

The Etnean Lavas, 1977-1983: Petrology and Mineralogy

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ABSTRACT

The products emitted by Mount Etna in the 1977-1983 period are porphyric, sodic trachybasalts («etnaïtes») that, though substantially higher in K_2O , resemble most of the historic lavas.

The 1983 flows, for instance, are composed of 50-55% glassy groundmass and abundant phenocrysts or microphenocrysts: plagioclase (25-30%), clinopyroxene (12-15%), olivine (3-5%), titanomagnetite (2%). Scarce olivine Fo 83-78 and diopsidic pyroxene are present in the cores of some phenocrysts. Outer zones and/or more numerous crystals are olivine Fo 75-68, salite En 43-37 Fs 10-15, plagioclase An 83-55 an Al-Mg rich magnetite Usp 43-33. The chemical composition of glass inclusions interpreted as trapped liquids suggests that olivine and magnetite crystallize first and are followed by pyroxene and plagioclase. The early appearance of olivine has been determined by optical thermometry to about 1170°C, soon followed by plagioclase and pyroxene (1160-1140°C). Pre-eruptive crystallization further progresses until 1073°C which is the field-measured temperature at the lava vent. Then, the appearance and composition of microlites (and outer rims of phenocrysts) depend upon the cooling rate of the samples (water quenching or natural cooling). Electron microprobe analyses of chlorine and sulphur have been performed on crystal trapped and groundmass glasses. Sulphur ranges from an initial content of 1500 ppm to 400 ppm in residual glass, leading to an average sulphur emission of 1500 tons/day (3000 t/d SO_2), as estimated from the volume of erupted lava.

The most striking chemical feature of the 1977-1983 lavas lies in the abnormal potassium behaviour, especially in the earliest flows of the 1978-1979 fissure eruptions. Although these

lavas are amongst the most ferric of the period, they are relatively high in K_2O , leading to an aberrant K/Na ratio (*i.e.* increasing with increasing basicity). Furthermore, a less pronounced but steady increase of K_2O/Na_2O is evidenced in all the lavas of the past 12 years. This ratio ranges from 0.42 in the 1971 lavas to 0.51 in the 1983 ones, for about the same differentiation index. Such an abnormal potassium behaviour first appeared during the 1974 eruption on the west slope of the volcano. It is unknown, however, in any other historic lava, nor in any lava of entire Etna so far analyzed.

RESUME

Les produits rejetés par l'Etna de 1977 à 1983 sont des trachybasaltes porphyriques («etnaïtes») semblables à ceux qui caractérisent la majorité des laves de ce volcan, mais avec une teneur en K plus élevée.

Les coulées de 1983, par exemple, sont formées de 50-55% de mésostase et par de nombreux phéno et microphénocristaux de plagioclase (25-30%), clinopyroxène (12-15%), olivine (3-5%), titanomagnétite (2%). De l'olivine Fo 83-78 et un peu de diopside-salite cristallisent d'abord, passant rapidement à une olivine Fo 78-68, une salite (Wo 47,5 - En 43/37 - Fs 10/15), du plagioclase An 83-55, une titanomagnétite Usp 43-33 riche en Al et Mg. Le domaine de température de cristallisation commençante des phénocristaux établi par thermométrie optique est compris entre 1170° et 1140°C. La cristallisation intratellurique progresse ensuite jusqu'à 1073°C, qui représente la température d'émission de la lave mesurée sur le terrain. La nature et la quantité des microlites, la composition des stades termi-

naux de cristallisation des phénocristaux et celle du verre résiduel de la mésostase dépendent du mode de refroidissement de la lave: trempe à l'eau, à l'air, ou refroidissement lent naturel. La quantité de soufre dans les verres inclus et la mésostase varie de 1500 à 400 ppm, celle du chlore de 1700 à 2800 ppm.

La composition chimique est celle d'un trachybasalte sodique (hawaïite basaltique). Le caractère le plus marquant réside dans le comportement anormal du potassium, en particulier dans les laves du début des éruptions de 1978 et 1979. Alors que ces produits sont parmi les plus basiques de la période considérée, leur teneur en K est relativement élevée, ce qui conduit à un rapport K/Na aberrant (augmentant avec la basicité de la roche). En dehors de ces cas extrêmes, on note une augmentation régulière, quoique plus faible, de K/Na dans tous les produits des 12 dernières années. Ce comportement anormal du potassium était déjà apparu dans les produits de l'éruption excentrique de 1974 sur le versant ouest. Cependant, on ne trouve aucune variation aberrante du potassium dans les autres laves historiques, ni même dans aucun des produits connus de l'Etna.

INTRODUCTION

The historic lavas of Mount Etna are largely basaltic in character. Although they might be inadequately termed phonolitic tephrite or latite andesite following some classifications (see, e.g. CRISTOFOLINI and ROMANO, 1982), they can rather be considered as slightly evolved alkaline basalts or basaltic hawaiites, only very few samples approaching mugearites. To emphasize the femic character of recent etnean lavas, RITTMANN (1960) introduced the term «etnaite», which may be more generally defined as a sodic trachybasalt showing a porphyritic structure. Typical etnaites have high contents of CaO (10%), MgO (5%) and total Fe₂O₃ (11%), the sum of which (= CMF) may be conveniently used as a differentiation index⁽¹⁾. They are largely porphyritic - another substantial

difference compared with hawaiites and mugearites - the phenocrysts being calcic plagioclase, a slightly titaniferous salite, and rare olivine and titanomagnetite. In completely crystallized samples, the same minerals are present in the groundmass, together with a highly alkaline residuum made of sodic sanidine and small amounts of nepheline and sodalite.

Full discussions of the problems related to the composition of etnean rock types have been published elsewhere (TANGUY, 1966, 1973, 1978, 1980). The 96 analyses of historic lavas given in the last of these works can be considered as a basis for the present study.

The source and location of the 1977-1983 samples are listed in Table 1. A summary of the eruptions that generated these rocks is reported separately (TANGUY and PATANE, this volume). The same samples have also been studied for trace-element geochemistry (JORON and TREUIL, in preparation).

ANALYTICAL PROCEDURES

Most of the 1977-1983 etnean products were sampled at or very close to eruption vents, either as pyroclasts (scoriae, bombs, lava lumps) or taken from lava flows. Because they were poorly degassed at the time of sampling, traces of sublimates were sometimes evident. Sample 83-03, for instance, exhibited white sublimates that proved to be mainly Na₂CO₃ and Na₂SO₄ from X-Ray diffraction patterns. To avoid any sublimate deposit that could have biased analytical results, all samples were immersed for at least two hours in distilled water. After drying at 60° C, they were crushed in a tungsten carbide grinder, following a procedure previously described (TANGUY, 1980, pp. 37-38). For trace-element analyses, a separate piece of rock was ground using an agate bowl grinder. Comparison of major-element analyses on powders obtained by the two methods showed no significant difference and, therefore, some major-elements analyses were performed on agate grinder powders. All major-

⁽¹⁾ Because of the unusual behaviour of alkalis in etnean lavas, the Thornton-Tuttle index is not used here (TANGUY, 1980, p. 36).

TABLE 1 - Chemical and modal analyses of 1977-1983 (84) lavas. Fe_2O_3 T = Total Fe as Fe_2O_3 , CMF = CaO + MgO + total Fe_2O_3 (see text).

	77-01	77-02	77-05	77-14	78-01	78-03	78-07	78-09	78-18	78-51	79-07	79-06	79-02	80-04	80-01
SiO ₂	48.53	48.50	48.64	48.30	47.50	47.70	47.51	47.78	47.43	47.92	47.54	47.97	47.94	48.17	47.97
Al ₂ O ₃	18.49	18.54	18.44	18.25	17.31	17.44	16.78	17.17	17.27	17.29	17.01	17.25	17.59	17.78	17.24
Fe ₂ O ₃	3.50	3.49	2.73	3.59	4.59	3.72	4.56	3.85	4.42	3.53	4.35	4.13	3.24	3.35	3.85
FeO	6.22	6.28	6.94	6.49	6.16	6.92	6.45	6.67	6.38	7.11	6.54	6.45	7.16	6.75	6.73
MnO	0.17	0.17	0.17	0.17	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
MgO	4.56	4.58	4.56	4.79	5.35	5.57	5.90	5.81	5.66	5.35	5.61	5.35	5.38	5.24	5.55
CaO	9.89	9.38	9.90	10.13	10.64	10.50	10.66	10.55	10.65	10.39	10.73	10.43	10.45	10.28	10.40
Na ₂ O	4.27	4.31	4.32	4.49	3.85	3.82	3.67	3.91	3.79	4.07	3.77	4.06	4.00	4.04	3.89
K ₂ O	2.01	2.01	2.03	2.00	1.89	1.98	2.03	1.85	1.91	1.92	2.00	1.92	1.86	1.93	1.91
TiO ₂	1.65	1.66	1.66	1.68	1.73	1.72	1.71	1.70	1.72	1.69	1.72	1.69	1.71	1.67	1.71
P ₂ O ₅	0.59	0.58	0.60	0.59	0.58	0.54	0.54	0.53	0.54	0.53	0.54	0.54	0.53	0.56	0.55
Fe ₂ O ₃ t	10.41	10.47	10.44	10.73	11.43	11.41	11.72	11.26	11.51	11.43	11.62	11.30	11.20	10.86	11.33
C.M.F.	24.86	24.93	24.90	25.63	27.62	27.48	28.26	27.62	27.92	27.17	27.96	27.08	27.03	26.38	27.28
K ₂ O/Na ₂ O	0.460	0.466	0.470	0.489	0.491	0.492	0.553	0.473	0.504	0.472	0.531	0.473	0.465	0.490	0.491
Plagioclase		27.7	28.5			17.5	11.1	24.0			20.7	15.4	20.6		
Pyroxene		6.0	6.9			7.9	8.1	12.2			10.0	9.7	8.1		
Olivine		1.1	1.4			3.9	3.1	2.8			2.4	2.1	1.5		
Titanomagnetite		1.0	1.4			0.3	1.2	1.2			1.9	1.4	1.2		
Groundmass		64.2	61.3			70.8	76.5	59.8			65.0	71.4	68.6		
Porph. index		35.8	38.2			29.2	23.5	40.2			35.0	28.6	31.4		
	80-02	80-05	80-06	81-07	81-06	81-05	83-01	83-03	83-05	83-09	83-15	83-22	83-26	83-35	84-12
SiO ₂	47.89	48.15	48.33	48.33	48.11	48.09	47.72	47.63	47.72	47.75	47.77	47.76	47.56	47.70	47.88
Al ₂ O ₃	17.31	18.24	18.15	18.13	17.78	17.72	16.98	16.94	16.87	17.02	16.94	17.07	17.13	17.01	16.95
Fe ₂ O ₃	3.54	3.32	3.52	3.27	3.10	3.51	3.60	3.67	3.33	3.27	3.34	3.09	3.21	3.22	3.44
FeO	6.99	6.64	6.36	6.66	7.00	6.64	7.02	6.99	7.35	7.38	7.28	7.47	7.39	7.42	7.25
MnO	0.18	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
MgO	5.60	4.96	4.96	4.85	5.27	5.38	5.97	5.96	5.98	5.81	5.83	5.76	5.89	5.78	5.65
CaO	10.39	10.22	10.20	10.26	10.25	10.37	10.59	10.68	10.64	10.60	10.59	10.59	10.55	10.63	10.56
Na ₂ O	3.93	4.10	4.12	4.08	4.05	3.94	3.76	3.80	3.74	3.80	3.87	3.88	3.88	3.87	3.89
K ₂ O	1.90	1.98	1.96	2.02	2.00	1.93	1.92	1.91	1.92	1.92	1.93	1.92	1.94	1.90	1.90
TiO ₂	1.72	1.65	1.66	1.66	1.68	1.67	1.72	1.72	1.73	1.72	1.72	1.72	1.73	1.73	1.75
P ₂ O ₅	0.55	0.56	0.57	0.58	0.58	0.56	0.54	0.53	0.54	0.55	0.55	0.54	0.54	0.54	0.54
Fe ₂ O ₃ t	11.30	10.69	10.59	10.67	10.87	10.89	11.40	11.43	11.50	11.47	11.43	11.39	11.42	11.46	11.49
C.M.F.	27.29	25.87	25.75	25.78	26.39	26.64	27.96	28.07	28.12	27.38	27.85	27.74	27.86	27.87	27.70
K ₂ O/Na ₂ O	0.483	0.483	0.476	0.495	0.494	0.490	0.511	0.503	0.513	0.505	0.499	0.495	0.500	0.491	0.488
Plagioclase		16.5	17.0	22.0	24.3								30.5		
Pyroxene		7.7	7.0	5.7	6.7								12.2		
Olivine		1.5	2.1	1.1	1.8								3.1		
Titanomagnetite		1.1	0.9	0.8	1.0								1.9		
Groundmass		73.2	73.0	70.4	66.2								52.3		
Porph. index		26.8	27.0	29.6	33.8								47.7		

77-01, scoria from the beginning of NE Crater eruption, 16 July 1977.

77-02, compact bomb erupted at 16.30, 16 July 1977.

77-05, air quenched specimen of lava flow at vent, N slope of NE cone, 20 July.

77-14, flow from 14 August eruption.

78-01, very vesicular scoria from Jan. 7, 1978 eruption.

78-03, last flow from NE Crater, March 1978.

78-07, early flow from the upper part of SE fissure near 3000 m a.s.l., 29 (?) April 1978.

78-09, flow from SE hornito (2880 m a.s.l.), May 1978.

78-18, overflow from SE Crater toward Padella, 26 August 1978.

78-51, flow from SE fissure in Valle del Bove (1800 m a.s.l.), Nov. 1978.

79-07, early flow from upper part of SE fissure, 3 August 1979.

79-06, lava flow near Fornazzo, from E fissure in Valle del Bove, 4 August 1979.

79-02, flow from NE «1928» fissure above Citelli refuge, 6 August 1979.

80-04, lava lump from Central Crater Chasm, mid-April 1980.

80-01, scoria from SE Crater, 3 May 1980.

80-02, scoria from SE Crater, 3 June 1980.

80-05, flow from NE Crater, 1 Sept. 1980.

80-06, flow from NE Crater, 6 Sept. 1980.

81-07, first flow emitted at the upper part of NNW fissure (2550 m a.s.l.), 17 March 1981.

81-06, main flow from NNW fissure (1400 m a.s.l.), 17 March 1981, sampled near Montelaguardia.

81-05, late flow from the lower part of the NNW fissure (1180 m a.s.l.), 22 March 1981.

83-01, front of the first flow erupted from the South flank fissure (2400 m a.s.l.), morning of 28 March 1983.

83-03, front of a flow near Sapienza refuge, emitted on the evening of 28 March at 2300 m a.s.l.

83-05, air quenched specimen at the main lava vent (2300 m a.s.l.), night 31 March/1 April.

83-09, same conditions as above, 16 April.

83-15, partly quenched (?) specimen, 1 May.

83-22, water quenched specimen, 14 June.

83-26, air quenched specimen, 20 June.

83-35, air quenched specimen from a resurgent flow near Sapienza refuge, 7 July.

84-12, partly water quenched lava flow at vent, E slope of SE Crater, 5 June 1984.

TABLE 2 - Representative EPMA (Electron probe microanalyses) of olivines from 1983 lavas. Ph, phenocrysts (c, core; r, rim); mPh, microphenocrysts; m, microlites.

	Ph	Phc	Phc	Ph	Ph	mPh	mPh	m	m
SiO ₂	40.22	39.54	38.46	38.48	38.19	38.39	37.46	37.29	36.40
FeO	17.43	17.63	25.09	22.75	23.38	26.27	28.06	30.38	34.46
MnO	0.32	0.55	0.50	0.29	0.62	0.64	0.50	0.82	0.68
MgO	42.89	42.59	36.34	38.82	36.89	34.61	33.17	32.05	27.20
CaO	0.26	0.27	0.45	0.29	0.37	0.78	0.53	0.57	0.74
Total	101.11	100.57	100.84	100.65	99.45	100.69	99.72	101.11	99.48
Mg/Mg+Fe	81.5	81.3	72.2	75.4	73.9	70.3	68.0	65.5	58.6
cations	2.993	3.001	2.976	3.005	2.996	2.988	2.994	2.999	2.985

elements, excepted FeO, were determined by XRF spectrometry (Lab. de Pétrologie minéralogique, Univ. de Paris VI) using the BCR-1 standard. In Table 1, the analyses are recalculated to 100% on a water-free basis.

The mineralogy of various 1977-1983 (84) samples has been investigated using methods described in CLOCCHIATTI and METRICH (this volume). Electron-probe microanalyses (EPMA) of minerals were performed on CAMEBAX microprobes at Paris-Sud and Paris VI universities. EPMA of Cl and S were carried out as indicated in BIZOUARD *et al.*, 1982. The temperature of trapping of some glass inclusions was determined by means of a heating stage under optical microscope (CLOCCHIATTI, 1975; CLOCCHIATTI and METRICH, this volume).

MINERALOGY

As previously reported (*e.g.* TANGUY, 1980) the mineralogy of Etna historic lavas is quite uniform; the same holds true for the 1977-1983 period. The most significant variations result from differences in the relative proportions of nearly identical mineral phases and in the total phenocryst content of the lavas (porphyritic index). These will be discussed together with the chemical analyses (whole-rock chemistry section).

The general description given below mainly pertains to the 1983 lavas, but it may be extended to all the samples studied. Crystals larger than 0.2 mm are termed phenocrysts, those between 0.2 and 0.01 mm are microphenocrysts, <0.01 mm are microlites.

TABLE 3 - Representative EPMA of pyroxenes.

	Ph	Ph	Ph	Ph	mPh	mPh	mPh	m	m
SiO ₂	49.96	49.66	48.71	50.71	48.10	45.80	48.55	48.33	44.32
TiO ₂	1.07	1.12	1.45	1.37	1.73	2.48	2.24	1.90	3.90
Al ₂ O ₃	4.59	5.07	5.15	4.18	5.74	7.17	4.83	6.27	9.05
FeO	6.13	6.62	7.55	8.28	8.82	9.22	10.34	11.13	11.99
MnO	0.11	0.05	0.19	0.31	0.17	0.15	0.41	0.24	0.18
MgO	15.06	14.37	13.86	13.61	12.67	11.97	12.42	11.55	9.00
CaO	23.19	22.80	22.75	21.35	22.07	22.17	21.35	20.14	19.60
Na ₂ O	0.35	0.30	0.31	0.60	0.71	0.46	0.53	0.76	0.94
Cr ₂ O ₃	-	0.27	-	-	0.01	-	-	-	-
Total	100.45	100.35	99.98	100.42	100.01	99.42	100.68	100.31	99.01
Mg	43.0	41.9	40.4	40.7	38.0	36.3	37.2	36.0	30.3
Fe	9.7	10.7	12.2	13.7	14.7	15.6	17.2	19.3	22.5
Ca	47.3	47.4	47.4	45.6	47.3	48.1	45.6	44.8	47.2
Mg/Mg+Fe	0.816	0.796	0.768	0.747	0.721	0.700	0.684	0.651	0.575

Olivine (Table 2)

In the 1983 lavas, olivine is present as scarce, fractured phenocrysts Fo 82-75, often forming aggregates (samples 83-01 and 83-15), and more frequently as microphenocrysts Fo 75-68, having a rather homogeneous composition (Fig. 1a and 1b). The phase observed at the eruption temperature (1073°C, see below: 1983 flank eruption lavas) is an olivine Fo 68.5. In water quenched specimens (83-22), this olivine corresponds to modal microphenocrysts and microlites larger than 50 microns. Under natural cooling conditions, however, microlites and the outer rims of phenocrysts can reach Fo 58.

This evolution trend may be found in all the samples studied for the period 1977-1983, and also for a 1984 lava flow from the SE crater (84-12). Sometimes, a slight reverse zoning (Fo 74 to Fo 76) is observed especially in microphenocrysts, where inclusions are also frequent: they consist of glass, spinel, plagioclase, pyroxene, apatite, sulphides.

Clinopyroxene (Table 3)

Clinopyroxene forms abundant euhedral phenocrysts and contains numerous crystalline or glass inclusions. They are salites (Fig. 1) showing slight variations that seem related to sector zoning (*e.g.*, rims of the most magnesian crystals En 43.0 Fs 9.7). Usual compositions range from En 40 Fs 12 to En 39 Fs 15. Ratios Mg/Mg+total Fe are between 0.816 and 0.690 and more frequently around 0.750. The Mg/Mg+Fe ratios cover the same range as olivine, suggesting that equilibrium has been reached for the two phases during crystallization.

For samples cooled under natural conditions (*e.g.*, 83-01), microlites and outer rims of phenocrysts reach En 30.3 Fs 22.5 and, on occasion En 20.5 Fs 32 (Fig. 1).

The composition En 40 Fs 12 to En 32 Fs 15 is rather representative for pyroxenes of the 1977-1983 (84) period (Fig. 2). A detailed study (*s.* 83-22, water quenched) suggests that the compositional

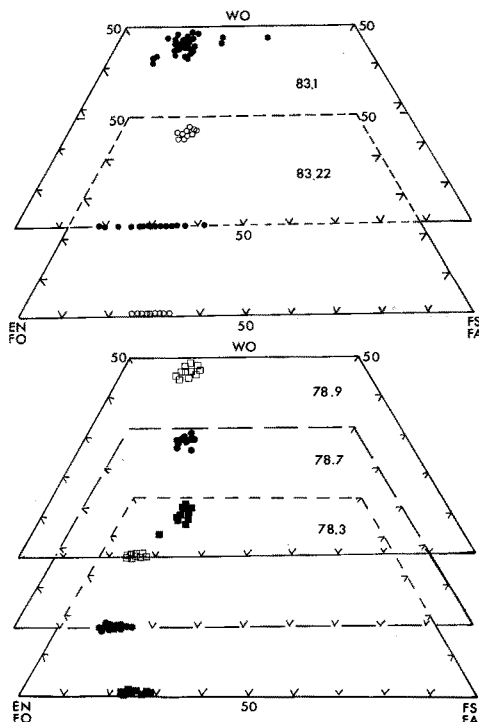


FIG. 1 - Composition of ferromagnesian silicates in 1983 lava flows (above) and other flows from the 1977-83 period (below). 83-01 is a slowly cooled flow, 83-22 is a water quenched specimen at the lava source. Note the slightly more forsteritic olivine 78-07, which is the most basic lava of the period, through having the highest K/Na ration (see whole-rock chemistry).

range for all samples of this period may be found within a single crystal (Fig. 3). Mineral inclusions in pyroxenes have also been analysed. Plagioclase is present either as euhedral or rounded grains, both containing glassy inclusions usually trapped during the last stages of crystallization; euhedral crystals are 400 to 600 microns in length and have a composition of An 85-45, rounded grains are An 65-55 and smaller than a few tens of microns in size. Other minerals are also included in pyroxene: olivine Fo 75-69, oxides and apatite.

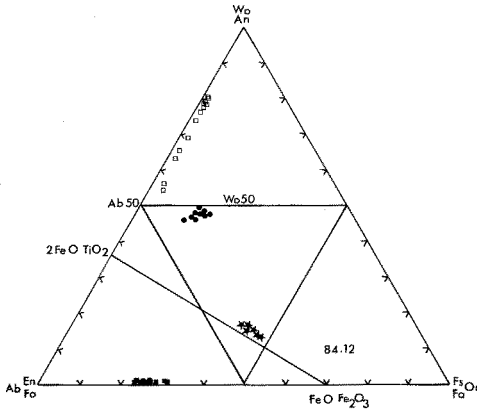


FIG. 2 - Mineralogy of a 1984 flow from SE crater. Solid squares, olivine; open squares, plagioclases; dots, pyroxenes; stars, magnetites.

Oxides are titanomagnetites Usp 39.5 to 34.5, that exist as euhedral or rounded microphenocryst, or as thin overgrowth in pyroxene, of which only one analysis has given a composition of Usp 20.

Plagioclase (Table 4)

Plagioclase phenocrysts barely exceed one millimeter in their largest dimension. The exhibit a core containing abundant glass inclusions and a surrounding zone some tens of microns large, free of inclusions. Glass-rich cores An 85-75 and the outer zones range from An 75 to more

sodic compositions depending of the crystallinity, related to the cooling rate. For slowly cooled samples (natural conditions), microlites and the outer rims of phenocrysts may reach An 40-35, while in a water quenched sample at 1073°C (83-22) the crystallization stops at An 55. It is inferred, therefore, that this phase is in equilibrium with the magma at 1073° C (Fig. 4).

In all the 1977-1983 lavas, the first plagioclase to appear is a bytownite An 85-80. Anorthite An 92-90 has been found in one 1983 specimen, but may represent a xenocryst. In some samples, a bimodal distribution of compositions may correspond to the glass-rich cores and inclusion-free zone described above.

Iron Titanium Oxides (Table 5)

Oxides are represented by titanomagnetites, as either isolated microphenocrysts or aggregates. They also occur as inclusions in olivine (from Fo 75) and in salitic pyroxene. Oxides frequently are associated (95% of the observed examples) with ferromagnesian silicates, which provide nucleation. This explains their abundance as inclusions in olivine and pyroxene phenocrysts.

Early crystallized titanomagnetites are Al and Mg rich, with an average composition of Usp 30. They become richer in Ti and poorer in Al and Mg as crystal sizes decrease, with a composition around Usp 40-45 (Fig. 5).

TABLE 4 - Representative EPMA of plagioclases.

	Ph	Ph	Ph	Ph	Ph	Ph	mPh	mPh	m	m	m	m
SiO2	46.05	47.52	48.23	48.20	48.10	49.20	50.82	50.93	53.70	55.11	56.46	58.03
Al2O3	33.95	32.80	32.99	32.76	32.43	32.08	31.20	30.34	28.48	27.46	26.77	25.11
Fe2O3	0.53	0.78	0.63	0.77	0.67	0.75	0.88	1.02	0.97	0.96	0.87	1.40
CaO	18.80	16.72	16.45	16.35	16.09	15.03	13.84	13.93	11.61	10.35	9.68	7.83
Na2O	1.00	1.71	2.06	2.16	2.31	2.56	3.35	3.65	4.71	5.20	5.41	6.02
K2O	0.09	0.14	0.20	0.25	0.24	0.24	0.31	0.34	0.68	0.74	1.02	1.52
Total	100.45	99.67	100.56	100.49	99.84	99.88	100.40	100.21	100.16	99.82	100.20	99.90
An	90.78	83.76	80.63	79.61	78.33	75.38	68.37	66.62	55.52	50.22	46.89	38.23
Ab	8.79	15.49	18.26	19.06	20.38	23.25	29.89	31.53	40.71	45.60	47.34	53.05
Or	0.57	0.89	1.24	1.47	1.42	1.51	1.88	1.99	3.91	4.31	5.90	8.85
cations	5.00	4.98	5.00	5.00	5.00	4.99	4.99	5.01	5.01	5.00	4.99	4.99

TABLE 5 - Representative EPMA of magnetites. Fe_2O_3 and FeO calculated by assuming stoichiometry.

	m	mPh	mPh	mPh	mPh	mPh	m	m
SiO ₂	0.19	0.12	0.10	0.22	0.12	0.21	0.13	0.17
TiO ₂	7.30	11.80	12.51	12.77	13.45	13.74	14.16	14.57
Al ₂ O ₃	7.76	6.41	6.44	5.83	6.11	6.16	5.32	6.34
FeO	28.57	34.35	35.22	34.47	36.71	37.55	37.81	37.59
Fe ₂ O ₃	47.72	41.37	39.96	39.79	37.60	36.63	36.82	35.83
MgO	6.42	5.47	5.36	5.91	4.91	4.45	4.34	5.08
CaO	0.52	0.19	0.04	0.05	0.07	0.03	0.07	0.31
Cr ₂ O ₃	0.45	0.10	0.11	0.01	0.07	0.01	0.20	0.17
MnO	0.64	0.52	0.49	0.43	0.40	0.51	0.61	0.58
Total	99.58	100.33	100.24	99.46	99.55	99.29	99.45	100.64
% USP	20	31.7	33.5	34.8	36.7	37.7	38.7	39.1

Crystallization Temperature of Phenocrysts

The phenocrysts crystallization temperature has been estimated by determining the homogenization temperature of trapped glasses (see below), using a heating stage under microscope. Because the phenocrysts are strongly cracked (thermal fracturing) and/or contain large amounts of glass, they are often broken during heating. A temperature of $1172 \pm 20^\circ\text{C}$ has been found for an olivine Fo 75, while various plagioclases of composition An 80-60 have given results between 1168 and

1140 (± 20) $^\circ\text{C}$. As the crystallization of salitic pyroxene appears very close to that of plagioclase, similar temperatures are also probably valid for this mineral. A lower limit for intratelluric crystallization is given by the 1073°C value, which is the eruption temperature of the lava measured in the field (see below: 1983 south flank lavas).

Groundmass

Because of the particular sampling conditions (quenching at the vent, pyroclast or surface of flow), the mineral above described are embedded in a more or less homogeneous glass. Microlites, close in size to microphenocrysts, are scarce and sometimes lacking. Therefore, typical groundmass minerals (alkali feldspar and feldspathoids; TANGUY 1966, 1980) do not crystallize. The composition of the glass is discussed in the following section.

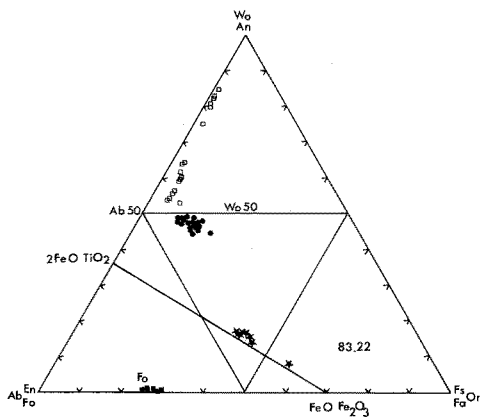


FIG. 3 - Composition of a single pyroxene crystal and related mineral inclusions. 83-22 quenched lava. Symbols as in Fig. 2.

INTER- AND INTRA-CRYSTALLINE GLASSES

Glasses included in minerals during their growth and residual glasses from the groundmass of five 1983 samples (and also 84-12) have been studied by electron microprobe. Chlorine and sulphur have been determined on the various types of glass from the 1983 eruption.

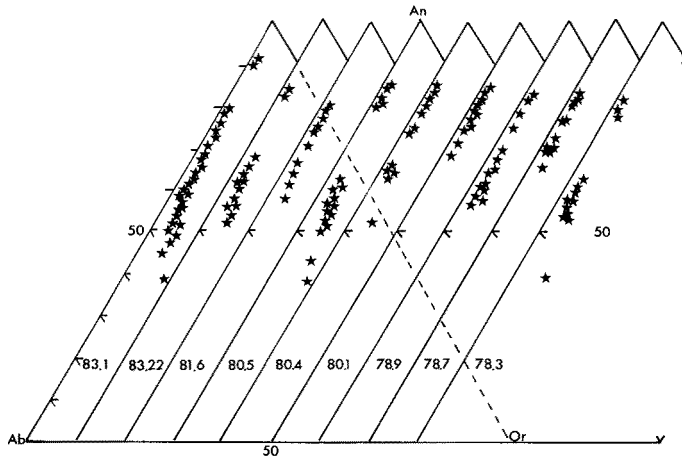


FIG. 4 - Composition of 1978-83 plagioclases.

Residual Glasses (Table 6)

The composition of each residual glass has been compared to that of the corresponding whole-rock (Fig. 6). The whole rock composition is akin to that of an alkaline basalt (JORON and TREUIL, in preparation), whereas residual glasses range from trachybasalt (hawaiite) (83-05, 83-21, 83-22, 84-12) to trachyte (83-01), through trachyandesite (mugearite) (83-15). This evolution is linked to the cooling history. Samples 83-22 and 84-12, which contain the less evolved glass, were water quenched from 1073 and 1076°C, respectively. 83-05, 83-21 and 83-15 were air

quenched and 83-01 has been taken at a lava front slowly cooled in natural conditions.

Figure 6 shows that Mg/Mg+Fe ranges from 0.550 to 0.375 during the intratelluric stage of crystallization (within the eruptive channel) and by the same order of magnitude (0.375 to 0.250) after the lava effusion, depending on the cooling rate. During crystallization the alkali content increases almost linearly by a factor of 1.4 to 1.5, the K_2O/Na_2O ratio being nearly constant (0.7). Thus, if crystal fractionation concentrates alkalis in residual glass, it cannot account for a K/Na increase of the magma (see below, K_2O enrichment during the last decade).

TABLE 6 - EPMA of average groundmass glasses.

	83-22	83-21	83-05	83-15	83-01	84-12
SiO ₂	50.04	49.34	50.01	49.58	50.18	50.06
TiO ₂	2.03	2.20	2.06	2.34	2.18	2.17
Al ₂ O ₃	16.35	16.07	16.32	15.79	16.18	16.41
FeO	10.42	10.64	10.19	10.45	10.70	10.30
MgO	3.12	3.10	2.97	2.46	1.80	3.22
CaO	7.04	7.14	7.09	7.22	5.78	7.46
Na ₂ O	5.51	5.43	5.51	6.22	7.05	5.47
K ₂ O	3.64	3.87	3.98	4.44	5.02	3.51
MnO	0.21	0.18	0.23	0.24	0.37	0.18
Total	98.36	97.97	98.36	98.72	99.26	98.78
S*	400	410	-	-	435	-
Cl*	1680	1800	-	-	2870	-

Calculations of crystal fractionation by the least squares method (WRIGHT and DOHERTY, 1970) demonstrate that the residual glass from specimen 83-22 can be obtained from the whole rock composition by subtracting 45.5% phenocrysts by weight, of which 24.9% plagioclase (An 78.8 Or 0.7), 12.3% pyroxene (En 41.4 Fs 12.2), 5.3% olivine (Fo 76.6), 2.9% titanomagnetite (Usp 39). This is in general agreement with the modal analyses presented in Table 1; the small discrepancies observed probably result from the mineral compositions used for the compu-

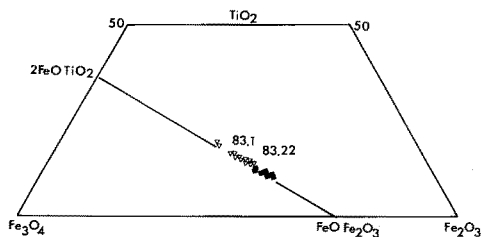


FIG. 5 - Composition of magnetites. Solid diamonds, olivine trapped crystals; open triangles, microphenocrysts and microlites.

tations. In slow cooling conditions (83-01), the crystal content reaches a maximum of 54.3% of the whole rock, as calculated by the same least squares method.

Glasses Included in Crystals (Table 7)

A detailed study of mineral inclusions in pyroclasts from the 1669 (Monti Rossi) and 1892 (Monti Silvestri) eruptions has been made and results are reported elsewhere (CLOCCHIATTI and METRICH, this volume). In the present paper, only the 1983-84 samples will be considered.

Glass inclusions have been analysed in olivines Fo 75, salites, plagioclases An 80-

65, titanomagnetites Usp 30. Data are against the Kuno solidification index (S.I. = $MgO/MgO + FeO + Na_2O + K_2O$) and compared to the compositions of whole rocks and residual glasses (Fig. 7). The included glasses (filled circles) fall between S.I. = 18-12. Some points (from oxides, olivines, and a few pyroxenes) are located along the line (AB) joining whole rocks to residual glasses, while others (mainly from plagioclases) fall on another line AC. This means that plagioclase become enriched in alkalis and depleted in Ca and Al, thus indicating growth at the expense of the included liquid. The phenomenon can be easily observed under optical microscope.

By comparison with inclusions in minerals of 1669-1892 pyroclasts, there is a gap between S.I. = 28 and 18. This may result from the scarcity of olivine more magnesian than Fo 75 in 1983-84 lavas, perhaps indicating crystal settling.

Volatile Components

Chlorine and sulphur have been determined in mineral trapped glasses and residual glasses from 1983 lavas. Although K_2O has been found to have an unusual

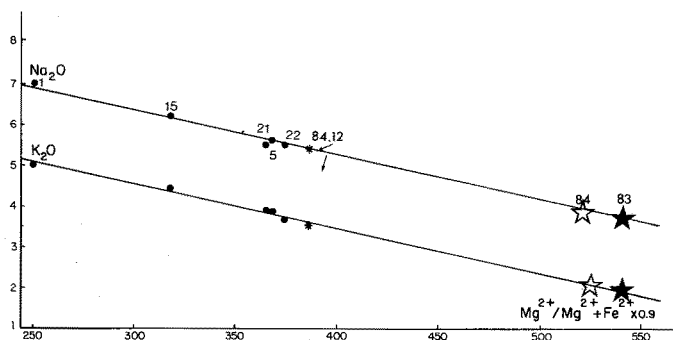


FIG. 6 - Alkali content of groundmass glasses versus Mg/Mg+Fe. Stars indicate the average whole-rock composition of 1983 samples (solid) and that of 84-12 (open); asterisks, glassy groundmass of 1984 (March), lava flow, water quenched sample; solid dots, glassy groundmass of 1983 (June) lava flow 22 water quenched sample, 21 and 5 air quenched samples, 15 and 1, natural cooling, scoria and lava flow.

TABLE 7 - EPMA of crystal trapped glasses.

	83 OX	83 OX	83 FL	83 PL	83 PX	83 PX	83 OL	83 OL	84 OL	84 OL	84 PL	84 PL	84 PX	84 PX
SiO ₂	49.42	50.79	48.84	48.92	50.43	50.60	48.71	48.77	48.80	49.24	49.12	49.11	52.31	52.30
TiO ₂	1.92	1.71	2.00	1.78	1.65	2.34	2.60	2.27	1.68	1.67	2.06	2.03	2.82	2.70
Al ₂ O ₃	16.71	16.39	16.35	17.17	18.34	17.32	16.36	17.16	17.38	17.54	16.17	16.87	17.08	16.93
FeO	10.63	9.05	10.24	9.01	9.55	10.88	10.94	11.49	11.13	11.15	10.51	9.66	8.12	7.44
MgO	3.70	3.76	3.05	3.08	3.14	2.66	2.21	2.14	3.61	3.41	4.34	3.43	2.68	2.93
CaO	8.32	8.66	6.86	7.24	6.33	6.67	8.81	8.78	8.72	8.68	6.08	5.90	6.52	6.93
Na ₂ O	5.30	5.61	5.42	7.43	6.18	5.50	5.80	5.86	5.87	5.92	5.52	6.69	5.47	5.58
K ₂ O	3.06	2.94	3.52	3.63	2.59	2.72	2.65	2.60	2.06	2.06	4.86	5.51	2.82	3.36
MnO	0.21	0.23	0.26	0.14	0.09	0.17	0.07	0.21	0.19	0.20	0.17	0.28	0.15	0.18
Total	99.32	99.14	99.54	98.38	98.31	98.86	98.15	99.28	100.44	99.88	98.82	99.49	97.42	98.35
S*	970	-	710	800	810	-	1200	-	-	-	-	-	-	-
Cl*	2300	-	2190	1950	2080	-	1930	-	-	-	-	-	-	-

* ppm

behaviour in lavas of the 1977-1983 period (see whole-rock chemistry), potassium does not show any significant variation throughout the 1983 eruption (Table 1). It can be used, therefore, as a tracer of the differentiation of the liquid during the final stage of crystallization (Figs. 6 and 7). As for the 1669-1892 eruption (CLOCCHIATTI and METRICH, this volume), there is a negative correlation between S and K₂O as crystal fractionation proceeds, the S values ranging from 1200 ppm in inclusions trapped in olivine to 400 ppm in the groundmass. Conversely, chlorine seems to exhibit a rather magmaphile behaviour. The gradual loss of sulphur leads, therefore, to a steady decrease of S/Cl ratio during crystallization of the liquid.

Various cooling rates (leading to more or less important groundmass, see above) do not seem to affect sulphur content in the groundmass glass. However, the effect is important on chlorine, whose concentration varies from 1680 to 2800 ppm.

If the volume of 1983 lava, the sulphur content before degassing and that of partially degassed groundmass are known, it is possible to calculate the gas budget for this component. Although the content of primary liquids has not been measured in the 1983 lavas, it can be approximated by extrapolating the straight line of sulphur decrease (ROSE *et al.*, 1982). The extrapolated value is 1500 ppm (Fig. 8), according to a K₂O content of about 2% in the magma. If the 1500 ppm value is representative of the initial S content of

the 1983 lavas, these have been degassed by as much as 73%. By assuming a total amount of lava around $70 \times 10^6 \text{ m}^3$ (TANGUY and PATANE, this volume), corresponding to 18×10^7 tons of magma ($d = 2.6$), then 20×10^4 tons of sulphur should have been emitted during the 130 days long eruption, *i.e.* 1500 tons/day, or 3000 t/d SO₂. This result is of the same order of magnitude as those obtained by direct measurements (HAULET *et al.*, 1977; MALINCONICO, 1979) and confirms the considerable amounts of sulphur emitted by Mount Etna.

WHOLE-ROCK CHEMISTRY

As previously observed (TANGUY, 1973, 1980), there has been no distinct variations as a function of time within single eruptions of the period 1971-1976. Relatively large differences, however, were evident between lavas erupted even contemporaneously on different parts of the volcano: 1971 or 1974 flank eruptions, or Central Crater, or North-East Crater (Fig. 9).

For the 1977-1983 lavas, such differences are still present, but significant variation as a function of time are found for some of the eruptions (1977-78 paroxysms of the NE Crater, or 1978-79 flank eruption), while other eruptions have supplied nearly identical material from their beginning to their end (*e.g.* 1983).

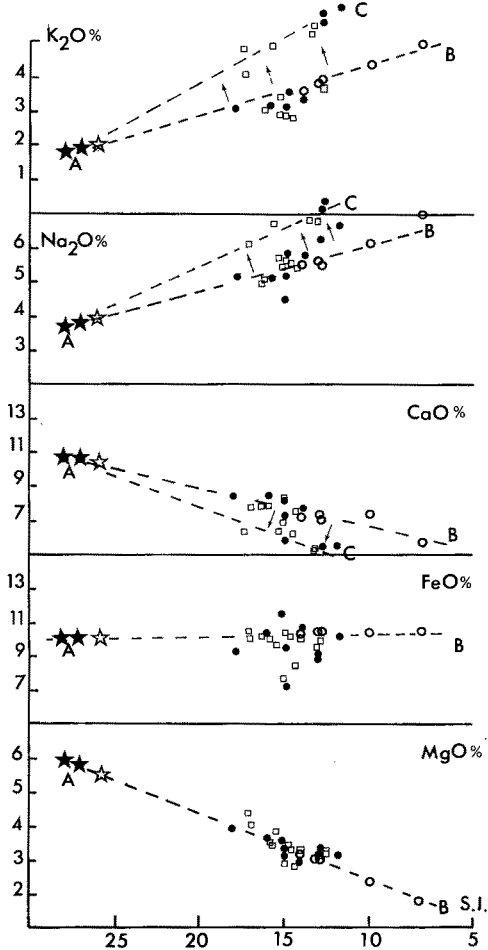


FIG. 7 - Glass composition versus Kuno solidification index (S.I.). Open circles, groundmass; solid circles, 1983 crystal trapped glasses; squares, 1984 crystal trapped glasses; stars, whole-rock (solid, 1983; open, 1984). Arrows indicate departure from line AB for plagioclase trapped liquids (see text).

1977-78 Lavas from the NE Crater

Lavas erupted from the NE Crater in July 1977 are the most evolved of the 1971-1983 period (Fig. 9 and Table 1). Three analyses performed on pyroclast and flow samples from this one week

eruption show no variation, and a CMF index of 24.9. However, a lava flow erupted on 14 August during a similar, but shorter paroxysm, is distinctly more femic, with CMF = 25.6. The same evolution apparently continued during subsequent eruptions, the CMF reaching 27.5 to 27.6 in January and March 1978.

The porphyritic index of these lavas is medium, slightly decreasing (38 to 29, Table 1 and Fig. 10) with increasing femic character (CMF), from July 1977 to March 1978. It is interesting to note that this phenocryst content is distinctly lower than that measured for usual «subterminal lavas» from the same NE Crater (*e.g.* 1955-1971), which had commonly 40 to 50% phenocrysts (TANGUY, 1980). This is consistent with the 1977-78 eruptive behaviour: the magma was intermittently and violently erupted from depth by short-lived paroxysms; it did not appear to be stagnant at high level in the vent as during the normal «persistent activity» (1955-1971). Both petrological and volcanological characters, therefore, suggest a

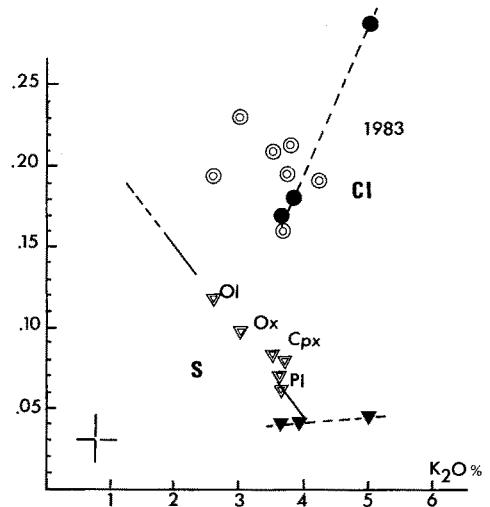


FIG. 8 - Cl (circles) and S (triangles) content versus K_2O of crystal trapped glasses (open symbols) and groundmass glasses (solid symbols) in 1983 lavas. Extrapolation of the full line enables an estimate initial sulphur content in the magma (see text).

relatively deep origin (at least several hundred meters) for the 1977-78 eruptions of the NE Crater. The variation observed may be explained by postulating a vertically zoned magma body from which batches were erupted. The most femic and less porphyritic lavas could have come from a deeper and hotter layer with sufficiently rapid ascent to minimize crystal fractionation.

1978-79 Flank Eruptions

A lava flow (78-07) produced during the earliest stage of the April-June 1978 eruption on the SE flank shows an even more femic composition (CMF = 28.3) and lower phenocryst content (23%). This is, indeed, the most femic and least crystallized lava of the 1977-1983 period.

Another remarkable feature is its high K_2O content, leading to an abnormal K/Na ratio for such a femic lava. This value is similar, in this respect, to that found in the 1974 West flank lava (TANGUY and KIEFFER, 1976). The significance of the K_2O enrichment will be discussed later.

This anomalous behaviour of K_2O was short-lived. From at least 10 May 1978 onwards (unpublished analysis on a sample given by R. Cristofolini), the chemical composition returns to more normal values (78-09, 78-18, 78-51), that are less femic (CMF = 27.8 to 27.1) with a higher phenocryst content (35-40%).

The 1979 eruption, which occurred first on the SE fissure and then on E and NE flanks, produced lava showing the same initial K_2O anomaly (79-07) as did the 1978 one. The high K_2O content was restricted to the earliest, SE flow, on the

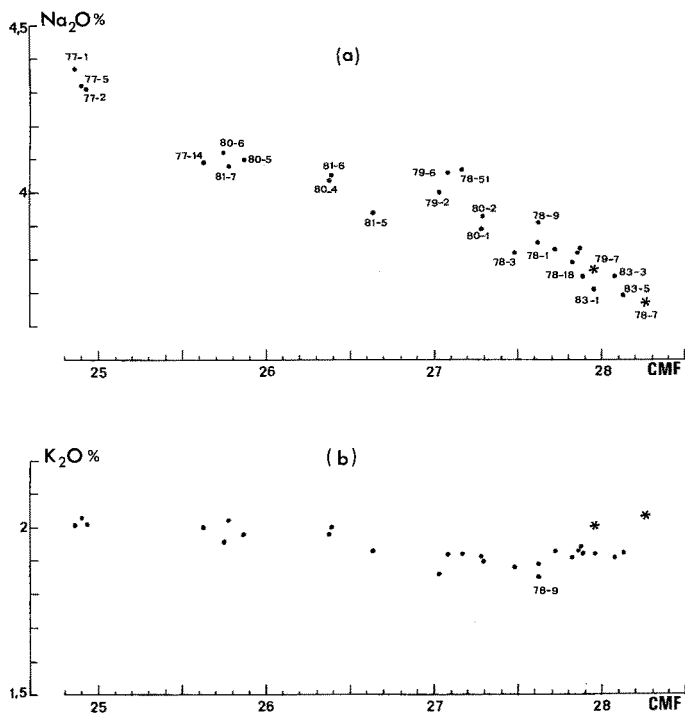


FIG. 9 - Variation of (a) K_2O/Na_2O and (b) CMF (= $CaO + MgO + \text{total } Fe_2O_3$; wt%) versus time for whole-rock analyses of 1977-84 lavas. Values of CMF are represented so as the less evolved lavas are located downwards.

evening of the 3 August. Lavas emitted only a few hours or days later on the E and NE side (79-06, 79-02) have a lower K/Na ratio although they are substantially less femic (CMF around 27).

These observations suggest a complex mechanism for the 1978-79 flank eruptions. It seems that they were triggered by a «K₂O rich» intrusion coming from depth (more basic with low phenocryst content). The deep origin of this magma could be attested by its similarity with the W 1974 lava, for which a 15-20 km depth source has been deduced (TANGUY and KIEFFER, 1976).

1980 Summit Lavas. 1981 North Flank Eruption

The products erupted between April and September 1980 in the summit area are slightly different, depending on vent

location: SE Crater (CMF = 27.3), Central Crater (CMF = 26.4), NE Crater (CMF = 25.8). As no temporal variation can be detected for each separate center (compare samples 80-01 and 80-02, or 80-05 and 80-06), it seems likely that these slight differences result from contemporaneous tapping at various levels of a zoned magma body. It must be pointed out that the central, SE and NE Craters are less than one kilometer apart from one another.

The earliest and topographically highest lava flow from the long (8 km) 1981 fissure is practically identical to the September 1980 lavas of the NE Crater (CMF = 25.8, with 27-29% phenocrysts). During the development in space (*i.e.*, downslope) and time of the 1981 fissure, the lava became slightly more femic (CMF = 25.8 to 26.6), with a constant K/Na ratio. This evolution is inverse, therefore, from that observed for the lavas from the 1978-79 flank eruptions.

1983 South Flank Lavas

Despite the over 4 months duration of the 1983 eruption and the substantial volume of lava emitted (60 to 80×10^6 m³, TANGUY and PATANE, this volume), no significant petrochemical variation has been observed. The products are decidedly femic (CMF around 28) and by far the most porphyritic emitted in the 1977-1983 period, the phenocryst content reaching almost 50%.

The quiet effusion of lava was exceptionally favourable for systematic sampling and accurate temperature measurements. Almost all samples were taken at the main lava vent and air or water quenched (Table 1). The lava temperature was measured at 40-60 cm depth in the main flow using Pt-PtRh and Chromel-Alumel thermocouples (detail are given in SEAN bulletin, vol. 8, n. 4 to 6, 1983). Various sets of measurements showed a nearly constant temperature of 1067-1073°C. Although unusually low for a basaltic lava, this temperature is consistent, however, with the high crystal

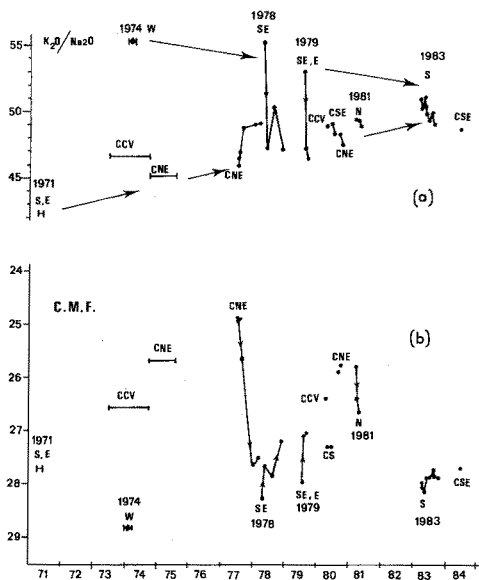


FIG. 10 - Porphyritic index (a) and pyroxene/plagioclase + pyroxene (b) versus time for 1977-83 lavas (phenocryst vol %).

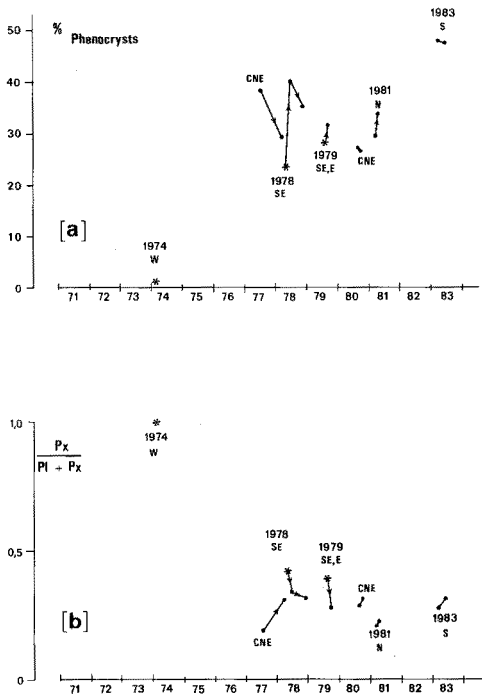


FIG. 11 - Na_2O and K_2O versus CMF for 1977-83 lavas. Asterisks represent 78-07 and 79-07 samples, with abnormally high K/Na ratio.

content observed (temperature of 1070-1080°C have been recorded in subterminal flows with the same crystal content, see ARCHAMBAULT and TANGUY, 1976). The consequent high viscosity of the liquid could explain, at least in part, the lack of differentiation, by preventing crystal settling before the eruption.

It must be recognized, however, that other lavas with low crystal content and high temperature of emission (1950, 1971) did not show evidence of chemical evolution either. As all these lavas are obviously not primary magmas (see Introduction), another explanation could be considered, *i.e.*, the fast rise from a deeper source where a comparatively large volume of melt exists.

K_2O ENRICHMENT OF LAVAS DURING THE LAST DECADE

The most remarkable petrochemical feature of the recent lavas lies in the abnormal behaviour of K_2O . This anomaly was first noticed for the 1974 eruption on the west slope and observed again in the first 1978 and 1979 outflows from the SE fissure. Although these products are the most femic of the past 12 years, they also have the highest K_2O content, leading to aberrant $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio (*i.e.*, increasing with increasing basicity). Figure 11 shows that while Na_2O is decreasing regularly, as expected, with increasing femic character (CMF index), K_2O remains nearly constant and even increases for the most anomalous samples (78-07 and 79-07). Such an abnormal behaviour of K_2O is unknown in all historic lavas, as well as in all Etna products analyzed so far (Fig. 12).

In addition to the 1974-1979 samples, a steady increase of $\text{K}_2\text{O}/\text{Na}_2\text{O}$ is observed for all the lavas erupted since 1971 (Fig. 9). This is clear when comparing the 1983 and the 1971 lavas which have a nearly identical differentiation index (CMF ca. 28). Such an evolution suggests that the «normal» magma standing in the central conduit may have been replaced by a more potassic liquid that first erupted independently as an eccentric eruption on the West slope (1974) (see also variation of pyroxene/plagioclase ratio, which roughly follows $\text{K}_2\text{O}/\text{Na}_2\text{O}$ during the 1977-1983 period, fig. 10).

It is not possible, as yet, to understand the origin of the «potassic» magma. For a better approach of the problem, however, the following considerations should be kept in mind:

1) the most potassic lavas were produced during violent explosive eruptions, though other strong outbreaks may not have produced this particular magma (*e.g.*, 1977-78 paroxysms of the NE Crater). On the other hand, it is often difficult to determine accurately the explosivity index of a flank eruption, as degassing may occur through the central vents;

2) as previously mentioned, the most

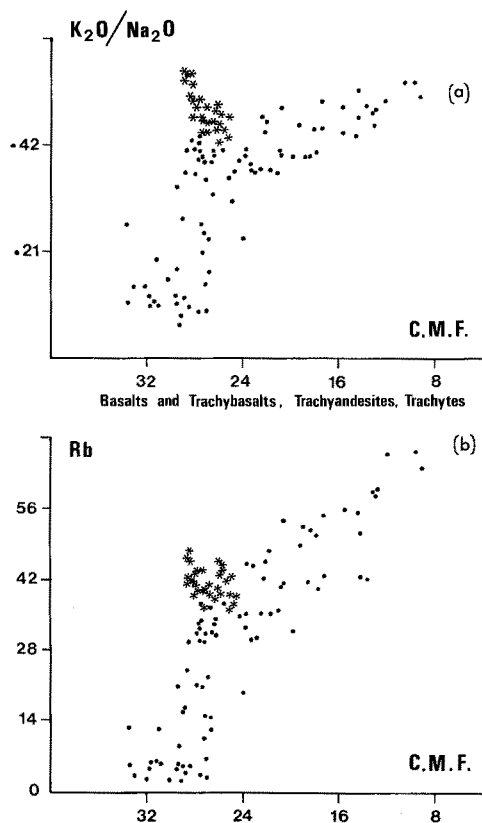


FIG. 12 - K_2O/Na_2O versus CMF of Etna lavas (TANGUY, 1980). Rb versus CMF (JORON and TREUIL, in prep.). Asterisks indicate lavas from the last decade, dots represent lavas from the whole Etna area, including pre-etnean tholeiitic basalts.

potassic lavas are the most femic and have lower phenocryst content. This seems to indicate a relatively deep source. Particularly, any kind of alkali enrichment by upward gaseous transfer must be precluded. It has been shown, moreover, that Na_2O follows a normal behaviour;

3) the potassium enrichment cannot be the result of some local process, for all the lavas of the past decade are more or less involved.

New investigations, using trace-element geochemistry (JORON and TREUIL, in

preparation) show that the excess of K is linked to an excess of Rb and, to a lesser extent, of Cs. The Rb anomaly is particularly strong and even more sensitive than for K, showing a beginning of «contamination» as early as 1971. It has been suggested that selective diffusion of K, Rb and Cs from rocks of the basement may account for the anomaly observed (see also Watson, 1982). This hypothesis is substantiated by the presence of strongly altered K-rich inclusions from the Etna basement in some historic lavas (CLOCCIATTI and METRICH, this volume). However, this does not explain why these lavas are not anomalous with respect to K, Rb and Cs, nor the fact that inclusions are not especially abundant in lavas emitted during the last decade.

Whatever the cause of the abnormal behaviour of the present etnean magma, this example demonstrates the importance of an accurate petrological monitoring of an active volcano. The exceptional activity displayed by Mount Etna during the past ten years clearly results from a magmatic process that seems, at the present state of our knowledge to have no equivalent in the geological history of the volcano.

ACKNOWLEDGEMENTS

The authors are indebted to P. Mousnier-Lompré, S. Scalia and G. Scarpinati for their assistance in carrying out temperature measurements and lava sampling during the 1983 eruption. Prof. R. Cristofolini provided efficient support for reaching the field of the same eruption. The SITAS s.p.a. is also acknowledged for transporting researchers and equipments on the volcanic zone in numerous occasions. Our work was greatly facilitated, moreover, by the cooperation of etnean guides. Some samples of the 1977-83 period were generously given by C. Archambault, R. Cristofolini, G. Kieffer and G. Scarpinati. In the laboratory, the chemical analyses were carried out by Ms M. Lenoble, N. Vassard and A. Bérard (Lab. de Pétrologie minéralogique, Univ.

Paris VI). The present paper has been reviewed by Prof. Danielle Velde, who is gratefully acknowledged for her constant interest in this work.

This is a contribution of the French program of volcanology (PIRPSEV, CNRS/INAG), in the context of a French-Italian cooperation (GNV, CNR).

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Ms. submitted June 1984. Revised ms. received Oct. 1985.