGIOGGERO et al., 1982-83; DEL MORO et al., 1982-83). The granitic orthogneisses of the Moncucco-Orselina Unit, the root-like southern extension of the Gran San Bernardo nappe, have supplied a Rb-Sr whole-rock isochron of 271 Ma, interpreted as the intrusion age of the magmatic body (BIGIOGGERO et al., 1982-83). The age of the Barbassiria (Savonese) epiplutonic granite (DEL MORO et al., 1982-83) also turns out to be Permian, and may thus be correlated with that of similar bodies intruded in the Permo-Carboniferous sequences between Modane and the Aosta valley.

Triassic events

An age of about 248 Ma ((Permian/Triassic boundary) has been defined by eight Rb-Sr and K-Ar measurements on the phlogopite intercumulus of the Matterhorn-Mt. Collon layered gabbros (DAL PIAZ et al., 1977). These gabbro bodies are inserted, with a mylonitic contact, in the granitic crust of the lower unit of the Austroalpine nappe system, and certainly predate the opening of the Western Alpine Tethyan ocean. They

have been interpreted as ensialic or sub-crustal intrusions which took place during the pre-rift extensional process of tearing and thinning of the continental crust leading to the Upper Jurassic opening of the Tethyan basin.

Similar significance may be given to the five Triassic-Lower Liassic age determinations (192-212 Ma), obtained with the fission track method, on zircons from acid differentiates associated with blueschist gabbros of the Piedmont ophiolitic nappe in the Cottian Alps (CARPENA & CABY, 1984). Some of the 30 K-Ar age determinations (range 38-220 Ma) performed by BERTRAND & DELALOYE (1976) on metaophiolites associated with the Gets flysch of the Préalpes fall within these values.

Alpine events

The early-Alpine *HP/LT* tectonometamorphic event has been dated on fragments of oceanic lithosphere and on both Austroalpine and Penninic continental crust. It should be noted that, in the North-western Alps, this event involves large and coherent tectonic units, and not mélange formations as in most circum-Pacific blueschist belts. It developed eclogite mineral associations, under *P-T* gradients consistent with a subduction environment, with ages from 128 Ma (Rb-Sr whole-rock isochron; DAL PIAZ et al., 1978) to 80 Ma (eclogite climax) and to 60 Ma (cooling) during decompressional evolution (DAL PIAZ et al., 1972; HUNZIKER, 1974; BOCQUET et al., 1974; OBERHÄNSLI et al., 1982). The isochron was determined on the eclogitic granite of Mt. Mucrone (Austroalpine continental crust) by HUNZIKER (in DAL PIAZ et al., 1978). Other Early Cretaceous ages were obtained on granite gneisses of the Monte Rosa nappe (125 ± 20 Ma, Rb-Sr whole-rock isochron) and a talc-chloritoid - kyanite quartzite also from this nappe ($^{39}\text{Ar}/^{40}\text{Ar}$ on phengite) by HUNZIKER (1970) and CHOPIN and MONIÉ (1984), respectively. The age of the metamorphic climax was obtained by means of numerous Rb-Sr and K-Ar determinations on white micas and amphiboles from the Austroalpine eclogitic micaschists (HUNZIKER, 1974) and from eclogite sections of the Piedmont oceanic crust (BOCQUET et

al., 1974; HUNZIKER, 1974). These radiometric ages allowed dating of the penetrative schistosity and the first two folding phases accompanying the *HP-LT* metamorphic event (Gosso, 1977; Gosso et al., 1979; LARDEAUX et al., 1982). The *HP-LT* associations occurring in the Penninic crystalline basement of the Gran Paradiso nappe, tectonically sited under the Piedmont ophiolite nappe, have recently supplied $^{39}\text{Ar}/^{40}\text{Ar}$ ages on white micas of 60-75 Ma (CHOPIN & MALUSKI, 1980). These ages may correspond to the cooling evolution of the Early Alpine event (CHOPIN & MONIÉ, 1984; DAL PIAZ & LOMBARDO, in press).

Early Alpine ages have also been obtained for the anchizone-greenschist metamorphism of the Canavese sedimentary sequences, a strongly deformed tectonic unit interposed between the Ivrea-Verbano Zone and the Austroalpine Sesia-Lanzo unit (ZINGG et al., 1976).

K/Ar ages ranging from approximately 70 to 40 Ma (Uppermost Cretaceous to Middle Eocene) have been obtained on phengites from metasediments of the blueschist Piedmont Units of the Cottian Alps (DELALOYE & DESMONS, 1976; BONHOMME et al., 1981; LIEWIG et al., 1981). These ages may record a *HP-LT* event younger than the Early Alpine metamorphism of the North-western Alps or, alternatively, cooling ages of the latter event. The first interpretation appears to agree better with the stratigraphical evidence preserved in the internal Briançonnais Units of the Cottian and Ligurian Alps, which suggests that the blueschist assemblages are in this region of Paleogene age.

The Lepontine (or mid-Tertiary) tectonometamorphic event is pervasively recorded in the whole Penninic area, over vast sectors of the Piedmont ophiolite nappe (specially on the Combin units *s.l.*), and on the external sectors of the Lower Austroalpine Unit (Arolla and Gneiss Minuti complexes). The equilibrium conditions reached by the Lepontine metamorphism in the Monte Rosa nappe are discussed by FREY et al. (1976). This metamorphism developed typical greenschist mineral assemblages and related post-nappe deformations in the Piedmont-Aosta Valley area, reaching the highest thermal conditions (intermediate pressure-amphibolite

facies) in the Ossola-Ticino window. Its thermic peak occurred 38-40 Ma ago (HUNZIKER, 1970, 1974; JÄGER, 1973; DEL MORO et al., 1982-83) as indicated by the age of newly formed micas. Numerous Rb-Sr and K-Ar cooling ages on minerals are available for the lower Penninic units of the Ossola-Ticino area (JÄGER et al., 1967; HUNZIKER, 1970; JÄGER, 1973; PURDY & JÄGER, 1976), on the middle-upper Penninic units between the Ossola and Aosta Valleys (HUNZIKER, 1969, 1970, 1974; DELALOYE & DESMONS, 1976; DEL MORO et al., 1982-83), and on the Piedmont ophiolite nappe in the Penninic/Cottian Alps (BOCQUET et al., 1974; HUNZIKER, 1974). Similar ages are reported for the Gran Paradiso ($^{39}\text{Ar}/^{40}\text{Ar}$: CHOPIN & MALUSKI, 1980) and the Austroalpine continental crust (HUNZIKER, 1970, 1974). The set of data shows that the younger the cooling ages, the higher the temperature of the Lepontine thermal peak. Ages are thus progressively younger going downwards through the nappe pile, from the capping Austroalpine units towards the lowest units of the Ossola-Ticino window, where Neogene ages are common.

Radiometric age determinations have thus demonstrated that, in the North-western Alps, there is a time delay of at least 50 Ma between the climaxes of the tectono-metamorphic events. In this region, there was no single orogenic cycle, with an early HP phase produced by the tectonic overload of nappe piling, immediately followed by the Lepontine thermal re-equilibration, as postulated unanimously until the beginning of the 1970s. Instead, there were two separate orogenic cycles, distinct in time and developing under different geodynamic conditions: the Early Alpine HP-LT tectono-metamorphic event predates the continental Africa-Europe collision and is related to subduction and exhuming processes. Instead, the Lepontine tectonometamorphic event is a typical post-collisional process involving deformation and shortening of the pile of basement nappes as well as regional metamorphism linked to thermal doming (DAL PIAZ et al., 1972; HUNZIKER, 1974).

In the Italian NW Alps, the upper limit of the Lepontine event is fixed by the intrusion of post-metamorphic lamprophyre

to andesite dykes of 31 Ma crosscutting the external sector of the Austroalpine Sesia-Lanzo unit and the underlying metasediments of the Piedmont ophiolite nappe (DAL PIAZ et al., 1973). Similar radiometric ages have been obtained for the plutons of Biella and Traversella (CHESSEX & VUAGNAT, 1961) and Miagliano (CARRARO & FERRARA, 1968), and the related dyke swarms crosscutting the Early Alpine eclogitic micaschists of the internal Sesia-Lanzo unit, as well as the cover and basement sequences of the Southern Alps (BIGIOGGERO et al., 1983).

Conclusions

The available radiometric data on the pre-Alpine metamorphic events of the Penninic Units outcropping in the Italian sector of the Western Alps are relatively few and scattered over a large area. The existence of pre-Westphalian regional metamorphism is well documented on stratigraphical grounds, but the pervasive Alpine tectono-metamorphic overprinting makes radiometric dating difficult and generally produces Alpine rejuvenations. The granulitic continental crust of the Upper Austroalpine Unit, which largely escaped Alpine transformations, shows Late Hercynian cooling ages. The high-grade metamorphism is not dated but, due to its close similarity to the Ivrea-Verbano Zone, is probably of Lower Paleozoic age. The sedimentary and pre-metamorphic magmatic history also probably corresponds to that of the Ivrea-Verbano Zone, briefly described in the Framework.

Better known from the viewpoint of radiometric geochronology is the history of the pre-Alpine magmatism of some sectors of the Italian Western Alps. Local Ordovician ages (Savona basement units) are available, together with numerous Upper Carboniferous and Permian ages for the intrusive granitoids of the Helvetic basement and middle and upper Penninic nappes.

Instead, the Italian North-western Alps represent a classic region for the study of Alpine tectono-metamorphic events. It should be noted that the Early Alpine event, dated in the Austroalpine units of the Eastern Alps (SASSI et al., this volume), is distinguished by its different *P-T* conditions

from the Early Alpine metamorphism in the Western Alps. However, in the Penninic continental crust and in the metaophiolites of the Central Alps and the Tauern Window, there are eclogitic associations similar to those of the Western Alps, although they have been only locally dated so far. An Early Alpine *HP-LT* evolution, common to the Penninic and ophiolitic units of the whole Alpine chain, with differentiated history for the overlying Austroalpine units, may thus be hypothesized.

In conclusion, brief mention may be made of some of the most stimulating issues still open to solution by means of new research in the field of radiometric geochronology. As regards the pre-Alpine metamorphic history, the Helvetian basement of the Argentera massif may be mentioned, where there is the definite possibility of dating the regional Hercynian metamorphism and, perhaps, also the granulitic-eclogitic relics existing before

the granitoid intrusion (now orthogneisses and migmatites), of probable Ordovician age. The dating of the granulitic event in the upper Austroalpine Unit (Valpelline Series and 2nd Diorito-kinzigitic Zone, *Auct.*) and of the *HT* assemblages preserved as mesoscopic relics in the Penninic Monte Rosa and Gran Paradiso nappes may also be expected.

The age determination of the pre-Alpine granitic plutonism in the Gran Paradiso and Dora Maira nappes will update current knowledge on the Penninic and Maritime Alps and will probably confirm the importance of the Late Hercynian events or reveal an even greater diffusion of the Ordovician intrusives.

As regards the Alpine tectono-metamorphic events, much work still remains to be done on the Italian Cottian Alps, especially on the Penninic continental crust of Dora Maira and the Pinerolo units.

TABLE 1
Rb-Sr whole-rock isochrons on granites from the Helvetic Mont Blanc and Argentera massifs

Rock type	Sample	Material	Rb ppm	Sr ppm	$^{87}\text{Rb}/^{86}\text{Sr}$	$(^{87}\text{Sr}/^{86}\text{Sr})_m$	$(^{87}\text{Sr}/^{86}\text{Sr})_i$	AGE Ma
MONT BLANC (Baggio et al.,1967)								
Granite	1543	WR	228	160	4.1	0.7280	0.709±0.002	313
Aplitic granite	2052	WR	165	57	8.3	0.7470		
Granite	2143	WR	250	127	5.7	0.7299		
Granite	2578	WR	212	172	3.6	0.7267		
Granite	2640	WR	201	130	4.5	0.7254		
Aplitic granite	3068	WR	115	105	3.1	0.7269		
Granite	3722	WR	169	87	5.6	0.7358		
Mylonitic granite	4030	WR	28	20	4.1	0.7243		
Idem	4335	WR	265	208	3.7	0.7209		
Granite	5380	WR	255	135	5.4	0.7294		
Granite	5584	WR	243	140	5.0	0.7336		
ARGENTERA (Ferrara & Malaroda,1969)								
Granite	1	WR	248	58	12.4	0.760	0.712	285
Granite	2	WR	282	40	20.4	0.800		
Granite	3	WR	447	17.4	74.3	1.020		
Granite	5	WR	291	32.56	25.9	0.819		
Aplitic granite	7	WR	314	18.7	48.6	0.921		
Anatexite	10	WR			3.5	0.730		

TABLE 2
Rb-Sr whole-rock isochrons on Penninic intrusives

Rock type	Sample	Material	Rb ppm	Sr ppm	$^{87}\text{Rb}/^{86}\text{Sr}$	$(^{87}\text{Sr}/^{86}\text{Sr})_m$	$(^{87}\text{Sr}/^{86}\text{Sr})_i$	AGE Ma
MONTE ROSA (Hunziker, 1970)								
Metagranite	86	WR	73.3	76.3	9.85	0.757	0.712	310 $\pm$ 50
Metagranite	92	WR	60.9	195	3.21	0.728		
Metagranite	369	WR	77.9	74.9	10.01	0.755		
Metagranite	376	WR	71.2	81.1	9.03	0.755		
Metagranite	411	WR	65.5	122	5.50	0.734		
Metagranite	416	WR	81.8	64.2	13.10	0.772		
MONCUCCO-ORSELINA (Bigioggero et al., 1982-83)								
Metagranite	Mo79-2	WR	147	180	2.37	0.7217	0.7123 $\pm$ 0.0004	271.6 $\pm$ 4.8
Metagranite	Mo79-1	WR	246	116	6.14	0.7352		
Metagranite	Mo79-3	WR	150	110	3.94	0.7300		
Metagranite	Mo79-4	WR	248	109	6.62	0.7378		
Metagranite	Mo79-5	WR	223	107	6.05	0.7360		
Metagranite	Mo79-6	WR	238	103	6.70	0.7381		
Metagranite	Mo81-7	WR	237	85	8.08	0.7434		
Metagranite	Mo81-8	WR	191	109	5.11	0.7352		
Metagranite	Mo81-9	WR	204	212	2.78	0.7227		
Metagranite	Mo81-10	WR	233	106	6.34	0.7372		

TABLE 3
Rb-Sr whole-rock and mineral data on Middle-Penninic units

Rock type	Sample	Material	Rb ppm	Sr ppm	$^{87}\text{Rb}/^{86}\text{Sr}$	$(^{87}\text{Sr}/^{86}\text{Sr})_m$	$(^{87}\text{Sr}/^{86}\text{Sr})_i$	AGE Ma
CALIZZANO-SAVONA (Del Moro et al., 1982-83)								
Orthogneiss	SAV81-1	WR	102	95	3.12	0.7307	0.7157 $\pm$	333 $\pm$ 12
Orthogneiss	SAV81-2	WR	152	38	11.59	0.7711		
Orthogneiss	SAV80-4	WR	188	108	5.08	0.7391		
Orthogneiss	SAV81-1	Mu	416	21.2	58.37	0.9877		327 $\pm$ 5
Orthogneiss	SAV81-2	Mu	556	5.7	324.55	2.1967		320 $\pm$ 5
Orthogneiss	SAV80-4	Mu	450	13.4	101.37	1.1654		311 $\pm$ 5
Orthogneiss	SAV80-4	Bi	849	6.8	431.59	2.6458		314 $\pm$ 5
Orthogneiss	SAV79-4	Bi	548	5.9	303.83	2.1197		325 $\pm$ 5
Granodioritic gn.	SAV79-5	Bi	484	11.8	125.57	1.2808		317 $\pm$ 5
Granodioritic gn.	SAV79-7	Bi	509	7.6	212.51	1.6443		311 $\pm$ 5
Granodioritic gn.	SAV79-8	Bi	414	8.6	147.89	1.3316		297 $\pm$ 5
BARBASSIRIA (Del Moro et al., 1982-83)								
Mylonitic granite	SAV80-5	Mu	1579	3	3304.86	12.7349	250 $\pm$ 3	
Mylonitic granite	SAV81-3	Mu	1968	4.7	2043.00	7.8038		
Mylonitic granite	SAV81-4	Mu	1341	4.1	1397.96	5.5619		
Mylonitic granite	SAV81-5	Mu	1802	3.2	3951.22	14.9882		
Mylonitic granite	SAV81-6	Mu	894	28.5	93.71	1.0307		
Mylonitic granite	SAV81-7	Mu	996	6.6	517.04	2.5304		
MONCUCCO-ORSELINA (Bigioggero et al., 1982-83)								
Metagranite	Mo79-2	Bi	703	2.07	776.5	0.9534		21.1 $\pm$ 0.7
Metagranite	Mo79-2	Mu	347	20.1	50.0	0.7395		26.3 $\pm$ 2
Metagranite	Mo79-1	Bi	1085	1.48	2265	1.4249		21.5 $\pm$ 0.3
Metagranite	Mo79-1	Mu	541	9.78	161.6	0.7992		29.0 $\pm$ 0.6
Metagranite	Mo79-3	Bi	825	1.90	1309	1.1147		20.7 $\pm$ 0.3
Metagranite	Mo79-3	Mu	402	10.9	107.9	0.7728		29.0 $\pm$ 0.6
Metagranite	Mo79-4	Bi	1192	2.22	1636	1.2216		20.9 $\pm$ 0.4
Metagranite	Mo79-4	Mu	580	10.3	164.8	0.8004		27.9 $\pm$ 0.8
Metagranite	Mo79-5	Bi	1003	1.4	2231	1.3833		20.5 $\pm$ 0.3
Metagranite	Mo79-5	Mu	495	14.8	97.6	0.7691		25.4 $\pm$ 0.6
Metagranite	Mo79-6	Bi	1069	1.1	2988	1.5982		20.3 $\pm$ 0.3
Metagranite	Mo79-6	Mu	531	11.3	136.8	0.7886		27.3 $\pm$ 0.6

TABLE 4
Rb-Sr data on the Upper-Penninic Monte Rosa nappe and on the Austroalpine units

Rock type	Sample	Material	^{87}Rb ppm	Sr ppm	$^{87}\text{Rb}/^{86}\text{Sr}$	$(^{87}\text{Sr}/^{86}\text{Sr})_m$	$(^{87}\text{Sr}/^{86}\text{Sr})_i$	AGE Ma
MONTE ROSA (Hunziker, 1970)								
Metagranite	86	Mu	196	6.4				248 $\pm$ 10
Paragneiss	91	Mu	93.4	23.4				255 $\pm$ 22
Orthogneiss	92	Mu	133	10.7				197 $\pm$ 8
Orthogneiss	411	Mu	153	11.8				222 $\pm$ 12
Orthogneiss	416	Mu	250	6.2				226 $\pm$ 10
Orthogneiss	369	Mu	213	12.7				29.7 $\pm$ 4.8
Gneiss	371	Mu	230	3.4				37.4 $\pm$ 1.5
Orthogneiss	405	Mu	213	15.7				37.9 $\pm$ 5.9
Albite-gneiss	413	Mu	282	7.4				45.4 $\pm$ 2.6
Orthogneiss	415	Mu	122	4.6				42.2 $\pm$ 3.3
Orthogneiss	418	Mu	302	3.4				26.3 $\pm$ 1.4
SESIA-LANZO AND DENT BLANCHE AUSTRALPINE SYSTEM (Hunziker, 1974)								
Paragneiss	558	Bi	102	6.04				184 $\pm$ 7
Paragneiss	560	Bi	177	8.1				207 $\pm$ 8
Paragneiss	682	Bi	105	3.5				190 $\pm$ 8
Banded gneiss	474	Mu	95.3	46.2				86 $\pm$ 60
Orthogneiss	476	Mu	62	24.5				70.7 $\pm$ 38
Phengite-eclogite	485	Mu	94.2	12.8				70.8 $\pm$ 13

TABLE 5
*K-Ar data on micas from the Lower and Upper Austroalpine units
 and from the Gran San Bernardo units in Western Liguria*

Rock type	Sample	Material	K%	^{40}Ar rd ml/g	^{40}Ar rd%	AGE Ma
SESIA-LANZO (Hunziker, 1974)						
Eclogitic micaschist	414	PH	8.35	30.3	88.6	90 $\pm$ 5
Eclogitic micaschist	473	PH	8.52	23.4	87.3	76.7 $\pm$ 3.9
Eclogitic micaschist	474	PH	8.75	22.5	92.4	63.4 $\pm$ 3.4
Albite-schists	475	PH	8.86	16.9	88.9	47.3 $\pm$ 2.7
Orthogneiss	476	PH	9.19	22.8	70.0	61.3 $\pm$ 4.4
Eclogite	485	PH	9.29	23.2	96.1	61.7 $\pm$ 3.2
Eclogitic micaschist	698a	PH	6.19	18.1	90.4	72.1 $\pm$ 3.2
Eclogitic micaschist	698b	PH	7.75	24.0	89.3	76.2 $\pm$ 4
Eclogitic micaschist	685	PH	8.50	27.4	87.0	79.2 $\pm$ 2.5
Eclogitic micaschists	989	PH	8.54	24.1	89.2	71.2 $\pm$ 3.2
VALPELLINE AND 2nd DIORITO-KINZIGITIC UNIT (Hunziker, 1974)						
Paragneiss	682	Bi	7.07	53.3	94.9	180 $\pm$ 9
Paragneiss	682	Mu	8.05	45.0	88.4	135 $\pm$ 8
Paragneiss	699	Mu	8.85	65.6	94.5	177 $\pm$ 9
MONTE ROSA (Frey et al., 1976)						
Metagranite	86	Mu	8.98	23.23	61.1	63.8 $\pm$ 3.1
Metagranite	92	Mu	9.23	9.41	87.3	25.4 $\pm$ 0.9
Metagranite	366	Mu	8.97	20.40	91.4	57.0 $\pm$ 2.5
Metagranite	416	Mu	9.31	19.79	89.1	52.6 $\pm$ 1.8
BARBASSIRIA AND CALIZZANO-SAVONA UNITS (GRAN SAN BERNARDO NAPPE) (Del Moro et al., 1982-83)						
Mylonitic granite	SAV80-5	MU	8.37	8.20	98	231 $\pm$ 2
Mylonitic granite	SAV81-5	MU	8.37	8.58	97	241 $\pm$ 3
Orthogneiss	SAV79-8	MU	7.01	8.87	94	293 $\pm$ 15

TABLE 6
*K-Ar data on pre-Alpine and Alpine minerals of Middle-Penninic
 the Gran San Bernardo Nappe from Valais and Cottian Alps*

Rock type	Sample	Material	K%	^{40}Ar rd ml/g	^{40}Ar rd%	AGE Ma
GRAN SAN BERNARDO BASEMENT AND COVER (Bocquet et al., 1974)						
Micaschist	KA548	Bi	5.62	113.14	96.8	449 $\pm$ 18
Micaschist	KA549	White mica	8.18	117.77	97.6	317 $\pm$ 13
Micaschist	KAW	White mica	8.18	111.9	97.7	301 $\pm$ 12
Casanna schist	KA52	Mica	2.67	24.076	92.3	213 $\pm$ 8
Casanna schist	KA65	Green mica	2.72	23.577	48.3	205 $\pm$ 8
Casanna schist	KA199	White mica	5.05	9.463	51.0	46 $\pm$ 2
Thyon gneis	KA66	Bi	4.72	8.849	74.6	47 $\pm$ 2
Casanna schist	KA198	White mica	4.60	7.872	62.2	42 $\pm$ 2
Casanna schist	KA202	White mica	4.69	18.059	53.7	94 $\pm$ 4
Casanna schist	KA205	White mica	4.34	11.899	45.9	68 $\pm$ 3
Quartzite	KA207	White mica	7.92	10.822	73.2	33 $\pm$ 1
Basement schist	349	Fe-mu	7.72	81.28	96.5	247 $\pm$ 10
Modane orthogn	KA545	White mica	8.49	96.44	95.0	265 $\pm$ 11
Modane orthogn	KA546	PH	8.67	22.08	91.6	62 $\pm$ 2
Modane orthogn	KA547	White mica	8.87	73.47	97.0	213 $\pm$ 8
Basement schist	965	PH	8.12	30.56	92.3	92 $\pm$ 4
Basement schist	1012	White mica	8.41	16.02	87.3	47 $\pm$ 2
Basement schist	1034	White mica	8.28	17.60	71.6	53 $\pm$ 3
Cover marble	484	PH	7.86	15.59	87.7	49 $\pm$ 2
Cover quarzschist	12	PH	8.63	15.27	79.2	44 $\pm$ 2
Cover quarzschist	565	PH	9.08	14.70	90.6	40 $\pm$ 2
Cover quarzschist	630	PH	8.69	15.32	88.3	45 $\pm$ 2
Cover marble	662	Crossite	0.046	0.151	14.5	68 $\pm$ 19

TABLE 7
*Selected K-Ar data on HP/LT minerals of metaophiolites and calcschists
 of the Piedmont nappe from Valais and Cottian Alps*

Rock type	Sample	Material	K%	^{40}Ar rd ml/g	^{40}Ar rd%	AGE Ma
PIEDMONT OPHIOLITE NAPPE (Hunziker, 1974; Bocquet et al., 1974)						
Eclogite	653	Parag	0.519	0.713	21.9	34.1 $\pm$ 6.2
Eclogite	655	Parag	0.353	0.647	25.0	45.4 $\pm$ 9.1
Eclogite	657	Glauc	0.130	0.411	41.6	77.9 $\pm$ 9.3
Eclogite	657	Parag	0.616	0.916	32.4	36.9 $\pm$ 6
Metabasite	750	Glauc	0.045	0.087	15.8	48.1 $\pm$ 15
Glaucophanite	794	Glauc	0.045	0.132	14.6	74.2 $\pm$ 2.5
Calcschist	735	PH	7.37	8.251	87.5	62.0 $\pm$ 0.5
Calcschist	734	Parag	2.95	3.566	39.6	67.0 $\pm$ 4
Calcschist	C88	PH	6.08	4.599	87.5	42.0 $\pm$ 0.1
Metagabbro	C89	Mariposite	8.11	5.385	72.3	37.0 $\pm$ 0.6
Calcschist	C97	PH	7.38	6.510	89.8	49.0 $\pm$ 0.4
Calcschist	C99	PH	6.95	4.638	86.0	37.0 $\pm$ 0.3
Schist	957	PH	6.33	4.390	84.5	39.0 $\pm$ 0.4
Schist	959	PH	8.07	5.706	85.5	39.0 $\pm$ 0.4
Metabasite	673	blue amph	0.035	0.097	12.7	69 $\pm$ 22
Schist	728	Fe-glauc	0.058	0.157	17.4	67 $\pm$ 15
Schist	854	Crossite	0.086	0.137	17.3	39 $\pm$ 9
Metabasite	1189	Fe-actinol	0.039	0.26	12.4	80 $\pm$ 26
Marble	840	Fe-glauc	0.021	0.088	9.0	104 $\pm$ 46
Calcschist	667	Riebeckite	0.29	0.488	8.5	38 $\pm$ 18
Marble	662	Crossite	0.046	0.151	14.5	68 $\pm$ 19
Metaophiolite	955	Fe-actinol	0.039	0.26	12.4	80 $\pm$ 26
Calcschist	1012	White mica	8.41	16.02	87.3	47 $\pm$ 2

TABLE 8

K-Ar apparent ages of different generations of phengite from calcschists of the Piedmont ophiolite nappe in the Northern Cottian Alps

Rock type	Sample	Material	K%	^{40}Ar rd ml/g	^{40}Ar rd%	AGE Ma
PIEDMONT OPHIOLITE NAPPE, COTTIAN ALPS (Liewig et al., 1981)						
Calcschist	200-165/2	PH	8.36	13.03	67.19	47.6 $\pm$ 1.5
Calcschist	200-165/3	PH	8.94	16.06	79.25	54.8 $\pm$ 1.4
Calcschist	200-165/4	PH	8.88	16.15	74.79	55.5 $\pm$ 1.5
Calcschist	200-165/5	PH	7.77	13.45	75.80	52.8 $\pm$ 1.5
Calcschist	200-165/6	PH	7.41	10.97	74.93	45.3 $\pm$ 1.3
Calcschist	200-165/7	PH	2.45	3.70	68.38	46.1 $\pm$ 1.5
Calcschist	165-125/4	PH	9.14	16.25	84.74	54.2 $\pm$ 1.4
Calcschist	63-50/2	PH	1.50	4.37	70.91	88.1 $\pm$ 2.8
Calcschist	63-50/3	PH	5.34	7.52	70.28	43.1 $\pm$ 1.3
Calcschist	63-50/4	PH	8.06	12.82	84.42	48.6 $\pm$ 1.2
Calcschist	63-50/5	PH	3.19	4.65	67.75	44.5 $\pm$ 1.4
Calcschist	Total	PH	4.09	6.67	84.80	49.8 $\pm$ 1.3
Calcschist	50-32/2	PH	2.21	2.96	62.38	41.0 $\pm$ 1.4
Calcschist	50-32/4	PH	8.27	12.31	84.38	45.5 $\pm$ 1.2
Calcschist	50-32/5	PH	4.65	6.71	74.38	44.1 $\pm$ 1.3
Calcschist	50-32/6	PH	0.92	1.14	32.81	38.1 $\pm$ 2.4
Calcschist	Total	PH	4.24	6.63	83.44	47.8 $\pm$ 1.3
Calcschist	32-20 Total	PH	4.20	6.56	83.05	47.7 $\pm$ 1.3
Calcschist	20	PH	4.70	7.16	81.25	46.6 $\pm$ 1.3

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