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R. Romano and C. Sturiale

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Some considerations on the magma of the 1971 eruption

By R. Romano[†] and C. Sturiale[‡]
[†] *Istituto Internazionale di Vulcanologia, C.N.R., Catania, Italy*
[‡] *Istituto di Vulcanologia, Università di Catania, Italy*

Lava samples, collected periodically during the 1971 eruption of Mt Etna, have been analysed. A certain evolution of their composition has been observed: the first lavas are phonolitic tephrites, while the last ones are mugearites. This evolution can be explained by assuming a pneumatolytic differentiation in the uppermost parts of the magma column and a subtraction of femic phenocrysts by gravitational differentiation in its deeper parts, where the last products originated.

Furthermore, the analyses of the 1971 lavas are compared with all available data of ancient products of this complex volcano and, particularly, with those of its historical eruptions.

During the Etna eruption of April to June 1971, fresh lavas were sampled periodically. Chemical and petrographical studies of these samples showed a certain evolution of the magma composition during the eruption, due to differentiation. Contrary to what would be expected, the first lavas show a higher colour index than the last ones. In order to find an explanation of this unusual fact, the results of our research have been compared with analyses of products of earlier historical eruptions of Mt Etna.

In the 1971 eruption of Mt Etna, two phases can be distinguished (figure 1):

(*a*) The first phase is characterized by the opening of four radial fissures at the southern and eastern base of the cone of the central crater. The activity of these fissures was mixed, explosive and effusive.

(*b*) During the second phase seven eruptive centres opened successively along a system of fissures with ENE alinement. The activity of these centres was almost exclusively effusive.

Seven specimens of lava emitted during the first phase (5 April to 7 May) have been analysed; six of them were collected at the most active centre near the observatory, and one at the centre on the eastern slope of the central cone. Six other analysed specimens of lava emitted during the second phase (7 May to 12 June) come from the eruptive centres at about 1800 m above sea level. It can be observed from tables 1 (chemical analyses and c.i.p.w. norms) and 2 (Rittmann-norms) that there was a considerable chemical difference between the first and the last lava to be erupted whereas all intermediate products show only slight variations among themselves.[†] This evolution of the magma is well illustrated by the Rittmann-norm of the first (A), the average of the intermediate (M) and the last (Z) lavas (figure 2). From A to Z nepheline, olivine and the colour index decrease, whereas plagioclase shows a considerable increase. The latter is confirmed by modal observation. Under the microscope a continuous decrease in the amount of glass from A to Z can be observed.

In short, these observations lead to the following:

(*a*) The magma emitted at the beginning of the eruption was relatively poor in silica and relatively enriched in pneumatophile elements, particularly sodium, titanium and iron.

[†] Since the preparation of this paper, we have learnt that J. C. Tanguy has published in a report to the Smithsonian Institution the results of four chemical analyses on lava samples collected between 7 and 12 May 1971 during the recent eruption. The chemical compositions recorded by Tanguy are in complete agreement with our findings for the lava emitted during that short period. However, we found different chemical compositions for the lava emitted at earlier and later dates of the eruptive period.

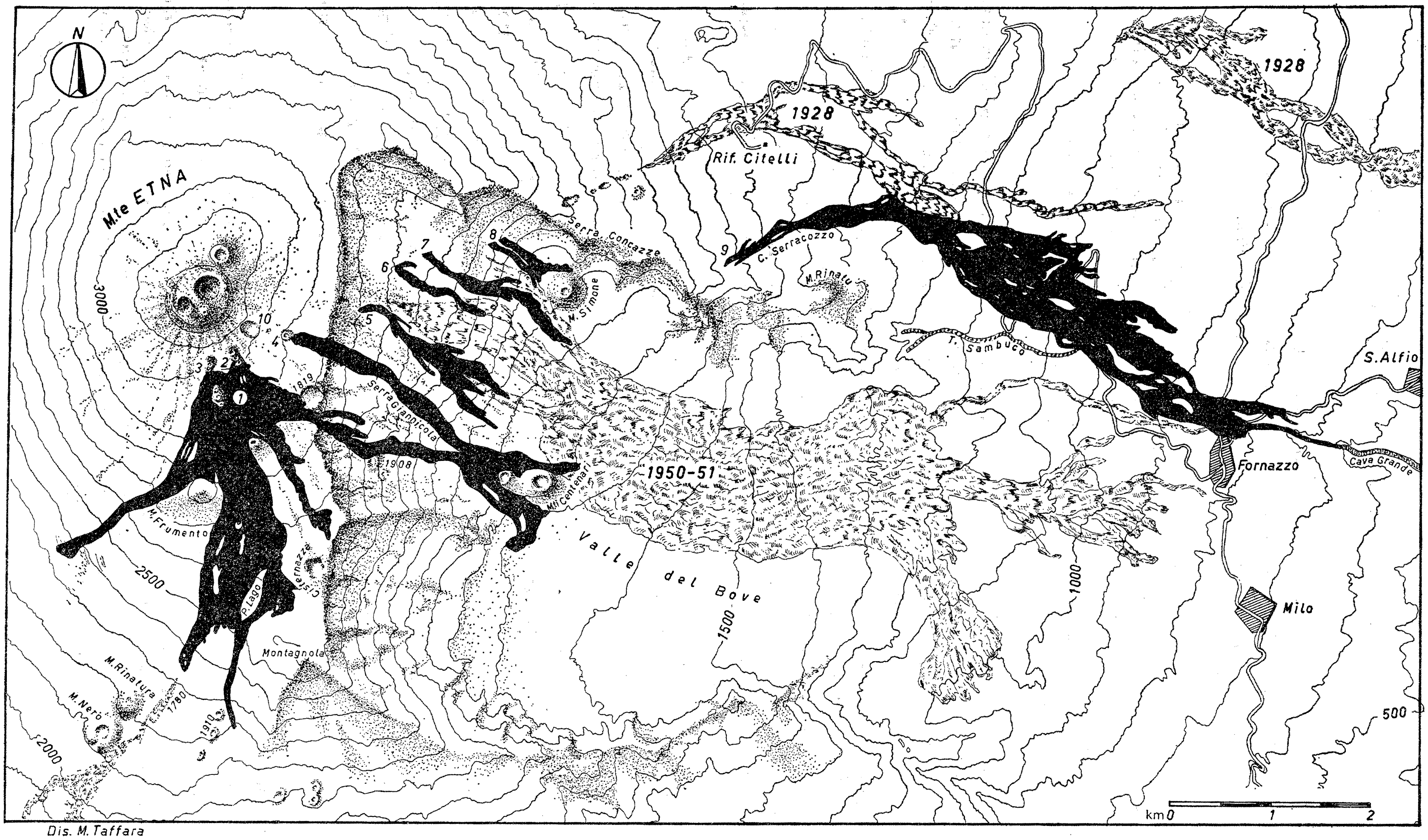

FIGURE 1. Sketch map of the vent and lava-flows in the 1971 eruption. (1) Observatory vent; (2) 'Vulcarolo' vent; (3) western vent; (4) eastern vent; (5) effusive eastern fissure at 2680 m; (6–7) effusive eastern fissures at 2580 and 2540 m; (8) effusive eastern fissures at 2300 m; (9) effusive fissures at Contrada Serracozzo; (10) explosion funnel at the eastern base of the central crater.

TABLE 1. CHEMICAL ANALYSES AND C.I.P.W. NORMS OF THE 1971 ERUPTION

		a	*b*	*c*	*d*	*e*	*f*+*g*	*h*	*i*+*j*	*k*+k_1	*l*
SiO_2		44.15	46.60	47.22	47.30	45.50	47.67	47.35	46.90	49.23	48.42
Al_2O_3		17.46	17.20	17.07	17.58	17.49	16.68	16.69	17.04	16.02	17.24
Fe_2O_3		3.82	6.14	4.91	3.93	4.74	4.31	4.41	4.84	4.62	7.46
FeO		7.18	4.45	5.88	6.89	6.10	6.64	6.46	6.06	6.13	3.59
MnO		0.19	0.19	0.17	0.18	0.19	0.18	0.18	0.19	0.17	0.17
MgO		6.65	6.65	6.55	5.64	6.75	6.19	6.55	6.29	6.40	6.04
CaO		10.37	10.37	10.37	10.37	10.23	10.65	10.37	10.37	9.60	9.67
Na_2O		3.90	4.06	3.80	3.90	3.98	3.62	3.66	3.91	3.92	3.84
K_2O		1.80	1.80	1.70	1.80	1.80	1.65	1.62	1.77	1.73	1.74
TiO_2		2.63	1.60	1.70	1.62	1.70	1.60	1.72	1.67	1.53	1.50
P_2O_5		0.50	0.42	0.60	0.66	0.44	0.55	0.50	0.51	0.47	0.51
H_2O^-		0.10	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
l.o.i.		0.80	0.85	0.65	0.76	0.67	0.73	0.71	0.67	0.68	0.39
total		99.55	100.43	100.62	100.63	99.69	100.47	100.22	100.22	100.50	100.57
total iron as Fe_2O_3		11.80	11.08	11.44	11.58	11.51	11.66	11.58	11.58	11.44	11.44
or		10.62	10.62	10.03	10.62	10.62	9.74	9.56	10.44	10.21	10.27
ab		11.13	18.37	20.68	19.79	14.45	21.21	21.07	18.89	26.99	27.73
an		24.83	23.40	24.51	25.16	24.55	24.40	24.34	23.73	21.02	24.68
ne		11.84	8.65	6.21	7.14	10.40	5.10	5.35	7.68	3.34	2.57
di	wo	9.74	10.56	9.61	9.17	9.74	10.37	9.95	10.18	9.82	8.33
	en	6.59	8.80	6.92	5.73	6.90	6.83	6.79	7.15	6.79	7.20
	fs	2.41	0.43	1.81	2.89	1.99	2.80	2.38	2.16	2.23	—
ol	fo	6.97	5.43	6.57	5.82	6.93	6.01	6.66	5.96	6.40	5.49
	fa	2.81	0.29	1.89	3.23	2.20	2.72	2.58	1.98	2.32	—
mt		5.54	8.90	7.12	5.70	6.87	6.25	6.39	7.02	6.70	7.77
hm		—	—	—	—	—	—	—	—	—	2.10
il		4.99	3.04	3.23	3.08	3.23	3.04	3.27	3.17	2.91	2.85
ap		1.16	0.97	1.39	1.53	1.02	1.27	1.16	1.18	1.09	1.18

(*a*) Phonolitic tephrite, scoriaceous lava, Piano del Lago (6/IV).
(*b*) Phonolitic tephrite, scoriaceous lava, Volcanological Observatory (9/IV).
(*c*) Phonolitic tephrite, scoriaceous lava, Volcanological Observatory (10/IV).
(*d*) Phonolitic tephrite, vent spatter, Observatory vent (11/IV).
(*e*) Phonolitic tephrite, vent spatter, Observatory vent (17/IV).
(*f*) Phonolitic tephrite, lava from the Observatory vent (28/IV).
(*g*) Phonolitic tephrite, lava from the eastern vent (5/V).
(*h*, *i*, *j*) Phonolitic tephrites, lavas from the fissure at 1840 m (12/V; 26/V; 3/VI).
(*k*, k_1) Mugearites, lavas from the fissures at 1800 and 1840 m (5/VI).
(*l*) Mugearite, lava from the fissure at 1800 m (12/VI).
(*f*+*g*; *i*+*j*; *k*+k_1) are averages from two analyses.

TABLE 2. RITTMANN-NORMS (VOL. %)

	a	*b*	*c*	*d*	*e*	*f*+*g*	*h*	*j*+*l*	*k*+k_1	*l*
sanidine	9.43	10.21	8.99	9.49	9.80	9.16	8.79	10.12	10.88	9.90
plagioclase	40.60	42.52	48.17	47.10	42.21	49.06	49.01	45.12	50.23	53.05
nepheline	13.16	11.06	7.79	11.71	12.09	6.10	6.53	9.20	4.42	5.28
clinopyroxene	21.03	22.29	20.25	18.53	20.63	22.02	21.19	21.56	20.80	17.49
olivine	10.11	9.38	9.80	8.21	10.48	8.86	9.69	9.14	9.11	9.55
magnetite	2.14	2.24	2.16	2.17	2.27	2.19	2.15	2.27	2.25	2.25
ilmenite	2.43	1.39	1.54	1.43	1.56	1.42	1.55	1.48	1.30	1.40
apatite	2.43	0.91	1.29	1.36	0.96	1.18	1.08	1.10	1.01	1.08
C.I.	36.82	36.21	35.05	31.70	35.89	35.68	35.66	35.56	34.47	31.78
A	14.9	16.0	13.8	13.9	15.3	14.2	13.7	15.7	16.6	14.5
P	64.3	66.7	74.2	69.0	65.8	76.3	76.2	70.0	76.7	77.7
F	20.8	17.3	12.0	17.1	18.9	9.5	10.1	14.3	6.7	7.8

(*b*) The magma emitted immediately afterwards was less desilicated but still rich in femic components. For nearly 2 months, its composition remained practically constant.

(*c*) The magma emitted towards the end of the eruption was only slightly desilicated and definitely poorer in femic components. Thus it differed considerably from the previous ones.

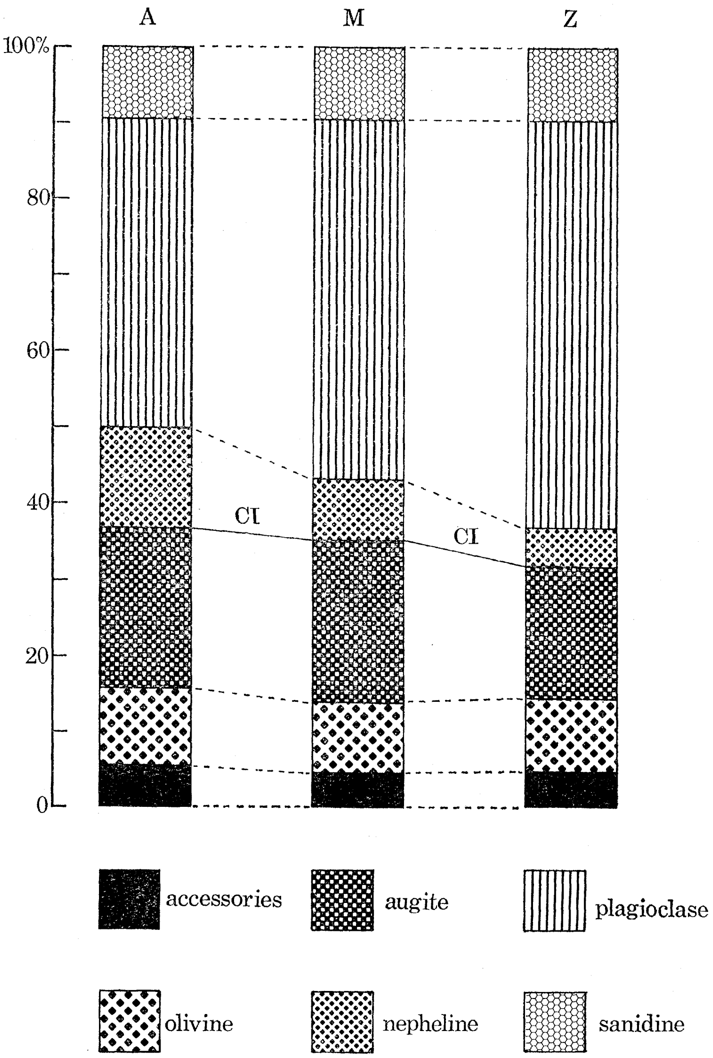

FIGURE 2. The evolution of the magma as shown by the Rittmann-norm values. (A) The first lava erupted; (M) average of the intermediate lavas; (Z) the last lava erupted.

The petrochemical continuity of the lavas erupted at the end of the first and the beginning of the second phase demonstrates that they originated in the same magma chamber. Hence, the interpretation is not valid that the feeders of the second phase were an abyssal fissure, along which magma arose from great depth to the surface.

The particular evolution of the magma during the 1971 eruption seems, on the basis of data in our possession, to be without precedent in the magmatic processes of other eruptions of the Etnean volcanic complex. In the double triangle of Streckeisen (figure 3) we have plotted Rittmann-norm values of volcanic rocks belonging to ancient edifices in the Etnean area and also others from the present volcano.† The two groupings of the plots imply a greater basicity for the more recent lavas, including those of the 1971 eruption, compared with those of other, more ancient edifices. In the latter the rocks with tephritic tendency are exceptions, such as in the Val Calanna edifice and the upper part of the Trifoglietto II volcano (Klerkx 1968).

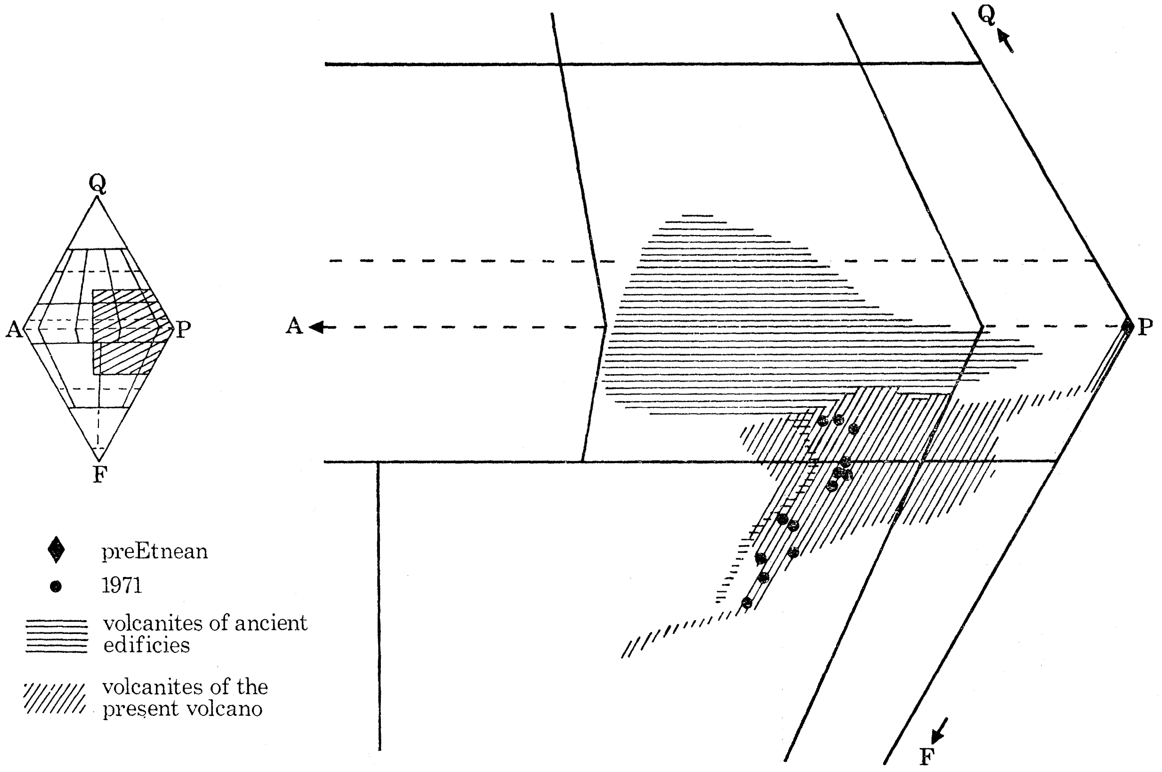

Figure 3. Plots in the double triangle of Streckeisen (1967) of the Rittmann–norm values of volcanic rocks belonging to ancient edifices in the Etnean area and to the present volcano.

Comparing (figure 4) the lavas of the recent eruption with those of other historical eruptions one observes that all of them show a certain evolution of the emitted magmas, but none of them comparable with that of the 1971 eruption, which appears to be unique.

The magmatic evolution during the eccentric eruption of 1669 can be explained by gravitational crystal fractionation, the earliest products being lighter than the last ones with which they are linked by gradual transition. In historical flank eruptions (1910, 1928 and 1950/51), analogous evolutions can be noted with the difference, however, that the degree of desilication varies during the eruption. This may be explained by a complex crystal fractionation – pneumatolytic differentiation of the magma before eruption.

The various processes of differentiation are conditioned by the mode of ascent of the magma along fissures, which may or may not be connected to the central vent of the active volcano, and by the possibility of degassing which, in its turn, may cause bi-phase convection in the pyromagma. The nature of the emitted magma depends furthermore on the depth at which the magma chamber is tapped.

† The analyses used for this have been taken from the literature; we have excluded those which were too old or of doubtful accuracy.

The particular character of the magma poured out at the beginning of the 1971 eruption can be explained in the following manner. After the terminal eruption of 1964, the eruptive activity shifted to the NE crater. However, in the central crater there was a relatively slow degassing in the form of fumarolic activity and, in 1968, through a blow hole in the western part.

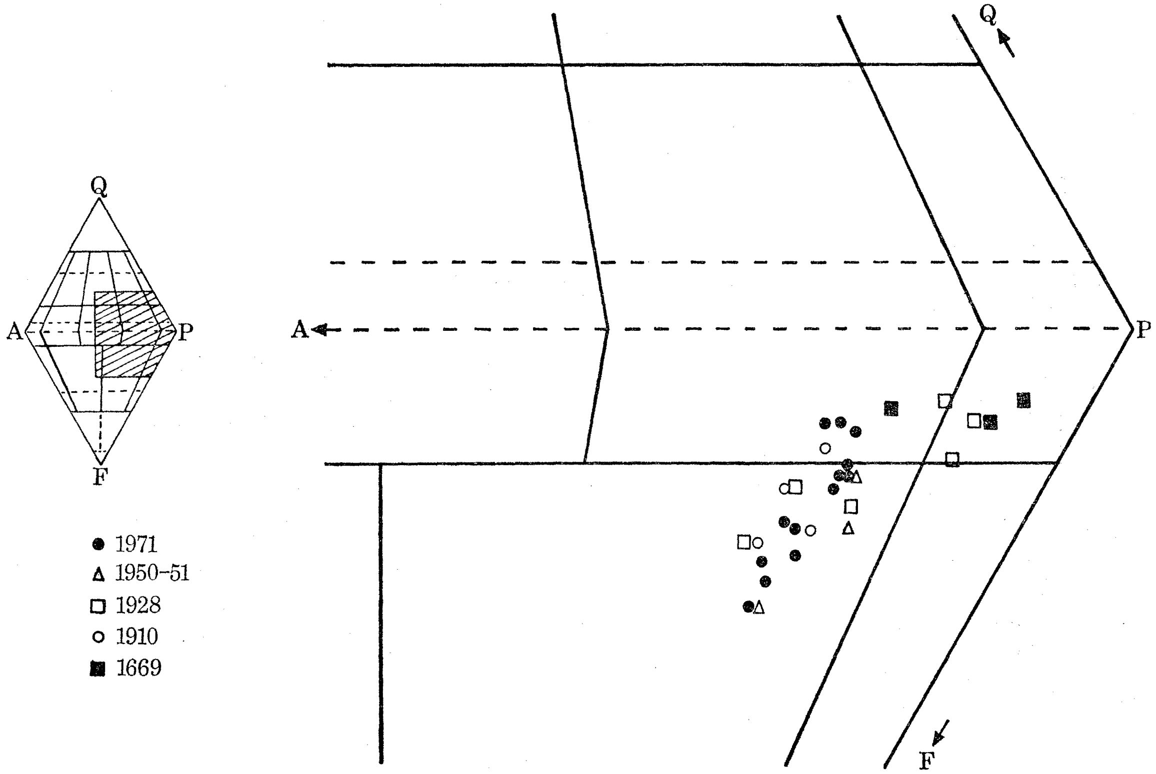

Figure 4. The Rittmann-norm values for the recent historical eruptions plotted in the double-triangle of Streckeisen (1967).

This moderate activity caused the formation of relatively slow bi-phase convection within the pyromagma and, thereby, favourable conditions for gaseous transfer and pneumatolytic differentiation. On the other hand the bi-phase convection hindered crystal fractionation. Thus, the uppermost pyromagma was enriched in sodium, titanium and iron and desilicated without varying the relative amount of femic components. The opening of eruptive fissures at the base of the central cone caused the tapping of the vent high up, and this allowed the uppermost magma to pour out at the very beginning of the effusions.

The unusual fact that the last magma erupted was lighter and less desilicated demonstrates a gravitational crystal fractionation which can be explained in different ways. According to Rittmann, this ligher magma originated in the uppermost parts of the hypomagma which, as opposed to the pyromagma, was not stirred by convection currents strong enough to prevent the settling of heavy femic crystals. Though the colour index and the density of the corresponding lava are slightly lower than those of the earlier lavas, supposed to have been derived from higher levels in the magma column, the foamy pyromagma was certainly much lighter than the underlying bubbleless hypomagma. This bubbleless hypomagma became, towards the end of the eruption, a pyromagma with bubbles because of the decrease in pressure.

Another possible explanation is the existence of a closed offshoot of the dykelike magma chamber where the conditions for gravitational differentiation were favourable, and the content of which formed the last effusion.

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