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1984-1985 Mount Etna effusive activity

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ABSTRACT. — The eruptive activity of Mt . Etna during 1984 and 1985 has been characterized by the occurrence of three effusive eruptions, that respectively affected the eastern upper slope of the volcano (April-October 1984), the southern upper slope (March-July 1985) and the eastern (December 1985), along the western wall of the Valle del Bove. A systematic sampling of the emitted lavas has been carried out during the eruptions, within the limit imposed by the accessibility to the effusive vents.

The petrographic and chemical study of the lavas, including microprobe analysis of solid phases and glass of representative samples, allowed the recognition of the effect of minor differentiation among the products of the same eruption, mostly related to the fractionation of mafic phases.

The observation carried out on the 1984 and 1985 lavas futherly sustain the hypothesis, already suggested by ARMIENTI et al. (1984), about refilling and fractionation processes affecting a shallow magma reservoir. The fractionation of the investigated products, almost comparable with that of the volcanics erupted in 1983, also suggests that at least March-July 1985 eruption was independently fed by a small magma batch whose short time of residence within the shallow part of the volcano feeding system can only produce minor differentiation processes, of the same order of magnitude as those observed within each single eruption.

Key words: Etna, Volcanology, Petrology.

RIASSUNTO. — L'attività eruttiva dell'Etna, tra il 1984 ed il 1985, è stata caratterizzata da tre diversi eventi a carattere effusivo, che hanno rispettivamente interessato l'alto versante orientale del vulcano (Aprile-Ottobre 1984), l'alto versante meridionale (Marzo-Luglio 1985) e ancora il suo versante orientale (Dicembre 1985), lungo la parete occidentale della Valle del Bove. Durante il corso delle eruzioni si è proceduto al sistematico campionamento delle lave emesse, fatte salve le limitazioni imposte dalle difficoltà di accesso alle bocche effusive, anche a causa della violenza delle manifestazioni esplosive associate (1984).

Lo studio petrologico e chimico delle lave, che ha compreso, tra l'altro, l'analisi in microsonda delle fasi solide e del vetro di campioni rappresentativi, ha consentito di porre in evidenza l'effetto di limitate differenziazioni tra i prodotti della stessa eruzione, prevalentemente connesso al frazionamento delle fasi solide femiche.

Le osservazioni condotte sulle lave emesse nel 1984 e 1985 hanno infine consentito di confermare le ipotesi precedentemente esposte (ARMIENTI et al. 1984) circa i processi di frazionamento e di ricarica delle porzioni più superficiali del sistema di alimentazione del vulcano.

Ulteriori deduzioni, che scaturiscono prevalentemente dal limitato grado di differenziazione dei prodotti studiati rispetto alle lave emesse nel corso della precedente eruzione (1983), fanno ritenere che almeno l'eruzione di Marzo-Luglio 1985 sia stata indipendentemente alimentata da modesti apporti di magma, il cui limitato tempo di residenza nelle porzioni più superficiali del sistema di alimentazione ha consentito solo frazionamenti modesti nel complesso paragonabili a quelli osservati nel corso di altre singole eruzioni.

Parole chiave: Etna, Vulcanologia, Petrologia.

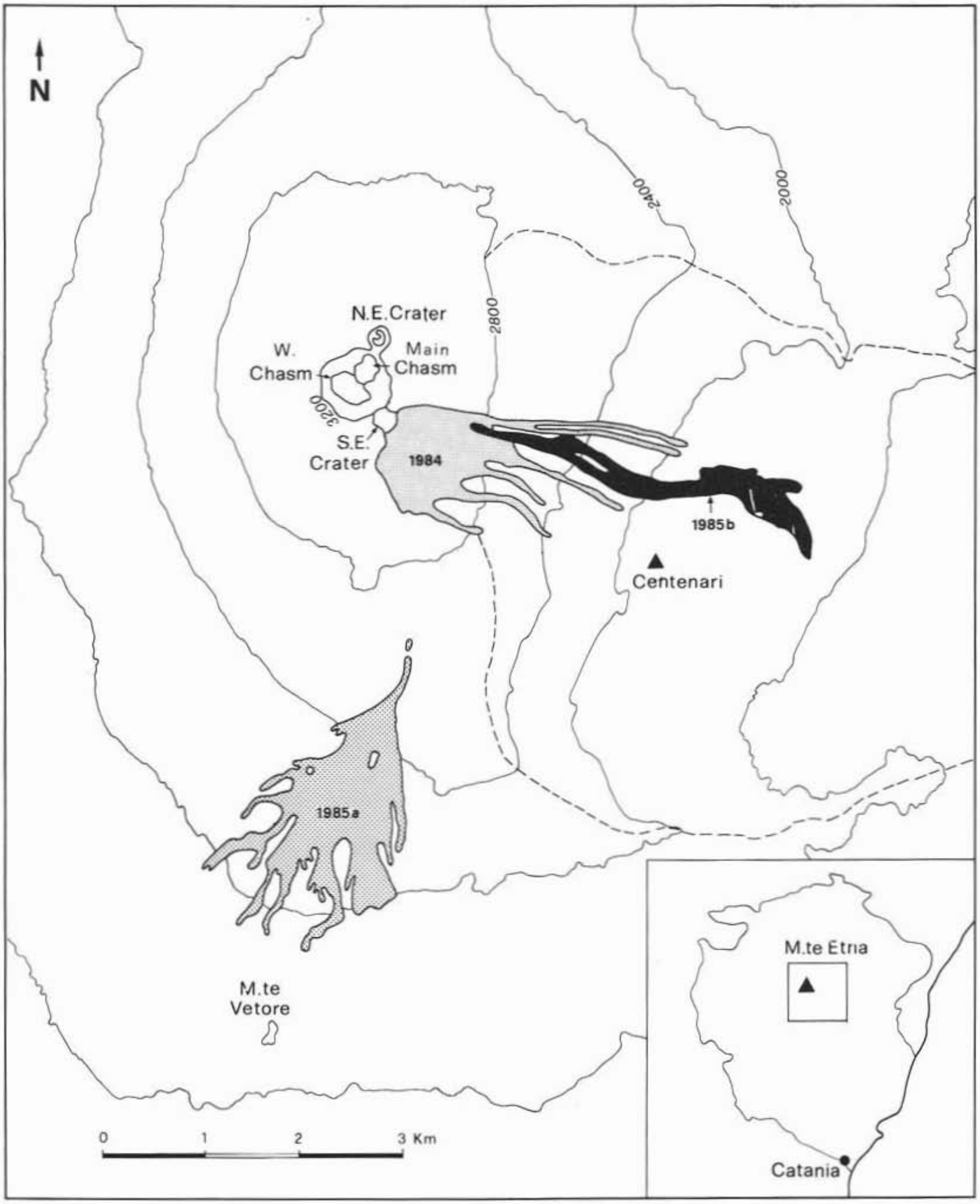

Fig. 1. — Sketch map of the summit area of Mt. Etna, with the location of the lava flows of 1984, March-July 1985 (a) and December 1985 (b).

Introduction

Since 1971 Mt. Etna has been characterized by a large number of eruptive events, which occurred at rate of about one eruption/year (CHESTER et al. 1985).

After the 1983 eruption, when about

$100 \cdot 10^6$ m^3 of lavas were emitted during a 131 days of activity (FRAZZETTA and ROMANO, 1984), the volcano erupted again in 1984 and 1985 (ARMIENTI et al., 1986).

During the 1984 eruption, the explosive activity affecting the vent area and the difficult access to the flows prevented a regular sampling of the emitted products.

Two eruptions occurred in 1985: the former started on March 8 and lasted until July 13, the latter, of minor importance, was characterized by two distinct phases, interrupetd by one day quiescence (Dec. 25-26 and Dec. 28-31). During the first eruption the quiet effusion and the easy access to the vents, allowed a continuous sampling of the lava flow.

The volcanological, chemical and petrographical features of the 1984 and 1985 eruptions will be described in the present paper and discussed within the framework of the last 16-years activity, in order to contribute with some constraints to the knowledge of the feeding system of the volcano.

1. The eruptive activity

1.1. The April-October 1984 eruption

The eruptive activity resumed on Mt. Etna in the night between 27 and 28 April, 1984, and manifested from the S.E. subterminal Crater, giving rise to the formation of a small cinder cone which grew within the crater depression. As the eruption proceeded, small lava flows were emitted at a low effusion rate from the base of the S.E. Crater, running to the South-East. The effusive activity lasted 172 days (see Tab. 1) and the volume of the lavas poured out was estimated at about 10^6 m^3 (ROMANO, 1984). The longest flows ran over the western wall of the Valle del Bove, reaching an altitude of about 2.000 m a.s.l. The moderate effusion rate favoured channelling and overlapping of the flows that originated a complex lava field, widening up to about 2 km (Fig. 1).

During 1984 some explosive activity of variable intensity occurred also at the summit craters when the effusive activity stopped at the S.E. Crater, strong explosions begun at the Main Chasm, then continuing at the N.E. Crater, where they lasted with phases of variable intensity, until the end of October 1984.

The 1984 eruption was preceded by an important inflation phase, associated with and increase of both the volcanic tremor energy and the microseismic activity, mainly affecting the summit area of the volcano. Soon after the end of eruption an important seismic crisis occurred on the eastern slope of the volcanic structure (earthquakes of October 19 and 25 1984, at Zafferana and Fleri, COSENTINO et al., 1986).

TABLE 1

Physical and volcanological parameters of 1984 and 1985 eruptions. (1) calculated following KILINK *et al., 1983. (2) calculated according to* GHIORSO *et al. (1983) using mean anhydrous composition. (3) mean of three replicate analyses in the sample with lowest ratio. (4) measured at a depht of 60 cm. (5) density calculated for the mean anhydrous composition* (BOTTINGA *et al., 1982) at T = 1200 C. (6) viscosity calculated from mean glass composition (T = 1070 °C;* SHAW, *1972) and corrected for observed crystallinity with R = 1.67* (MARSH, *1981). (7) viscosity estimated by using Jeffrey's equation (see text). (8) Reynolds number. Hydraulic diameter of channel Dh = 2.2 m*

eruption	1984	mar-jul/85	dec/85
Log(fO2) (1)	-6.99	-7.05	-6.85
Log(SiO2) (2)	-0.524	-0.505	-0.492
Fe2O3/FeO (3)	0.37	0.36	0.40
T°C (4)	******	1082-1062	******
d (g-cm^-3)(5)	2.65	2.66	2.64
log η Pa s (6)	3	3.3	2.3
log η Pa s (7)	******	3.9	******
Re (8)	******	0.74	******
mean eff.rate(m^3·s^-1)	0.7	2.8	1.6
quote of vent (m)	3000	2500	2850
length (m)	3000	3000	3500
surface (km^2)	1.5	2.2	0.7
volume (m^3·10^6)	10	30	0.7
duration (days)	172	123	5
N° of samples	22	26	6

1.2. The March-July 1985 eruption

After some days of strombolian activity at the S.E. subterminal Crater, a new effusive eruption begun on March 10, 1985, with a flow issuing from the base of the crater and running eastward on the western wall of the Valle del Bove. This short-lived effusion phase ended by the night between the 10 and 11 of March.

A new lava flow poured out from the southern upper slope of the volcano on March 12, from fractures that already opened during the preceding days, following the path of those active during the 1983 eruption.

Soon after the effusive activity moved further downslope and a steady vent formed at about 2.650 m altitude, near Piccolo Rifugio. The steady and low effusion rate (1-3 m^3/s) gave rise to a wide lava field that extended down to an altitude of about 1.830 m a.s.l., running a distance of about 3 km from the vent (Fig. 1).

Following a period of decreasing effusion rate, that begun on early June, the emission of lava temporarily stopped on June 11.

The eruptive activity resumed again from the same vent by the afternoon of June 13 and was accompanied by a seismic swarm with deep (about 15 km) and shallow earthquakes (COSENTINO et al., 1986). This second phase of eruption lasted until July 13, showing the same characteristics of the first phase.

1.3. The December 1985 eruption

A period of strombolian and phreatomagmatic activity, starting on November 30, 1985 characterized both the Western Chasm of the Central Crater (or «Bocca Nuova») and the N.E. subterminal Crater. It was followed, in the night between the 24 and 25 of December, by the opening of an eruptive fissure on the western wall of the Valle del Bove, at an altitude of about 2.850 m a.s.l. (Fig. 1). The opening was preceded by seismic activity that shook the Northern slope of the volcano, producing ground fracturing at Piano Provenzana. The lava pouring out from the fissure in the Valle del Bove, ran its maximum distance from the vent (about 3.5 km) during the night between

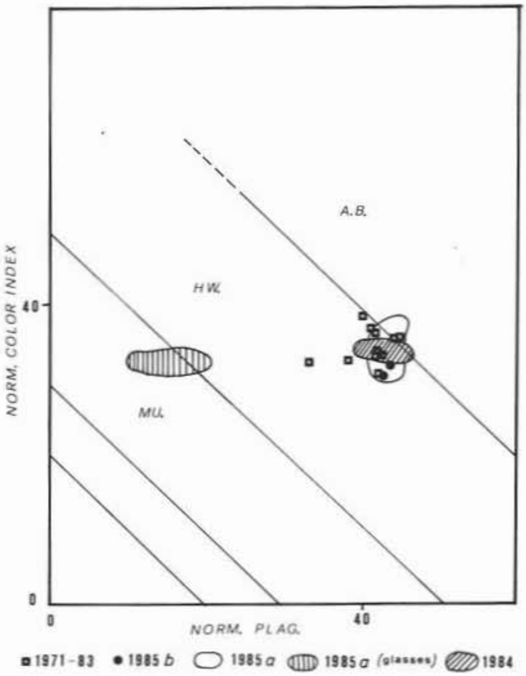

Fig. 2. — Classification diagram, according to IRVINE and BARAGAR (1971), of the products of the eruptive activity of Mt. Etna in the period 1971-1985. Squares show the mean composition of the 1971-1983 lavas. 1985a: lavas of March-July eruption, 1985b: lavas of December 1985. A.B.: Alkali Basalts, Hw: Hawaiite, Mu: Mugearite.

the 25 and 26 of December, reaching an altitude of about 1.750 m a.s.l. to the north of Mts. Centenari. The lava effusion temporarily ceased by the morning of December 26; during the following night, the seismic activity decreased (COSENTINO et al., 1986) and the emission of huge clouds of ashes from the summit craters, that characterized the whole day of December 26, stopped.

A new lava flow issued by December 28, from the uppermost portion of the eruptive fissure that opened in the Christmas night; the resumed activity was accompanied by ejection of overpressured gases and by sporadic trowing of cinders. The eruptive activity came to a complete stop by the night of December 31.

The field of E-W trending fractures feeding the eruption consisted of a vicariant system extending for some hundreds of meters and dotted with craters of phreatic origin, the

TABLE 2

Mean anhydrous chemical and modal composition of products of 1983, 1984 and 1985 eruptions. N.Ans.: number of analyses adopted for the mean calculation. P.I. = Porphyritic idex. Major elements were determined by XRF at Dipartimento di Scienze della Terra, University of Pisa on pressed pellets with full matrix effect correction after FRANZINI *et al. (1972); Na_2O and MgO were determined by AAS (analyses by E. Maccarone, University of Messina) and FeO by titration. Modal analisis was carried out on two to three sections (1500-2000 points per section) of each sample. The whole set of analyses is available up on request*

Eruption	1983		1984		1985		December 1985	
N.Ans.	31		20		26			
	Avg.	dev.st	Avg.	dev.st	Avg.	dev.st	251285	281285
SiO2	47.26	0.20	47.75	0.15	47.78	0.31	48.17	48.78
TiO2	1.79	0.03	1.75	0.04	1.79	0.05	1.67	1.71
Al2O3	17.83	0.26	18.19	0.25	17.96	0.40	18.77	18.80
FeO*	10.15	0.24	9.98	0.24	10.26	0.38	9.61	9.48
MnO	0.21	0.01	0.19	0.00	0.19	0.01	0.19	0.19
MgO	5.79	0.14	5.58	0.17	5.57	0.22	5.00	4.50
CaO	10.87	0.12	10.39	0.12	10.50	0.21	10.29	9.88
Na2O	3.75	0.20	3.90	0.11	3.62	0.09	3.94	4.07
K2O	1.83	0.03	1.81	0.04	1.88	0.03	1.89	2.06
P2O5	0.52	0.03	0.46	0.02	0.46	0.02	0.49	0.51
D.I.	34.56		36.22		35.35		37.50	40.08
Mgv	53.58		53.08		52.35		51.26	49.00
				Modes				
N.Ans	18		16		21			
Plg	18.4	2.2	19.9	4.0	23.0	2.1	15.4	17.8
Cpx	8.9	2.4	10.1	2.7	12.2	1.0	10.3	7.2
Ol	2.1	0.6	2.5	0.5	2.6	0.8	1.4	1.0
Ox	0.4	0.2	0.7	0.3	0.6	0.2	0.9	0.2
P.I.	29.8	3.8	33.2	5.5	38.4	2.2	28.0	26.0

largest of which had a diameter of about 12 meters.

2. Petrography

2.1. *The April-October 1984 lava flow*

Twenty lava samples were collected from the 1984 flow and analysed, as well as two scoriaceous bombs ejected from the summit craters as the effusive eruption was in progress. The sampling, however, was not strictly continous in time and did not allow a rigorous control on the composition throughout the evolution of the activity.

The composition of these products overaps the hawaiitic field covered by the 1983 (Fig. 2, Tab. 2). The examined volcanics exhibit porphyritic texture and shows a phenocryst assemblage characterized bythe occurrence of zoned plagioclase (An 56%-81%), augitic clinopyroxene (Wo 46%-49%, En 34%-41%) and olivine (Fo 68%-77%); Ti-magnetite occurs as microphenocrysts (Usp 31%-43%) (TANGUY and CLOCCHIATTI, 1984).

The observed phenocryst modal range of these lavas and their porphritic index (P.I.) are both larger than that observed in the 1983 products (Tab. 2). The higher P.I. is mainly related to the plagioclase abundance, that shows an overall increase in the final stages of the eruption, when the emission rate was lower.

2.2. *The March-July 1985 lava flow*

During the March-July 1985 eruption, 28 samples were collected at regular time intervals and air-quenched near the vent. Two specimen of the explosive activity from the S.E. subterminal Crater and from the Western Chasm of the Central Crater respectively, were also collected for comparative purposes. Six samples of the December 1985 effusive activity, were also available for the study.

The lava flow of March-July 1985 is a poorly evolved hawaiite, plotting astride the boundary between hawaiite and alkali basalt fields (Fig. 2).

It shows a porphyritic texture with plagioclase, augitic clinopyroxene and olivine phenocrysts. The composition of the analyzed phases is shown in Fig. 3.a; selected analyses are reported in Tab 3.

Olivine in zoned (Fo 82%-69%) and shows a mean composition of about Fo 74%. The salitic clinopyroxene has a narrow compositional range (En 41%-40%, Fs 13%-15%), while the microlites display a slight iron enrichment (Fs 18%). Plagioclase composition ranges between An 88% and An 55%, showing frequent oscillatory zoning. Phenocryst

TABLE 3

*Selected analyses of mineral of the 1985 lavas. The codes indicate the date of emission of host lava. P: phenocryst; m = microlite; * = mineral used for mess balance calculation. Usp percentage is calculated according to* ANDERSON *(1968). The composition were measured by a Cameca-Microbeam electron microprobe at the «Laboratoire Comparis, Universitè Paris VI». Analytical conditions: 15 KV, 10 Microamperes, spot diameter 2 micrometers*

Plagioclases

	P100385	P100385	m230585	m230585	251285a	251285b	P180585*
SiO2	50.47	45.52	55.63	50.78	53.97	45.20	51.12
Al2O3	28.23	33.92	26.23	30.68	30.47	34.50	30.75
FeO	1.80	0.61	1.50	0.76	0.73	0.64	0.74
MgO	0.51	0.05	0.25	0.11	0.09	0.05	0.01
CaO	12.84	17.71	9.83	14.13	11.42	17.99	13.50
Na2O	4.34	1.25	5.27	3.32	4.92	1.10	3.63
K2O	0.73	0.08	0.90	0.30	0.49	0.08	0.38
Tot	98.92	99.14	99.58	100.00	100.15	99.57	99.73
An	59.5	88.2	48.1	69.0	54.6	89.6	65.8
Ab	36.4	11.2	46.7	29.3	42.6	10.0	32.0
Or	4.0	1.4	5.2	1.7	2.8	0.4	2.2

Clinopyroxenes

	P120385	P230585	m230585	251285a	251285b	P230585*
SiO2	50.36	49.70	45.63	49.78	45.73	48.59
TiO2	1.20	1.17	2.57	1.34	2.20	1.59
Al2O3	5.76	4.36	7.61	3.90	8.00	5.88
FeO	7.64	6.81	9.74	7.50	7.90	7.94
MnO	0.19	0.22	0.10	0.27	0.15	0.08
MgO	12.06	11.37	11.53	13.80	12.19	13.39
CaO	21.99	22.73	22.24	21.99	23.07	22.25
Na2O	0.47	0.32	0.52	0.43	0.35	0.57
Tot	99.79	99.63	99.94	99.01	99.59	100.29
Wo	46.2	47.1	48.3	46.5	49.8	47.2
En	41.0	41.5	34.9	40.6	36.6	39.5
Fs	12.8	11.4	16.7	12.9	13.6	13.3

Olivines

	P100385	m100385	P180585	251285a core	251285b rim	P180585*
SiO2	39.03	37.83	39.14	37.63	38.39	37.71
FeO	18.64	24.90	16.93	24.21	21.97	23.15
MnO	0.32	0.56	0.27	0.56	0.48	0.47
MgO	42.00	35.71	44.10	37.23	39.98	38.95
CaO	0.24	0.41	0.23	0.37	0.31	0.36
Tot.	100.22	99.41	100.63	100.03	101.16	100.64
Fo	79.8	71.4	82.0	72.81	76.04	74.60

Oxides

	P100385	P120385	m120385	251285a	251285c	P120485*
SiO2	0.07	0.10	0.11	0.30	0.09	0.09
TiO2	10.97	13.44	10.33	13.54	10.66	12.21
Al2O3	6.37	6.2	6.86	4.00	7.10	6.38
FeO	32.77	36.43	32.88	34.27	33.35	34.69
Fe2O3	43.06	38.29	43.24	39.87	42.84	40.62
MnO	0.41	0.52	0.34	0.79	0.45	0.42
MgO	5.86	4.97	5.44	5.63	5.41	5.41
Cr2O3	0.07	0.13	0.13	-	-	0.08
Tot.	99.59	100.09	99.32	98.40	99.90	99.90
%Usp.	23.7	34.2	23.5	30.2	24.6	29.2

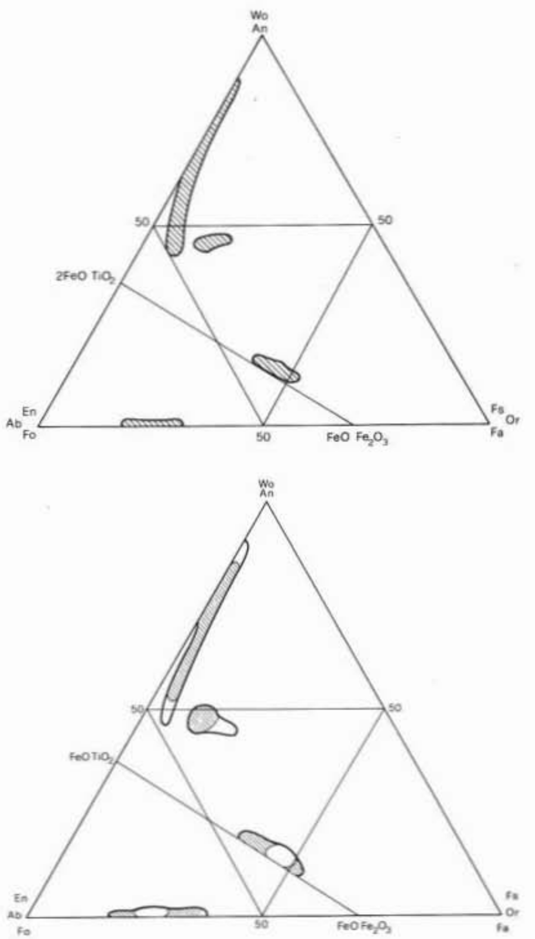

Fig. 3. — Composition of the phases occurring in the lavas of the eruptions of March-July 1985 (3a) and December 1985 (3b). Ruled area: analyses of the sample 301285.

cores sometimes show a patchy zoning; sieve textures are also often observed for compositions ranging between An 67% and An 72%. Ti-magnetite occurs as microlites and microphenocryst (Ups 32%-47%), displaying an increase of Ti content towards the rim. Modal composition have been measured on 21 samples collected at regular time intervals; the modes are reported in Tab. 2 and in Fig. 4. The dealt with lavas show an average P.I. (about 39) higher that those of two preceding eruptive events (mean P.I. of 1983 and 1984 eruptions < 32); while the products emitted at the beginning of the eruption and the samples of the contemporaneous explosive activity in the summit area, have a P.I. < 33.

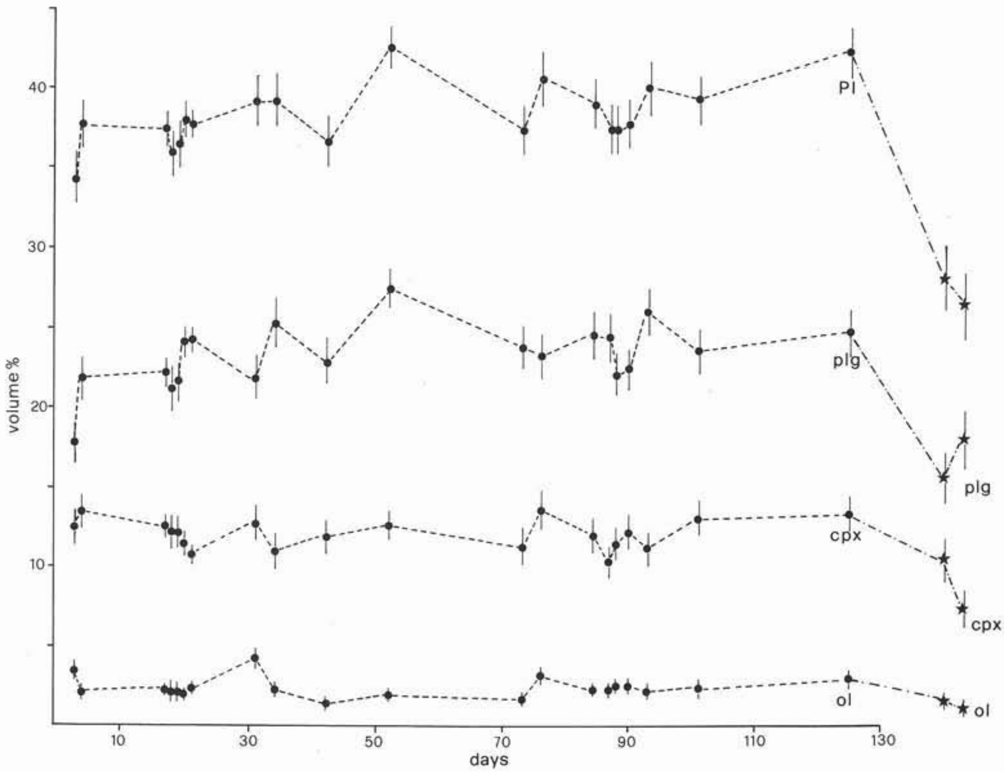

Fig. 4. — Temporal variation of modal composition of 1985 lavas. The modes of December 1985 lavas are plotted beyond the abscissa scale. P.I.: porphyritic index, cpx: clinopyroxene, ol: olivine, plg: plagioclase.

2.3. The December 1985 eruption

The petrographic features of the lavas erupted at the end of 1985 show marked differences if compared with those just described, in spite of the same phenocryst paragenesis: the P.I. has a wide range of variation (from 15 to 31) and a mean value of about 27 (Tab. 2).

Some compositional differences have been also observed between the minerals of the first (December 25) and the second (December 28-31) phase of the eruption, respectively. Plagioclase and clinopyroxene phenocrysts of the first phase span over a relatively wide compositional range (An 89%-47%; Wo 48%-45%; Fs 12%-20%) (Fig. 3.b and Tab. 3). Olivine has a slightly evolved mean composition (Fo 70%) and often shows reversed zoning (Fo 72% core, Fo 76% rim). The second phase plagioclase composition shows a narrower range of variation (An 83%-54%) while olivine exhibits no reverse zoning and a mean composition of about Fo 77% (CLOCCHIATTI et al., 1986).

3. Chemistry

3.1. The 1984 lavas

The variation of the chemical composition observed in the 1984 lavas covers a narrow range, almost comparable in extent with that of the 1983 volcanics. A significant linear correlation is observed however between the elements showing the larger variations (Al_2O_3, FeO*, CaO and MgO; see Figs. 5.a-b).

The good linear correlation between FeO* and Al_2O_3 ($r \doteq 0.94$) and CaO and Al_2O_3 ($r = 0.63$), suggests that the mafic phases played and important role in the differentiation process. The trends described by sample plots in Figs. 5.a-b, are parallel to the sub-

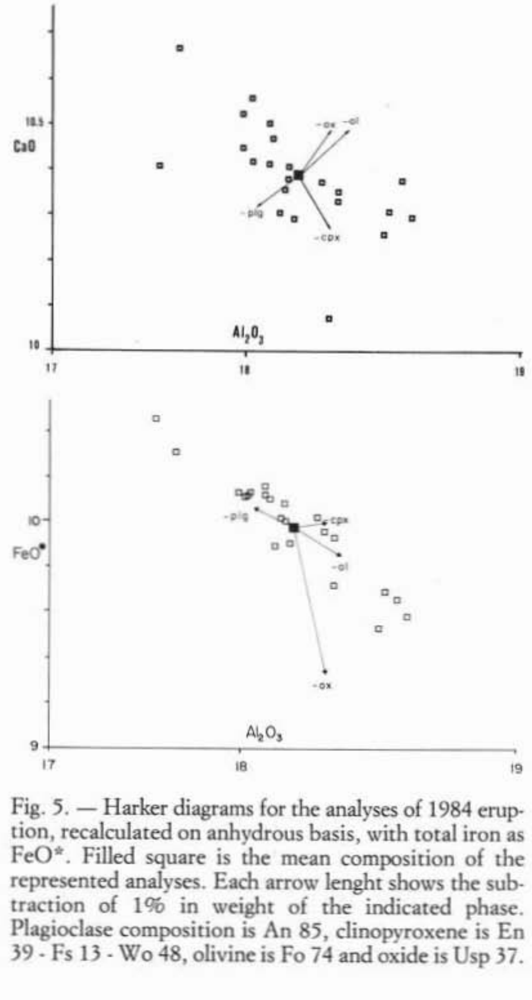

Fig. 5. — Harker diagrams for the analyses of 1984 eruption, recalculated on anhydrous basis, with total iron as FeO^*. Filled square is the mean composition of the represented analyses. Each arrow lenght shows the subtraction of 1% in weight of the indicated phase. Plagioclase composition is An 85, clinopyroxene is En 39 - Fs 13 - Wo 48, olivine is Fo 74 and oxide is Usp 37.

traction vectors, as drawn starting from the mean 1984 lava composition. Mass balance computations (STORMER and NICHOLLS, 1978) confirm that only mafic phases are involved in the fractionation. However, their modal abundance shows no correlation with FeO^* ($r = 0.308$), Al_2O_3 ($r = 0.370$), CaO ($r = 0.61$) and MgO ($r = 0.044$). It is therefore suggested: i) that the variation of the modes are hidden by uncertainities in counting; ii) and/or the selected threshold for phenocryst definition (0.3 mm) is such to include also minerals formed after the fractionating ones (first generation).

3.2. The March-July and December 1985 lavas

Variation diagrams of major elements Vs time are reported in Fig. 6. Most of the elements show relatively little variations with time, only slightly above the 95% confidence limit. Larger scattering is observed for SiO_2, Al_2O_3, FeO^*, Na_2O, and MgO (Fig. 6). These variations are interpreted as a consequence of the mafic phases fractionation. In fact, as far as the March-July 1985 lavas are concerned, the Al_2O_3 Vs CaO and Al_2O_3 Vs FeO^* plots show a marked linear correlation ($r = —0.84$ and $—0.92$ respectively), matching a trend parallel to the mafic phases subtraction vector (Fig. 7), in analogy of what already observed for the 1984 lavas.

Microprobe analysis was also carried out on the glass of the two samples collected from the vents at 2.320 m a.s.l. (T = 1077°C) and 2.480 m a.s.l. (T = 1062°C) respectively. The sample were chilled in water and the reported composition was obtained by the mean of 10 counts of 20 seconds with a defocussed beam. The composition field of the glasses is reported in Fig. 2, and plots astride the boundary Hawaiite-Mugearite.

The glass composition can be very closely approached ($\Sigma R^2 = 0.47$) by means of mass

TABLE 4

Fractionation model for the 1983-1985 lavas, according to STORMER *and* NICHOLLS *(1978). The parent magma is reported in the first column, the fractionated on in the second. All analyses are mean composition of the indicated year. Sample 85-n2, 251285 and 281285 are analyses of specific samples. The total added/removed solid (wt. %) is given as a percentage of the starting magma, its composition is reported in terms of olivine, clynopiroxene and oxide. Analyses od minerals are reported in Tab. 2; r^2 in the last column is the sum of the squared residuals between calculated and observed derived magma composition*

		solid added (+)/ removed (-)				r2
From	to	ol%	cpx%	ox%	tot.%	
1) 1985m	251285	-0.9	-3.7	-0.9	-5.5	0.05
2) 1985m	281285	-1.2	-5.8	-1.3	-8.3	0.21
3) 1985m	85-N2	-2.4	-8.6	-1.4	-12.4	0.05
4) 251285	281285	-0.3	-2.3	-0.4	-3.0	0.40
5) 1983m	1984m	-0.4	-2.7	***	-3.1	0.33
6) 1983m	1985m	-0.2	-1.8	***	-2.0	0.36
7) 1984m	1985m	+0.2	+0.9	***	+1.1	0.18

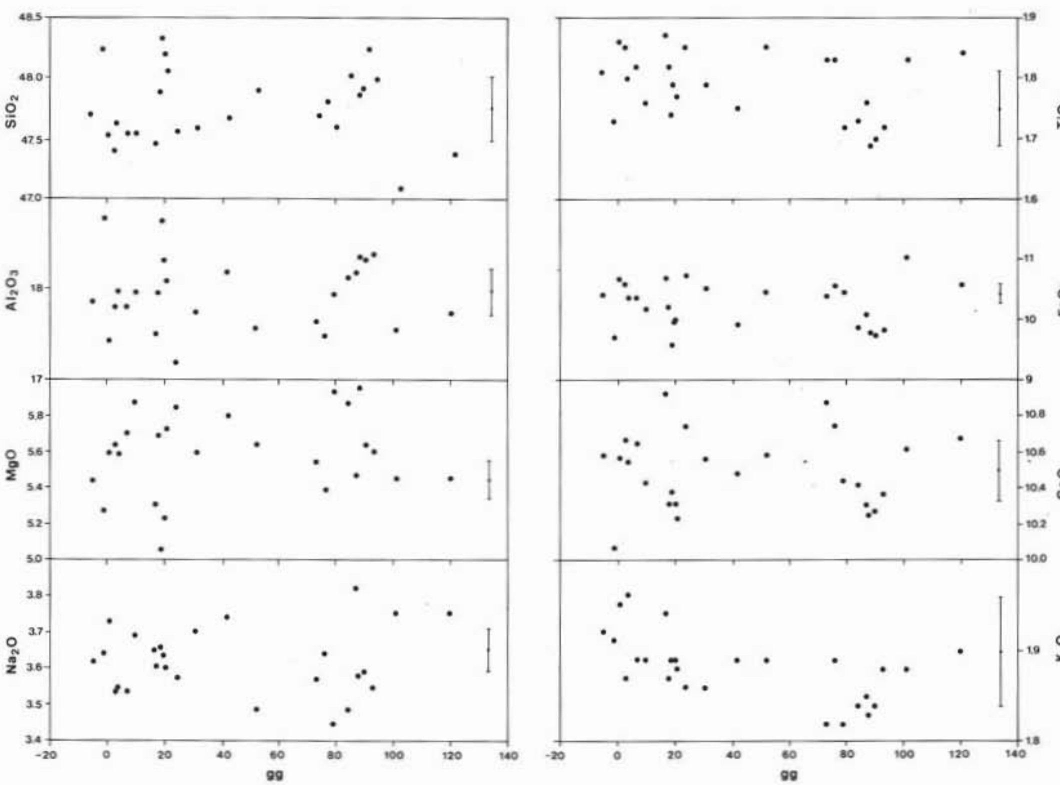

Fig. 6. — Temporal variation of composition for the products of 1985 activity. The temporal scale is in days since the beginning of the eruption. Error bars for reported element analysis is given in each diagram. Dots within the scale: March-July eruption; out of scale - square: II85, triangle: 080385CSE, asterisk: December 1985.

balance calculations, subtracting from the March-July 1985 lava mean composition a solid fraction made up of plagioclase (23.4 wt%), clinopyroxene (11 wt%), olivine (5.3 wt%) and oxides (1.2 wt%). The results are in good agreement with those obtained by modal analyses, taking into account the corrections for phase densities. These data so confirm the hypothesis that the measured modes represent the whole crystallization history of the magma and not only its intratelluric stage.

All the samples of December 1985 show a higher evolution, if compared to the lavas of March-July 1985, as stressed by the decrease of Mgv* (Mgv* = Mg/(Mg + Fe) with $Fe_2O_3/FeO = 0.15$) and the increase of D.I. (Tab. 2). Their chemical composition suggests a derivation from the March-July 1985 lavas trough a process of mafic phases fractionation (Tab. 4 and Fig. 7).

4. Physical-chemical characteristics

Table 1 includes the main physical-chemical parameters of the 1984 and 1985 lava flows.

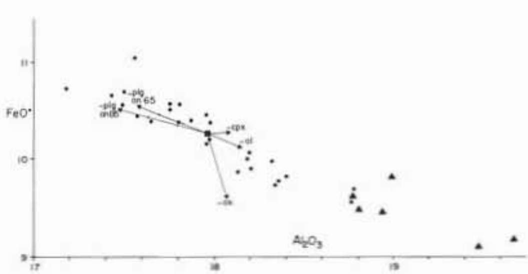

Fig. 7. — Harker diagram for the analyses of 1985 eruption, recalculated on anhydrous basis, with total iron as FeO*. Filled square: mean composition of the represented analyses, dots: March-July eruption, triangles: December eruption. Each bar on the arrows shows the subtraction of 1% by weight of the indicated phase. Plagioclase composition is An 85 and An 60, clinopyroxene is En 39 - Fs 13 - Wo 48, olivine is Fo 74 and oxide is Usp 37.

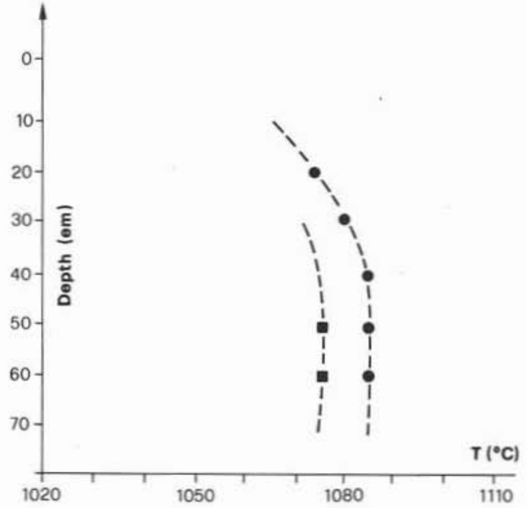

Fig. 8. — Temperature Vs depth diagram for May 1985 lava channel near the vent (2.480 m a.s.l.). The lower temperature curve was measured 10 cm far from the channel walls, the temperature curve is referred to measurements at the center of the flow. Temperature determined with TEMPTIP-MK4 pyrometric lance, with UNITIP E71 60 cm cartridges bearing Pt-PtRh thermocouple; the instrumental error was ± 4°C.

Field temperature measurements carried out at ephemeral vents (2.320 m and 2.480 m) reveal the existence of both horizontal and vertical T-gradient, Fig. 8). Temperature measured at 2.480 m a.s.l. resulted to be of 1062°C (mean) on May 23, in condition of low output rate, and of 1078°C (mean) on June 18, in condition of higher otuput rate. The temperature measured on these lavas fall within the interval of previous determination (1060-1125°C, ARCHAMBOULT and TANGUY, 1976; PINKERTON and SPARKS, 1978) even if they are near the lower limit of the range.

The temperature measured on March-July 1985 lavas, were then utilized to compute their viscosity, according to the model of SHAW (1972). Calculations were carried out on the basis of the composition of the glasses (liquid) and the phenocryst content desumed by the modal analyses. The obtained value ($\log \eta = 3.33$) is in good agreement with that estimated according to the formula:

$$\eta = \frac{gh^2 \varrho \sin\alpha}{4 V}$$

(were $g = 9.8$ m/sec^2; ϱ = density; V = flow velocity; h = channel depth; α = channel slope, and the denominator is 4V, since the formula holds for narrow channels), if we consider that both methods have an approximation of ± 1 log unit.

Tab. 1 contains also the viscosity of the crystal free magma (SHAW, 1972) and the density, estimated according to BOTTINGA and WEILL (1982), both computed at 1200°C. Tab. 1 contains also the fO_2 value calculated according to KILINK et al. (1983) on the lesser oxidized samples (Fe_2O_3/FeO = 0.34-0.38) of the three studied lava flows and assuming a temperature of 1200°C. The obtained results ($-7.2 < \log fO_2 < -7.0$) are in agreement with values by SATO and MOORE (1973) on the 1971 lavas at the same temperature ($\log fO_2 = -7.3$). The oxygen fugacity found in these lavas is higher than the QFM buffer at 1200°C and is comparable with the values observed for the oceanic island basalts and for ocean floor basalts (BASALTIC VOLCANISM STUDY PROJECT, 1981).

5. Conclusions

5.1. Within eruption variations

The chemical and petrographical variations observed in the 1984 products, appear to be, on the whole comparable with those observed for the 1983 lavas (ARMIENTI et al., 1984). They show, however, inter-element correlations suggesting the occurrence of minor fractionation of the mafic phases, mainly involving clinopyroxene (Tab. 4). Since no correlation between chemical and modal data are apparent, we argue that the measured P.I. (assuming the minimum dimension of phenocrysts = 0.3 mm) refers to the whole crystallization history of the magma including those crystals which formed after the settling relevant to the fractionation.

Similar conclusion can also be drawn for the March-July 1985 lavas.

The small Christmas 1985 eruption shows noticeable differences with the products of the preceding one: the collected data suggest, in fact, that the feeding magma was: i) more evolved, as a whole, than that of the preceding eruption in 1984 and 1985; ii) poorer in phenocrysts; iii) mineralogically and chemically more heterogeneous.

These data are interpreted as the results of the drainage of a small and shallow dike, which underwent minor differentiation due to fractional crystallization. Mass balance calculation show that the more evolved terms (D.I. about 41), can be obtained from the composition of magma feeding the preceding eruption, mainly fractionating clinopyroxene ($\sim$ 9 wt%) and minor olivine and oxides (row 2 and 3 in Tab. 4). The composition of the sample collected from the December 25 flow (less evolved, can also be obtained by the modeling of a fractionation process, still involving the same phases, but in a lesser amount.

The observed chemical and mineralogical heterogeneities are regarded as evidence of zonation in the feeding dike. It is suggested that the uppermost and external portions of this small magma reservoir (dike) had to be more evolved than its inner parts, owing to mineral settling and wall crystallization. In this view, the late products, tapped from the higher portion of the feeding dike, represent the drainage of the more evolved parts of the system.

5.2. *Inter-lava chemical variations: inferences on the feeding system*

In the general context of a constant steady-state output rate lasting since mid-eighteenth century (WADGE & GUEST, 1981) the compositional variations observed during the 1971-1983 time span, have been interpreted by ARMIENTI et al. (1984) as the results of a succession of cycles of refilling and fractionation in a shallow and small magma reservoir.

As previously suggested, significant amounts of magma fed such shallow magma reservoir in 1971, 1978 and 1983 but, while the first two magma inputs gave rise to well defined trends, evolving within two or three years, the data on 1984 and 1985 volcanics shows small compositional variations with respect to the 1983 lavas. Mass balance calculations reported in Tab. 4, point to a possible transition from 1983 to 1984 and 1985 lavas with subtracion of a small quantity (3% and 2% respectively) of a solid constituted mainly by clinopyroxene and subordinate olivine. On the contrary an addition of mafic phases is required to get 1985 mean composition from that of 1984; this strongly suggests an input of new magma before 1985 eruption. As matter of fact the overall steady state characterizing the plumbing system of the volcano has been approached more closely since 1983, through a frequent input of small batches of magma, whose short time of residence within a shallow part of the volcano can only produce minor differentiation processes, of the same order of magnitude as those observed within each single eruption.

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