RENDICONTI DELLA SOCIETÀ ITALIANA DI MINERALOGIA E PETROLOGIA, 1988, Vol. 43-2, pp. 411-428

Rb-Sr Geochronology of Lower Permian plutonism in Massiccio dei Laghi, Southern Alps (NW Italy)

LAURA PINARELLI, ALDO DEL MORO
Istituto di Geocronologia e Geochimica Isotopica del C.N.R., Via Maffi 36, 56100 Pisa

ATTILIO BORIANI
Dipartimento di Scienze della Terra, Università di Milano, Via Botticelli 23, 20133 Milano

ABSTRACT. — Based on Rb-Sr whole-rock isochrons and Rb-Sr biotite determinations, the emplacement age of the Montorfano, Baveno-Mottarone and Pella intrusives is 275-280 Ma.

The Quarna, Roccapietra granites and Sacromonte di Brissago, Pedemonte, M. Zuccaro, Quarna and Valsesia calcalkaline intermediate-mafic rocks, which lie along or near the Cossato-Mergozzo-Brissago (CMB) lineament, give significantly younger Rb-Sr biotite ages. These biotite dates are considered a result of the post - Permian reactivation of this fault.

The initial Sr isotopic ratios of the granitic bodies, around 0.7100, are generally higher than those of the appinites, which are between 0.7051 and 0.7103. As regards the protholith of the parental magmas, the two series of Sr-isotopic values do not permit an univocal interpretation. The suggested hypotheses are: a) a heterogeneous anomalized mantle; b) a «normal» mantle, with later contamination by crustal material; or c) a lower crust.

Key words: Rb-Sr dating, Sr Isotopic geochemistry, magmatogenesis, Southern Alps, Hercynian plutonism.

Introduction

In the western sector of the Southern Alps, the studied Hercynian plutonism occurs in some composite intrusive bodies, aligned parallel along or inside the NE-SW trending Cossato-Mergozzo-Brissago (CMB) lineament (Fig. 1).

This plutonism comprises two geographically associated but separately intruded magmatic series: a syn-orogenic prevalently gabbrodioritic to granodioritic (termed appinitic by BORIANI & SACCHI, 1973) suite and a late-orogenic, quartz-dioritic to granitic one. The former outcrops in small masses near the CMB system fault inducing partial melting in the country rocks between Valdossola and Valsesia. The latter is composed of the major plutonic complexes of Montorfano, Baveno-Mottarone, Quarna, Alzo-Roccapietra (and Biella, not considered in this paper).

Concerning the granitic complexes, many geological, geochemical and petrographical studies have been performed in the last 20 years (BURANI, 1965; MORTEN & ROSSI, 1971; D'AMICO & MOTTANA, 1974; GANDOLFI & PAGANELLI, 1974; ORIGONI GIOBBI et al., 1975; FONTANA, 1976; ZEZZA, 1977; ZEZZA et al., 1984; SASSI, 1985; SESANA, 1985; TOLOMIERI, 1985), whereas the appinitic suite is less well-known and an essentially geopetrographic study is that of BORIANI et al. (1974).

As regards geochronological knowledge, during the last thirty years many isolated radiometric data have been carried out on both series, which made it possible to determine a Lower Permian emplacement age. Among the more reliable results, we mention the papers of JAEGER and FAUL (1959, 1960)

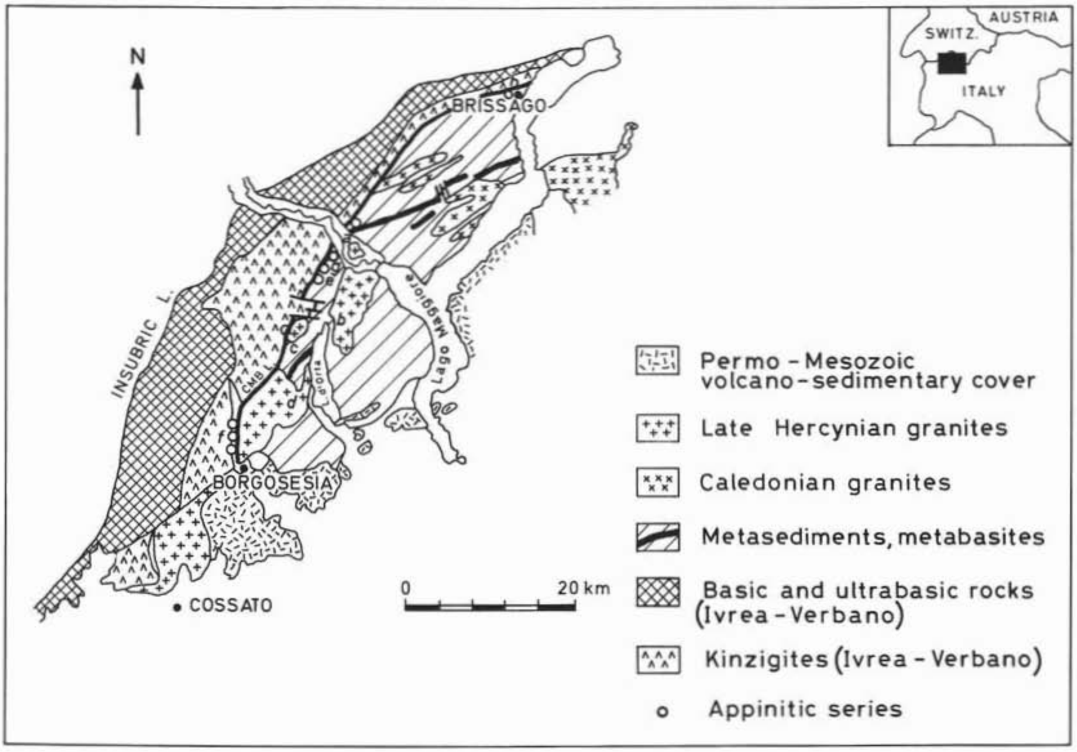

Fig. 1. — Simplified geological sketch map of Graniti dei Laghi (after BORIANI et al., 1988). a) Montorfano; b) Baveno-Mottarone; c) Quarna; d) Alzo-Roccapietra; e) M. Zuccaro; f) Valsesia; g) Pedemonte; h) Sacromonte di Brissago.

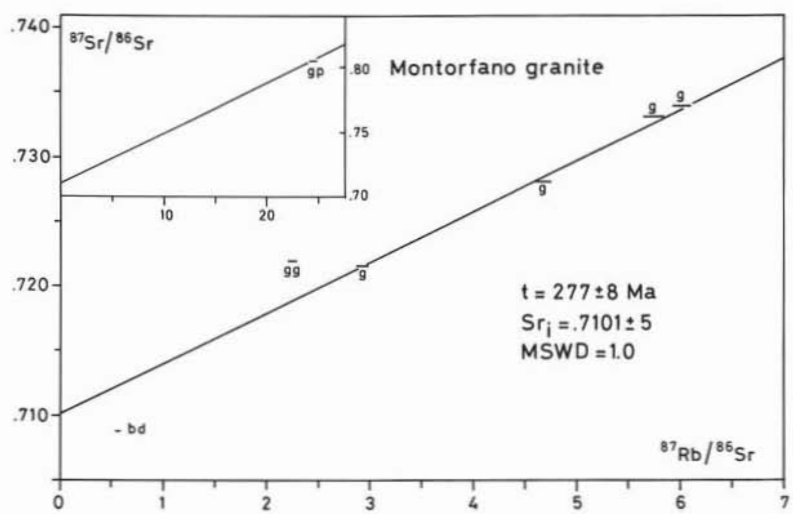

Fig. 2. — Rb/Sr whole-rock isochron for Montorfano samples. g = granite; *gp* = granite porphyry; *gg* = green granite of Mergozzo; *bd* = basic dyke.

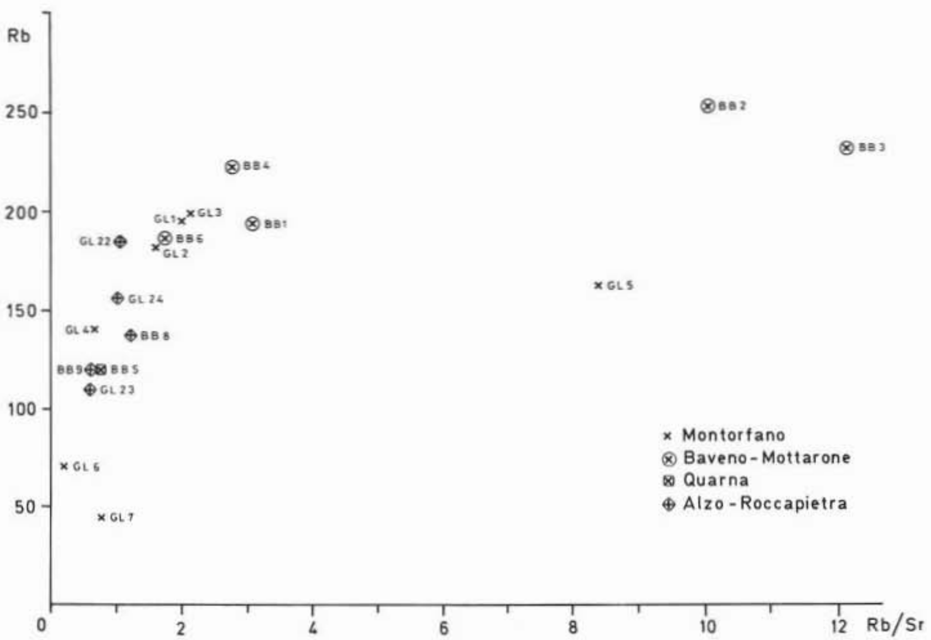

Fig. 3. — Rb vs. Rb/Sr plot for granitic rocks of Montorfano, Baveno-Mottarone, Quarna and Alzo-Roccapietra.

which give Permian K-Ar and Rb-Sr mineral ages on the Montorfano and Baveno granites.

Later, Koeppel (1974) analyzed a monazite concentrate determining an U-Pb age of 280 ± 5 Ma for the Montorfano granite, while Koeppel and Grunenfelder (quoted in Cumming et al., 1987) obtained an age of 285 ± 5 Ma on an appinitic diorite using the same dating method.

Lastly, by the Rb-Sr whole-rock isochron method, Hunziker and Zingg (1980) dated a heterogeneous set of rocks coming from different plutonic bodies whose radiometric age (276 ± 5 Ma) was strongly affected by the high Rb-Sr ratio specimens of the Baveno-Mottarone mass.

In this paper, we perform a detailed radiometric study on the Hercynian granitoids of the Massiccio dei Laghi, in order to ascertain possible temporal differences inside and between the two magmatic suites, differences that are suggested by the geological evidence. Moreover, we would like to provide further isotopic data dealing with the magmatogenesis of the Hercynian granitoids present in the circum-Mediterranean regions.

With this aim, eighteen granites (from Montorfano, Baveno-Mottarone, Alzo-Roccapietra and Quarna plutons), fifteen appinites (from Sacromonte di Brissago, Pedemonte, M. Zuccaro, Quarna, Valsesia), one granitic neosome (Valsesia) and one metapelitic-kinzigitic country rock (M. Zuccaro) were studied from a radiometric point of view (Tabs. 1-2). Moreover, major and some trace element data (Rb, Sr, Ba, Y, La, Ce, Nb, Ni, Cr, V and Zr) are presented for the appinitic samples of the M. Zuccaro area (Table 3). The numerous and good structural, petrographical and geochemical data collected from this area provide solid grounds for setting up such a discussion which, moreover, may throw light upon the debated problem regarding the origin of the Hercynian magmatism.

The South Alpine basement rocks, crossed by the Hercynian plutonites of the Massiccio dei Laghi, have been fairly well investigated and characterized from the Sr isotopic point of view (references quoted in Del Moro, 1987) and so the genetic relationships between the parental magma(s) and the country rocks

TABLE 1

Rb/Sr whole rock analytical data. Rb and Sr contents were analyzed by I.D. method using ^{87}Rb 98% and ^{84}Sr 99.89% mixed spikes. Uncertanity of the $^{87}Rb/^{86}Sr$ ratio was evaluated ± 3%. The error on $^{87}Sr/^{86}Sr$ ratio is $2\sigma_m$. Isotopic ratios were performed by a Varian MAT TH5 mass spectrometer equipped with an automatic acquisition and elaboration data system. Analysts: Giannotti U. and Pardini G.C. Reproducibility was periodically checked by determinations of NBS 987 $^{87}Sr/^{86}Sr$ ratio giving a value of 0.71028 ± 5 ($2\sigma_m$; n = 23)

Sample	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$(^{87}Sr/^{86}Sr)_m$	$(^{87}Sr/^{86}Sr)_i$
			GRANITIC SUITE		
MONTORFANO					
GL 1	195	98	5.76	0.73319± 4	0.7103
GL 2	181	112	4.67	0.72822± 4	0.7097
GL 3	199	96	6.02	0.73405± 4	0.7101
GL 4	140	216	2.93	0.72162± 7	0.7101
GL 5	163	19.5	24.43	0.80545±31	0.7083
GL 6	70	370	0.55	0.70877± 4	0.7066
GL 7	44.1	57	2.26	0.72196± 4	0.7130
BAVENO-MOTTARONE					
BB 1	212	68.9	8.95	0.74599±11	0.7104
BB 2	255	25.4	29.34	0.82468±27	0.7080
BB 3	234	19.3	35.53	0.84945±29	0.7082
BB 4	224	80.5	8.09	0.74214±29	0.7100
BB 6	187	107	5.09	0.73003± 9	0.7098
QUARNA					
BB 5	120	194	1.79	0.71671± 9	0.7096
PELLA					
GL 24	157	155	2.94	0.72117±10	0.7095
ROCCAPIETRA					
GL 22	185	175	3.07	0.71927± 7	0.7071
GL 23	110	160	2.02	0.71903± 5	0.7110
BB 8	139	116	3.47	0.72462±12	0.7108
BB 9	120	201	1.73	0.71681± 5	0.7099

will be less problematic than in other geological areas.

Analytical results

Montorfano granite

This is the northernmost portion of the «Graniti dei Laghi». The four granitic samples analyzed are fairly uniform in Rb/Sr ratio (0.7-2.0) and provide an isochron age of 283 ± 14 Ma (2 σ) with an initial Sr isotopic ratio of .7098 ± 9 (Fig. 2).

If we also consider the high Rb/Sr ratio porphyritic sample (GL 5), the Rb-Sr whole-rock age is practically unchanged (277 ± 8 Ma; $(^{87}Sr/^{86}Sr)_i$ = .7101 ± 5). This sample is representantive of an acidic dyke and, on the basis of its anomalous position on the Rb vs Rb/Sr diagram (Fig. 3), a derivation of the dyke from the granitic magma of Montorfano by a simple differentiation process can be excluded. The Rb-Sr ages for the biotites of two granitic samples are concordant (274 ± 8 and 278 ± 8 Ma) with the whole-rock isochron age, within analytical uncertainty.

A gabbroid dyke from the northern sector

TABLE 1 *(Continued)*

Sample	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$(^{87}Sr/^{86}Sr)_m$	$(^{87}Sr/^{86}Sr)_i$
			APPINITIC SUITE		
SACROMONTE DI BRISSAGO					
BB 13	133	273	1.41	0.71264± 7	0.7070
PEDEMONTE					
BB 14	30.6	388	0.23	0.70914± 5	0.7082
M. ZUCCARO					
GL 9	236	18.1	38.26	0.85041± 7	
GL 10	126	314	1.16	0.71095±16	0.7063
GL 11	180	293	1.78	0.71739±12	0.7103
GL 12	47.6	327	0.42	0.70676±17	0.7051
GL 13	25.6	276	0.27	0.70694±11	0.7059
GL 14	1.5	322	0.01	0.70661± 3	0.7066
QUARNA					
BB 11	116	259	1.30	0.71477± 5	0.7096
VALSESIA					
GL 16	19.6	478	0.12	0.71034± 7	0.7099
GL 17	17.0	342	0.14	0.71072± 7	0.7102
GL 18	58.4	350	0.48	0.71249± 5	0.7106
GL 19	43.5	489	0.26	0.70976± 7	0.7087
GL 20	50.0	390	0.37	0.71149± 5	0.7100
GL 21	75.4	355	0.61	0.71231± 4	0.7099
			METAPELITIC ROCK		
GL 8	85.9	354	0.70	0.72726± 6	0.7245
			GRANITIC MOBILIZED		
GL 15	72.6	256	0.82	0.71420± 4	0.7109

of the granitic body is not similar in initial Sr isotopic composition to the rest of the pluton, having a calculated ratio as low as .7066.

Lastly, the hydrothermally chloritized and albitized «Green granite of Mergozzo» is significantly depleted in both Rb and Sr relative to the unaltered granites, but it seems relatively enriched in ^{87}Sr, having an initial calculated $^{87}Sr/^{86}Sr$ ratio (280 Ma ago) of 0.7130.

This value, intermediate between that of the unaltered granitic facies (.7098) and that of the country rocks (Fig. 4), may be the result of an isotopic exchange between granite and crustal component enriched fluids.

Baveno-Mottarone

Southwards, beyond the alluvium of the Toce river, the composite, granitic Baveno-Mottarone pluton occurs. We were not concerned with the xenolithic granodiorite, but analyzed five samples belonging to the more diffused granitic facies: the porphyritic (BB1), white (BB4, BB6), pink (BB3) and transitional between the last two (BB2). The pink facies shows pneumatolitic-hydrothermal effects (PEYRONEL PAGLIANI, 1948 and references quoted therein). BB1, BB2 and BB4 come from the northern end, BB3 and BB6 from the southern part of the pluton.

All the samples define a good Rb-Sr whole-rock isochron of 276 ± 7 Ma (2 σ), with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7102 ± 8 (Fig. 5).

The rocks of the transitional and pink facies are characterized by the highest Rb/Sr ratio of the plutonic complex. These Rb-rich and Sr-poor values are typical of highly differentiated magmatic products. The perfect

TABLE 2

Rb/Sr mineral ages. Rb and Sr contents were determined by I.D. Analysts: Giannotti U. and Pardini G.C. Rb analyses were performed on an aliquot of mineral solution. Mineral ages were calculated with the corresponding whole-rock (except for pegmatite GL 9, whose age was calculated using biotite + feldspar), using the decay constant of $^{87}Rb = 1,42 \times 10^{-11}/a$. Quoted errors are $2\sigma_m$

Sample	Material	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$(^{87}Sr/^{86}Sr)_m$	AGE Ma
			GRANITIC SUITE			
MONTORFANO						
GL 2	Bi	645	4.9	443.01	2.46302±125	278± 8
GL 5	Bi	964	4.3	854.66	4.04310±156	274± 8
BAVENO-MOTTARONE						
BB 1	Bi	537	9.3	177.53	1.40776± 32	276± 9
BB 2	Bi	1029	11.6	285.22	1.83981± 45	279± 9
BB 3	Bi	1065	8.1	446.13	2.48285± 67	280± 9
BB 4	Bi	814	9.3	282.20	1.83769± 34	281± 9
BB 6	Bi	709	15.0	144.49	1.28570± 42	280± 9
QUARNA						
BB 5	Bi	583	7.1	256.47	1.51003± 26	219± 6
ROCCAPIETRA						
GL 22	Bi	906	8.0	366.47	1.92200± 43	233± 7
GL 23	Bi	511	3.9	430.61	2.05143± 37	219± 6
PELLA						
GL 24	Bi	664	4.7	482.90	2.60288±125	276± 8
			APPINITIC SUITE			
SACROMONTE DI BRISSAGO						
BB 13	Bi	739	3.2	803.23	2.65094± 77	170± 5
M. ZUCCARO						
GL 9	Mu	943	2.8	1525.84	6.32992±145	259± 8
	K-F	407	30.3	39.34	0.84752± 10	
GL 10	Bi	320	10.7	89.27	1.02608± 21	251± 7
GL 11	Bi	901	7.9	363.25	1.72239± 29	196± 6
QUARNA						
BB 11	Bi	448	2.9	514.51	2.44054± 99	236± 7
VALSESIA						
GL 16	Bi+Chl	148	30.6	14.01	0.75344±128	218± 9
GL 18	Bi	269	10.2	78.16	0.94928± 82	214± 6
GL 20	Bi	377	11.6	97.06	1.04154± 15	240± 7
			METAPELITIC ROCK			
GL 8	Bi	476	6.8	216.55	1.38051± 44	213± 6
	Mu	210	112	5.43	0.74604± 7	279±10
	Pl	7.4	758	0.03	0.72489± 4	
			GRANITIC MOBILIZED			
GL 15	Mu	227	33.7	19.60	0.78528± 15	266± 8

linear trend of the samples along the isochron suggests an exclusive magmatic origin for the hydrothermal and/or pneumatolitic fluids interacting and partially modifying the earlier crystalline phases (biotite, feldspars).

The Rb-Sr biotite ages confirm that of the

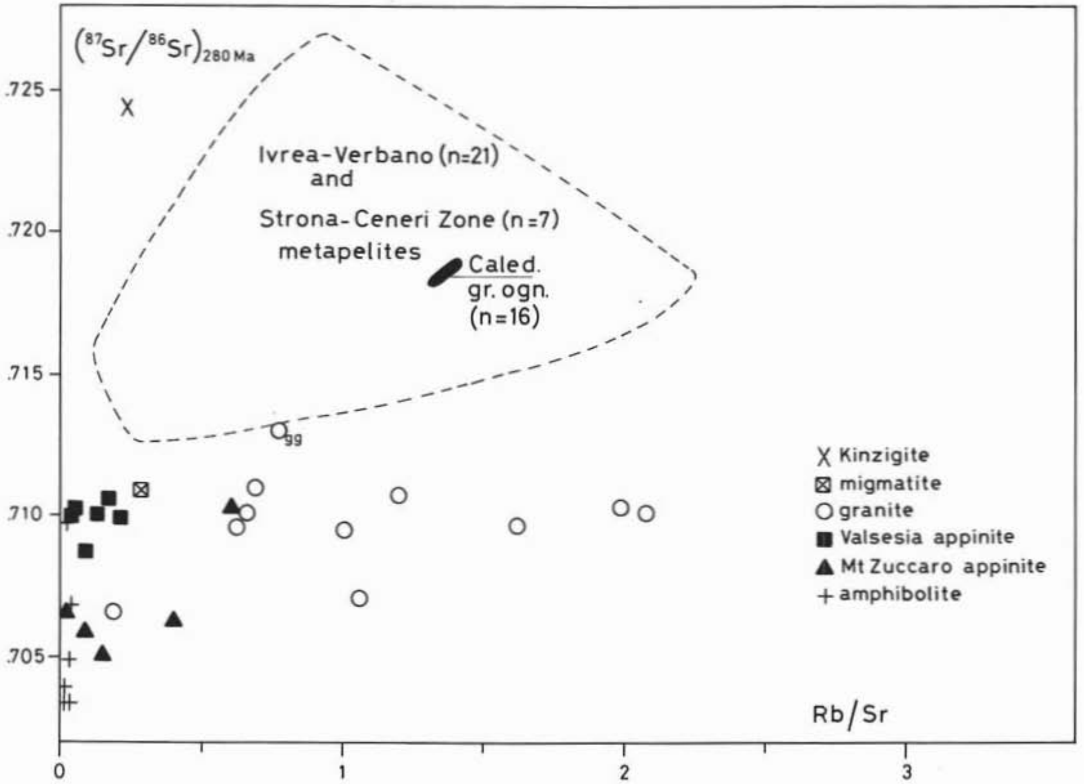

Fig. 4. — ($^{87}Sr/^{86}Sr)_{280\ Ma}$ vs. Rb/Sr plot showing relationship between Hercynian granitoids and main metasedimentary basement rocks of Ivrea-Verbano and Strona-Ceneri zones (GRAESER & HUNZIKER, 1968; HAMET & ALBAREDE, 1973; HUNZIKER & ZINGG, 1980). Cross: amphibolite from Alpe Morello, Val d'Ossola and Anzola quarry (DEL MORO, unpubl. data). Black area: «Caledonian» acidic orthogneisses (BORIANI et al., 1982). All data are corrected for an age of 280 Ma.

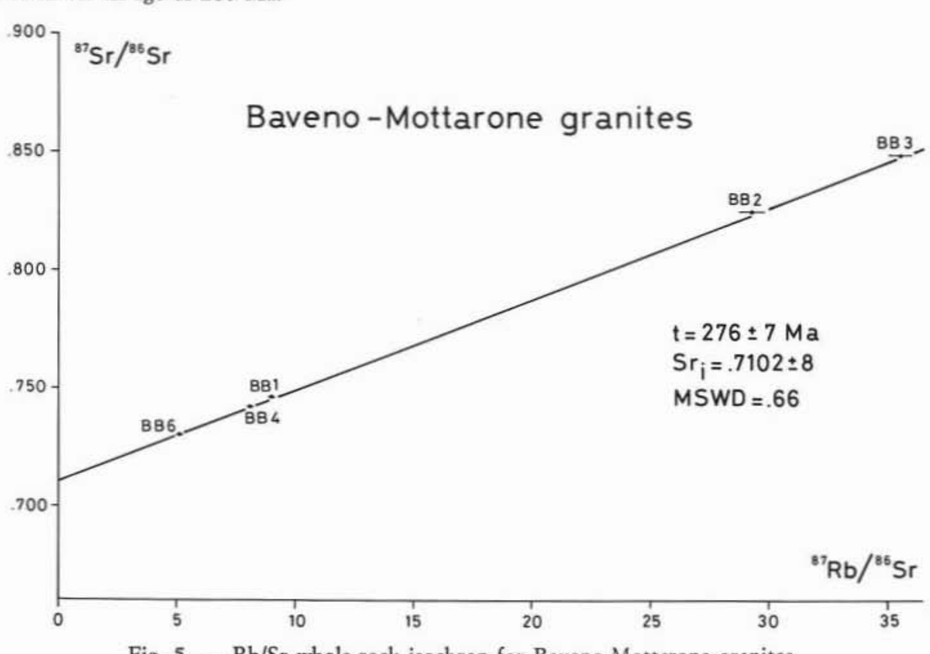

Fig. 5. — Rb/Sr whole-rock isochron for Baveno-Mottarone granites.

TABLE 3

Major and trace element contents of Valsesia samples. MgO and Na_2O were determined by A.A. spectrophotometry; other major and trace elements were determined by XRF

	VALSESIA							M. ZUCCARO			LA COLMA	
	GL 19	GL 17	GL 21	GL 20	GL 16	GL 18	GL 15	BLE 4*	BLE 12*	BLE 10*	BN 22 T*	BN 25 T*
Element (%)												
SiO_2	44.82	58.03	60.16	61.70	65.14	66.91	73.75	47.72	48.34	69.28	57.17	51.70
TiO_2	1.51	1.05	.75	.86	.75	.65	.13	.86	1.96	.52	1.72	.83
Al_2O_3	20.60	17.69	18.43	17.43	16.78	15.91	15.01	17.43	15.04	14.75	14.55	14.54
Fe_2O_{3T}	11.59	8.93	5.90	6.97	5.69	5.06	1.22	8.78	12.70	2.53	7.71	7.62
MnO	.18	.10	.11	.10	.09	.06	.01	.13	.21	.03	.16	.17
MgO	6.31	3.36	1.11	2.56	2.07	1.69	.67	9.51	6.43	0.80	4.25	9.19
CaO	11.45	5.92	3.47	5.18	4.33	3.70	3.78	10.18	10.93	1.86	5.26	8.08
Na_2O	1.91	3.89	3.97	3.20	3.59	3.30	3.78	2.39	2.87	3.09	2.61	2.41
K_2O	1.15	.58	4.91	1.43	.90	1.98	3.07	.61	.33	5.32	1.79	1.14
P_2O_5	.29	.24	.21	.28	.07	.21	.09	.11	.21	.19	.36	.12
L.O.I.	.20	.20	.92	.29	.60	.53	.68	.37	1.55	.73	2.25	2.82
Element (ppm)												
Rb	45	20	75	49	22	59	74	29	8	221	94	59
Sr	456	342	343	388	473	350	259	373	343	288	341	252
Ba	478	384	3200	453	369	700	463	99	172	906	768	208
Nb	12	10	21	13	10	14	2	4	6	10	13	4
Zr	147	115	832	210	191	191	21	70	100	293	86	70
La	16	24	172	42	33	23	9	11	10	68	21	14
Ce	52	55	344	94	77	50	21	21	37	126	68	35
Y	34	18	30	16	21	16	6	16	36	10	30	20
Ni	16	7	4	9	9	6	9	127	45	9	69	109
Cr	58	15	10	19	20	13	24	345	243	5	104	474
V	247	247	44	98	75	60	15	120	204	34	327	167

MgO and Na_2O were determined by A.A. spectrophotometry; the other major and trace elements were determined by XRF.
All the samples are appinites, except GL 15, which is a granitic neosome.
* Data from Burlini L. (unpublished thesis).

whole-rock isochron as being 276 ± 9 Ma (BB1), 279 ± 9 Ma (BB2) and 280 ± 9 Ma (BB3).

Alzo-Roccapietra

Our sample collection comes from the Roccapietra quarry and deals with three biotitic ± amphibolitic granites and one micrograniti sample (GL 22).

They do not define any isochron and, when plotted in the graph ($^{87}Sr/^{86}Sr$) vs. ($^{87}Rb/^{86}Sr$) of Fig. 6, scatter widely along the reference isochron, allowing no dating suggestive of either open-system behaviour of the total rocks or initial Sr isotopic heterogeneity. As the two biotites analyzed exhibit Rb-Sr «ages» significantly younger than those of Montorfano and Baveno-Mottarone, open-system behaviour for the total rocks is supported.

However, the specimen of the eastern granitic «tongue» of Pella behaved differently: its biotite did show an unaltered age of 276 ± 8 Ma, and the whole rock fits fairly well into the 277 Ma reference-line of the Sr evolution diagram (Fig. 6).

Quarna

Only one quartz-dioritic sample (BB5) was analyzed for the Quarna pluton, near the CMB lineament. This mass exhibits behaviour similar to that of the Alzo-Roccapietra pluton, and turns out to be isotopically disturbed (Fig. 6).

The biotite also shows a Rb-Sr «rejuvenated» age of 219 ± 6 Ma.

Appinitic suite

The chemical data presented here refer to olivingabbro to monzogranite specimens (Fig. 7) of the Valsesia , M. Zuccaro and La Colma areas (Table 3). Major elements show a regular decrease of CaO, MgO and $FeO_{tot.}$ with an increase in silica content, whereas other elements are scattered when plotted versus

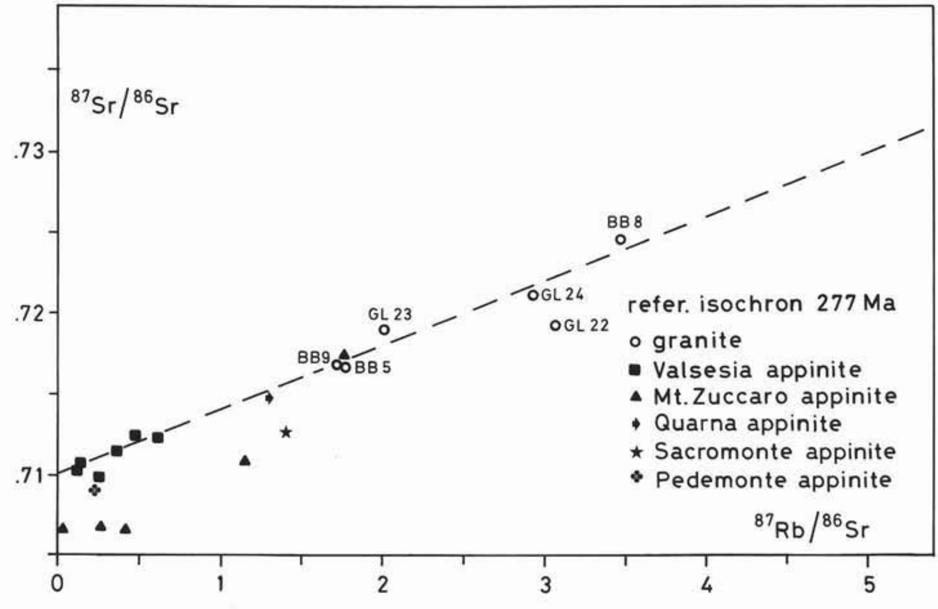

Fig. 6. — Rb/Sr evolution diagram for Quarna, Alzo-Roccapietra, Pella granites and M. Zuccaro, Valsesia and Quarna appinites.

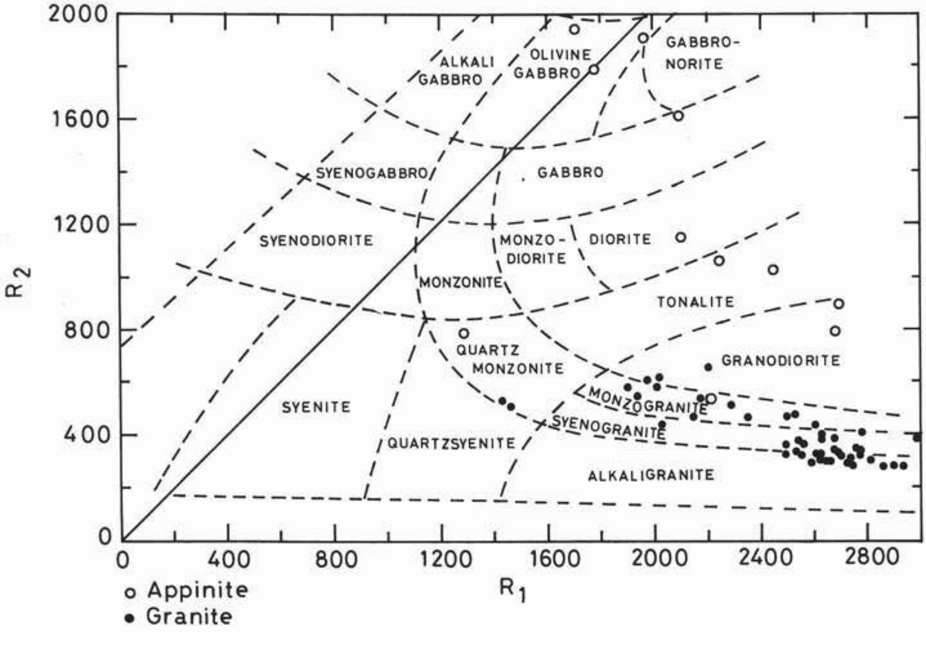

Fig. 7. — Projection of analyzed samples on DE LA ROCHE's R1-R2 diagram (after DE LA ROCHE et al., 1980). Open circles = appinites; full circles = granites.

SiO_2 (Fig. 8). In the Al_2O_3 vs. SiO_2 diagram, the Valsesia samples occupy a distinct field, being Al_2O_3-richer than the M. Zuccaro and La Colma specimens.

A significant difference between the Valsesia appinites and the others may also be noted in the trace element (Rb, Sr and Ni) vs. SiO_2 plots (Fig. 9). Moreover, the GL 21 granodioritic appinite from Valsesia is anomalously rich in K_2O, V, REE, Zr and Ba (Fig. 9).

The Rb-Sr data were determined on specimens from the M. Zuccaro (G 10-14) and Valsesia (GL 16-21) areas, from Pedemonte (BB14), Sacromonte di Brissago (BB13), and from an enclave in the Quarna granitic mass (BB11). The whole-rock data points of the M. Zuccaro, Sacromonte di Brissago and Pedemonte appinites lie markedly below the reference isochron of 277 Ma (Fig. 6), while those of Valsesia and Quarna scatter to a lesser extent from that line.

The Rb-Sr biotite dates of these samples range from 251 Ma (M. Zuccaro) to 170 Ma (Sacromonte di Brissago) (Table 2), while the muscovite of a pegmatite associated with the M. Zuccaro appinitic series yielded a Rb-Sr «age» of 259 Ma.

The kinzigitic sample collected in the same area displays a Rb-Sr muscovite age of 275 ± 8 Ma and also a calculated Sr isotopic ratio as high as .7240 for the total rock, whereas the granitic neosome from Valsesia has an apparent Rb-Sr muscovite age of 266 Ma and an initial Sr isotopic composition of .7110.

Discussion

The granitic masses of Montorfano and Baveno-Mottarone have the same emplacement age (275-280 Ma) and the same initial Sr isotopic composition: this age represents the most reliable age of the plutonic activity of this region. The Sr isotopic ratio, around .7100, recurs in the calc-alkaline Hercynian magmatism of the Southern Alps and is an intermediate values between those of a suboceanic mantle and a typical metasedimentary crust (Fig. 4). The nearly uniform values around .7100 exclude a random contamination process of the magma during its ascent through the crust or during its emplacement. Moreover, a direct derivation of the granitic series from the appinitic one can be ruled out on the basis of the sample distribution in the Rb/Sr vs. 1/Sr plot of Fig. 10 defining two distinct trends. It is more reasonable to hypothesize that the value of .7100 was acquired during evolution of the magma in a magmatic chamber or directly from the source region. In fact, the Sr isotopic composition value of .7100 is compatible with a medium-low Rb/Sr ratio material present in the lower crust or with a subcontinental mantle, enriched in ^{87}Sr before the magmatic event.

According to lead isotopic data of CUMMING et al. (1986), it is possible to observe an isotopic evolution of the mantle region in this area towards an apparently «crustal» characteristic, probably determined by a subduction related dehydration of the downgoing sediment, starting from a mantle similar to the source of the lower layered complex of the Valsesia (PIN & SILLS, 1986).

The remaining intrusive bodies of the granitic suite exhibit Rb-Sr biotite ages younger than 277 Ma, indicating an opening of the mineral systems. Moreover, from the scatter of the whole-rock data points in the isochron diagram (Fig. 6), open system behaviour may also be inferred for the rocks. It should be pointed out that the latter masses outcrop nearer the CMB line than the Montorfano and Baveno-Mottarone bodies. This fact suggests a strict relationship between the activity of the fault and the radiometric data. The open system behaviour of the granitic rocks in this area may in fact be determined by the deformative event related to the activity of the CMB lineament.

The «rejuvenated» mineral ages of the appinites, outcropping near the CMB line, confirm that the activity of this fault may have disturbed their chemical-isotopic system. A similar effect may be inferred for those whole rocks which do not fit the isochron of Fig. 6.

On the other hand, the diagram of Fig. 11 shows the correlation between the calculated initial Sr isotope ratio and the Sr content inside each appinitic suite. Such a relationship seems to exclude a major role of the disturbing

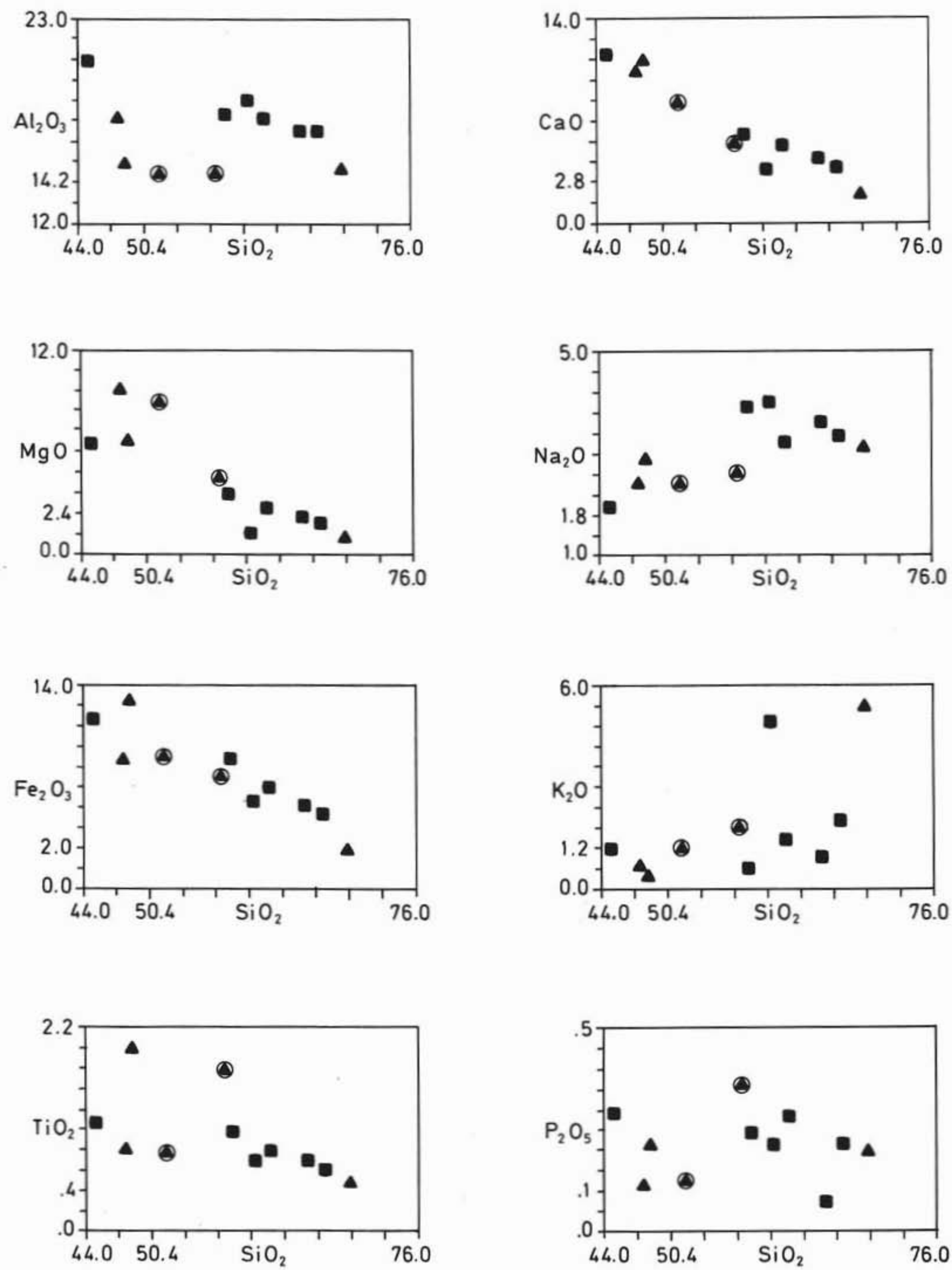

Fig. 8. — Major elements vs SiO_2 variation diagrams for appinitic rocks. Full square = Valsesia (this work); full triangle = M. Zuccaro (BURLINI L., unpubl. thesis); full triangle enclosed in circle = La Colma (BURLINI L., unpubl. thesis).

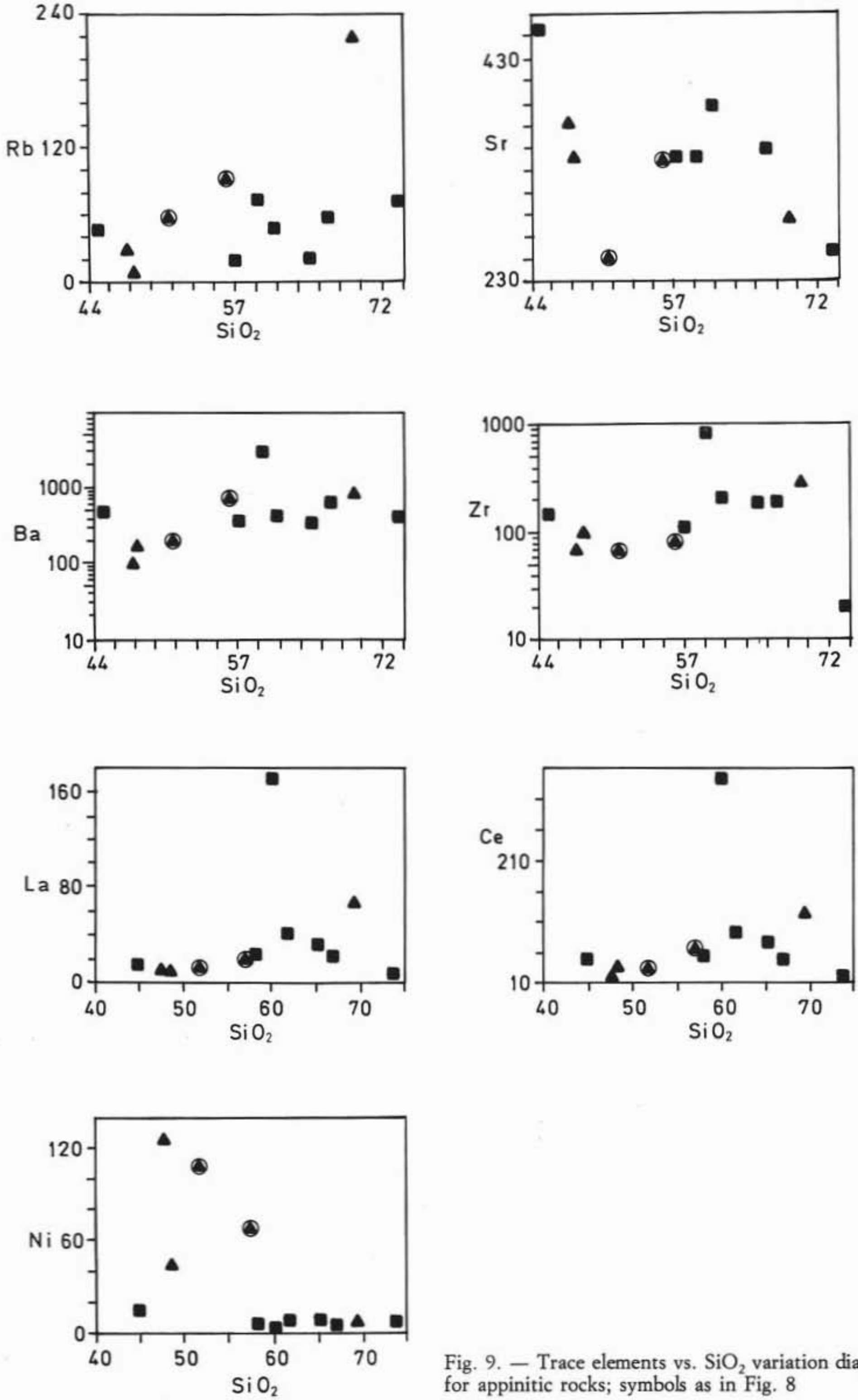

Fig. 9. — Trace elements vs. SiO_2 variation diagrams for appinitic rocks; symbols as in Fig. 8

tectonics on the whole rocks, as it ought to have caused random variations of the Sr elemental and isotopic composition. A linear relation between these two parameters is usually linked to mixing processes between two end-members with different Sr isotopic and geochemical characteristics.

The data on the M. Zuccaro and Valsesia series were separately tested for a process of combined assimilation - fractional crystallization (DE PAOLO, 1981), starting from the more primitive rocks, and assuming as contaminant an average crustal component

The good agreement of the observed and calculated trends (Fig. 11) confirms that the geochemical and isotopic variations inside the two series may be explained by the effectiveness of an AFC process involving the appinitic magma and a crustal component deriving, for example, from melting of the country-rocks: the neosomatic portion of a migmatized augengneiss outcropping in Valsesia (GL 15, Caneto quarry) does have a corrected-age Sr isotopic composition and a Sr content similar to that required for the contaminant, as can be seen in Fig. 11. At

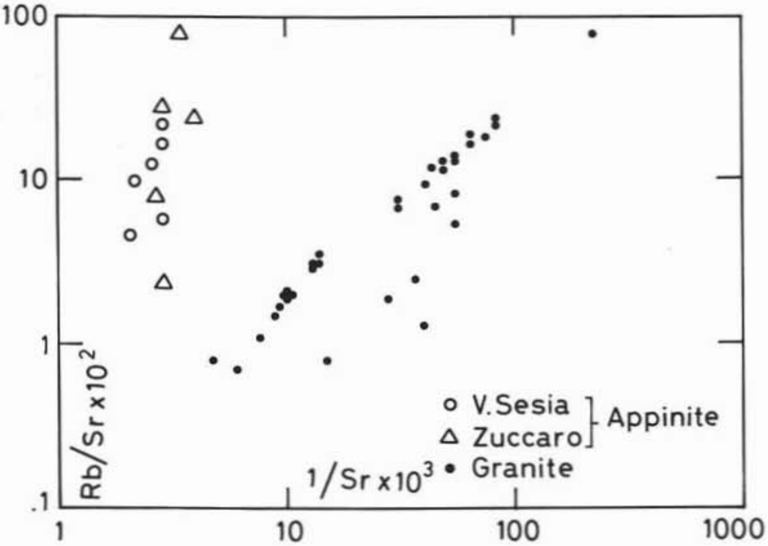

Fig. 10. — Rb/Sr vs. 1/Sr plot discriminating between granitic and appinitic series.

with Sr content of 150 ppm and ($^{87}Sr/^{86}Sr$) ratio of .720. The calculated mixing lines reported in Fig. 11 correspond to a theoretical AFC process, assuming a Sr bulk partition coefficient (D) of 1.5 for the Valsesia sample series and 1 for the M. Zuccaro series, and an assimilation to crystallization rate of .5.

The results of the least-squares mixing calculation based on major elements (STORMER and NICHOLLS, 1978) agree with the assumed D values. The Valsesia major element variations may in fact correpond to a crystallization process dominated by plagioclase, whereas those of M. Zuccaro are ascribed to a minor amount of plagioclase in the fractionated solid (Table 4).

the moment, no potential contaminant is known for the M. Zuccaro appinitic series, as there is no evidence of interaction between these rocks and the kinzigitic ones, e.g. GL 8, which, however, would not satisfy the isotopic characteristics of the contaminant end-member.

The lower values of the Sr isotopic composition (0.705-0.706), obtained on the more mafic samples of the M. Zuccaro suite, are compatible with a subcrustal origin, in agreement with their extremely basic composition.

The differences between the more primitive magma of M. Zuccaro and that of Valsesia still remains to be explained. In fact, it may

TABLE 4

Results of least-squares mixing calculation based on major elements (STORMER & NICHOLLS, 1978) *for Valsesia and M. Zuccaro appinitic suites. HO = Horneblende; PL = Plagioclase; MG = Magnetite; BI = Biotite; FS = Fractionated Solid; OX = Residue Oxides*

STEP	HO %	PL %	MG %	BI %	F.S. %	OX
Valsesia						
GL 17 - GL 20	7.6	9.0	1.4	1.8	20.0	1.60
GL 20 - GL 18	6.1	14.2	1.1	3.5	24.9	0.22
M.Zuccaro						
BLE 4 - BLE 12	23.0	10.6	-	14.4	48.0	1.98

be seen that the parental magma of the Valsesia series is richer in Sr and has a higher Sr isotopic composition than the M. Zuccaro one. Whether these differences must be ascribed to primary or secondary characteristics is, at the moment, unclear.

Concluding remarks

The results obtained by the investigation of the intrusion age of the late-orogenic granitic suite of the Montorfano, Baveno-Mottarone and Pella masses are concentrated around 275 Ma. This value is similar to those of other Hercynian plutonites of the Southern Alps: Bressanone massif (DEL MORO & VISONÀ, 1982), Cima d'Asta (BORSI et al., 1974) and Navazze (DEL MORO quoted in CASSINIS, 1982). For the remaining granitic samples studied (Alzo-Roccapietra and Quarna), the post-intrusive opening of the Rb/Sr system impeded the attainment of a reliable emplacement age but, on geological grounds, the same age of the other masses can be assumed. Evaluation of the intrusion age of the appinites was hindered by a probable fractional crystallization plus assimilation process, involving the parental magma and a crustal material and affecting both the M. Zuccaro and Valsesia magmas. Micas of appinites and granites outcropping near the CMB line tend to become younger towards

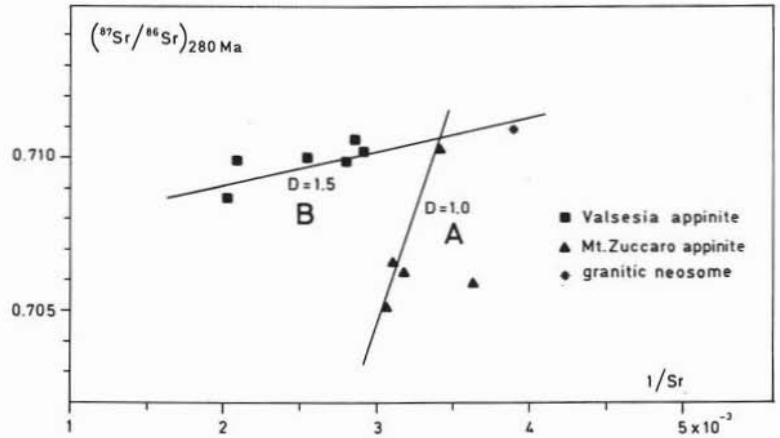

Fig. 11. — $(^{87}Sr/^{86}Sr)_i$ vs. 1/Sr plot for appinites. Lines *A* and *B*: calculated trend for two AFC processes, respectively of M. Zuccaro and Valsesia series. Parameters:

A: Init. magma: $(^{87}Sr/^{86}Sr) = 0.705$; Sr = 330 ppm
Cont. magma: $(^{87}Sr/^{86}Sr) = 0.720$; Sr = 150 ppm
DSr = 1.01; R (Ass. rate/Cryst. rate) = 0.5

B: Init. magma: $(^{87}Sr/^{86}Sr) = 0.7087$; Sr = 600 ppm
Cont. magma = $(^{87}Sr/^{86}Sr) = 0.713$; Sr = 260 ppm
DSr = 1.2 R; (Ass. rate/Cryst. rate) = 0.5

DSr values are obtained according to result of least-squares mixing calculations based on major elements reported in Table 4.

this lineament, up to about 180 Ma, suggesting a post-magmatic tectonic history of the basement along this fault system.

Based on Sr isotopic data, an anomalous mantle or a lower crust may be invoked as the source region of the Hercynian granitoids of the «Graniti dei Laghi».

APPENDIX: SAMPLE DESCRIPTION AND LOCATION

Montorfano

GL 1 - White medium grained granite (qtz, pl, Kf, bi, zir, ap). Cava Donna quarry.
GL 2 - White medium grained granite. Ponte Toce quarry.
GL 3 - White medium grained granite. Cirla quarry.
GL 4 - White medium grained granite (qtz, pl, Kf, bi, ho, zir, ap). Cava near the aqueduct.
GL 5 - Porphyritic granitic dyke. Along the trail towards Ansolo quarry.
GL 6 - Basic dyke. Locality as GL 5.
GL 7 - Hydrothermally altered «Green granite of Mergozzo» (ab, chl, qtz, ser, tit, carb). Ansolo quarry.

M. Zuccaro

GL 8 - High-grade metamorphite: kinzigite (bi, qtz, sil, Kf, gt ± hyp). Near Quaggione.
GL 9 - Muscovite-tourmaline-bearing pegmatite. Loc. as GL 8.
GL 10 - Appinitic dyke: chilled margin. Loc. as GL 8.
GL 11 - Appinitic dyke: leucocratic portion. Loc. as GL 8.
GL 12 - Biotite-horneblende-bearing appinitic dyke. Loc. as GL 8.
GL 13 - Cumulitic appinitic dyke. Loc. as GL 8.
GL 14 - Cumulitic appinitic dyke. Loc. as GL 8.

Valsesia

GL 15 - Granitic neosome. Caneto quarry.
GL 16 - Quartz-bearing appinitic diorite. Along the Sesia river.
GL 17 - Quartz-bearing appinitic diorite. Loc. as GL 16.
GL 18 - Granodioritic appinite. 200 m south Isolella.
GL 19 - Dioritic appinite. Along the road Isolella-Foresto.
GL 20 - Granodioritic appinite. 700 m north Isolella, towards Varallo.
GL 21 - Granodioritic appinite. Cross-road Val Verde-Riomaggiore.

Alzo-Roccapietra

GL 22 - Tourmaline-bearing micrograniric dyke. Roccapietra quarry.
GL 23 - Horneblende-bearing granodiorite (pl, Kf, bi, ho, qtz). Loc. as GL 22.
GL 24 - Pink heterogranular biotitic granite. Pella, along the Orta Lake shore.
BB 8 - Horneblende-bearing granodiorite. Loc. as GL 22.
BB 9 - White medium-grained biotitic granite with scarce horneblende. Loc. as GL 22.

Baveno-Mottarone

BB 1 - Heterogranular white granite (Kf, qtz, pl, bi, ms, all, zir, fl, fa). Madonna della Scarpia Sanctuary.

BB 2 - Transitional granite. Loc. as BB 1.
BB 3 - Pink medium-grained granite. M. Mottarone q. 1200 m. (Giacomini quarry).
BB 4 - White granite. Cascine Pironi inactive quarry, near Gravellona.
BB 6 - White coarse-granite. Road tunnel near Omegna.

Quarna

BB 5 - Granite (pl, qtz, bi, scarce ho). Quarna di Sotto.
BB 11 - Appinitic quartz-diorite. Pathway between Quarna di Sopra and Fontegno oratory.

Brissago

BB 13 - Appinitic granodiorite. Sacromonte di Brissago.

Pedemonte

BB 14 - Gabbrodiorite. Cascina Lucchini.

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