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

Band: 67 (1987)

Heft: 3

Artikel: Rb-Sr geochemistry of some Hercynian granitoids overprinted by eo-alpine metamorphism in the Upper Valtellina, Central Alps

Autor: Del Moro, Aldo / Notarpietro, Adalberto

DOI: https://doi.org/10.5169/seals-51606

SCHWEIZ. MINERAL. PETROGR. MITT. 67, 295-306, 1987

Rb-Sr Geochemistry of some Hercynian granitoids overprinted by eo-Alpine metamorphism in the Upper Valtellina, Central Alps

by *Aldo del Moro*[1], *Adalberto Notarpietro*[2]

Abstract

A radiometric study (Rb-Sr method) of several Austridic granitoids of the Upper Valtellina has confirmed that they belong to the Hercynian magmatic cycle. The mineral ages range between 267 and 277 m.y. for muscovites and between 78 and 263 m.y. for biotites. An age increase was noted for the biotites from SE to NW, with clustering of values around 125 and 80 m.y. These data are in agreement with the chronological framework of a wide region bordering the area studied.

A major tectonic event could have occurred around 125 m.y. ago, with relative overthrusting of the sheets forming the Austridic domain, whereas 80 m.y. could be the cooling age close to the Cretaceous thermal peak.

The initial $^{87}Sr/^{86}Sr$ values obtained on the granitoids indicate an intracontinental origin with a small contribution of sub-crustal material.

Keywords: Granitoids, Hercynian cycle, Alpine metamorphism, Rb-Sr method, Upper Valtellina, Central Alps.

Introduction

The Upper Valtellina area north of Tirano contains some small, mainly acid plutonic bodies and larger basic ones. Their composition varies, essentially, from granites s.s. to granodiorites, but a few diorites and rare gabbrodiorites also occur. These intrusive masses (Fig. 1), which are distributed fairly uniform among the structural units of the Austroalpine domain of the Central Alps (DEL MORO et al., 1983), have generally been attributed to the alpine magmatic cycle*. This attribution seems, in the light of recent studies, incorrect. Studies of the Brusio granodioritic body (BORIANI et al., 1983) and other smaller bodies (DEL MORO et al., 1983) have identified an Alpine metamorphic phase in the magmatic event that gave rise to the intrusions. The effects of the magmatic event can be observed in the surrounding country side where the intrusive masses overprint the main regional metamorphism. This regional metamorphism is probably Hercynian in age and definitely precedes the low grade (Alpine) metamorphism that affects the entire area studied. An attempt is made in this paper to further clarify the magmatic and post-intrusive evolution of the plutonic masses of Pizzo Bianco, Val Viola, Val Ferrata, Vernuga and Mattaciul, some of which have been studied recently (NOTARPIETRO and DE CAPITANI, 1985 a, b).

* (sheets 8 and 19 of the "Carta Geologica d'Italia" and relative notes)

[1] Istituto di Geocronologia e Geochimica Isotopica CNR, Via C. Maffi 36, 56100 Pisa (Italy).
[2] Centro di Studio per la Stratigrafia e Petrografia delle Alpi Centrali del CNR, Via Botticelli, 20133 Milano (Italy).

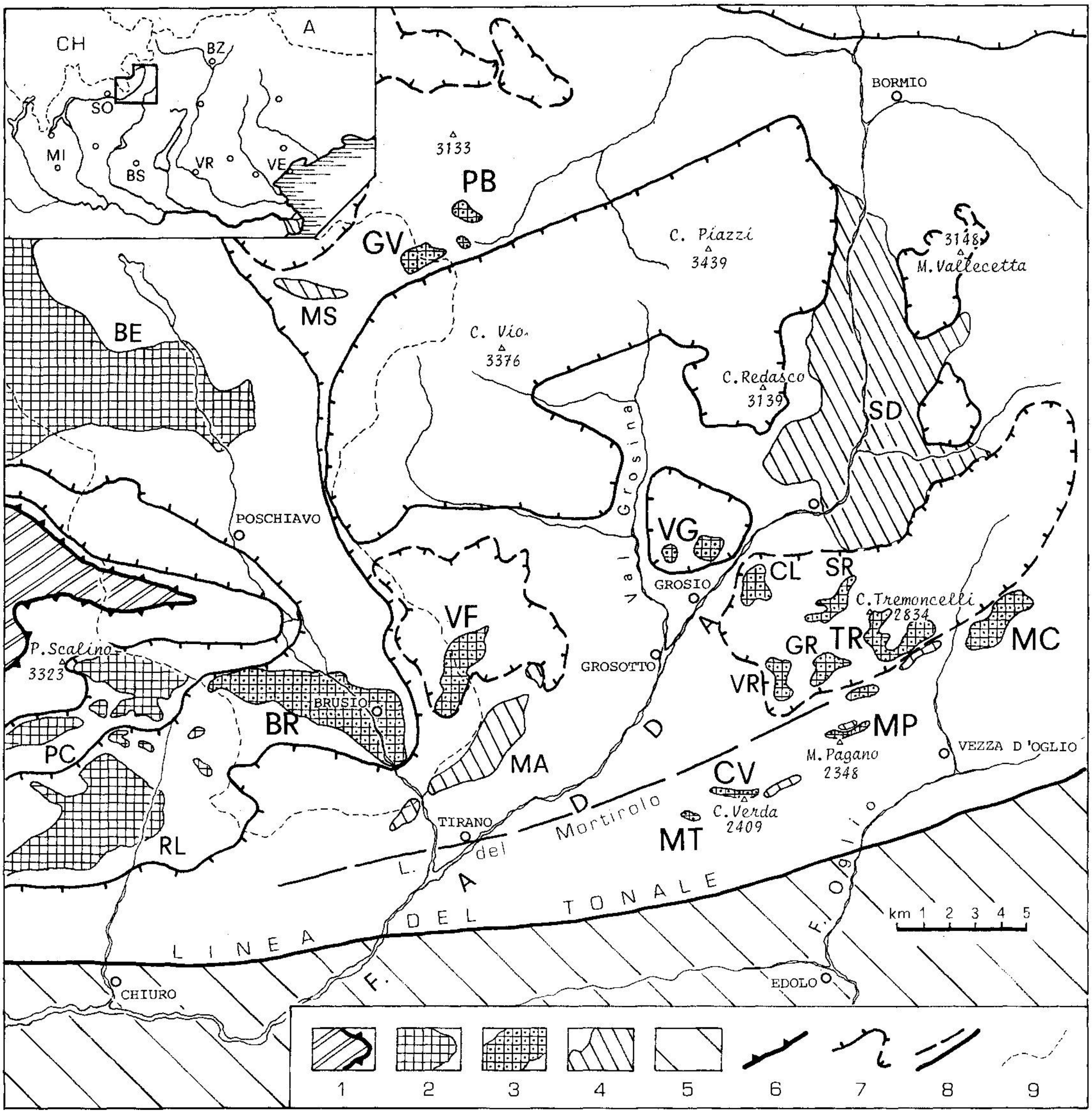

Fig. 1 Tectonic sketch map showing the distribution of magmatic bodies in the Northern Valtellina. BE = Bernina; BR = Brusio; CL = Carlot; CV = Cima Verda; GR = Cime di Grom; GV = Val Viola; MA = Masuccio; MC = Mattaciul; MP = Motto Pagano; MS = Murasciola; MT = Motta; PB = Pizzo Bianco; PC = Pizzo Calino; RL = Rolla; SD = Sondalo; SR = Serottini; TR = Tremoncelli; VF = Val Ferrata; VG = Vernuga; VR = Varadega;

1) Penninic; 2) Acid plutonites; 3) Acid plutonites analyzed (this work, Boriani et al., 1983, Del Moro et al., 1983); 4) Basic plutonites; 5) South Alpine; 6) Thrust, Austroalpine/Penninic limit; 7) Austroalpine nappes; 8) Faults and tectonic lines; 9) State boundary.

Geological background, petrological and geochemical features

One feature common to the bodies studied is the relatively small size of their outcrops. The biggest is the "Val Ferrata Granite" which covers an area of about 3 km^2.

The wall rocks consist mainly of gneisses and micaschists. The primary contacts between the granitoids and wall rocks have been strongly affected in places by deformational events. The transition towards the wall schists varies according to the strength of these events. It either maintains its original intrusive nature (Pizzo Bianco Granite) or appears concordant (Val Ferrata Granite). In other instances (the Vernuga mass), the transition affects only the texture. In the Mattaciul mass, the contact is complicated by the many apophyses penetrating the schists on the edges of the plutons. The dykes usually lie parallel to the main schistosity. The aplitic dykes connected with the "Val Ferrata Granite", for example, extend for hundreds of meters in the Val Piana, with a thickness of ten meters. Where composition tends to be more basic, as in the case of the Mattaciul and the Val Viola stocks, the dykes tend to differ in size and are not always parallel to the main schistosity.

From the petrographic viewpoint, the granitoids have a composition ranging from leucogranite to diorite. The relatively uniform chemistry within the single bodies can be observed in the normative QAP diagram in Fig. 2. The compositional range tends to widen as the acidity index of the rocks decreases, as revealed by

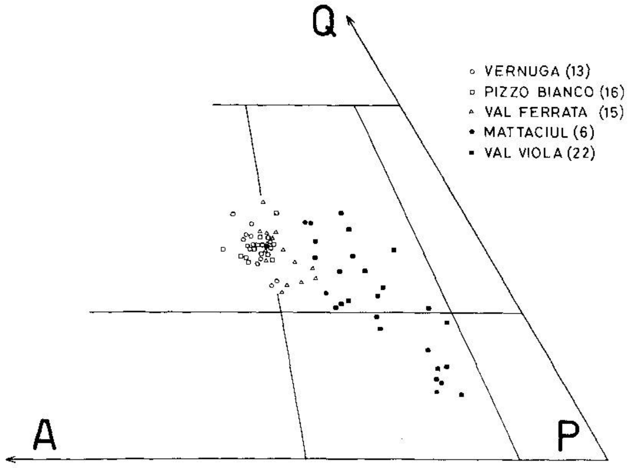

Fig. 2 QAP normative diagram; plot of the analyzed samples within calc-alkaline field with medium K.

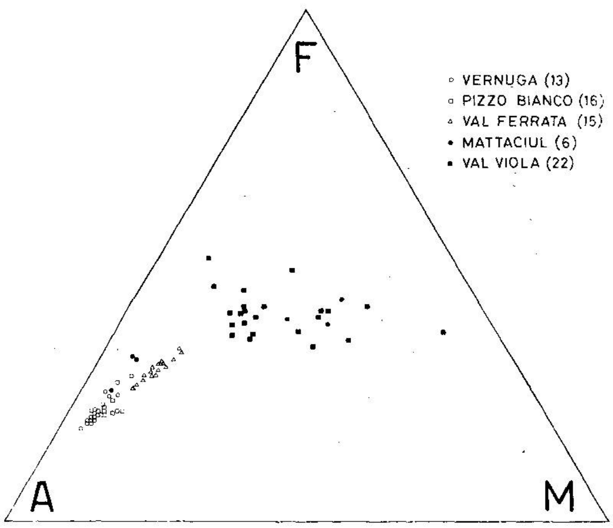

Fig. 3 AFM diagram: distribution of points in the calc-alkaline field. The end member represents the Vernuga Granit (high K) and the Val Viola Diorite (low K).

the geo-petrochemical behaviour of the Mattaciul intrusion.

The rocks studied have a calc-alkaline affinity as shown by the distribution of the sample points in the AFM diagram (Fig. 3).

Despite the presence of a late widespread metamorphism, optical examination still reveals the hypidiomorphic granular texture and the original magmatic paragenesis.

The presence of sillimanite and andalusite was noted overlying the main schistosity in some sections of samples near the intrusion.

The metamorphic (non-contact) blastesis has been considered Alpine for the following reasons, based on petrographical evidence:

- the main schistosity of the wall rocks is unequivocally Hercynian. Epidote, albite, tremolite, mica and stilpnomelane overprint this schistosity;
- the orthogneisses of 440 m.y. are oriented in conformity with this schistosity. The minerals produced in the area of contact with the intrusive bodies overlay the principal schistosity, but precede the Alpine crystallisation;
- the deformation at the contacts of the plutons can be ascribed to mechanical readjustment of the plutons following solidification, probably occurring during the Alpine deformational phases;
- the intrusions and wall rocks both show evidence of having been affected by same deformational events;

- the effects of the temperature rise produced by the granitic melts are imprinted to the main metamorphism and precede the Alpine blastesis;
- the low-grade parageneses are essentially post-kinematic.

Rb–Sr results on "whole rock", mica and feldspar

In order to determine the age of emplacement of these granitic bodies, 21 samples of "whole rock" were analyzed using the Rb–Sr method: Pizzo Bianco (8), Val Viola (2), Val Ferrata (8), Vernuga (1), Mattaciul intrusions (2). Fourteen concentrates of biotite, muscovite and feldspar were also analyzed using the same method. The Val Ferrata and Pizzo Bianco masses were examined in greater detail partly because their geological and petrographical characteristics are better known and partly because their isotopic characteristics, considering the partly rejuvenated Rb–Sr age of the biotite, are better preserved.
5–10 kg samples were obtained from well preserved granitic outcrops, and from these whole rock fractions were prepared by grinding a split of approximately 100 g in an agate mill. Biotite, muscovite, plagioclase and K-feldspar concentrates were obtained using conventional separation techniques by passing the samples through a magnetic separator and with heavy liquids. Micas were further purified by grinding under ethanol.

Rb and Sr contents were measured by isotopic dilution using 98% ^{87}Rb and 99.9% ^{84}Sr spikes, respectively. The precision of the $^{87}Rb/^{86}Sr$ ratio determination has been estimated at $\pm 1.5\%$.

All Rb and Sr measurements were carried out with a Varian MAT TH 5 machine on line to a Laben computer for data collection and analysis. The longtime reproductibility for the $^{87}Sr/^{86}Sr$ ratio was assessed by determination of NBS 987 $^{87}Sr/^{86}Sr$ ratio, and gave a mean value of 0.71028 ± 5 ($1\ \sigma$, n = 23). The value of $1.42 \times 10^{-11}\ a^{-1}$ was used for the ^{87}Rb decay constant. The mineral ages were calculated using the same Sr-correction of the corresponding whole rock.

Table 1 gives the results of the whole rock and mineral analyses. No isochron could be obtained from the analyses on the whole rocks, even when some of the bodies were considered

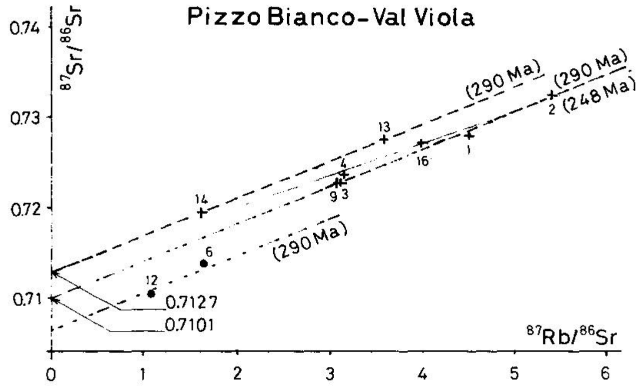

Fig. 4 Evolution diagram of the Strontium isotopic composition of samples from Pizzo Bianco plutonic mass. See text.

separately, e.g. the Pizzo Bianco–Val Viola masses (Fig. 4), or the Val Ferrata–Vernuga–Mattaciul intrusions (Fig. 5); this is evident from the distribution of the data points in these figures. The reasons for this can be attributed to:
- uniformity of composition of the rocks analyzed (i.e., granitoids of the Val Ferrata body);
- marked initial Sr isotopic heterogeneity;
- widespread post-intrusive alteration.

The "errorchron" of 248 m.y. obtained from the eight samples of the Pizzo Bianco granodiorite (Fig. 4) is not a realistic solution as it would give a lower age than that obtained on the muscovite of sample PB 2, i.e., 277 ± 4 m.y. (Tab. 1). The greater reliability of the age obtained from the muscovite led to a reinterpretation of the Pizzo Bianco data points in the isochron in Fig. 4. The graph closest to the age obtained from the muscovite consists of two separate isochrons, each giving an age of 290 m.y. The two samples from the Val Viola pluton, in spatial proximity to that of Pizzo Bianco (Fig. 1), could be attributed to a third isochron of similar age. Confirmation of this simplication by geochemical-petrographic evidence would lead to a more realistic geological solution and the conclusive attribution of these rocks to the late-Hercynian magmatic cycle. This solution would not only define the age of the granitoid intrusions, but would also reveal their composite nature, as indicated by the different Sr isotopic values (0.7101 and 0.7127) of the two isochrons of the rocks from the Pizzo Bianco body.

Tab. 1 Rb–Sr Analytical data

		Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 1\sigma$	m.y. $\pm 1\sigma$
Pizzo Bianco						
PB1	WR	188	122	4.48	.7278 ± 2	
PB2	WR	193	104	5.40	.7323 ± 2	
	Biot	960	3.4	1190.99	5.1735 ± 153	263 ± 4
	Musc	802	34.7	68.76	.9819 ± 8	277 ± 5
	K-feld	474	157	8.77	.7432 ± 4	
	Plag	29.4	157	.54	.7151 ± 2	
PB3	WR	132	123	3.10	.7226 ± 3	
PB4	WR	144	133	3.14	.7235 ± 3	
PB9	WR	117	111	3.07	.7225 ± 2	
PB13	WR	161	131	3.56	.7274 ± 2	
PB14	WR	110	200	1.60	.7193 ± 2	
PB16	WR	164	119	3.98	.7274 ± 2	
Val Ferrata						
VF5	WR	137	175	2.26	.7224 ± 4	
VF6	WR	134	173	2.26	.7227 ± 3	
	Biot	624	3.8	550.31	2.4402 ± 38	220 ± 3
	K-feld	197	180	3.17	.7239 ± 5	
	Plag	24.1	317	.22	.7175 ± 1	
VF7	WR	128	163	2.28	.7236 ± 3	
VF8	WR	131	162	2.35	.7235 ± 1	
VF9	WR	129	165	2.26	.7230 ± 3	
VF14	WR	142	151	2.73	.7232 ± 2	
VF15	WR	133	135	2.84	.7228 ± 2	
VFSF28	WR	127	132	2.78	.7240 ± 3	
Val Viola						
V6	WR	123	218	1.64	.7136 ± 4	
	Biot	541	1.7	1232.84	4.2988 ± 69	205 ± 3
V12	WR	77	208	1.08	.7104 ± 2	
	Biot	359	5.0	221.92	1.4434 ± 18	233 ± 4
Vernuga						
VR1	WR	197	94	6.09	.7336 ± 3	
	Biot	817	5.8	442.57	1.5231 ± 12	127 ± 2
	Musc	793	8.9	286.66	1.8060 ± 12	269 ± 4
Mattaciul						
VP4	WR	107	216	1.43	.7162 ± 1	
	Biot	614	2.2	882.46	1.7051 ± 27	79 ± 1
	Musc	315	16.9	55.16	.9201 ± 8	267 ± 4
VP8	WR	76	248	.89	.7086 ± 3	
	Biot	486	2.2	702.58	1.4867 ± 12	78 ± 1
Metamorphite of the "Scisti del Tonale"						
VA-GU231F	WR	10	918	.03	.7080 ± 5	
	Phlog	221	13.7	47.03	.7919 ± 38	126 ± 6

Analysts: GIANNOTTI, U., PARDINI, G. and TONARINI, S.

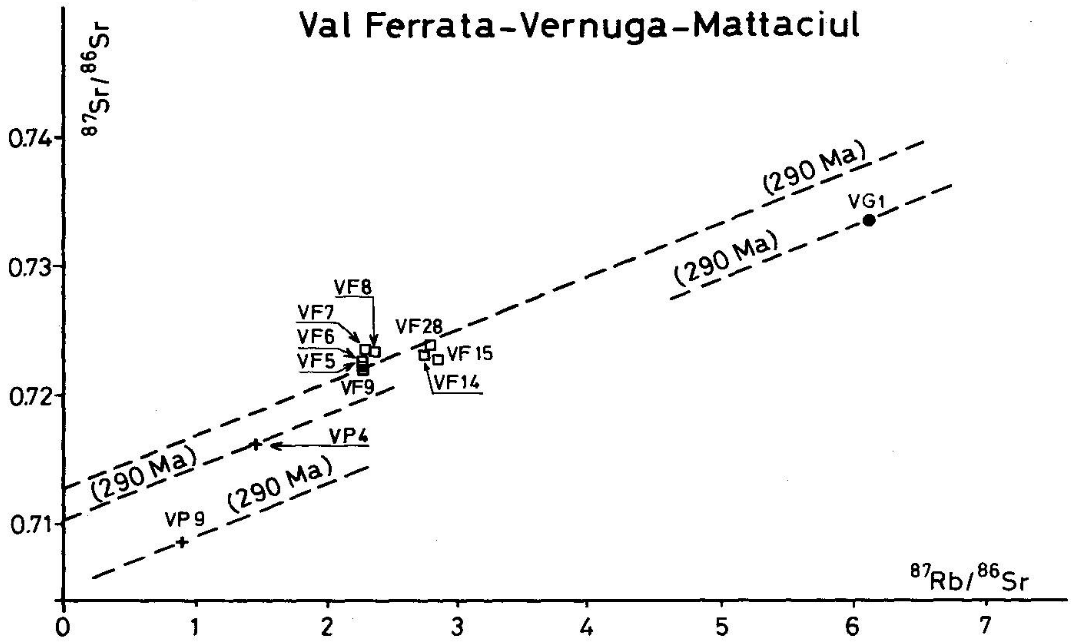

Fig. 5 $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ diagram. Val Ferrata (open squares), Vernuga (circles) and Mattaciul (crosses). The dashed lines show a reference isochron of 290 m.y.

Attempts to reconstruct an isochron for the "Val Ferrata Granite" were also unsuccessful, because of the uniform Rb/Sr ratios of the analyzed samples. Although more than twenty samples were available from this body, it was impossible to obtain rocks with enough difference in chemical composition to build a reliable isochron (Fig. 5).

Using the same procedure on the Mattaciul mass samples as we used on the Val Viola Pluton, i.e., considering the two samples comagmatic, the resulting isochron indicates an excessively high age of about 1,000 m.y. with a Sr I. R. of 0.696, which is far too low (an unrealistic value). The most reasonable deduction is that the two samples do not come from the same parental melt.

If this is the case the Mattaciul is another example of a small, isotopically heterogeneous magmatic body. These bodies are, therefore, of complex origin and they had a complex evolution. There were either a number of distinct sources, or a number of episodes at post-intrusive partial re-equilibration of the Rb-Sr system. The disturbance of the chemical-isotopic setting of these granitoids is shown by the behaviour of the principal minerals. Analysis of samples coming from the Pizzo Bianco and the Val Ferrata bodies provided one example of this phenomenon. Figure 6 shows the effect of a partial intermineral redistribution under the prevailing metamorphic conditions (low to very low-grade; NOTARPIETRO and DE CAPITANI, op. cit.) for radiogenic ^{87}Sr. This leads to different "apparent ages" Rb-Sr for the various minerals. The age difference between the muscovites and biotites can be explained by the different mobilization of radiogenic ^{87}Sr in the two micaceous phases. The ages of the muscovites vary from 267 m.y. (sample VP 4 of the Mattaciul pluton) to 277 m.y. (sample PB 2 of the Pizzo Bianco granite), as can be seen in Tab. 1. The variation interval extends from 259 to 262 m.y. if we also include the ages of the white micas belonging to the Cima Verda granodiorite and the Motto Pagano granite, respectively (DEL MORO et al., op. cit.). Considering the essentially igneous texture of the granitoids and the geological evidence outlined above, it may be concluded that these geochronological data do not represent cooling ages. They obviously show the minimum age of magmatism in this area. However, it must be remembered that a partial "rejuvenation" may have occurred during Alpine time (cf. ODDONE and VILLA, 1986).

The Rb-Sr ages of the biotites are varying much stronger than those of the muscovites. They range from 263 m.y. for the Pizzo Bianco body located in the northern part of the area

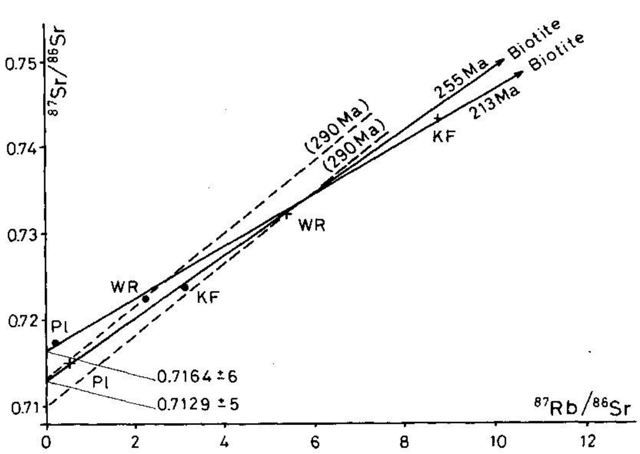

Fig. 6 $^{87}Sr/^{86}Sr$ vs $^{87}Rb/^{86}Sr$ diagram. Data points are scattered for a metamorphic event (eo-Alpine). Apparent ages are given by biotite whole rock isochron.

studied, to 78 m.y. for the Mattaciul and Cima Verda samples from the southern border of the Upper Valtellina, near the Insubric Lineament (Fig. 7).

Intermediate ages were found on the Vernuga, Val Ferrata and Tremoncelli bodies, which are located between the Pizzo Bianco, in the north-west, and the Tonale Line, in the south-east. The Rb–Sr "ages" obtained on the biotite of the Brusio mass (BORIANI et al., op. cit.) belonging to the Bernina Unit of the Lower Austroalpine Alps, also fall within this "age" interval.

Regional thermal history

The Rb–Sr "ages" obtained on biotites of the bodies analyzed tend to decrease from NW to SE. In our opinion, this variation is rather a differentiated reaction of the Rb–Sr system of the mineral to the same "rejuvenation" process than evidence of occasional pulses of a secondary event lasting over a long period in post-Hercynian time.

The Rb–Sr "age" spectra obtained from samples of individual plutons, such as the Brusio (BORIANI et al., op. cit.), Cima Verda and Vernuga, fit easily with this interpretation. It should be noted that the Rb–Sr "ages" on biotites are concentrated around 125 m.y. (samples from north of the Mortirolo Line and the Tonale Line) and around 80 m.y. (samples from south of the Mortirolo Line). An age of 126 m.y. was also obtained using the Rb–Sr method on the phlogopite of a Ca-silicate rock from the Tonale Schist series. The geochronological picture drawn from the Rb–Sr "ages" of the biotites of the Upper Valtellina granitoids has many features that are similar to that of the zones further east, which form, geologically, the Austroalpine part of Western Alto Adige.

The Rb–Sr "ages" from biotites of samples representing some typical lithologies of the crystalline basement of the Ortles Nappe (Upper Austroalpine Alps) range from 72 to 127 m.y. (data to be published).

Using the K–Ar method on white mica and biotite, "ages" in the same 75–125 m.y. interval (THOENI, 1980) were again obtained for the Austroalpine area, particularly in the Val Venosta, Val Solda, Val Monstar, Scarl and Southern Ötztal Units.

This pattern is confirmed in the sectors further east, facing the Mules-Merano-Anterselva Complex, between the Monteneve area and the sector east of the Ötztal where there is evidence of a thermal peak between 80 and 100 m.y. (THOENI, 1983), with temperatures as high as 600°C (ZANETTIN, 1971). These ages are, therefore, extremely common in the region between the Tauern Window and the Val Masino-Bregaglia massif. Considering the radiometric trend and its systematic repetition, we cannot rule out the possibility that the "rejuvenation" was caused by a Cretaceous tectonometamorphic event. Only one small area, west of the Pennes Pass, appears to be unaffected by this event (DEL MORO et al., 1982) and by metamorphic phases occurring later than 80 m.y., both being recorded radiometrically.

Geotectonic implications

The radiometric data obtained on the biotites of Hercynian granitoids of the Upper Valtellina are in agreement with available data on both the nearby Austroalpine area of Western Alto Adige and the region south and east of the Tauern window.

Rb–Sr ages on micas of nearly 80 m.y. were frequently recorded in the Eastern Alps and in the Austroalpine basement of the Gleinalpe (FRANK et al., 1976); Rb–Sr and K–Ar ages on Altkristallin micas of the Kor- and Saualpe in southern Austria range between 70 and 120 m.y. (MORAUF, 1981, 1982). Other authors (OXBOURG et al., 1966; BREWER, 1969; LAMBERT, 1970; HAWKESWORTH, 1976) recorded Creta-

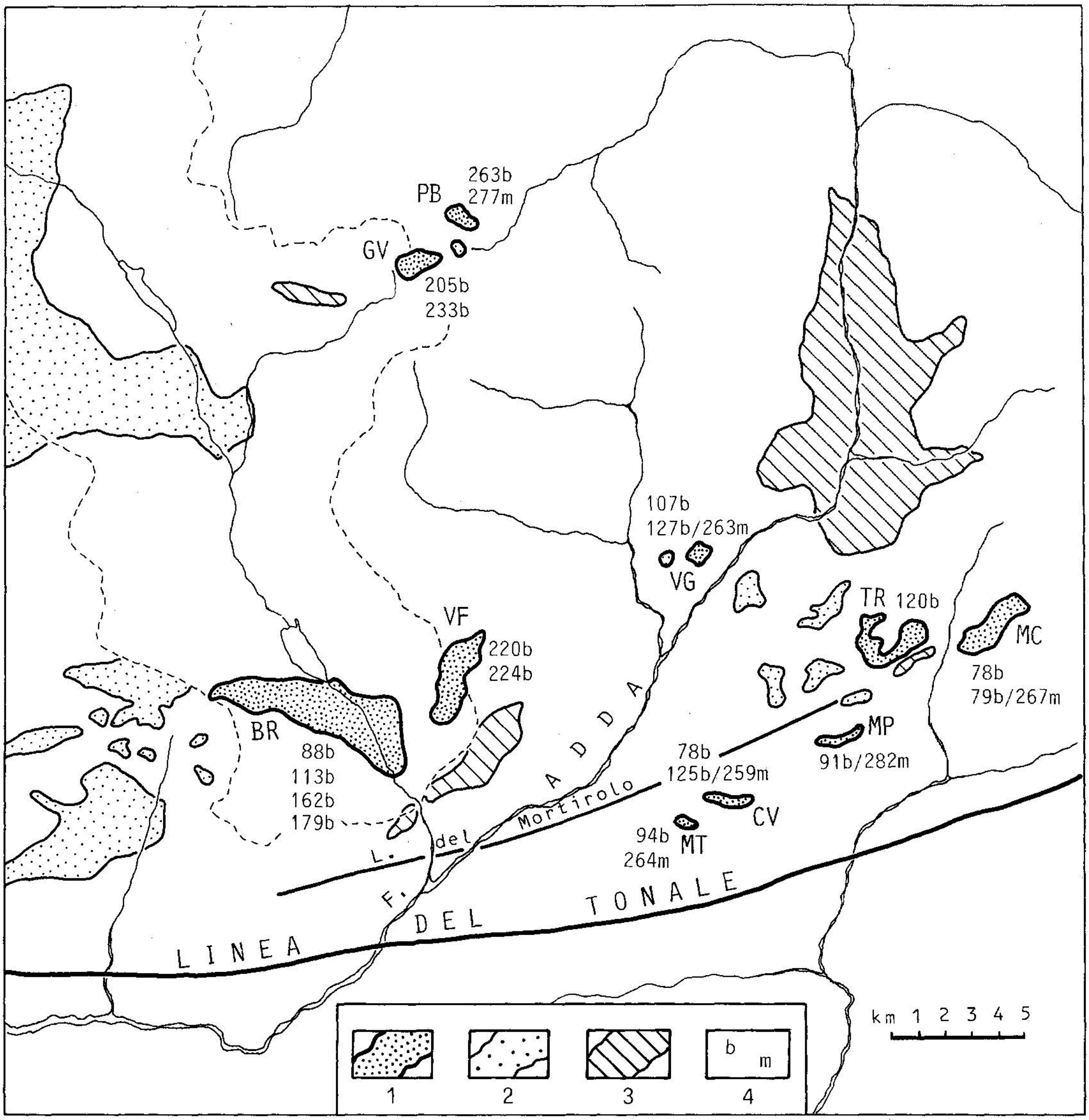

Fig. 7 Distribution of Rb–Sr mica age in the Northern Valtellina. The "age" values decrease from NNW (263 m.y. of Pizzo Bianco mass) to SSE (78 m.y. of Cima Verda and Mattaciul masses).
1) Acid plutonites analyzed; 2) Acid plutonites; 3) Basic plutonites: b = biotite, m = muscovite.

ceous events south-east of the Tauern window, where BREWER (1970, in HAWKESWORTH et al., 1975) observed a post-deformational metamorphic phase at the base of the Austroalpine Alps dated at 105 m.y. STOECKERT (1984) also recorded a tectonic-metamorphic phase older than 102 m.y. south-east of the Tauern window, north of the Deferegger-Anterselva-Valles Line.

All these authors associated the radiometric data with translative movements that brought the Austroalpine Units to their present setting, or with metamorphism linked to a temperature increase following a hypothetical subduction process.

In the Central Alpine area between the Engadine Line and the Tonale Line, THOENI (1980, 1981, 1983) obtained Rb–Sr and K–Ar ages on white micas and biotites that decrease from NW to SE. The same author records ages between 75 and 95 m.y. in the Ötztal, which he associates with the metamorphism following the empilement of the Upper Austroalpine Alps. He obtains an isochron of 113 m.y. on whole rock in the Scarl–Umbrail, and correlates it to a deformative process.

K-Ar determinations (BREWER, 1969; LAMBERT, 1970; MORAUF, 1982) on biotites of Austroalpine rocks from the Central-Eastern Alps show high ^{40}Ar concentrations that produce quite unrealistic ages. Biotites and amphiboles of the Upper Valtellina granitoids were also characterized by an excess of ^{40}Ar, with very high apparent ages (VILLA, personal commun.). The high ^{40}Ar concentrations in the biotites and in the amphiboles could be the result of degassing of deeper rocks (BREWER, 1969) after the thermal peak connected with the Upper Cretaceous metamorphism. This ^{40}Ar was probably trapped within the crystalline structure of the biotite by sharp drop in temperature, as result of the cooling undergone by the Austroalpine units during their Eo-Alpine shift towards the Penninic domain (THOENI, 1981).

The ages measured on the biotites of the granitoids located in the northernmost part of the Upper Valtellina are mixing ages. They are related to the different positions of the host rocks within the Austroalpine basement. Thus the highest values (263 m.y.) indicate that the pluton was stationed in the highest structural units, where the biotites were not completely reset at zero. Conversely, relatively low values (e.g. 127 m.y.) can be interpreted as cooling ages following the emplacement of tectonic thrust sheets that displaced the upper units north-wards and uncovered the layers near the overthrust surface. The similarity in radiometric behaviour of the Upper Valtellina granitoids, aside from the structural aspect, suggest that overthrust took place almost at the same time as the 125 m.y. age recorded in the southern parts of the studied area. The isochron of 129 ± 15 m.y. obtained on the metagranitoids in the M. Mucrone area, Sesia–Lanzo Zone was attributed to a thickening of the crust caused by the overthrust of sheets of Austroalpine basement along the principal tectonic surface. The superposition of the different Austroalpine units would, after a certain delay, cause the temperature increase in the deepest layers, that was responsible for the Upper Cretaceous metamorphism. We have too few data to define, within a reasonable approximation, the time span in which this thermal event reached its peak nor can we describe its size. To evaluate the exact age of this thermal event in the Upper Valtellina we would need, apart from the Rb-Sr ages on biotite already available, further age determinations obtained with different isotope chronometers. The youngest age recorded in the area, around 80 m.y., is probably the result of relative movements associated with the NE-SW and NW-SE alignements. Pushing along mainly vertical planes these movements uncovered deeper layers and also revealed the radiometric record of the detachment of the Austroalpine plate, which occurred after the Upper Cretaceous metamorphism. A more successful attempt was made fixing the time of this metamorphic event in the Monteneve area, where the evidence is clearer; THOENI (1981) dated the thermal peak in this area at 85–90 m.y.

Isotopic characteristics of the magmatic sources

Assuming that the Upper Valtellina granitoids which were examined radiometrically (BORIANI et al., 1983; DEL MORO et al., 1983; this paper) are all of late Hercynian age and have more or less retained their original chemical-isotopic characteristics, the initial $^{87}Sr/^{86}Sr$ ratios will range from 0.7049 to 0.7149 (Tab. 2). The width of this interval leads to differing hypotheses on the magmatic origin of these rocks. We could add to the list in Tab. 2 a diorite sample from the Cima Verda, with a low I.R. of 0.7039, which is clearly indicative of a subcrustal origin. The presence of the Sondalo gabbro in the area should not be neglected. One analysis of a sample from this body gave an I.R. of 0.7064. This value suggests that the basic mass could represent a product similar to subcrustal parent magma, but with the addition of material richer in ^{87}Sr.

The medium-to-low I.R. values were obtained on samples of intermediate compositions, VP 8 from the Mattaciul mass with an I.R. of 0.7049 and V 6 and V 12 from Val Viola with an I.R. of 0.7060 and 0.7069, respectively. These indicate an origin tied to a differentiation of basic melts coming from the mantle that had been contaminated by crustal material and thus enriched in radiogenic ^{87}Sr. In the case of

Tab. 2 ($^{87}Sr/^{86}Sr$) values calculated (this work, BORIANI et al., 1983 and DEL MORO et al., 1983) for the Upper Valtellina samples assuming an age of 290 m.y.

VAL VIOLA		PIZZO BIANCO	
VV 12	0.7060	PB 1	0.7094
VV 6 GD	0.7068	PB 3	0.7098
TREMONCELLI		PB 9	0.7099
79 - 6 GR	0.7083	PB 2	0.7101
VERNUGA		PB 4	0.7106
VR 1 GD	0.7085	PB 16	0.7110
79 - 4 GD	0.7100	PB 14	0.7127
MATTACIUL		PB 13	0.7127
VP 8	0.7049	VAL FERRATA	
VP 4	0.7103	VF 15 GD	0.7111
BRUSIO		VF 14 GD	0.7120
VA 94	0.7086	VF 2 GR	0.7124
78 - 7	0.7091	VF 28 GD	0.7126
78 - 4	0.7093	VF 6 GD	0.7134
78 - 3	0.7101	VF 8 GD	0.7137
VA 96	0.7101	VF 9 GD	0.7137
VA 1	0.7102	VF 7 GD	0.7142
78 - 6	0.7104	CIMA VERDA	
78 - 5	0.7107	78 - 11 D	0.7039
78 - 2	0.7108	78 - 12 GD	0.7119
78 - 8	0.7127	MOTTO PAGANO	
VA 51	0.7132	79 - 10	0.7122
VA 73	0.7132	LA MOTTA	
		78 - 10 GR	0.7149

rocks with I.R. values between those typical of the suboceanic mantle and those of crustal origin, such as the Tremoncelli (0.7083) and the Vernuga granite (0.7085 and 0.7100), the magmatic origin is less certain. The strontium isotopic data obtained for the magmatites of Brusio, Pizzo Bianco, Val Ferrata and the smaller masses of Motto Pagano and La Motta indicate that the origin of these rocks requires an abundant crustal component, albeit with occasional contributions of material with a lower $^{87}Sr/^{86}Sr$ ratio.

So far very few isotopic studies have been directed at defining the main lithologies of the Austroalpine basement. It is therefore difficult to find indications as to the possible crustal protoliths of the granitoids in the area. As far as possible crustal sources are concerned, we refer to the study of granulitic-amphibolitic paraderivates of the Ivrea Zone, in the Southern Alps, by HUNZIKER and ZINGG (1980). If we assume lithologic similarities and a genesis similar to that of the rocks analyzed by these authors, the metapelites of the Austroalpine basement, with an average I.R. of 0.7140, could represent isotopically the anatectic-crustal origin of the granitoids of Pizzo Bianco, Val Ferrata, Motto Pagano and Mattaciul masses in the Permo-Carboniferous. Following the same reasoning the metasediments of the intermediate South-Alpine crust could be considered, on the basis of the isotopic data (HUNZIKER and ZINGG, op. cit.; GRAESER and HUNZIKER, 1968; HAMET and ALBARÈDE, 1973), as the possible protoliths of some of the Hercynian granitoids of the Upper Valtellina.

We may assume a compositional affinity between the host schists of the late Hercynian granitoids of the Upper Valtellina and the analogous metamorphites south of the Tauern window. The rocks being found in the surrounding country side, can thus be compared, isotopically, to some of the granitoids studied here and probably be considered as potential protoliths. The average $^{87}Sr/^{86}Sr$ ratio of the metamorphites of the Tauern window, approximately 290 m.y. ago, was 0.7160 (BORSTI et al., 1973; 1978).

If, on the other hand, the abundant late Ordovician plutonites were converted to magmas by direct melting, these would give rise to products with a slightly richer radiogenic strontium content (e.g. I.R. = 0.7190, obtained from the orthogneiss of the Massiccio dei Laghi, BORIANI et al., 1983). These plutonites therefore could not be considered as original material of the late Hercynian granitoids of the Upper Valtellina.

It is interesting to note that the Hercynian magmatic activitiy gave rise to a relatively large number of granitic bodies in this alpine region (BORSI et al., 1980; CAVAZZINI, 1983) while they appear only rarely in the relatively younger eastern sectors (BORSI et al., 1980; CAVAZZINI, op. cit.; LIPPOLT and PIDGEON, 1974; CLIFF et al., 1974; SCHARBERT, 1975).

One other point worth emphasizing is the greater abundance of radiogenic Sr-enriched terms in the Hercynian granitoids of the Upper Valtellina as compared to the coeval granitoids of the Southern Alps (Table 3).

On the whole, the strontium isotopic data available for the Austroalpine Units in this area (not being values typical of the mantle) are more indicative of a mainly intracontinental genesis with a minor contribution from subcrustal material.

Tab. 3 Range of the Strontium isotopic composition for some magmatic masses of the Southern Alps.

Plutonic mass	$(^{87}Sr/^{86}Sr)_i$	Authors
Cima d'Asta Complex	0.7067 - 0.7119	Borsi et al.,1974; unpublished data
Bressanone Massif	0.7076 - 0.7121	Del Moro & Visonà,1982
Granit-qzdior. Baveno Serie	0.7087	Hunziker & Zingg,1980
Val Navazze Granodiorite	0.7087	unpublished data

Conclusions

The conclusions that can be drawn from the radiometric and petrographic studies of granitoids of the Upper Valtellina are as follows:

- The Rb-Sr ages of the muscovite-whole rock relative to the igneous masses of the Pizzo Bianco, Vernuga and Mattaciul suggest a late Hercynian intrusive age that can reasonably be attributed to all the granitoids in the Upper Valtellina area.
- The recurring ages (approx. 125 m.y.) seem to indicate that the Upper Valtellina granitoids, together with the rocks in which they are embedded, were affected by intense tectonic activity during the lower Cretaceous period. This could, in our opinion, constitute the initial phase of prolonged geological activity that led to the formation of the Austroalpine domain.
- The Austroalpine emplacement gave rise to geoisotherms and the subsequent Cretaceous metamorphism. It also caused a recrystallisation phase that is particularly marked in the deeper layers. The ages (approx. 80 m.y.) recorded near the NE-SW and NW-SE alignements (alignements creating prevalentely vertical displacements which in turn caused the deeper layers of the basement to move upwards) should be regarded as cooling ages very close to that of the thermal peak of the Cretaceous metamorphism.
- Taking into consideration the possibility that the Rb-Sr system of the granitoids behaved as an open system during the Cretaceous tectono-metamorphic event, the initial strontium isotopic ratio that can be extrapolated to their origin, should be used with some care. The calculated values, however, indicate an essentially crustal origin of these granitoids, although there is some evidence of a minor magmatic contribution from sources with a low $^{87}Rb/^{86}Sr$ ratio (e.g. the granodiorite of Val Viola and tonalite of Mattaciul).

References

BORIANI, A., TRAVERSI, G., DEL MORO, A. and NOTARPIETRO, A. (1982-83): Il "Granito di Brusio" (Val Poschiavo-Svizzera): Caratterizzazioni chimiche, petrologiche e radiometriche. Rend. S.I.M.P. 38(1), 97-108.

BORSI, S., DEL MORO, A., SASSI, F.P. and ZIRPOLI, G. (1973): Metamorphic evolution of the Austridic rocks to the south of the Tauern Window (Eastern Alps): Radiometric and Geo-petrologic data. Mem. Soc. Geol). It. 12, 549-571.

BORSI, S., D'AMICO, C. and DEL MORO, A. (1974): Studio radiometrico delle rocce intrusive del Massiccio di Cima d'Asta (Trentino). Mem. Soc. Geol. It. Suppl. Vol. XIII, 145-159.

BORSI, S., DEL MORO, A., SASSI, F.P., ZANFERRARI, A. and ZIRPOLI, G. (1978): New geopetrologic and radiometric data on the Alpine history of the Austridic continental margin south of the Tauern Window (Eastern Alps). Mem. Sc. Geol. XXXII, pp. 17.

BORSI, S., DEL MORO, A., SASSI, F.P. VISONA, D. and ZIRPOLI, G. (1980): On the existence of Hercynian aplites and pegmatites in the lower Aurina valley (Ahrntal, Austrides, Eastern Alps). N. Jb. Miner. Mh., 501-514.

BREWER, M.S. (1969): Excess radiogenic argon in metamorphic micas from the Eastern Alps, Austria. Earth Planet. Sci. Lett. 6, 321-331.

BREWER, M.S. (1970): Rb/Sr Geochronology in the Eastern Alps. Contr. Miner. Petr. 54, 225-244.

CAVAZZINI, G. (1983): Nuovi dati radiometrici nell'area fra Mules e la valle dell'Isel (Alpi Orientali). Mem. Acc. Patavina SS. LL. AA., Cl. Sc. Mat. Nat., 95, 85-99.

CLIFF, R.A., HOLZEN, H.F. and REX, D.C. (1974): The Age of the Eisenkappel Granite, Carinthia and the History of the Periadriatic Lineament. Verh. Geol. B.-A. 2-3, 347-350.

DEL MORO, A., SASSI, F.P. and ZIRPOLI, G. (1982):

New radiometric data on the Alpine Thermal History in the Ötztal-Merano Area (Eastern Alps). Mem. Sc. Geol. XXXV, 319-325.

DEL MORO, A. and VISONA, D. (1982): The epiplutonic Hercynian Complex of Bressanone (Brixen, Eastern Alps, Italy). Petrologic and radiometric data. N. Jb. Miner. Abh. 145,1, 66-85.

DEL MORO, A., NOTARPIETRO, A. and POTENZA, R. (1982-83): Revisione del significato strutturale e geocronologico delle masse intrusive minori dell'Alta Valtellina: risultati preliminari. Rend. Soc. It. Min. Petr. 38(1), 89-96.

FRANK, W., KLEIN, P., NOWY, W. and SCHARBERT, S. (1976): Die Datierung geologischer Ereignisse in Altkristallin der Gleinalpe (Steiermark) mit der Rb/Sr-Methode. Tschermaks Min. Petr. Mitt. 23, 191-203.

GRAESER, S. and HUNZIKER, J.C. (1968): Rb-Sr und Pb-Isotopen-Bestimmungen an Gesteinen und Mineralien der Ivrea-Zone. SMPM, 48, 189-204.

HAMET, J. and ALBARÈDE, F. (1973): Rb-Sr geochronology of the Ceneri Zone (Southern Alps). Fortschr. Mineral, 50, Beiheft 3, 80-82.

HAWKESWORTH, C.J., WATERS, D.J. and BICKLE, M.J. (1975): Plate tectonics in the Eastern Alps. Earth Planet. Sci. Lett. 24, 405-415.

HAWKESWORTH, C.J. (1976): Rb/Sr Geochronology in the Eastern Alps. Contrib. Mineral. Petrol. 54, 225-244.

HUNZIKER, J.C. and ZINGG, A. (1980): Lower paleozoic amphibolite to granulite facies metamorphism in the Ivrea Zone (Southern Alps, Northern Italy). SMPM 60, 181-213.

LAMBERT, R.ST.J. (1970): A Potassium-Argon study of the Margin of the Tauernfenster at Dollach, Austria. Eclogae geol. Helv. 63/1, 197-205.

LIPPOLT, H.J. and PIDGEON, R. (1974): Isotopic Mineral Ages of a Diorite from the Eisenkappel Intrusion, Austria. Z. Naturforsh. 29a, 966-968, Wiesbaden.

MORAUF, W. (1981): Rb-Sr and K-Ar Isotopen-Alter an Pegmatiten aus Kor- und Saualpe, SE-Ostalpen, Österreich. Tschermaks Min. Petr. Mitt. 28, 113-129.

MORAUF, W. (1982): Rb-Sr- und K-Ar-Evidenze für eine intrusive alpidische Beeinflussung der Paragesteine in Kor- und Saualpe, SE-Ostalpen, Österreich. Tschermaks Min. Petr. Mitt. 29, 255-282.

NOTARPIETRO, A. and DE CAPITANI, L. (1985a): Contributo alla conoscenza delle plutoniti austridiche dell'Alta Valtellina. Il granito del Pizzo Bianco. Rend. S.I.M.P. 40(2), 353-363.

NOTARPIETRO, A. and DE CAPITANI, L. (1985b): Contributo alla conoscenza delle plutoniti austridiche dell'Alta Valtellina. Il granito di Val Ferrata. Rend. S.I.M.P. 40(2), 365-375.

ODDONE, M. and VILLA, I.M. (1986): Neutron activation in geochronology: $^{40}Ar/^{39}Ar$ technique, J. Radioanalytical and Nuclear Chemistry Articles, Vol. 99, n.1, 153-159.

OXBOURG, E.R., LAMBERT, R.ST.J., BAADSGAARD, H. and SIMONS, J.G. (1966): Potassium-Argon age studies across the southeast margin of the Tauern Window, the Eastern Alps. Verh. Geol. Bund. Wien, Ba. A., 17-33.

SCHARBERT, S. (1975): Radiometrische Altersdaten von Intrusivgesteinen im Raum Eisenkappel (Karawanken, Kärnten). Verh. Geol. B.-A.4, 301-304.

STOECKERT, B. (1984): K-Ar determinations on muscovites and phengites from deformed pegmatites, and the minimum age of the old Alpine deformation in the Austridic basement to the south of the western Tauern Window (Ahrn valley, Southern Tyrol, Eastern Alps). N. Jb. Miner. Abh. 150, 103-119.

THOENI, M. (1980): Distribution of pre-Alpine and Alpine Metamorphism of the Southern Ötztal Mass and the Scarl Unit, based on K/Ar Age Determinations. Mitt. Österr. geol. Ges. 71/72, 139-165, Wien.

THOENI, M. (1981): Degree and Evolution of the Alpine Metamorphism in the Austroalpine Unit W of the Hohe Tauern in the light of K/Ar and Rb/Sr Age Determinations on Micas. Jb. Geol. B.-A., 124, 111-174.

THOENI, M. (1983): The thermal climax of the Early Alpine metamorphism in the Austroalpine thrust sheet. Mem. Sc. Geol. XXXVI, 211-238.

ZANETTIN, B. and JUSTIN-VISENTIN, E. (1971): Considerazioni geologico-petrografiche sul "Tratto di Monteneve" (Schneeberg-Gesteinzug) (Alto Adige). Mem. Ist. Geol. Miner. Univ. Padova 29, pp. 40.

Manuscript received July 4, 1987; revised manuscript accepted December 20, 1987.