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Permian and Triassic Rb-Sr dating in the Permian rhyodacitic ignimbrites of Trentino (Southern Alps)

CLAUDIO D'AMICO
Dipartimento di Scienze Mineralogiche, Università di Bologna, Piazza di Porta S. Donato, 1, 40126 Bologna, Italy

ALDO DEL MORO
Istituto di Geocronologia e Geochimica Isotopica, CNR, Via C. Maffi, 36, 56100 Pisa, Italy

ABSTRACT. — Three Rb-Sr isochrons and several Rb-Sr model ages in a number of Permian rhyodacitic ignimbrites in Trentino, Southern Alps, provide biotite ages of about 272 Ma. This is assumed to be the age of the volcanic event. A rejuvenation event is suggested by some scattered feldspar data, by three whole-rock errorchrons (252-229 Ma), and by some biotite ages measured in the rhyodacites nearest the Triassic pluton of Predazzo (2-15 km from the outcropping contact), the zone from which the lower (229 Ma) whole-rock age also originates.

The rejuvenation age is therefore assumed to be linked to the hydrothermal activity of the Triassic magmatism.

Key words: Rb-Sr dating, Permian volcanism, Triassic hydrothermalism, Trentino Permian volcanics.

RIASSUNTO. — Lo studio radiometrico effettuato col metodo Rb-Sr su due formazioni di ignimbriti riodacitiche del Permiano inferiore del Trentino, l'una appartenente al Gruppo inferiore e l'altra al Gruppo superiore, conferma la situazione già rivelata in precedenza da analogo studio su ignimbriti riolitiche della stessa regione.

Tre isocrone Rb-Sr su biotiti e varie età-modello sempre su biotiti danno valori attorno a 272 Ma; questa viene assunta come età del vulcanismo. Tre errorcrone, ottenute su campioni di roccia totale, danno valori tra 252 e 229 Ma, la più bassa delle quali vale per biotiti più vicine al plutone triassico di Predazzo. L'evento di ringiovanimento rivelato da questi ultimi dati è in linea con dati su feldspati e con singole, disperse età-modello di biotiti (237-255 Ma) nella zona vicina al plutone di Predazzo (2-15 km dal contatto affiorante).

Sull'insieme dei dati, il ringiovanimento viene riferito all'idroterminalismo legato al magmatismo triassico delle Alpi Meridionali.

La pratica sovrapposizione di età tra le riodaciti inferiori e quelle superiori è indicazione di una durata breve del pur potente vulcanismo permiano del Trentino.

Parole chiave: Datazioni Rb-Sr, Vulcanismo Permiano, Idrotermalismo Triassico, Vulcaniti Permiane Trentino.

1. Introduction

1.1. *Foreword*

In a previuos paper on the lower Permian rhyolitic ignimbrites of Trentino, D'AMICO et al. (1980) obtained the following results:

a) Rb-Sr biotite data indicating Permian ages around 270 Ma (biotite model-ages between 263 and 274 Ma); a biotite isochron of 267 ± 2 Ma, and a Sr initial ratio of 0.7171 ± 0.0052 (1 σ).
b) Rb-Sr feldspar data suggesting a Triassic age (isochron of 226 ± 8 Ma).
c) Rb-Sr whole-rock data giving an intermediate age (isochron of 239 ± 8 Ma, with a Sr initial ratio of 0.7103 ± 0.0006).

The 270 Ma biotite values were interpreted as the true age of the volcanism, in full accordance with the stratigraphic position of the rocks; the 226 Ma feldspar data as the age of the Triassic rejuvenation event, and the 239 Ma isochron as a mixed age.

No data with other systems (K-Ar, U-Pb, etc.) are available.

This paper aims at extending research to two other Permian volcanic formations of the same region, to obtain more information on the Permian and Triassic ages. For this reason, a zone near the Triassic pluton of Predazzo was also sampled.

1.2. *Permian volcanic stratigraphy*

The lower Permian volcanites in the Trentino-Alto Adige (Süd-Tyrol) form a thick (max 2000 m) extensive volcanic sequence, covering an area of about 4000 Km^2, including the areas with outcrops of the overlying Mesozoic series. Their distribution and thickness vary widely, so that the stratigraphy differs from place to place. The volcanic sequences overlie a low-grade metamorphic basement (phyllites, albite-epidote paragneisses, microcline porphyroids, chlorite-albite schists, etc.) that was eroded but not fully peneplained before the volcanic period.

In the southern part dealt with here, the general stratigraphy may be given as in Fig. 1 (cf. D'AMICO, 1986). This stratigraphy is not, however, valid for the whole system (e.g. MITTEMPERGHER, 1958; BRONDI et al., 1970; BARGOSSI et al., 1982).

Two groups can be distinguished, each with a number of formations. The *lower group* begins with discontinuous *basal clastic horizons*, which contain volcanic material increasing upwards, covered by small *K-andesitic to basaltic - andesitic volcanic edifices* (BARGOSSI et al., 1981, 1983) and, in only one area, *trachyrhyolitic domes,* (D'AMICO & SEGATTA, 1979). A *rhyodacitic formation*, with prevalent ignimbrites and local tuffaceous and clastic interlayers (BARGOSSI, 1982; SEGATTA, 1979), is stratigraphycally more widespread. It is overlain by *domes of dacitic-rhyodacitic* composition bearing some low-SiO_2 rhyolites (D'AMICO & VENTURELLI, 1968), covered by a thicker andesite *formation* (up to 400 m): qz-andesites up to dacites, K-andesites, true andesites (CALANCHI, 1981; BARGOSSI & CALANCHI, 1985).

The *upper group* consists mainly of two large ignimbritic formations: the *lower rhyodacitic* and the *upper rhyolitic*, with sudden changes between them. In the upper part of the rhyodacitic formation, there is an irregular development of *dacitic-rhyodacitic and rhyolitic lava domes*, with minor flows and volcanoclastics.

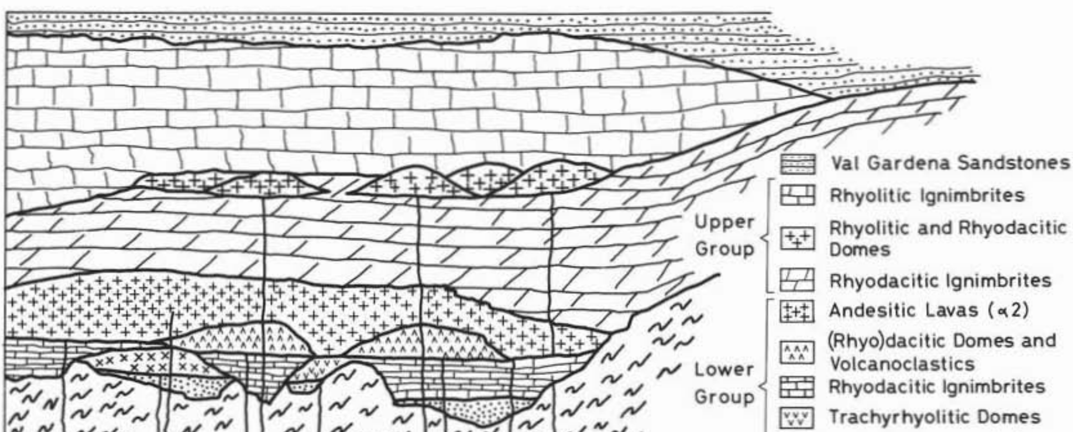

Fig. 1. — Section about W-E accross the Permian volcanic system of Trentino (Southern Alps). Maximum thickness, about 2000 m.

1.3 *Sampling*

The Permian volcanites are almost always strongly affected by hydrothermal alteration and are thus not entirely suitable for detailed geochemical studies of their primary magmatic composition. These alterations are described in all the above-mentioned papers and can also be seen from Table 2, particularly in the CaO, Na_2O, K_2O, Sr and $H_2O + CO_2$ contents.

However, the ignimbrites, particularly those of the upper group, provide a fair number of samples with unaltered primary mineral phase, unlike the lavas, which only sporadically contain relicts of magmatic minerals.

These rhyodacitic and rhyolitic ignimbrites are also the thickest and most widespread formations (Fig. 1), and are thus the most suitable for large-scale checking. Moreover, they are geochemically the most useful for Rb/Sr systematics.

For the above reasons ignimbrite rocks and, when possibile, those with unaltered biotite, were selected for this research. Only one rhyolitic dyke of the lower group (TN38) with unaltered biotite was added, owing to the scarcity of biotite-bearing rocks preserved in the entire lower group.

Fig. 2 shows the sampling area, Table 1 the stratigraphic position of the samples, with some petrographic data and references. Table 2 provides the essential composition data. On the whole, the upper and lower rhyodacites are very similar in composition and petrography. Both are quite different from the rhyolitic ignimbrites (cf. D'Amico et al., 1980: $SiO_2 \geq 72\%$; $MgO \ll 1\%$; sanidine phenocrysts = 5% or more). The rhyolitic dyke of Table 2 is also different, with a distinctly low K_2O content.

Fig. 2. — Geographic map of Permian volcanic outcrops in Trentino-Alto Adige (Southern Alps). Sample localities: A = Buss, Serso, Montagnana, Castelliere, Marezzi; B = Gocciadoro; C = Val Cembra; D = Val Fersina; E = Val Travignolo; F = Val Calamento; G = Val Isarco.

TABLE 1
Essential information on analyzed samples

	UPPER GROUP (continues)	
DAV 24 DAV 25	Val Fersina area (Freddo, 1980) D in Fig. 2	Rhyodacitic ignimbrites. 400 m thick. Similar to the above.
DAV 31 DAV 32 DAV 33 DAV 34 DAV 37 DAV 38 DAV 39 DAV 40 DAV 41 DAV 41 bis DAV 42 DAV 43 DAV 44	Val Travignolo area (Ghezzo, 1967) E in Fig. 2 Fig. 3	Rhyodacitic ignimbrites in seven cooling units with two tuffaceous major levels. Thickness about 700 m. Volcanoclastic texture with euhedral to rounded, embayed splintery phenocrysts and phenoclasts. P.I. = 45-77: Qz, Pl, Bi (rare Kf and Hbl). Microgranular to felsitic and spherulitic groundmass, with residual welding textures. Variable autometasomatism, often with, more rarely without oxidation. Biotite often unaltered.
VA 48 VA 52	Val Calamento area (Domeniconi, 1985; Scoccimi, 1985) F in Fig. 2	Rhyodacitic ignimbrites, similar to the above; some more Kf as phenocryst.
VG 00 VG 008	Val Isarco (cfr. Mittempergher, 1958) G in Fig. 2	Rhyodacitic ignimbrites, similar to the above.
	LOWER GROUP	
DAV 16 DAV 17 DAV 18 DAV 19 DAV 20 DAV 21 DAV 23	Pinè - Pergine area (Bargossi, 1982) A in Fig. 2	Rhyodacitic ignimbrites: maximum thickness about 350 m. P.I. = 37-55. Volcanoclastic texture: Qz, Pl, Bi (rare Kf) as phenocrysts or phenoclasts, often rounded and embayed (Qz); microgranular--felsitic groundmass. Autometasomatism very widespread, rarely giving oxidation. Biotite always altered.
DAV 30 TN 39	Gocciadoro East of Trento (Bargossi et al. 1983) B in Fig. 2	Rhyodacitic ignimbrites similar to DAV 16-23, save for frequently unaltered biotite.
TN 38		Rhyolitic dyke intruded in ignimbrites. Fluidal texture, microlitic groundmass. P.I. = 12: Qz, Pl, Bi as phenocrysts. Biotite unaltered.
	UPPER GROUP	
DAV 11 DAV 12 DAV 13 DAV 14	Val Cembra area (Urani, 1980, Valli, 1980) C in Fig. 2	Rhyodacitic ignimbrites. 100-200 m thick. P.I. = 43-49. Volcanoclastic texture with phenocrysts and phenoclasts, idiomorphic to rounded, embayed, splintery. Qz, Pl, Bi (rare Kf, Hbl). Micro-granular-felsitic groundmass. Widespread autometasomatism with general oxidation. Biotite only partly unaltered.

The Val Travignolo area (Fig. 3) was chosen because of the thickness and extent of the formation, and because it is near the Triassic Predazzo intrusion, permitting samples to be collected relatively near the plutonic contact,

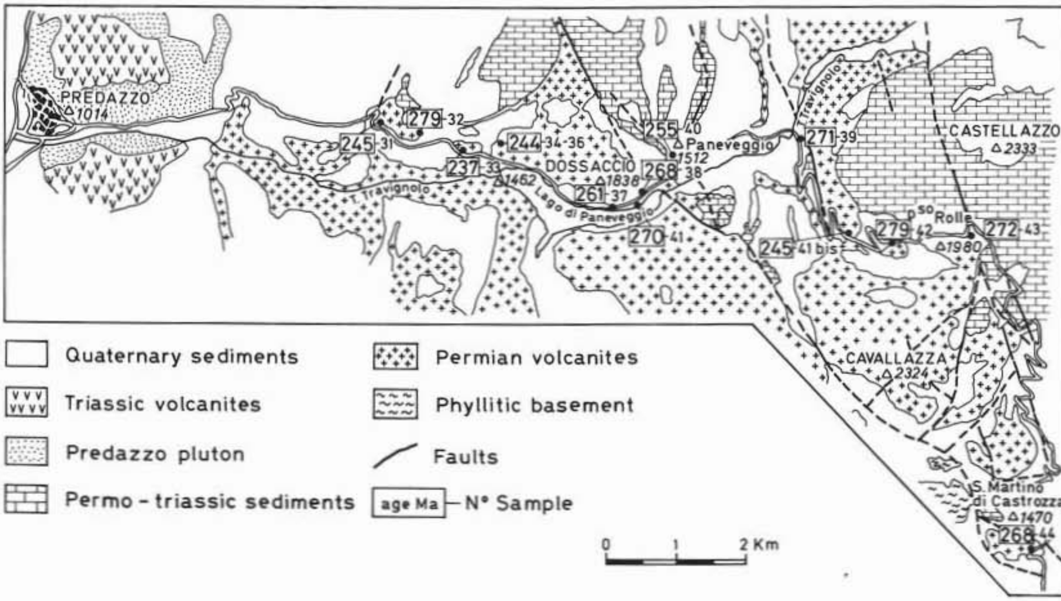

Fig. 3. — Geological map of Val Travignolo area with Rb/Sr biotite model ages.

so that the chemical and thermal influence of the intrusion on the isotopic ratios could be checked.

2. **Results**

2.1. *Analytical procedures*

The analytical procedures used in this study have been described in D'AMICO et al. (1980). Generally, the isotopic analyses were done on a Varian Mat TH5 mass spectrometer. Repeated analyses of E&A $SrCO_3$ standard gave an average $^{87}Sr/^{86}Sr$ value of 0.70812 $\pm$ 8 (1 σ); the Sr isotopic ratio of samples was not adjusted to the conventional $^{87}Sr/^{86}Sr$ value of 0.7080 of E&A.

The Sr isotopic composition of the plagioclases was determined on a VG Isomass 54E mass spectrometer. The average value of 14 runs on E&A $SrCO_3$ standard during this study was 0.708058 $\pm$ 12 (1 σ).

The biotite model ages and isochron ages were calculated with $^{87}Rb = 1.42.10^{-11}y^{-1}$ and with an error of 1.5% for the $^{87}Rb/^{86}Sr$ ratio and one standard deviation of the relative analysis for the $^{87}Sr/^{86}Sr$ ratio.

Samples weighting 5-10 Kg were used for analysis.

2.2. *Choice of the initial $^{87}Sr/^{86}Sr$ ratio for biotite model ages*

The partial opening of the Rb-Sr whole-rock system, which accompanied the hydrothermal process, means that the whole-rock - biotite isochron is not reliable.

All the Rb-Sr biotite model ages were calculated using an initial $^{87}Sr/^{86}Sr$ ratio of 0.7100, in accordance with the feldspar isochron from the cogenetic rhyolitic ignimbrites (D'AMICO et al., 1980).

The initial Sr isotopic ratio of the biotite isochron (the value of which falls in the interval provided from the feldspar isochron within an error limit of 2 σ) was not used, because it was obtained on the high Rb/Sr ratio system.

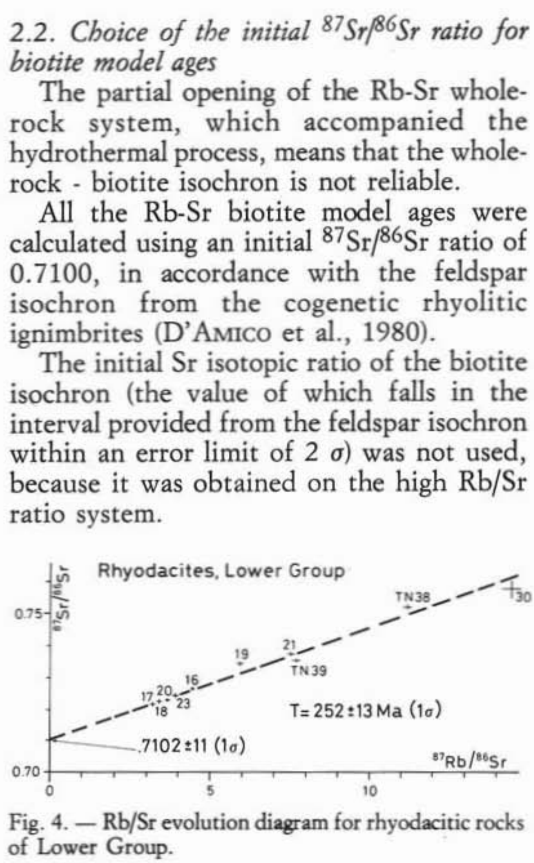

Fig. 4. — Rb/Sr evolution diagram for rhyodacitic rocks of Lower Group.

TABLE 2
Composition of ignimbritic rhyodacites

MAJOR ELEMENTS AND TRACE ELEMENTS DATA							
	DYKE	LOWER IGNIMBRITES			UPPER IGNIMBRITES		
	%	(18)	(3)	(5)	(11)	(8)(6)	(18)
SiO_2	75.58	67.20	66.25	66.18	67.33	66.85	65.57
TiO_2	0.16	0.53	0.54	0.54	0.49	0.53	0.58
Al_2O_3	12.34	14.68	14.78	15.36	15.27	15.31	15.46
Fe_2O_3t	2.01	4.50	4.56	4.45	4.01	4.30	4.23
MnO	0.03	0.11	0.08	0.09	0.10	0.06	0.05
MgO	0.42	1.35	1.93	1.46	1.34	1.27	1.45
CaO	0.90	1.54	0.73	2.48	1.23	1.59	2.43
Na_2O	3.21	2.05	2.51	2.56	3.39	3.57	2.99
K_2O	2.79	4.63	5.44	3.36	4.06	4.59	3.97
P_2O_5	0.08	0.13	0.12	0.12	0.13	0.17	0.13
H_2O_+ CO_2	2.48	3.31	3.10	3.39	2.25	2.01	3.36
ppm							
Rb	119	219	230	164	200	208	--
Ba	320	492	466	505	626	521	--
Sr	64	117	61	200	168	115	--
Y	30	36	38	32	30	29	--
Nb	15	18	16	14	14	16	--
Zr	134	187	187	193	209	197	--

Low-K rhyolitic dyke, TN 38, Bargossi et al., 1983
(18) Average in Bargossi, 1982
(3) Average in Bargossi et al., 1983
(5) and (11) Averages in Domeniconi, 1985; Scoccini, 1985
(8) (6) Averages of major elements and trace elements (6); not-weighted averages in Bargossi, 1982
(18) Average in Ghezzo, 1967

MODES							
	DYKE	LOWER IGNIMBRITES				UPPER IGNIMBRITES	
	%	(18)	(36)	(2)	(9)	(13)	(36)
Qz	1.2	12.2	12.85	15.95	11.6	9.5	10.5
Kf	--	--	pr.	pr.	3.5	2.7	--
Pl	9.0	24.0	25.9	27.3	19.4	19.8	27.5
Bi, others	2.4	10.5	7.5	8.45	7.7	7.1	9.1
Ground mass	87.4	53.4	53.75	48.3	57.8	60.9	52.9

Low-K rhyolitic dyke, TN 38, Bargossi et al., 1983
(18) Average in Bargossi, 1982
(36) Not-weighted average composition of samples reported in Bargossi, 1982
(2) Average in Bargossi et al., 1983
(9) and (13) Averages in Domeniconi, 1985; Scoccini, 1985
(36) Not-weighted average composition of samples reported in Bargossi, 1982
Bi, others = Biotite and its pseudomorphic assemblage; occasional and rare pseudomorphic assemblages on hornblendes and pyroxenes; rare accessories.

In any case, using either 0.7100 or 0.7074 as the initial Sr isotopic ratio (see biotite isochron, Fig. 9), the lowest Rb/Sr ratio biotite (DAV 37) gave model ages of 261 and 273 Ma respectively; in the other cases, the age difference was even smaller, so that the choice between the two possible values for initial Sr composition was not determinant.

2.3. *Lower group rhyodacitic ignimbrites*

The ten samples of Table 3 define a whole-rock errorchron of 252 ± 13 Ma with a $(^{87}Sr/^{86}Sr)_i$ ratio of 0.7102 (Fig. 4); the «age» is less than expected from the stratigraphy.

The determinations on biotite are limited to only two samples from Gocciadoro (Trento), because all the rocks of the formation in the other localities are hydrothermally altered and practically lacking in biotite, which is replaced by chlorite or white mica + Fe-Ti-oxides. These determinations provide model ages of 273-275 Ma (Table 5), in agreement with the stratigraphic position. A 273 Ma age was also obtained from the biotite of the subpotassic rhyolitic dyke (Table 5) which intruded the rhyodacitic ignimbrites. The same age (272 ± 1 Ma) can be obtained from the position of the data points of the biotites of the three Gocciadoro samples in Fig. 10. The feldspar concentrates (Table 4) do not provide significant indications on either age or isotopic data.

2.4. *Upper group rhyodacitic ignimbrites*

2.4.1. Southern zone

Eight samples were analysed (four from Val Cembra, two from Val Fersina and two from Val Calamento), giving a whole-rock errorchron of 250 ± 12 Ma with a $(^{87}Sr/^{86}Sr)_i$ ratio of 0.7088 (Fig. 5). The biotites of four samples (Table 5) give a model-age of 266-270 Ma for Val Cembra and 273-274 Ma for Val Calamento.

An isochron of the four biotites (Fig. 6) gave a stright-line valid for 276 ± 2 Ma.

2.4.2. Val Travignolo area

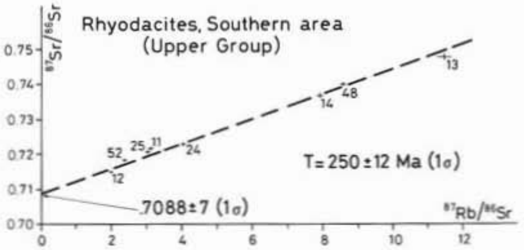

Fig. 5. — Rb/Sr evolution diagram for rhyodacitic rocks of Trentino area (Southern part).

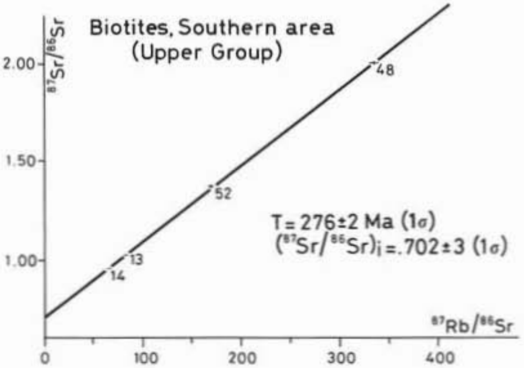

Fig. 6. — Rb/Sr biotite isochron for rhyodacites in Val Calamento and Val Cembra areas.

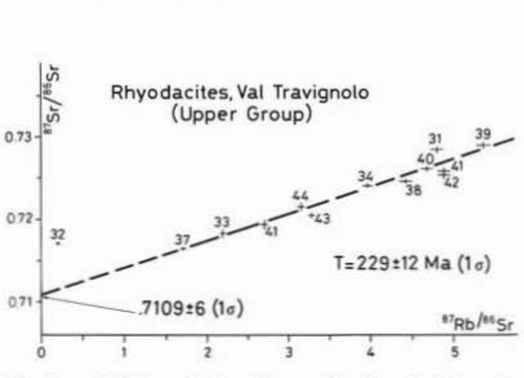

Fig. 7. — Rb/Sr evolution diagram for rhyodacitic rocks of Val Travignolo.

Thirteen samples were collected on a strip moving away from the Predazzo pluton (Fig. 3). A 229 Ma errorchron (Fig. 7) was constructed from 12 samples (excluding DAV 32, which has decidedly anomalous

TABLE 3

Composition of ignimbric rhyodacites (continued)

Sample	Locality	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
		LOWER GROUP			
DAV 16	Al Buss	207	135	4.44	0.7265± 4
DAV 17	Castelliere	148	133	3.21	0.7215± 4
DAV 18	"	235	201*	3.39	0.7226± 4
DAV 19	Montagnaga	289	141	5.93	0.7344± 4
DAV 20	"	188	148	3.67	0.7228± 3
DAV 21	Marezzi	255	98	7.52	0.7374± 4
DAV 23	Serso	172	127	3.93	0.7242± 5
DAV 30	Gocciadoro	298	60	14.43	0.7584± 5
TN 38	"	172	45	11.18	0.7526± 3
TN 39	"	237	89	7.68	0.7355± 3
		UPPER GROUP			
DAV 11	Val Cembra	225	208	3.13	0.7217± 5
DAV 12	"	178	261	1.98	0.7149± 2
DAV 13	"	282	71	11.50	0.7477±10
DAV 14	"	243	89	7.94	0.7367± 2
DAV 24	Val Fersina	195	139	4.05	0.7231± 6
DAV 25	"	195	186	3.04	0.7207± 4
DAV 31	Val Travignolo	206	125	4.79	0.7284± 4
DAV 32	"	127	1614	0.23	0.7171± 2
DAV 33	"	134	177	2.19	0.7183± 5
DAV 34	"	211	154	3.96	0.7240± 3
DAV 37	"	127	215	1.71	0.7165± 2
DAV 38	"	143	94	4.41	0.7246± 2
DAV 39	"	171	93	5.36	0.7289± 4
DAV 40	"	196	122	4.67	0.7261± 2
DAV 41	"	131	141	2.70	0.7194± 5
DAV 41bis	"	176	104	4.88	0.7258± 4
DAV 42	"	130	77	4.88	0.7254± 7
DAV 43	"	113	100	3.27	0.7205± 4
DAV 44	S. Martino di Castrozza	145	134	3.14	0.7216± 2
VA 48	Val Calamento	233	79	8.60	0.7398± 4
VA 52	"	128	153	2.41	0.7182± 3

TABLE 4

Rb/Sr data on rhyodacitic whole-rocks

Sample	Mineral	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
		LOWER GROUP			
DAV 30	Sanidine	254	68	10.87	0.7442± 1
TN 38	"	156	43	10.57	0.7502± 3
TN 39	"	133	155	2.49	0.7172± 2
		UPPER GROUP			
DAV 37	Plagioclase	31.0	227	0.40	0.71246± 6
DAV 38	"	33.2	164	0.58	0.71312± 5
DAV 39	"	18.6	200	0.27	0.71181± 7
DAV 41	"	29.3	249	0.34	0.71207±11
DAV 41bis	"	26.8	217	0.36	0.71211± 6
DAV 42	"	49.4	164	0.87	0.71315± 3
DAV 43	"	20.7	208	0.29	0.71031± 1
DAV 44	"	55.6	211	0.76	0.71329± 8
VA 48	Sanidine	211	133	4.62	0.72405± 2
VA 52	"	120	217	1.60	0.71530± 6

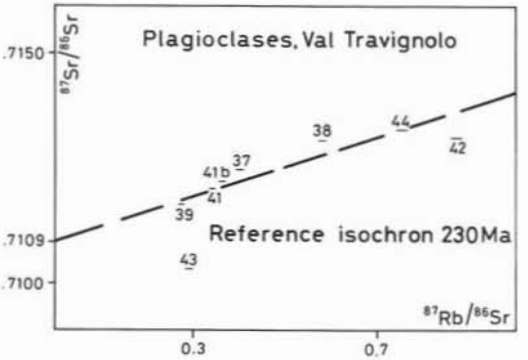

Fig. 8. — Rb/Sr evolution diagram for plagioclase concentrates of Val Travignolo. T = 229 Ma reference line correspond to whole-rock errorchron (Fig. 7).

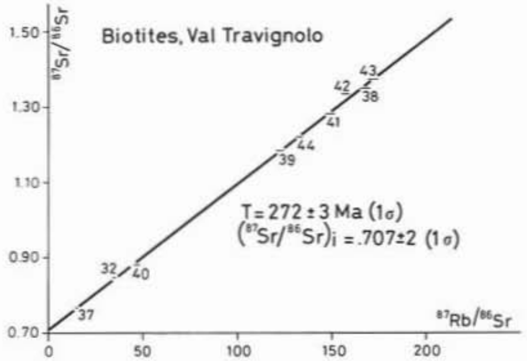

Fig. 9. — Rb/Sr biotite isochron for rhyodacites furthest from the Predazzo pluton in Val Travignolo.

geochemical and isotopic features - see Table 3) and shows a much lower value than the stratigraphic age.

The plagioclase data-points show a very wide scatter in Fig. 8.

The model-ages obtained from biotite separates of the thirteen samples (Table 5) vary between 237 to 279 Ma with distribution clearly linked, though with fluctuations, to the distance from the Predazzo plutonic contact (Fig. 3).

An isochron reconstructed from the nine biotites furthest from the contact gave an age of 272 ± 3 Ma with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7074 (Fig. 9).

2.4.3. Val Isarco

The two Val Isarco rhyodacites, at the extreme north of the Permian volcanic system, belong to the lower part of the upper rhyodacitic ignimbrites. They are presented here only for comparison.

Two biotite samples fit well in a reference biotite isochron of all the previous rhyodacites, its age being 272 Ma and

TABLE 5

Rb/Sr data on feldspars

Sample	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	AGE Ma
		LOWER GROUP			
DAV 30	423	11.1	115.13	1.1597±15	275±4
TN 38	465	9.2	154.95	1.3117±17	273±4
TN 39	427	7.4	179.20	1.4061±10	273±4
		UPPER GROUP			
DAV 13	434	15.7	82.53	1.0275±27	270±5
DAV 14	427	19.2	65.76	0.9586±45	266±6
DAV 31	424	11.3	113.09	1.1041±23	245±4
DAV 32	354	29.8	34.83	0.8485±19	279±6
DAV 33	313	21.5	42.67	0.8538± 3	237±4
DAV 34	342	31.6	31.67	0.8200±18	244±5
DAV 37	154	29.9	14.97	0.7655± 8	261±6
DAV 38	432	7.9	167.46	1.3480±24	268±4
DAV 39	417	10.3	122.67	1.1829±15	271±4
DAV 40	368	23.1	46.87	0.8802± 9	255±4
DAV 41	426	8.7	149.04	1.2817±26	270±4
DAV 41bis	343	11.7	87.29	1.0129±10	245±4
DAV 42	388	7.6	156.81	1.3332±20	279±4
DAV 43	456	8.2	171.58	1.3734±25	272±4
DAV 44	374	8.5	133.10	1.2177±12	268±4
VA 48	615	6.0	333.20	2.0058±61	273±4
VA 52	453	8.2	170.23	1.3746±22	274±4
VG 005	411	12.6	98.14	1.0987±13	278±4
VG 008	447	7.7	178.80	1.4021±18	272±4

Model ages have been calculated assuming $(^{87}Sr/^{86}Sr)_i$ = 0.710

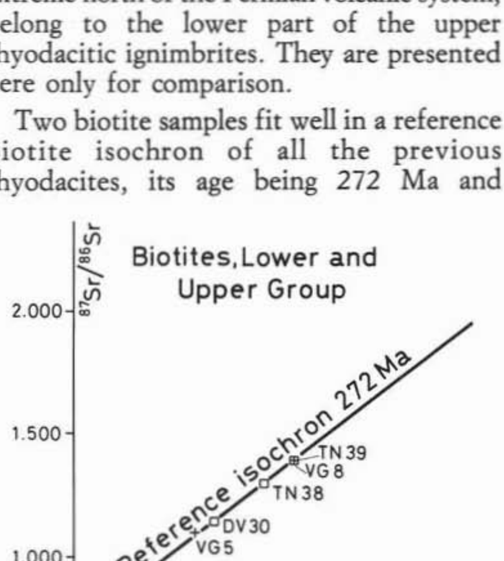

Fig. 10. — Rb/Sr evolution diagram for biotites from Val Isarco (crosses) and Gocciadoro locality (squares).

TABLE 6

Rb/Sr data on calcites (Val Travignolo) and barites (Val Calamento)

Sample	Rb ppm	Sr ppm	$^{87}Sr/^{86}Sr$	$(^{87}Sr/^{86}Sr)_{230Ma}$
CALCITES:				
DAV 35	1.0	30.1	0.7164±3	0.7162
DAV 36	0.1	36.7	0.7121±2	0.7121
BARITES:				
VA 158/159	n.d.	n.d.	0.7147±2	0.7147
VA 195	n.d.	n.d.	0.7172±2	0.7172
VA 29	n.d.	n.d.	0.7147±3	0.7147

Obtained from a partial dissolution of the sample

n.d. = not determined

$(^{87}Sr/^{86}Sr)_i$ ratio = 0.7072 (Fig. 10).

2.4.4. Calcite and barite data

Two samples of calcite in veins in the upper rhyodacites of Val Travignolo, and three of barite in veins in the upper rhyodacites of Val Calamento were analyzed. The data (Table 6) indicate a Sr isotopic ratio between 0.7121 and 0.7172. The Sr isotopic ratios are significantly higher than the initial Sr isotopic ratios shown in Figs. 4 to 10.

3. **Discussion and interpretation**

3.1. *Undisturbed ages and rejuvenated ages*

The data in Section 2 give clear evidence of two major events: one, from the biotites, aroud 270 Ma, and a second, from whole-rock data, feldspars and a few biotites, showing a subsequent disturbance of the Sr isotopic system, producing rejuvenation «ages» between approximatively 250 and 230 Ma. The 270 Ma age obtained from the biotite data — excluding a few Val Travignolo samples — is in agreement with the lower Permian stratigraphic position and with the assumption that the biotite phenocrysts exactly fix the emplacement age in a rapidly cooling volcanic system.

The younger, scattered whole-rock and feldspar data seem to be linked directly to the hydrothermal alteration of the ignimbrites (Section 1.3 and papers mentioned therein) and to the related chemical isotopic disturbance.

The present situation is the same as that found in the upper rhyolitic ignimbrites (D'AMICO et al., 1980), which was interpreted as being due to Permian volcanism of about 270 Ma, followed by a Triassic hydrothermal rejuvenation of about 225 Ma.

As regards the whole-rock data, the present work shows a more marked rejuvenation (229 Ma) in the Val Travignolo area, near the Triassic magmatic bodies of Predazzo, than in other areas (250-252 Ma). These data reveal a close relation between rejuvenation age and Triassic magmatism, because the Val Travignolo whole-rock errorchron (Fig. 7) approximately coincides with the age of the Triassic magmatites (BORSI & FERRARA, 1967).

This relation is again evident for the biotite ages (Table 5) in the distribution map (Fig. 3), where the rejuvenated biotites lie near the pluton and the older biotites, with few exceptions, are far away.

The Val Travignolo area near the Predazzo pluton is the only zone where the collected data show a post-Permian thermal disturbance higher than the closing temperature of the Rb/Sr system in the biotites. This suggests a direct influence of the Triassic pluton on the Permian rocks, while elsewhere (Southern zone, Val Isarco, rhyolitic area in D'AMICO et al., 1980) the isotopic distrurbance was of lower temperature and only hydrothermal in nature.

3.2. *Sr isotopic data*

As discussed above, scattering of Sr isotopic data in the various groups of rocks and feldspars is due to hydrothermal alteration. For this reason, the $(^{87}Sr/^{86}Sr)_i$ ratio values no longer reflect the original Rb/Sr system, but are the result of an interaction between volcanites and hydrothermal fluids. Nor can the initial Sr isotopic ratios obtained with the biotites be utilized for genetic interpretation, because biotites are minerals with high Rb/Sr ratios.

Contrary to the result of the study on rhyolites (D'AMICO et al., 1980), no Sr isotopic equilibrium was achieved in the feldspars. This may be interpreted as a non-attainment of isotopic equilibrium during hydrothermalism, or as subsequent disturbance due to weathering (SCHLEICHER et al., 1983). On the other hand, it could be related to an irregular influence of the long

Triassic hydrothermalism assumed by BORSI & FERRARA (1967) in the Predazzo region.

An indirect method was used to evaluate the significance of the Sr isotopic ratios. Assuming that the calcite and barite veins were produced by the Triassic hydrothermal activity on the ignimbrites, their Sr isotopic ratio should be compatible with that of the hydrothermalized ignimbrites. Of the five samples analyzed (Table 6) only one appears to be compatible, whereas the others have higher Sr isotopic ratios than those calculated to be 230 Ma old.

Moreover, the rhyodacite DAV 32 (a tuffaceous level) has a higher Sr isotopic ratio than all the other rhyodacites (Fig. 7); calculated at 230 Ma (0.7164), its ratio is similar to the Sr isotopic ratio of calcite and barite (Table 6). This rhyodacitic tuff, anomalously rich in Sr (1614 ppm, Table 3), thus apppears impregnated with the same solutions which constituted the veins and, in particular, the nearby calcite DAV 35 ($^{87}Sr/^{86}Sr = 0.7162$).

The high Sr isotopic ratios of these hydrothermal deposits cannot be explained by a simple hydrothermal remobilization of the rhyodacites, but require the addition of a source richer in radiogenic ^{87}Sr than the ignimbrites.

In the geological context of the region, this source can be referred, only to the metamorphic basement (phyllites, albite phyllitic paragneisses, K-rich porphyroids) capable of enriching ^{87}Sr in the solutions. We therefore conclude that the basement was possibly affected, at least partly, by the Triassic hydrothermalism, which gave rise to small mineralizations (present also in the upper Permian sediments), that were reported before our isotopic study (DESSAU & PERNA, 1966; BAKOS et al., 1972).

3.3. *Open questions on Permian ages*

The results given in Section 2 do not entirely solve the problem of understanding the lower Permian age indicated by stratigraphy and biotite radiometric data.

The model ages of unrejuvenated single biotites vary between 273 and 275 Ma for the lower rhyodacites, and between 266 and 279 Ma for the upper rhyodacites, with a maximum analytical error of ± 6 Ma. The biotite isochrons give values of 272 ± 3 Ma (nine samples) and 276 ± 2 Ma (four samples) for the upper rhyodacites of the two areas considered (Val Travignolo and southern zone), and again a value of 272 ± 2 Ma for the overall population of the thirteen samples.

An indipendent isochron using the three biotites of the lower group is not reliable, but they are very well placed on the same 272 ± 2 Ma reference isochron. Lastly, the Val Isarco biotites lie on the same isochron. There is therefore no definite answer as regards the exact age of the lower and upper rhyodacitic ignimbrites respectively, nor the age difference between the two.

However, it is most probable that there is a small difference in age between the two formations, despite the interposing of 400 - 600 meters of dacites + qz - andesites + andesites + K-andesites.

Apparently there is a greater age difference between the upper ignimbrites and the rhyolitic ignimbrites immediately above them, with the 267 Ma biotite isochron (D'AMICO et al., 1980), although the model ages of these biotites overlap with those reported in this paper.

The latter problem is worth further investigation. However, with the information available at present, the Permian volcanism in this region of the Southern Alps can definitely be assumed to have developed during a rather short period around 270 Ma age.

4. **Conclusions**

In conclusion, the following points can be considered as proved or suggested.

— On the basis of the biotite data, the Permian stratigraphic age can be defined at around 272 Ma for both lower and upper rhyodacitic ignimbrites. The period of Permian volcanism was therefore a short one, considering the stratigraphic series of Fig. 1. Only the upper rhyolitic ignimbrites may appear younger (267 Ma), but this difference must be verified.

— The isotopic system was disturbed (whole-rock, feldspars, biotite in part) by a hydrothermal event around 225-230 Ma. The rejuvenation is interpreted as being directly due to the Predazzo ladinian intrusions; in fact, only near the pluton are the biotites of the Permian volcanites disturbed in their Rb/Sr systematics, and the whole-rock system is completely rejuvenated.

—The Triassic hydrothermal circulation probably affected the metamorphic basement, which enriched the solutions with radiogenic ^{87}Sr; this can be deduced from the high $^{87}Sr/^{86}Sr$ ratio of barite and calcite in veins in the ignimbrites. The Triassic hydrothermalism also led to mineral deposition, in accordance with the hypothesis of a Triassic metallogenesis in the region, forwarded by previous authors.

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