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Sr isotope evidence for short magma residence time for the 20th century activity at Stromboli volcano, Italy

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Abstract

Stromboli is the type locality of continuous and moderately explosive volcanic activity. Monitoring temporal variations in the composition of the material erupted allows constraints to be made on the magma chamber dynamics and volcanic hazard. Here we present an Sr isotope survey of scoriae and lavas erupted from Stromboli volcano during this century. The material erupted is transitional between shoshonite and High-K basalt, with relatively constant major and trace element composition. This implies no substantial physical separation of minerals during crystallization (ca. 50 vol% minerals in both lavas and scoriae) and hence a relatively homogeneous reservoir. $^{87}Sr/^{86}Sr$ values are constant from 1900 to ca. 1980, then, beginning prior to the major lava flow eruption of December 1985, there is a smooth decrease. The Sr isotope decrease records the arrival of a new feeding magma, and allows estimation of the magma residence time and the volume of the reservoir beneath Stromboli volcano. Our results, along with a critical assessment of magma flux estimates, are best reconciled with steady state conditions, and establish the existence of a relatively small, $\sim$0.3 to 0.04 km^3, reservoir with a magma residence time (τ) of ca. 19 years. Monitoring the temporal variation of isotopic ratios in active volcanoes appears a successful tool in forecasting some major volcanic eruptions.

Keywords: Stromboli; Strombolian-type eruptions; strontium; isotopes; magmas; residence time; magma chambers

1. Introduction

Understanding the magma chamber dynamics of active volcanoes has fundamental implications for models of magma differentiation, and provides the basis for volcanic hazard assessment [1–3]. In particular, monitoring the temporal variation of geochemical tracers in active volcanoes can be a robust tool to unravel the dynamics of magma chambers [4] and could represent a valuable aid for forecasting major volcanic eruptions [5]. Here we present an Sr isotope survey of scoriae and lavas erupted from the Stromboli volcano during this century. The time series analysis applied to conservative geochemical tracers, such as Sr isotopes, potentially allows assessment of magma residence time and, in combination with output and input magma fluxes (e.g., [6–9]), determi-

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nation of the dynamics of the entire volcanic system at Stromboli.

2. Volcanological background

Stromboli is a stratovolcano located in the Aeolian island arc, southern Italy [10], which rises ca. 2900 m above the Tyrrhenian sea floor (ca. 920 m a.s.l.) and has a volume of ~300 km^3. It is one of the most famous volcanoes in the world due to its 'continuous' and moderately explosive 'Strombolian' activity over at least the last 2000 years [11,12]. The subaerial part of the main cone was built up during the last 100 kyr [13] through six periods of activity (Paleostromboli I, II, III, Vancori, Neostromboli and Recent), all characterized by prevalent lava flows and minor explosive eruptions [10]. The most recent period consisted mainly of strombolian eruptions, whilst more violent and phreatomagmatic eruptions were scarce and mainly concentrated in the Paleostromboli I and III periods. The Strombolicchio neck, located about 1.7 km offshore from Stromboli and belonging to the same submarine cone, represents the oldest subaerial portion of the volcano, with an age of 200 kyr [13]. The age of the submarine structure of the volcano is unknown. The steepness of the volcanic flanks has favored several sector and flank collapses, such as those leading to the formation of the Sciara del Fuoco depression [14]. The rocks of Stromboli record a large range in composition, varying from calc-alkaline (Strombolicchio, Paleostromboli II) to potassic-alkaline (Neostromboli), through high-K calc-alkaline (Paleostromboli I, III, Recent Period) and shoshonitic (Vancori, Recent Period). The increase in potassium content is associated with a similar variation of incompatible elements and Sr isotope ratios (0.70519–0.70757) [15–18].

The present day activity forms three NE–SW aligned craters on a terrace inside the Sciara del Fuoco at 750 m a.s.l. The volcano has been in steady-state for the last 2000 years, with activity related to an open conduit system (e.g., [6,7,19]), and the magma commonly visible inside the vents. The present day activity is moderately explosive and persistently erupts bombs, black scoriae, lapilli and ash (ca. 4–5 events per hour). Eruptions of lavas, which occur periodically (ca. 15 in 100 years), generally flow down along the Sciara del Fuoco scar. The last lava flow was in December 1985 [16,20, 21]. More violent eruptions than typical, with ejecta erupted far from the craters, occur periodically, the last occasion being September 1996. During the more violent eruptions, highly vesiculated yellowish scoriae has been recently recorded together with the 'normal' ejecta [22].

Highly porphyritic (hereafter HP) lavas and black scoriae, the most common present day ejecta, have almost constant petrographic characteristics, with phenocrysts of olivine (4–8 vol%) and clinopyroxene (12–20 vol%), and microphenocrysts of plagioclase (20–25 vol%) [16,18,20,22,23]. The groundmass is generally glassy and makes up ca. 50 vol% of the rock. In contrast, the highly vesiculated yellowish scoriae have a low phenocryst content ($\leq$5 vol%) (hereafter Low Porphyritic, LP), with microphenocrysts of olivine, clinopyroxene and rare plagioclase. No direct record of these LP scoriae is available for eruptions prior to 1993 [22], although detailed stratigraphic analyses along the summit flanks of the volcano demonstrated that the LP scoriae are common throughout ejecta related to the more violent eruptions of the 'Strombolian activity' of the past 2000 years [12]. During the more violent eruptions, the LP scoriae make up a small amount ($\leq$10 vol%) of the juvenile material, the remainder being composed by the 'normal' ejecta (HP scoriae). Despite low abundance the LP scoriae are critical to understand the magma dynamics at Stromboli.

3. Chemical and Sr isotope data

Details of mineralogical, major and trace element compositions of recent and past Strombolian magmas have been discussed elsewhere [15–18]. Here we present a brief summary of geochemistry of lavas and scoriae erupted in this century. Their composition is generally basaltic, transitional between shoshonitic and high-K calc-alkaline (Fig. 1), and does not change substantially with time. This is illustrated in Table 1 where the mean and standard deviation of major and trace element composition of 48 HP lavas and scoriae are reported. The Sr content of lavas and scoriae, for example, does not change substantially with time (Fig. 2), averaging 726 ppm

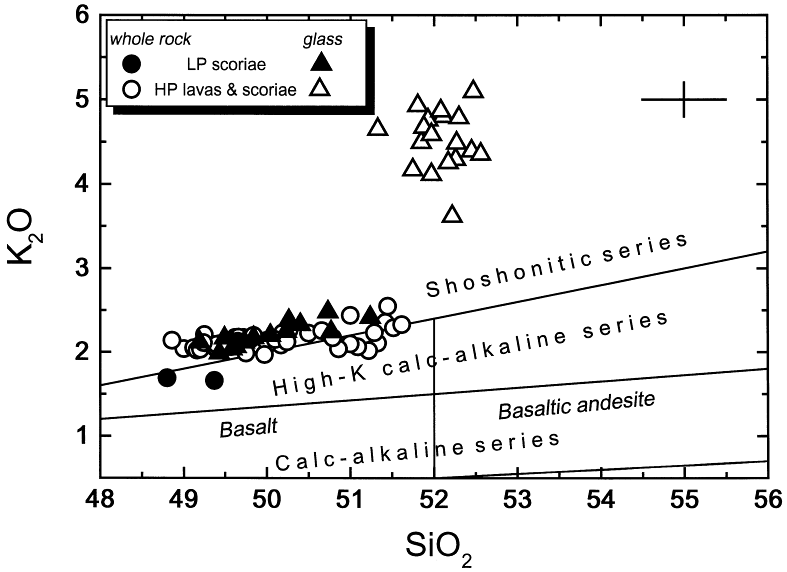

Fig. 1. K_2O vs. SiO_2 classification diagram [35] of the post 1900 lavas and scoriae erupted from Stromboli volcano. Samples are plotted on a water-free basis and include those in Table 2 along with other samples presented elsewhere [10,15,16,18,22,36]. Elemental contents of highly porphyritic (*HP*) and low porphyritic (*LP*) scoria glasses are authors' unpublished data. Error bars in the top-right corner represent typical analytical uncertainty (2σ).

$\pm 15\%$ (2σ, Table 1). These data provide compelling evidence of relatively constant [Sr] in the HP lavas and scoriae in the past 100 yr. The glass of HP lavas and scoriae also has a relatively constant composition, with higher SiO_2 and alkalis and lower MgO and CaO than the whole rock (Fig. 1, Table 1). Similar differences exist between the glasses of HP and LP scoriae, the latter having a composition identical to the whole rock of the HP lavas and scoriae (Fig. 1, Table 1).

The whole rock composition of the LP scoriae is slightly less evolved than the HP lavas and scoriae (although almost within analytical uncertainty, Fig. 1, Table 1). Owing to the few LP samples available, it is unclear whether the less evolved character is real or due to a sampling bias. These data do suggest, however, that the LP scoriae represent a fresh, phenocryst poor magma feeding the volcanic system of Stromboli that upon storage, crystallization and mixing, forms the magma erupted as HP lavas and scoriae. The relatively constant composition of the HP magma demonstrates negligible crystal removal during crystallization of the magma and efficient mixing (i.e., homogenization time < residence time) leading to the formation of a compositionally homogeneous reservoir. It is unclear exactly how the LP scoria magma is erupted, although its association solely with the more violent eruptions suggests that the injection of a greater volume of fresh magma than 'normal' causes a minor amount of this new magma to be erupted with little interaction with the pre-existing magma.

The $^{87}Sr/^{86}Sr$ of lavas and scoriae erupted during this century (Table 2), exhibits a constant value for ca. 80 yr (0.70626 ± 2, 2σ). Starting some time around 1980, however, there is a smooth decrease in $^{87}Sr/^{86}Sr$ that averages ca. -6×10^{-6} per year (Fig. 3). The Sr isotope composition of LP scoriae is lower than that of lavas and HP scoriae and, although based on just two samples, does not appear to have a time dependent covariation (Fig. 3). It is perhaps significant that the beginning of the Sr isotope decrease appears to predate the major lava flow eruption of December 1985.

4. Discussion

In general, the dynamics of a volcanic system can be divided into three parts: (i) input of fresh magma;

Table 1
Major (wt%) and trace (ppm) element averages of scoriae and lavas erupted from Stromboli volcano in this century

	Whole rock			Glass	
	LP scoria STR9/96d	HP scoria		LP scoria	HP scoria
		XX century	post-1975		
	$n = 1$	$n = 48 \pm 2\sigma$	$n = 38 \pm 2\sigma$	$n = 14 \pm 2\sigma$	$n = 22 \pm 2\sigma$
SiO_2	48.59	49.81 ± 1.61	49.50 ± 1.12	49.51 ± 1.24	51.76 ± 0.42
TiO_2	0.99	0.96 ± 0.11	0.98 ± 0.08	0.95 ± 0.19	1.60 ± 0.08
Al_2O_3	16.31	17.87 ± 0.98	17.99 ± 0.77	17.72 ± 0.65	15.59 ± 0.19
FeO_{tot}	8.99	8.25 ± 0.79	8.38 ± 0.65	7.84 ± 0.79	9.86 ± 0.44
MnO	0.18	0.16 ± 0.02	0.17 ± 0.02	0.16 ± 0.06	0.19 ± 0.03
MgO	7.84	6.06 ± 0.77	6.09 ± 0.63	6.01 ± 0.47	3.53 ± 0.13
CaO	12.21	11.05 ± 0.73	11.11 ± 0.55	10.83 ± 0.69	7.10 ± 0.34
Na_2O	2.05	2.51 ± 0.27	2.49 ± 0.24	2.69 ± 0.42	3.46 ± 0.22
K_2O	1.68	2.13 ± 0.23	2.11 ± 0.18	2.18 ± 0.29	4.44 ± 0.35
P_2O_5	0.37	0.44 ± 0.12	0.42 ± 0.11	0.62 ± 0.17	1.17 ± 0.09
LOI	0.43	0.44 ± 0.40	0.45 ± 0.43		
V	287	273 ± 26	268 ± 15		
Co	37	33 ± 6	33 ± 4		
Ni	46	37 ± 12	36 ± 7		
Rb	66	75 ± 18	76 ± 14		
Sr	748	726 ± 109	748 ± 54		
Y	27	26 ± 4	26 ± 5		
Zr	142	165 ± 22	164 ± 15		
Nb	19	20 ± 5	21 ± 4		
Ba	818	970 ± 128	990 ± 67		
La	42	49 ± 10	50 ± 8		

LP scoria: low porphyritic scoria; HP scoria: highly porphyritic scoria; 2σ: standard deviation; n: number of samples averaged for whole rocks and number of analyses averaged for glasses (1 sample for LP glass and 7 samples for HP glass). Data sources: averages and standard deviations (2σ) of HP scoria are based on data in [10,15,16,18,22] and this work (26 analyses); averages and standard deviations of LP and HP scoria glasses are based on unpublished data. Analytical techniques: major elements by XRF and AAS (Na, and Mg), after [31]. Trace elements by XRF. Precision (2σ) is $\leq$2% for major elements and $\leq$5% for minor and trace elements. Glass analyses were performed using a JEOL JXA 8600 electron microprobe equipped with WDS system, operating at 10 nA beam current and 15 kV accelerating voltage. Matrix effect correction was performed after [32], and estimated analytical precision (2σ) is $\leq$2%.

(ii) storage and differentiation in a reservoir; (iii) output as either exogenous (e.g., lava flows, pyroclastic materials) or endogenous (e.g., hypoabyssal dikes and sills) material. In the case study of Stromboli volcano, there are indirect estimates of a continuous input flux of fresh magma into the system based upon SO_2 [7] and heat [6,9] fluxes. There are also direct records of a continuous exogenous flux of magma [11], coupled with time integrated volumetric calculations [8] of the material partially filling the Sciara del Fuoco scar. The open conduit system provides evidence for steady state conditions in the magmatic reservoir underneath the volcano (e.g., [6,7,19]). There is no information, however, on critical parameters, such as the size of the reservoir and the average time magma spends in the chamber (residence time, τ).

The decrease in $^{87}Sr/^{86}Sr$ with time (Fig. 3) sets important constraints on the residence time and allows the dynamics of the volcano to be constrained over the last decades. Three extreme possibilities can potentially account for the Sr isotope decrease: (i) assimilation of unradiogenic country rock material, and (ii) gradual or (iii) instantaneous change of $^{87}Sr/^{86}Sr$ in the feeding magma. Crustal assimilation is incompatible with the high $^{87}Sr/^{86}Sr$ of the crustal basement of southern Italy [24,25] and also requires special pleading to preserve a substantially constant [Sr] in the erupted magma (Fig. 2). Independent arguments against crustal assimilation have

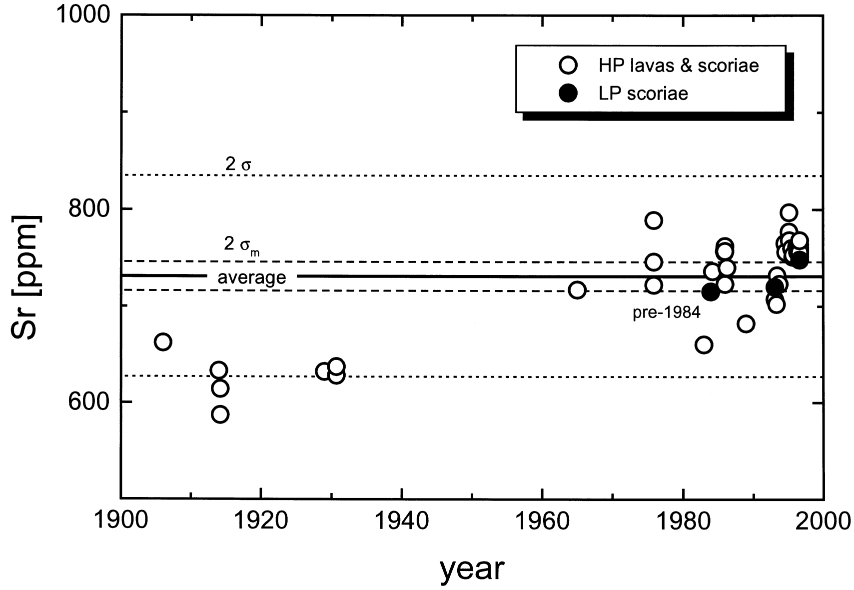

Fig. 2. Sr vs. time diagram of the post 1900 lavas and scoriae erupted from Stromboli volcano. Our samples are plotted along with other samples presented elsewhere [10,15,16,18,22,36]. Despite the high porphyritic index of lavas and scoriae (ca. 50 vol%), i.e. the possibility for plagioclase accumulation, the Sr content is relatively constant (726 ppm ±15%, 2σ), and exhibits no difference between lavas, HP and LP scoriae. The average content is also reported along with the standard error ($2\sigma_m$) of the mean and the standard deviation (2σ) of the sample population.

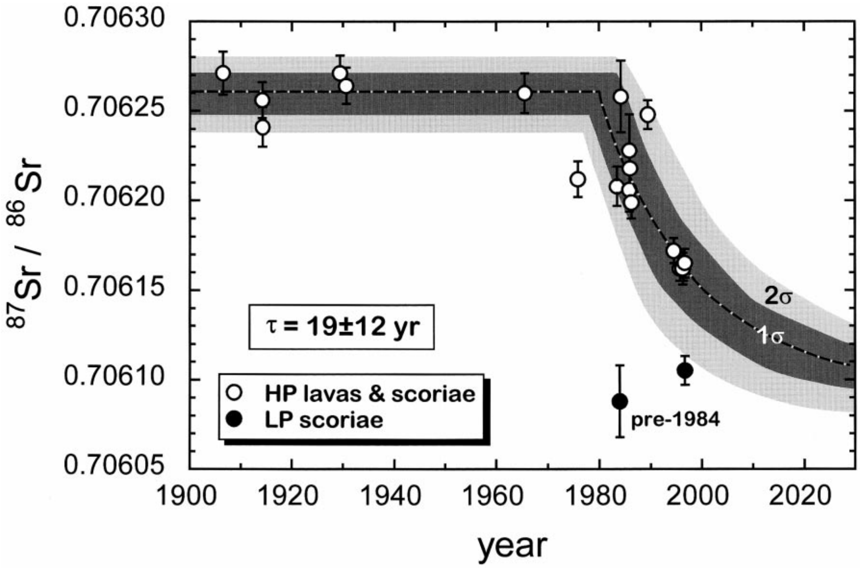

Fig. 3. $^{87}Sr/^{86}Sr$ vs. time diagram of the post 1900 lavas and scoriae erupted from Stromboli volcano. Error bars represent $\pm 2\sigma_m$ run precision. The magma residence time ($\tau = 19 \pm 6$ yr, 1σ) has been estimated using Eq. 2 and taking into account error propagation with the Monte Carlo method allowing a normal distribution of input variable uncertainties. The input variables and relative uncertainties (1σ) were $^{87}Sr/^{86}Sr(0)_{liq} = 0.706260 \pm 11$; $^{87}Sr/^{86}Sr_{inp} = 0.706096 \pm 11$; $^{87}Sr/^{86}Sr(1996)_{liq} = 0.706164 \pm 8$; $\Delta t = (1996 - 1980 \pm 2.5)$. The evolution of Sr isotope with time (dashed line) has been estimated solving Eq. 2 for $^{87}Sr/^{86}Sr(t)_{liq}$ and re-using the Monte Carlo method for error propagation. The error envelope reported in the diagram is at the 68% (dark grey) and 95% (light grey) confidence level.

Table 2
Chemical and Sr isotope data of scoriae and lavas erupted from Stromboli volcano during this century

Sample	Date eruption	Lithotype	SiO_2	MgO	K_2O	Sr	Ref.	$^{87}Sr/^{86}Sr \pm 2\sigma_m$	Ref.
Lava flows and highly porphyritic (HP) scoriae									
ST 06	1906	scoria	51.31	5.16	2.28	662	[10]	0.706271 ± 12	
ES 21	15/3/14	lava	51.44	5.04	2.32	633	[10]	0.706256 ± 10	
ES 10	30/3/14	scoria bomb	51.19	5.42	2.10	614	[10]	0.706241 ± 11	
ES 281	1929	lava	50.77	6.49	2.05	632	[10]	0.706271 ± 10	
ES 204	11/9/30	bomb	50.87	6.44	2.09	628	[10]	0.706264 ± 10	
ST 65.2	1965	scoria	50.23	6.65	2.21	717	[10]	0.706260 ± 11	
Sr1	12/11/75	lava	49.47	5.50	2.14	789	[16]	0.706212 ± 10	[33]
ST 346	1983	scoria	50.03	6.30	2.25	660	[10]	0.706208 ± 11	
STR45	1/4/84	scoria	51.03	5.80	2.22	736	[15]	0.706258 ± 20	[15]
Sr5	6/12/85	lava	49.33	5.66	2.16	757	[16]	0.706206 ± 12	[33]
STR202	1/12/85	lava	49.62	6.01	1.98	762	[18]	0.706228 ± 20	[18]
Sr4	1/1/86	lava	49.51	5.89	2.18	757	[16]	0.706218 ± 10	[33]
Sr7	16/4/86	lava	49.25	6.08	2.13	740	[16]	0.706199 ± 9	[33]
ST 89.0	1989	scoria	50.63	6.22	2.16	682		0.706248 ± 8	
STR 7/94	26/7/94	scoria bomb	48.80	6.58	2.03	765		0.706172 ± 7	
STR 9/95c	27/9/95	scoria bomb	49.17	6.57	2.04	753		0.706162 ± 7	
STR 4/96a	16/4/96	scoria bomb	49.33	5.55	2.08	760		0.706162 ± 9	
STR 6/96	1/6/96	scoria	49.22	5.34	2.06	754		0.706164 ± 9	
STR 9/96e	4/9/96	scoria	49.31	5.54	2.08	754		0.706165 ± 8	
Low porphyritic (LP) scoriae									
STR 24	pre-1984	scoria	49.51	6.50	2.12	715	[15]	0.706088 ± 20	[15]
STR 9/96d	4/9/96	scoria	48.79	7.14	1.68	749		0.706105 ± 8	

Major elements (wt%) and Sr (ppm) are from [10,15,16,18] and this study. $^{87}Sr/^{86}Sr$ are from [15,18,33] and this study. The new Sr isotope analyses have been performed at the Vrije Universiteit, Amsterdam, using standard analytical procedures and are presented normalized to $^{86}Sr/^{88}Sr = 0.1194$. Uncertainty in isotopic ratios refers to the least significant digits and represent $\pm 2\sigma_m$ run precision. The external precision of NIST SRM987 was $^{87}Sr/^{86}Sr = 0.710243 \pm 13$ (2σ, $n = 28$). To compare our new with previous published analyses [15,18,33], all isotopic ratios have been normalized to the NIST SRM987 $^{87}Sr/^{86}Sr = 0.710248$ [34]. The sample STR 24 (LP scoria) was already emplaced when collected in 1984. The freshness of its surface, together with the extreme alteration conditions found around the craters of the volcano, lead us to consider an eruption date younger than ca. 5–10 years.

been established on the basis of $\delta^{34}S$ values [7,16]. A gradual change in the isotopic composition of the input magma could be a viable mechanism for the observed variations in $^{87}Sr/^{86}Sr$. However, the two LP scoriae, which are interpreted as the feeding magma, have distinctly lower Sr isotope composition than the HP scoriae (Fig. 3). These scoriae were erupted more than 10 years apart and provide evidence that the magmatic reservoir started, some time around 1980, to be fed by a new magma with Sr isotope signature comparable to that of the LP scoriae. This new input caused the evolution of the volcanic system towards a new isotopic equilibrium condition and resulted in the observed and ongoing time dependent decrease of Sr isotopes.

The dynamics of a continuously erupting and replenished magma chamber can be successfully unravelled using isotopic tracers that vary in response to changes in time dependent physico-chemical parameters [4]. The application of the time series analysis to the Stromboli volcano rests on the assumption that its products are derived from a reservoir that is chemically homogeneous, i.e. magma mixing time is shorter than magma residence time. The homogeneous composition of lavas and scoriae erupted during this century (Fig. 1, Table 1) along with thermodynamic arguments on input fluxes [26], give us confidence that a well-stirred and chemically homogeneous reservoir is feeding the Stromboli volcano. Moreover, there is no significant compositional variability of HP samples after 1975, i.e. from the earliest possible onset of Sr isotope decrease (Table 1). The variability in [Sr] of the HP samples, for example, which is critical to the residence time analysis (see below), is ±15% (2σ) for the 20th century but only ±7% (2σ) since 1975. We can, thus, envisage a reservoir containing a volume V of magma, which is fed by (Q_{inp}) and erupts (Q_{out}) an equal and constant flux of magma. The output flux can be further subdivided into two parts: an endogenous flux ($Q1_{out}$), composed of the material intruded as hypoabyssal sills and dikes, and an exogenous flux ($Q2_{out}$), composed of the material actually erupted at the surface. Being Sr_{inp} and Sr_{liq}, the concentrations of Sr in the input and output fluxes, respectively, elemental mass balance requires that [4]:

$$\frac{dV Sr_{liq}}{dt} = Q_{inp} Sr_{inp} - Q_{out} Sr_{liq} \tag{1}$$

The relatively constant [Sr] in the post 1900 lavas, HP scoriae and LP scoriae (Fig. 2), and particularly after 1975 (Table 1), permits the conservative assumption of no time dependent variation in Sr_{liq} (i.e., $dSr(t)_{liq}/dt = 0$). At steady state (i.e., $Q_{inp} = Q_{out} = Q1_{out} + Q2_{out}$), the magma residence time (τ) is obtained by solving the first order differential Eq. 1 applied to isotopic ratios:

$$\tau = \Delta t \cdot \left[\ln \frac{^{87}Sr/^{86}Sr(0)_{liq} - ^{87}Sr/^{86}Sr_{inp}}{^{87}Sr/^{86}Sr(t)_{liq} - ^{87}Sr/^{86}Sr_{inp}} \right]^{-1} \tag{2}$$

where $^{87}Sr/^{86}Sr(0)_{liq}$ and $^{87}Sr/^{86}Sr(t)_{liq}$ denote the isotopic ratio of the magma in the reservoir at the beginning of the decrease ($t = 0$) and at a given time t, respectively; $^{87}Sr/^{86}Sr_{inp}$ is the isotopic ratio of the new feeding magma; Δt is the time elapsed between $t = 0$ and t (see Fig. 3 for details). Considering the Sr isotope decrease started some time between 1975 and 1985 (Fig. 3), and the $^{87}Sr/^{86}Sr(t)_{liq}$ is 0.706164 ± 15 (2σ) in 1996 (Table 2), the magma residence time at Stromboli appears to be extremely short ($\tau = 19 \pm 12$ yr, 2σ), indicating an almost continuous turnover of magma and a likely attainment of Sr isotope equilibrium, provided boundary conditions remain unchanged, some time around 2050.

The estimated τ, along with the available data on magma fluxes at Stromboli, permits an insight into the dynamics of the magmatic reservoir. Estimates of magma input flux at Stromboli vary from 0.01–0.02 km^3 yr^{-1} (SO_2 flux [7]) to 0.004–0.016 km^3 yr^{-1} (heat flux [9]) and $\sim 2 \times 10^{-3}$ km^3 yr^{-1} (heat flux [6]). These values cover an order of magnitude but are currently the best available estimates. The high input flux of Allard et al. [7] is to be considered an upper limit given that their measured SO_2 is from glass inclusions in olivine and clinopyroxene in the HP scoriae, i.e. possibly an already degassed magma. The short inferred t from this study implies a present magma chamber volume ($V = Q_{inp}\tau$) between 0.3 and 0.04 km^3, based upon the average Q_{inp} of Allard et al. [7] and the Q_{inp} of Giberti et al. [6], respectively. If we envisage the magmatic reservoir as a hypothetical spherical body, the two volume estimates correspond to spheres with a radius of ~400 and ~200 m. These estimates, whichever is correct, represent <0.1% and <0.01% of the total volume of Stromboli volcano (~300 km^3).

Exogenous output flux estimates ($Q2_{out}$) at Stromboli are mainly based upon volumetric calculations [8] of the material partially filling the Sciara del Fuoco scar, and amount to 0.3–1 km^3. The onset of the present-day Strombolian activity began ~2000 years B.P. [12], and establishes an exogenous output flux between 1×10^{-4} and 5×10^{-4} km^3 yr^{-1}. This flux is a lower limit given that it does not take into account the juvenile material accumulating in the sedimentary succession of the South Marsili Basin (NW of Stromboli) and the mass of tephra (lapilli and ash) ballistically and convectively dispersed elsewhere on the island and offshore [8]. Kokelaar and Romagnoli [8] suggested that this unknown erupted material could be of the same order of magnitude as the material partially filling the sector-collapse scar, implying a twofold increase of the exogenous output flux ($Q2_{out}$). Considering the average upper input flux of Allard et al. [7], the $Q2_{out}$ would represent only 1–4%, and possibly 2–8%, of the total output flux, the remainder being the endogenous output flux ($Q1_{out}$). In contrast, considering the lower input flux of Giberti et al. [6], the $Q2_{out}$ would amount to 7–27%, and possibly 14–54%, of the total output flux. Over the 2000 years of Strombolian activity, the endogenous output flux would thus range from ~30 km^3 to some 2–4 km^3, depending upon which of the input fluxes [6,7,9] is correct. The clinometer network of the Italian I.I.V. demonstrates that there is considerable magma subtracted from the plumbing system of the volcano through a lateral escape into dikes, which extends toward NE from the crater zone [27].

In summary, our data confirm that isotopic ratios provide a robust tool to estimate the magma residence time and the dimension of magmatic reservoirs (e.g., [4], and permit a more accurate analysis than other methods based upon the amount of erupted material following a major eruption event [28] and the crystal size distribution [29,30]. This technique can also compete with the rapidly improving seismic tomography methods in resolving small 'features' within the crust such as magma chamber volumes. The estimated size of the magma chamber at Stromboli (0.3–0.04 km^3) establishes a tiny reservoir compared to other major volcanic systems [26].

Finally, the onset of Sr isotope decrease, due to the arrival of a feeding magma with different compositional and isotopic characteristics, predates the major lava flow eruption of 1985 at Stromboli. Consequently, isotopic tracers in general (e.g., [5]) may prove to be a powerful tool in monitoring magma chamber dynamics and possibly in forecasting major eruptions.

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