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journal or publication title	鹿児島大学理学部紀要. 地学・生物学
volume	17
page range	1-22
別言語のタイトル	桜島火山灰の生成メカニズムと環境に与える影響
URL	http://hdl.handle.net/10232/00009974

Rep. Fac. Sci., Kagoshima Univ. (Earth Sci., Bio.),
No. 17, p.1–22, 1984.

MECHANISM OF THE FORMATION OF VOLCANIC ASHES FROM SAKURAJIMA VOLCANO, JAPAN, AND ITS INFLUENCES TO THE ENVIRONMENTS

By

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(Received July 2, 1984)

Abstract

Modal and chemical analyses, X-ray diffraction, differential thermal analysis, microscopic observation, scanning electron microscopy, and measurements of grain-size distribution and refractive indices have been carried out for volcaic ashes erupted out from Sakurajima Volcano, Japan.

Volcanic ashes can be classified into four: black ash, i. e., most common volcanic ash characterized by blackish grey in mass color appearance, the presence of irregular shaped-matrix grains which sometimes show the porphyritic texture; red ash characterized by reddish dark grey in mass color appearance, abundant rounded matrix grains showing reddish brown-color, the low-content of FeO and the high-content of Fe_2O_3 in chemical composition, a wide range of refractive index in matrix volcanic glass, and by the presence of α-cristobalite, gypsum and anhydrite; black ash analogous to the red ash characterized by both natures of the black ash and the red ash; and white ash characterized by greyish white in mass color appearance, abundant colorless- and irregular shaped-grains in which abundant vesiculated matrix volcanic glass is contained and by the higher refractive index in some major constituents as compared to other volcanic ashes.

Many evidences show that the black ash came from solidifying lavas, by which the summit crater of the volcano had been burried, those which were explosively crushed and ejected out by volcanic gas pressure which was accumulating within the volcanic vent. The red ash is possibly considered to be a mixture of the preexisted volcanic ash which was affected by alteration due to action by volcanic gases, perhaps, nearby the summit crater bottom, and recent volcanic ash. The presence of the black ash analogous to the red ash shows a gradational process between the black ash and the red ash. It seems that the white ash was blown up in a vesiculated state in accompanying with the adiabatic expansion through a narrow volcanic vent successively and immediately from magma which came up to the summit crater from magma chamber at depths.

The presence of gypsum was identified by X-ray diffraction, differential thermal analysis and scanning electron microscopy not only in the red ash, but also in the black ash. With respect to the origin of gypsum crysals less than 5 μm in size adhered to the surfaces of the black ash-grains, it is reasonable to consider that sulfate ions, calcium ion and water those which were accompanied as volcanic gases together with the black ash just after the eruption were combined with each other at temperatures less than 150°C while the black ash was floating and falling down in the air.

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Plots of most of the volcanic ashes fall within a field of the calc-alkalic rock series on MIYASHIRO's (1974) SiO_2–total FeO/MgO diagram. The field occupied by the plots of the volcanic ashes is, however, located away from the field occupied by the plots of volcanic rocks and bombs of Sakurajima Volcano on both the SiO_2–total FeO/MgO diagram and the AFM diagram. This is originated in the presence of gypsum in the volcanic ashes. The presence of grains of the vesiculated matrix volcanic glass in most common volcanic ashes represented by the black ash, shows that the volcanic ashes were subjected to the adiabatic expansion and vesiculation.

The natural and social environments are affected by major two factors due to volcanic ash; physical factor and chemical factor. The physical factor by which the environments are affected is attributed to the substantial nature and grain size of volcanic ash, and the chemical factor to the presence of volcanic gases and its chemical action.

The result of the measurement of grain-size distributon shows that micrograins ranging in grain size from 5.0 to 0.5 μm occupy approximately 2.0–1.5 wt. % in the accumlative ratio in volcanic ashes consisting of grains less than 250 μm at maximum. Micrograins, essentially, of silicate substances, ranging in grain size from 5 to 2 μm in volcanic ash, invade into every environments and give them undesirable influences, for example, when they fill epidermal stomata of plants or pulmonary alveoli of animals, respiration is stopped or hypofunction occurs. Volcanic gases, such as sulfer oxides and hydorgen chloride, those which are adhered to the surfaces of volcanic ash-grais, accompanied with native volcanic ash just after the eruption, are combined with water and converted into acids such as sulfuric acid and hydrochloric acid while they are floating and falling down in the air. Acid volcanic gases invade into every environments and give them undesirable influences, for example, when functions as to be the organisms are subjected to volcanic gases or acids, they are lowered or disordered. Besides, discussions will be also given to mechanisms that farm products and human body are affected by the physical and chemical factors due to volcanic ash.

Introduction

Volcanic activity of Sakurajima Volcano has interruptedly maintained for thirty years since the time when volcanic activity represented by the summit explosion with smoke started again in 1955. Amount of volcanic ash fell down so greatly has increased since 1972 that the natural and social environments, such as farm products, industries, civic life, etc., have been affected by serious damages. However, mechanism that the environments are subjected to undesirable influences, as represented by dying down of fluits and atrophy die of silkworms due to volcanic ash, has been obscure on the reason that nature of volcanic ash itself has not been clear.

Social demand for the nature of volcanic ash has become too much strong. Thus, analyses of mineral and chemical compositions, X-ray diffraction, differential thermal analysis, measurement of grain-size distribution, optics of constituent minerals, microscopy and scanning electron miroscopy have systematically and synthetically been carried out for volcanic ashes to make clear their physicochemical nature and factors by which the environments are affected since 1977, though collection and microscopic observation of volcanic ashes have been maintained by one of the present authors since 1955.

Some of the cooperative research products have been reported in 1980 and 1981 (ŌBA and others, 1980, 1980a, b, 1981). This paper is an outgrowth of the cooperative researches having been carried on upto date. Major attention will be given to mechanism of the formation of volcanic ashes and the influences due to volcanic ash to the environments. It is most important that multifaceted approach by means of observation, descripton, measurement and other various analyses, as is treated in paper, is maintained for volcanic ash for a long period in order to make clear various subjects which already occurred or those are going to occur toward the future throughout over the natural and social environments.

Volcanic ashes available for academic research and nomenclature

Volcanic ashes used for academic research must be fresh and pure so that their own essential nature is reflected well. When volcanic ashes were encountered to rain and washed out with water, and volcanic gases adhered to surfaces of volcanic ash-grains were flowed away, they are not native volcanic ashes, but just only sorted sand. Volcanic ashes with impurities or those which fell down in rain time should also be avoided. Only volcanic ashes which were carefully collected by one of the authors at the environment as clean as possible at the time when they were falling down, were used for study.

Collected samples of volcanic ash are given in Table 1. Volcanic ash of sample no. 681013 looks reddish dark grey, that of sample no. 140111 looks greyish white, those of sample no. 79083001 and no. 79110801 look dark grey tinged with red, and others look blackish grey, in mass color appearance. They are called, in convenience, red ash, white ash, black ash analogous to the red ash and black ash, respectively (Ōba and others, 1980a). Black ash is most common in volcanic ashes.

Table 1. Samples of volcanic ashes from Sakurajima Volcano used for study

Sample no.	Date of eruption & collection	Coll.	Name of ash	Mass color in appearance	Localities	Weather & time
820917*	Sep. 17, 1982	NO	Black ash	Blackish grey	Faculty of Science, Kagoshima Univ.	Cloudy, windy, 11:30
820730*	July 30, 1982	"	"	"	"	Fine, gentle windy
820524	May 24, 1982	"	"	"	"	"
81081901	Aug. 19, 1981	"	"	"	"	" , 09:00
80051101	May 11, 1980	"	"	"	"	Fine, windless
79110801	Nov. 8, 1979	"	Black ash analogus to red ash	Dark grey tinged with red	"	"
79083001	Aug. 3, 1979	"	"	"	"	Fine, gentle windy, 09:00
78052301	May 23, 1978	"	Black ash	Blackish grey	"	Fine, weak windy, 10:00
77052301	May 23, 1977	"	"	"	"	Fine, gentle windy, 11:00
741025	Oct. 25, 1974	"	"	"	"	Fine
740723	July 23, 1974	"	"	"	"	"
681013	Oct. 13, 1968	TS	Red ash	Grey tinged with red	Ushine, Tarumizu, Kagoshima	Unknown
140111	Jan. 11, 1914	SK	White ash	Greyish white	Kagoshima City	"

*Used for only differential thermal analysis. NO, N. Ōba; SK, S. Kijima; TS, T. Sakurai.

Mineral composition

Modal analyses of major constituents were made of eight samples of vocanic ashes, as shown in Table 2. Volcanic ashes represented by the black ash are composed mainly

Table 2. Modal analyses (vol. %) of volcanic ashes from Sakurajima Volcano

ample no.	Name of ash	Measured grain size	Plagioclase	Hypersthene	Augite	Olivine	Magnetite	Matrix	Transparent volcanic glass	Anal.	Ref.
80060601	Black ash	300-100 μm	21.8	5.4	4.8	n	1.2	65.0	1.8	KI	
80051101	"	"	16.5	4.7	2.1	n	0.6	76.2	?	TN	
79110801	Black ash analogus to red ash	250- 50	20.4	2.9	5.8	p	1.5	69.3	p	KI	(1)
79083001	"	"	20.8	2.8	5.2	n	0.8	70.4	p	TN	(1)
78052301	Black ash	300-100	22.5	5.2	3.4	n	1.4	67.2	0.3	KI	(2)
77052301	"	200-100	21.2	5.5	4.9	n	3.7	64.7	p	KI	(2)
681013	Red ash	200- 50	11.4	1.5	1.1	n	1.3	84.7	p	KI	(3)
140111	White ash	"	19.9	3.8	3.2	n	2.4	70.7	p	KI	(3)
	Volcanic bomb* ejected out in 1977 from South Peak	-	20.9	1.9	2.8	n	1.1	73.8**	-	MY	(4)
58031901-F	1946 lava	-	19.9	3.4	1.3	n	1.1	62.7	-	NO	(5)
58031901-H	"	-	20.1	4.0	2.2	n	1.1	60.0	-	NO	(5)

* Collected by T. Kakuta. ** Cavities are included. Abbreviations.–p, present; n, not present; KI, K. INOUE; MY, M. YAMAMOTO; NO, N. ŌBA; TN, T. NAKAMURA. References.–(1) ŌBA and others (1981); (2) ŌBA and others (1980); (3) ŌBA and others (1980a); (4) ŌBA and others (1980b); (5) NAGASAWA and ŌBA (1959).

of lithic grains, plagioclase, hypersthene and augite. Magnetite and other iron oxide minerals, apatite and zircon are accompanied. Olivine is present only in the black ash analogous to the red ash, sample no. 79110801. The reason is obscure. For comparison, modal analyses of 1946 lava, so-called "Shōwa lava", and volcanic bomb ejected out from South Peak (Minami-dake) crater of Sakurajima Volcano in 1977 are tabulated in the same table. From this table, it can be seen that most volcanic ashes except only the red ash are nearly similar in modal composition to the 1946 lava.

Observation for the constituent materials under the microscope, as will be mentioned later, shows that lithic grains came from matrix of lava on the summit crater. So, the lithic grains are called, in convenienece, matrix grains in this paper. The matrix grains are composed mainly of volcanic glass, microlite and crystallite, and, sometimes, phenocrystic minerals are accompanied. The matrix grains in the black ash attain 65–76 % in volumetric prportion, while the red ash is characterized by the fact that the matrix grains are distinctly abundant, but rock-forming minerals are few.

Refractive indices of major constituents

Refractive indices were measured of hypersthene, plagioclase and volcanic glass from volcanic ashes. Measured refractive indices were adjusted as to be those at 20°C. The results are tabulated in Table 3.

Hypersthenes:

Refractive indices of hypersthenes from the black ash were measured to be $\gamma = 1.693 - 1.711$. Hypersthenes from the red ash are lower, and, in contrast, those from the white ash are higher, as compared to those from the black ash in refractive index.

Plagioclases:

Table 3. Refractive indices of constituent minerals of volcanic ashes from Sakurajima Volcano

Sample no.	Name of ash	Hypersthene	Plagioclase		Matrix volcanic glass	Transparent volcanic glass	Measurement	Ref.
		(γ)	n_1	An %				
80060601	Black ash	1.710	-	-	1.506-1.536	n.m.	KI	
80051101	"	1.693	1.572	84	1.517-1.528	1.506	TN	
78052301	"	1.711	1.557	55	1.524	<1.512	NO	(1)
77052301	"	1.711	1.559	59	1.524	<1.524	NO	(1)
681013	Red ash	1.707	1.559	59	1.517-1.538	<1.517	NO	(2)
140111	White ash	1.716	1.560	60	1.530	1.530	NO	(2)

n.m., not mesured. Other abbreviations are the same as those in Table 2. References. –(1) ŌBA and others (1980); (2) ŌBA and others (1980a).

Most of plagioclases ranges in refractive index n_1 from 1.557 to 1.560.

Matrix volcanic glass and transparent volcanic glass:

Volcanic glass, which occupies a major portion of the matrix grain and contains microlite and crystallite, is called matrix volcanic glass; and reddish brown-colored transparent volcanic glass, which is judged to have been derived from inclusions which had been contained within phenocystic minerals, is called brown-colored transparent volcanic glass or simply transparent volcanic glass, in convenience (ŌBA and others, 1980, 1980b).

The matrix volcanic glass from the black ash ranges in refactive index from 1.506 to 1.528. That from the red ash has higher refractive index ranging from 1.517 to 1.538 as compared to that from the black ash, while high refractive index, 1.530, was measured to that from the white ash. Meanwhile, refractive index of the transparent volcanic glass from volcanic ashes except the white ash is lower than that of the matrix volcanic glass. Such a fact suggests that the transparent volcanic glass was formed under the physicochemical condition different from the matrix volcanic glass.

Chemical analyses

Volcanic ashes were chemically analyzed by a combination of the fluorescence X-ray spectroscopy method or gravimetric method for SiO_2 and TiO_2, the gravimetric method for $H_2O\pm$, the volumetric method for FeO, and the atomic absorption metbod for Al_2O_3, total Fe_2O_3, MnO, MgO, CaO, Na_2O and K_2O. They were puverized by a vibrating mill in advance for analysis. Chemical analyses are given in Table 4.

Judging from chemical composition, the black ash erupted out in 1978, sample no. 78052301, and that in 1977, sample no. 77052301, are quite the same. The black ashes erupted out in 1974, 1980, 1981 and 1982 are, in chemical composition, almost the same as the former two. These volcanic ashes are, roughly speaking, composed of SiO_2 59 %, Al_2O_3 17 %, FeO 5–6 %, Fe_2O_3 2 %, MgO 2.5–3.0 %, CaO 6 %, Na_2O 3.0–3.5%, and K_2O 1.5 %.

The red ash erupted out in 1968 is apparently different from the black ash in the respect that it is very rich in Fe_2O_3, and, in opposite, poor in FeO, SiO_2, Al_2O_3 and Na_2O, particularly in FeO. The white ash clearly differs in the contents of SiO_2, FeO, Fe_2O_3, MgO and CaO against the black ash. Two black ashes analogous to the red ash erupted

Table 4. Chemical analyses of volcanic ashes from Sakurajima Volcano

No.	1	2	3	4	5	6	7	8	9	10	11	Methods
Sample	820524	81081901	80051101	79110801	79083001	78052301	77052301	741025	740723	681013	140111	
Ash	BA	BA	BA	BAR	BAR	BA	BA	BA	BA	RA	WA	
Anal.	MY	MY	MY	MY	MY	MY	MY	MY,YY,TF	MY,YY,TF	MY	MY	
Ref.				(1)	(2)	(2)	(2)	(3)	(3)	(3)	(3)	
SiO_2	59.58(G)	59.40(G)	59.07(G)	59.18(G)	59.85(XS)	59.68(XS)	59.28(XS)	57.64(G)	59.56(G)	54.45(G)	61.68(G)	XS,G
TiO_2	0.83(C)	0.80(C)	0.90(C)	0.71(C)	1.41(XS)	0.85(XS)	0.82(XS)	0.82(XS)	0.85(XS)	1.19(C)	1.24(C)	XS,C
Al_2O_3	16.68	16.86	16.13	16.95	16.91	17.51	16.92	17.53	17.64	15.44	16.59	AA
Fe_2O_3	2.41	2.32	2.01	2.99	2.70	1.92	1.53	1.82	0.36	4.90	2.19	"
FeO	5.23	4.93	6.49	3.98	3.85	5.17	5.80	4.78	6.12	2.65	3.77	V
MnO	0.17	0.16	0.19	0.15	0.15	0.15	0.16	0.12	0.13	0.09	0.13	AA
MgO	2.89	2.69	3.74	2.76	2.72	2.88	2.89	2.47	2.64	1.49	1.79	"
CaO	6.12	6.45	6.31	6.59	5.63	6.14	6.37	6.12	6.05	5.75	4.86	"
Na_2O	3.47	3.50	3.32	3.46	3.17	3.19	3.07	3.10	3.30	2.41	3.68	"
K_2O	1.53	1.53	1.51	1.56	1.41	1.38	1.27	1.57	1.49	1.12	1.70	"
H_2O+	0.78	0.87	0.50	1.32	1.55	0.78	1.51	3.41	1.74	8.32	1.58	G
H_2O-	tr	0.10	0.06	0.28	0.38	0.06	0.20	0.68	0.46	2.26	0.40	"
P_2O_5	0.13	0.17	0.07	0.11	0.08	0.10	0.09	0.03	0.13	nd	0.06	C
Total	99.82	99.78	100.30	100.04	99.81	99.81	99.91	100.09	100.47	100.07	99.67	

Abbreviations.–BA, black ash; BAR, black ash analogous to the red ash; WA, white ash; MY, M. YAMAMOTO; TF, T. FUKUDA; YY, Y. YAMASHITA; AA, atomic absorption spectroscopy; C, colorimetry; G, gravimetry; V, volumetry; XS, fluorescence X-ray spectroscopy. References.–(1) ŌBA and others (1981); (2) ŌBA and others (1980); (3) ŌBA and others (1980a).

out in 1979, those which are judged to have been affected by heating and oxidation (ŌBA and others, 1980a), are apparently high in Fe_2O_3-content and low in FeO-content.

X-ray diffraction

X-ray powder diffraction was made of black ashes erupted out in 1977, 1978, 1980, 1981 and 1982, black ashes analogous to the red ash in 1979, white ash in 1914, and red ash in 1968. X-ray powder diffraction patterns are given in Figs. 1, 2, 3 and 4. The followings were made clear.

(i) Strong peaks indicating the presence of feldspar (see F in Fig. 1) or plagioclase (see Pl in Figs. 2 and 3) at 2θ 28°, 21.8°, 23.5°, 24.4° and 26.4°, particularly, a double peak characteristic to feldspars at 2θ 28° are recognized. Although two volcanic ashes erupted out in 1979 belong in chemical feature to the black ash analogous to the red ash, they are quite the same as the black ash in the d-value and intensity of peaks appeared on the X-ray powder diffraction patterns.

(ii) The bias upward of the base between 2θ 10° and 30° seen in the white ash of 1914 (sample no. 140111 in Fig. 1), suggests that the white ash is dominant in amorphous silica.

(iii) As a result of the X-ray powder diffraction of the red ash of 1968 (no. 681013 in Fig. 4), α-cristobalite, anhydrite and gypsum were detected. They were, furthermore, examined by the heat treatment. The peak indicating the presence of gypsum disappeared at 130°C, and, in place, the peak indicating the presence of hemihydrate appeared. The peak indicating the presence of hemihydrate disappeared at 600°C, and, in place, the peak indicating the formation of anhydrite appeared. Meanwhile, the peak indicating the presence of β-cristobalite appeared at 600°C in place of the peak of α-

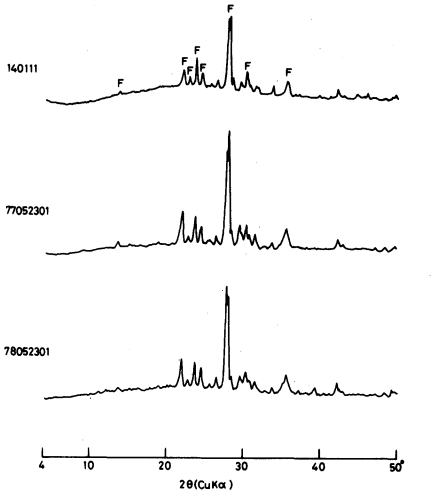

Fig. 1. X-ray powder diffraction patterns for black ashes and white ash from Sakurajima Volcano. 30 KV, 15 mA. Sample no. 140111, no. 77052301 and no. 78052301 are white ash erupted out in 1914, black ash in 1977 and black ash in 1978, respectively. F, feldspar. Analyst. K. TOMITA.

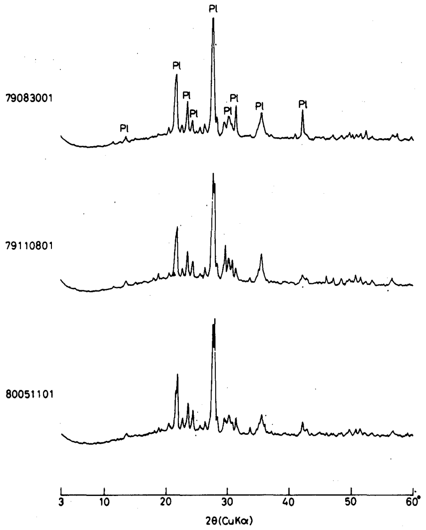

Fig. 2. X-ray powder diffraction patterns for black ashes analogous to the red ash and black ash from Sakurajima Volcano. 30 KV, 15 mA. Sample no. 79083001 and no. 79110801 are black ashes analogous to the red ash erupted out in 1979, and no. 80051101 is black ash erupted out in 1980. Pl, plagioclase. Analyst. K. TOMITA.

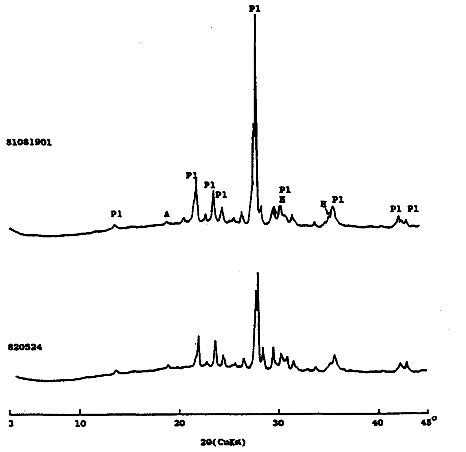

Fig. 3. X-ray powder diffraction patterns for black ashes from Sakurajima Volcano. 30 KV, 15 mA. Sample no. 81081901 and no. 820524 are black ash erupted out in 1981 and that in 1982. Pl, plagioclase; A, augite; H, hypersthene. Analyst. K. TOMITA.

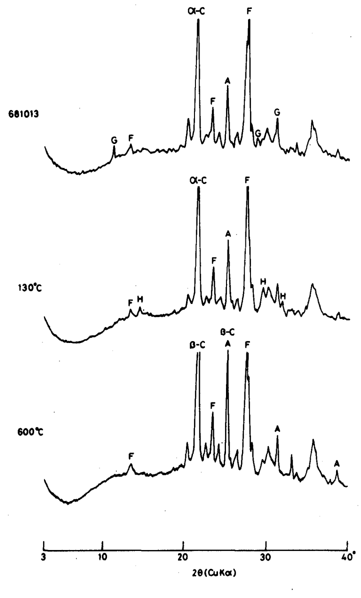

Fig. 4. X-ray powder diffraction patterns for red ash erupted out in 1968 from Sakurajima Volcano. 30 KV, 15 mA. α-C, α-cristobalite; β-C, β-cristobalite; F, feldspar; G, gypsum; H, hemihydrate; A, anhydrite. Analyst. K. TOMITA.

cristobalite. Thus, the presence of α-cristobalite, anbydrite and gypsum in the red ash was identified. Besides, the bias upward of the base between 10° and 30° in 2θ, as seen in the white ash, is recognized in the red ash too. This suggests the presence of the dominant amorphous silica.

(iv) Augite and hypersthene were detected in the black ashes of 1981 and 1982 (no. 81081901 and no. 820524 in Fig. 3).

Differential thermal analysis

Differential thermal analysis (DTA) was made of four black ashes erupted out in 1981 and 1982. DTA curves are given in Fig. 5. Low temperature endothermaic peaks due to dehydration in gypsum are recognized at 170°C and 190°C in all black ashes. The presence of gypsum, as will be mentioned later, could be detected by the scanning electron microscope. On the DTA curve of the black ash, sample no. 820917 (see 4 in Fig. 5), a strong endothermic peak at 110°C, which appears to have been originated from the presence of sulfide minerals, and a strong exsothermic peak at 300°C, which also appears to have been related to sulfide minerals, are observed. Meanwhile, an endothermic peak at 240°C seen in two black ashes, samples no. 81081901 and no. 820730(see 1 and 3 in Fig. 5), appears to be originated in the presence of Na_2SO_4.

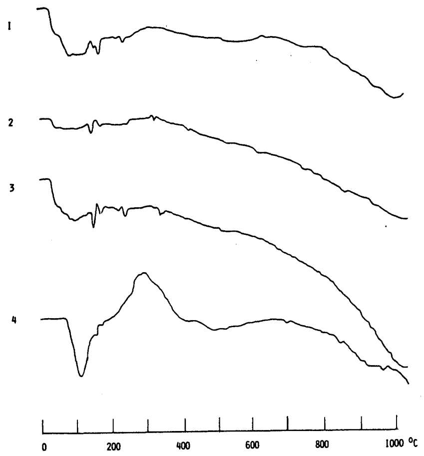

Fig. 5. Differential thermal analysis curves for black ashes from Sakurajima Volcano. 1, sample no. 8108190; 2, sample no. 820524; 3, sample no. 820730; 4, sample no. 820917. Analyst. K. TOMITA.

Microscopic observation of volcanic ash-constituents and microstructures

Volcanic ashes were sieved into three groups of grains following to grain size; group of grains ranging in grain size from 200 to 50 μm, group of grains ranging from 50 to 10 μm and group of grains less than 10 μm. Grains were immersed in different immersion oil for purpose and examined under the microscope.

1. Grains ranging in grain size from 200 to 50μm

(1) Black ashes

Observed black ashes are quite the same in color, form and microstructure of their constituent grains. Hyalopilitic texture, porphyitic texture and felty or flow textures can frequently be observed in the matrix grains. Grains containing bubbles, that is, grains of vesiculated matrix volcanic glass are recognized. Plagioclases with inclusions of the brown-colored transparent volcanic glass and those without them are present. The inclusions of the brown-colored transparent volcanic glass are arranged parallel to cleavage of its host mineral (ŌBA and others, 1980b), and concentrically line along zonal structure of plagioclase. The brown-colored transparent volcanic glass is rarely contained in pyroxene too.

(2) Red ashes

Red ashes are dominant in smaller grain in grain size as compared to the black ash. Grains of rounded matrix vocanic glass showing reddish brown-color owing to the presence of iron oxids, are distinctly abundant (ŌBA and others, 1980b). Grains of the brown-colored transparent volcanic glass, which is judged to have been derived from inclusions contained within phenocrystic minerals, are rarely observed. None of bubble is recognized in grains of the matrix volcanic glass.

(3) White ash

Among all kinds of volcanic ashes, the white ash is most dominant in the smallest grain in grain size. Irregular shaped-grains with acute angle, such as splitted flake, ascicular form and long prismatic form, are abundant (ŌBA and others, 1980b). Most of the matrix grains are composed of colorless-transparent volcanic glass and crystallite. Too many grains of vesiculated volcanic glass containing bubbles are recognized (ŌBA and others, 1980b). Plagioclases which contain inclusions of the brown-colored transparent volcanic glass are rarely observed.

2. Grains ranging from 50 to 10 μm and grains les than 10 μm in grain size

Results of microscopic observation which was made mainly of black ashes are summarized in brief as follows.

(1) Forms of grains

Observed forms of grains are grouped into the following three.

(a) Grains showing ascicular form or long prismatic form

This type of form is observed mainly in grains of plagioclase, microlite and crystallite.

(b) Grains showing millet-like form, lath-shaped form or short prismatic form

This type of form is observed mainly in grains of microlite and crystallite.

(c) Grains showing rounded form or irregular-shaped form

Many of the matrix grains and the matrix volcanic glass show this type of form.

(2) Differency in mineral association depending on different grain size

(a) Grains of more or less 50 μm in grain size

The matrix volcanic glass containing crystallite and microlite or both, and plagioclase are most frequently observed in grains of more or less 50 μm in grain size. Following to them, grains of the brown-colored transparent volcanic glass are also observed.

(b) Grains ranging in grain size from 10 to 5 μm and grains less than 5 μm

Most frequently observed grains are microlite, crystallite and volcanic glass. Submicron and micron grains are impossible to be discriminated.

Scanning electron microscopy

Microstructure, shape and form of micrograins, which are called in convenience for micron or submicron grains in size, of black ashes erupted out in 1980, 1981 and 1982 were examined by the scanning electron microscope. Scanning electron microphotographs are shown in Fig. 12. The following two characteristic features were noted.

(a) Gypsum crystals, which show a long prismatic form with oblique cut at both edges of less than 5 μm in elongation, adhred to the surfaces of the matrix volcanic glass were recogizad (see Gy in B, C and D in Fig. 12).

(b) Many cavities showing that volcanic gases passed through out were apparently recognized on the surfaces of the matrix volcanic glass.

Grain-size distribution

Measurments of the grain-size distibution were made of black ashes erupted out in 1974, 1977 and 1978 and black ash analogous to the red ash erupted out in 1979. For the reason of technical accuracy on the range of grain size, the measurement for the grain-size distribution in a broad range was made at the first step, and, in separate with this, that for the grain-size distribution in a narrow range was made at the second step, and, furthermore, that for the grain-size distribution in a specified narrow range was made at the third step. That is, the measurements were made of the range in grain size from 300 to 0 μm and the range from 50 to 0 μm for the black ashes, and, next, the range from 180 to 0 μm and the range from 10 to 0 μm for the black ash analogous to the red ash. Measurement for both the red ash and the white ash was impossible to do on the reason of too small amount of sample. The measurements were made by Micron-photosizer SKN-1000 at Seishin Co., Ltd.

1. Grain-size distribution ranging in grain size from 300 to 0 μm

Grain-size distribution ranging in grain size from 300 to 0 μm was measured for

Table 5. Grain-size distributions ($\phi < 300$ μm) of volcanic ashes from Sakurajima Volcano

Sample no.	78052301		77052301		741025	
Name of ash	Black ash		Black ash		Black ash	
S.G.	2.48		2.46		2.39	
Micron interval	AV	AR	AV	AR	AV	AR
0 - 10 μm	0.703	3.6	0.571	3.1	0.641	3.9
10 - 20	2.127	10.9	2.247	12.3	2.342	14.3
20 - 60	8.247	42.1	8.127	44.5	7.102	43.3
60 -100	11.127	56.8	11.007	60.2	10.062	61.4
100-150	15.252	77.8	15.257	83.5	13.187	80.5
150-200	19.102	97.4	17.532	95.9	15.637	95.4
200-300	19.602	100.0	18.282	100.0	16.387	100.0

AV, accumulative value in weight; AR, accumulative ratio in weight %.

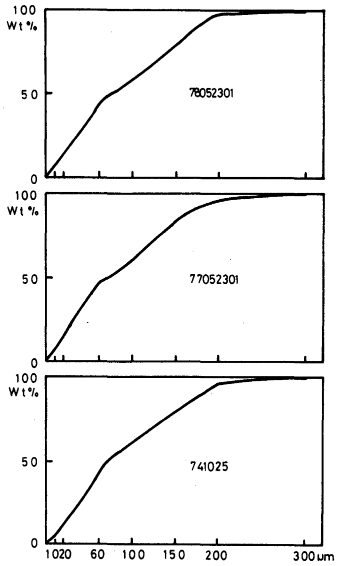

Fig. 6. Grain-size accumulation curves ($\phi < 300$ μm) for black ashes from Sakurajima Volcano. Sample no. 78052301, no. 77052301 and no. 741025 are black ashes eruped out in 1978, 1977 and 1974.

black ashes of 20 gr of sample no. 741025, 40 gr of sample no. 77052301 and 52 gr of sample no. 78052301. The results are tabulated in Table 5, and the grain-size accumulation curves constructed from these data are given in Fig. 6. Measured three samples of the black ash, as seen from Fig.6, show to be almost the same in the grain-size distribution. Grains less than 50 μm in grain size occupy 35–39 wt. % in the accumulative ratio in the whole grains less than 300 μm.

2. Grain-size distribution ranging in grain from 50 to 0 μm

Measurements for the range from 50 to 0 μm in grain size of black sahes, 30 gr of sample no. 77052301 and 50 gr of sample no. 78052301, were made in order to know the grain-size distribution of grains corresponding to cell unit in size. The results are tabulated in Table 6, and the grain-size accumulation curves constructed from these data are

Table 6. Grain-size distributions ($\phi < 50$ μm) of volcanic ashes from Sakurajima Volcano

Sample no.	78052301		77052301	
Name of ash	Black ash		Black ash	
S.G.	2.65		2.65	
Micron interval	AV	AR	AV	AR
0.0- 0.5 μm	0.027	0.6	0.050	1.2
0.5- 1.0	0.085	1.9	0.092	2.2
1.0- 2.0	0.192	4.3	0.233	5.6
2.0- 4.0	0.345	7.7	0.382	9.3
4.0- 5.0	0.496	11.1	0.521	12.6
5.0- 6.0	0.607	13.5	0.629	15.2
6.0-10.0	1.011	22.5	0.963	23.3
10.0-20.0	2.069	46.1	1.883	45.6
20.0-30.0	3.044	67.9	2.808	68.0
30.0-50.0	4.484	100.0	4.128	100.0

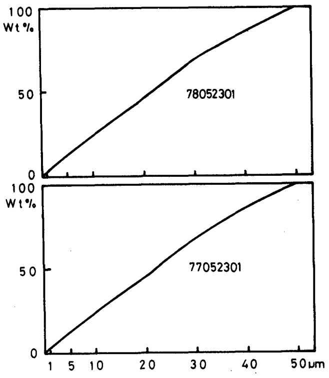

Fig. 7. Grain-size accumulation curves (ϕ <50 μm) for black ashes from Sakurajima Volcano.

given in Fig. 7. Grains ranging from 5.0 to 0.5 μm corresponding in size to epidermal stoma of plants or pulmonary alveolus of animals occupy 10.5–11.4 wt. % in the accumlative ratio in the whole grains less than 50.0 μm.

3. Grain-size distribution ranging in grain size from 180 to 0 μm

Measurement for the range from 180 to 0 μm in grain size was made of black ash analogous to the red ash of 25 gr of sample no. 79110801. The result is tabulated in Table 7, and the grain-size accumulation curve constructed from the data is shown in Fig. 8, A. Grains less than 10 μm in grain size occupy 7.4 wt. % in the accumulative ratio in the whole grains less than 180 μm. Grain size at 50 wt. % in the accumulative ratio denotes about 61 μm.

Table 7. Grain-size distribution (ϕ <180 μm) of volcanic ash from Sakurajima Volcano

Sample no.	79110801	
Name of ash	Black ash analogus to red ash	
S.G.	2.65	
Micron interval	AV	AR
0- 5 µm	0.286	2.3
5- 10	0.915	7.4
10- 20	2.339	18.9
20- 40	4.799	38.8
40- 50	5.474	44.3
50- 60	6.079	49.2
60- 80	7.759	62.8
80-100	8.749	70.8
100-120	10.509	85.1
120-150	11.859	96.0
150-180	12.354	100.0

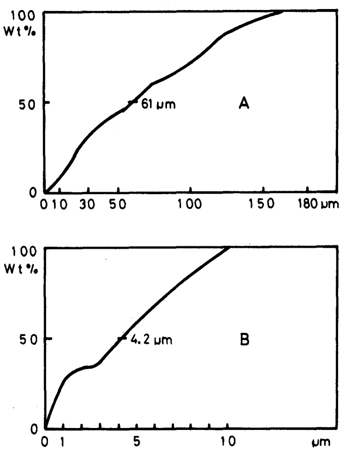

Fig. 8. Grain-size accumulation curves for volcanic ash from Sakurajima Volcano. Sample no. 79110801, black ash analogous to the red ash. Measured ranges in grain size: A, ϕ 100 ~ 0 μm; B, ϕ 10.0 ~ 0.0 μm.

4. Grain-size distribution ranging in grain size from 10 to 0 μm

Measurement for the range from 10 to 0 μm in grain size for the black ash analogous to the red ash of 25 gr of sample no. 79110801 was made in order to know the grain-size distribution of grains corresponding to cell unit in size. The result is given in Table 8, and the grain-size accumulation curve constructed from the data is shown in Fig. 8, B. From these, it can be seen that grains ranging from 5.0 to 0.5 μm corresponding in size to epidermal stoma of plants or pulmonary alveolus of animals occupy 43.3 wt. % in the accumlative ratio in the whole grains less than 10.0 μm, and 57.6 wt. % in grains less than 5.0 μm.

Besides, the grain-size accumulation curve of Fig. 8, B shows a sharp decreasing in the accumulative ratio between 1.5 and 0.0 μm in grain size, no distinctive change in the accumulative ratio in the range from 3.0 to 1.5 μm in grain size, and a positive relatioship between the grain size and the accumulative ratio in grains ranging in grain size from 10.0 to 3.0 μm.

Table 8. Grain-size distribution ($\phi < 10$ μm) of volcanic ash from Sakurajima Volcano

Sample no.	79110801	
Name of ash	Black ash analogus to red ash	
S. G.	2.65	
Micron interval	AV	AR
0.0- 0.1 μm	0.0004	0.03
0.1- 0.5	0.1779	14.30
0.5- 1.0	0.3297	26.40
1.0- 2.0	0.4228	33.90
2.0- 3.0	0.4585	36.70
3.0- 4.0	0.5972	47.90
4.0- 5.0	0.7182	57.60
5.0- 7.0	0.9433	75.60
7.0-10.0	1.2477	100.00

Summary and discussions

1. Mechanism of the formation of black, red and white ashes

On the basis of mass color appearance, X-ray diffraction patterns, chemical composition, presence of sepcific constituents and refractive index of minerals, volcanic ashes from Sakurajima Volcano can be classified into four; black ash, red ash, black ash analogous to the red ash, and white ash. Mechanism of the formation of the respective volcanic ash will be as follows.

(1) Black ash

The whole black ashes erupted out in 1974, 1977, 1978, 1980, 1981 and 1982 have quite the same nature in both mineral and chemical compositions, refractive index and microstructure of constituent materials, X-ray powder diffraction pattern and grain-size distribution. With respect to mineral composition, chemical composition and refractive index of constituent materials, these black ashes are almost the same with or very similar to volcanic bombs ejected out in 1956 and 1977 from South Peak (Minami-dake) crater and lava erupted out in 1946 (Ōba and others, 1980a); that is, they correspond to just crushed and pulverized materials of the volcanic bombs or lava. Some of the matrix grains retain the porphyritic texture. The texture as represented by the hyalopilitic texture is also recognized. Such a fact shows that the matrix grains had formed the groundmass of volcanic rock before the time when lavas were blasted out into volcanic ash. Irregular shaped-grains with acute angle are abundant.

These facts mentioned above show that the black ashes came from essentially the same substance, and they were ejected out intermittently from the same source under the same environmental condition. That is, it is judged that they came from solidifying lavas, by which the summit crater of the volcano had been burried, those which were explosively crushed and blown up into volcanic ash by volcanic gas pressure which was accumulating beneath a volcanic vent.

(2) Red ash

Some volcanic ashes such as those which were erupted out in October 1968 and October 1972 belong to the so-called "red ash" reported by Ōba and others (1980a). The red ash clearly differs from either of the black ash or the white ash in mineral and chemical compositions, refractive index of constituent minerals and form of grains. That is, in mineral composition, the red ash is few in rock-forming minerals, and, in opposite, abundant in rounded matrix grains showing reddish brown-color owing to the presence of iron oxides; in chemical composition, it is poor in FeO, SiO_2, Al_2O_3 and Na_2O, particularly, in FeO, but, in contrast, distinctly rich in Fe_2O_3 as compared to the black ash, as shown apparently in the SiO_2–Fe_2O_3/FeO diagram, Fig. 9 ; and a wide range of refractive index, which is not detected in other volcanic ashes, is measured on its matrix volcanic glass.

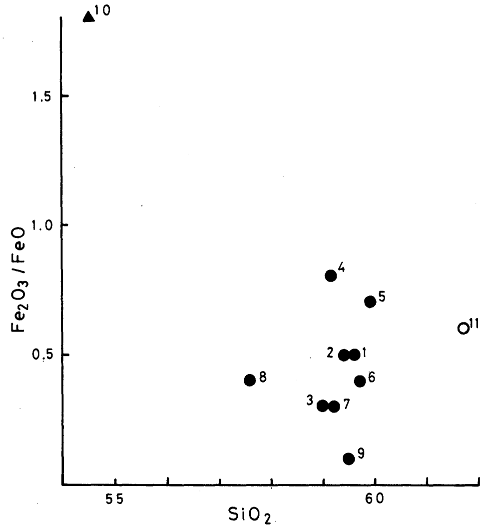

Fig. 9. Diagram showing a relationship between the Fe_2O_3/FeO ratio and the SiO_2-content for the analyzed volcanic ashes from Sakurajima Volcano. Symbols.–Solid circles, black ashes; solid triangle, red ash; open circle, white ash. Numbers attatched to symbols are accod with those in Table 4.

The fact that a wide range of refractive index is measured of grains of the matrix volcanic glass suggests that the red ash is composed of a mixture of newly erupted volcanic ash and pre-erupted volcanic ash. The fact that the red ash is, in chemical composition, poor in SiO_2, Al_2O_3 and Na_2O as compared to the black ash, appears to indicate that these oxides were leached out from the initial volcanic ash nearby or at the summit crater. The facts that the red ash is distinctly rich in Fe_2O_3, while very poor in FeO, and that the presence of anhydrite, gypsum and α-cristobalite and the suggested dominant amorphous silica were detected by X-ray diffraction, show that the red ash before the eruption had been at the environment where volcanic gases such as sulfer oxides and hydrogen chloride as well as water are abundant, and that the red ash was subjected to alteration due to heating, oxidation and chemical reaction.

Thus, mechanism of the formation of the red ash will possibly be illustrated as follows. A mixture consisting of newly erupted ejecta and pre-existed ejecta at the environment where volcanic gases are abundant, perhaps, nearby or at the summit crater, was affected by heating, oxidation, and chemical action due to volcanic gases, and, as a result, it was subjected to alteration accompanied by the leaching out of various components and the formation of new minerals.

(3) Black ash analogous to the red ash

Volcanic ashes erupted out in 1979, samples no. 79083001 and no. 79110801, look dark grey tinged with red in mass color appearance. They are, in chemical composition, clearly very rich in Fe_2O_3 and poor in FeO, and, in mineral composition, they contain much more the matrix grains showing reddish brown color owing to the presence of iron oxides which denote to tave been subjected to oxidation, as compared to the black ash. Meanwhile, other natures of the red ash are quite the same as those of black ash. From the features as pointed out above, they were called "black ash analogous to the red ash" by ŌBA and others (1980a).

Mechanism of the formation of the black ash analogous to the red ash will possibly be illustrated as follows: lavas which had been at the summit crater were subjected in part to alteration accompanying with oxidation, heating and action by volcanic gases for a certain period, and, successively, they were explosively ejected out. The fact that volcanic activity represented by the summit eruption accompanying with volcanic ash had been in the ceased state throughout the period during from April 30 to August 18, 1979, before the time when the black ash analogous to the red ash, sample no. 79083001, was erupted out, suggests the condition of the formation of the black ash analogous to the red ash or the red ash itself. That is, an possibility attributable to such a condition is that this kind of volcanic ash is ejected out after a ceaed period of the volcanic activity of the summit eruption with smoke.

(4) White ash

So-called "white ash" (ŌBA and others, 1980a) erupted out in 1914, sample no. 140111, is different from either of the black ash or the red ash in many respects: the white ash contains abundant colorlss- and irregular shaped-grains with acute angle; volcanic glass and hypersthene are higher in refractive index as compared to those of other volcanic ashes; in chemical composition the white ash is somewhat different from the black ash in the contents of SiO_2, FeO, Fe_2O_3, MgO and CaO; grains of the vesiculated matrix volcanic glass are too much abundant; and X-ray powder diffraction patern suggests the presence of the dominant amorphous silica.

Regarding the mechanism of formation of the white ash, the facts mentioned above suggest the followings. Source magma from which the white ash was originated would have had been different in chemical nature from magmas from which volcanic ashes have been erupted out since 1955. At the time when the magma containing abundant volcanic gases would have come up to the crater from magma chamber at depths, and abruptly been pushed out into the atmosphere of relatively lower temperatures and pressures immediately through narrow volcanic vents, the adiabatic expansion would have taken place, and, as a result, the white ash composed dominantly of grains in a vesiculated state would have successively been erupted out.

2. Significance of the presence of gypsum in the black ash

As a result of differential thermal analysis and scanning electron microscopy, the presence of gypsum in the black ash was made clear.

(1) Origin of gypsum crystals adhered to the surfaces of volcanic ash-grains

The formation of gypsum was made clear not only in the red ash in which the presence of gypsum was identified before by means of X-ray powder diffraction (ŌBA and others, 1980a), but also in most common volcanic ashes represented by the black ash. It is readily to understand that volcanic gases such as sulfer dioxide, hydrogen sulfide, hydrogen chloride and hydrogen fluoride are accompanied with volcanic ash at the same time when the eruption takes place, and, at that time, calcium hydrosulfate, $CaSO_4 \cdot 2H_2O$, i. e., gypsum, is formed if sulfate anions are combined with calcium cation and water. The fact that gypsum crystals are formed and become to grow up when sulfate anions are accompanied with native volcanic ash-grains just after the eruption and water and calcium cation are present, has been observed by one of the authors under the microscope in 1955 (ŌBA, 1970).

(2) Place where gypsum crystals were formed

If gypsum crystals were formed at or nearby the crater, some of them must have grown up, and, accordingly, an aggregate of gypsum crystals must have become into a mixture of small crystal and big crystal in size. Observation under the scanning electron microscope, however, shows that most gypsum crystals adhered to the surfaces of volcanic ash-grains are regular crystals less than 5 μm in size. It is impossible to consider that gypsum was formed at places at temperatures more than 200°C, while it is possible to consider that gypsum was formed at places at temperatures lower than approximately 150°C which is a stability temperature for gypsum at atmospheric pressure. Therefore, it is reasonable to consider that gypsum crystals adhered to the surfaces of black ash-grains were formed while the black ash in a state of smoke was floating and falling down in the air.

3. Volcanic rock series

Plotting of the analyzed volcanic ashes on MIYASHIRO's (1974) SiO_2–total FeO/MgO diagram, Fig. 10, regarding the general boundary between the calc-alkalic rock series and the tholeiitic series for westerm Pacific island arcs, most of the plots fall within a field of the calc-alkalic rock series. For comparison, volcanic rocks and bombs from Sakurajima Volcano are also plotted in the same diagram. The field occupied by the plots of the analyzed volcanic ashes is located away from the field occupied by the plots of volcanic rocks and bombs, except a few cases. It must be that this is originated in the presence of gypsum adhered to grains of the analyzed volcanic ashes. When the analyzed volcanic ashes are plotted on the A (Na_2O+K_2O)$-$F (total FeO)–M (MgO) diagram, Fig. 11, the field occupied by the plots is highly biased in location toward the apex M against the field occupied by the plots of volcanic rocks and bombs. This comes from the same reason mentioned above.

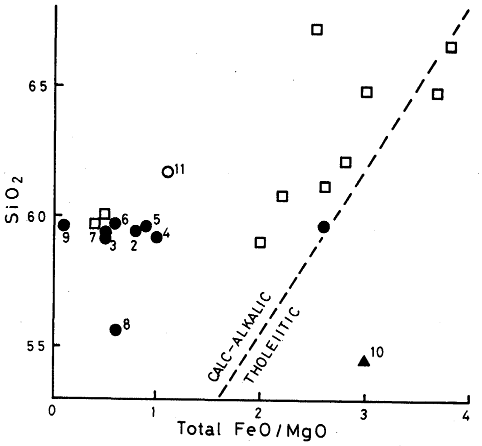

Fig. 10. Plots of the analyzed volcanic ashes from Sakurajima Volcano on MIYASHIRO's (1974) SiO_2–total FeO/MgO diagram. Symbols.–Open squares, volcanic rocks and bombs from Sakurajima Volcano; other symbols are the same as those in Fig 9. Analytical data for volcanic rocks and bombs from FUKUYAMA and ONO (1981), TANEDA and MORITA (1958) and YAMAMOTO (1979).

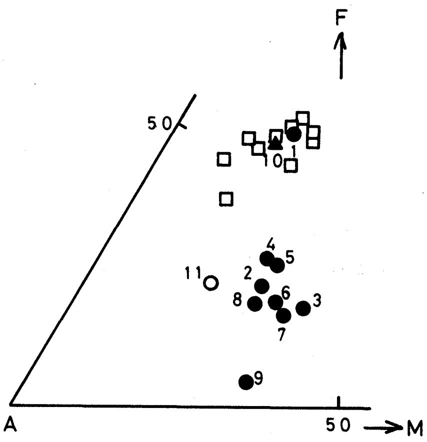

Fig. 11. Plots of the analyzed volcanic ashes from Sakurajima Volcano on the A (Na_2O+K_2O) – F(total FeO) – M(MgO) diagram. Volcanic rocks and bombs are also plotted for comparison. Symbols are the same as those in Fig 10.

4. Relationship between the mechanism of formation of volcanic ashes and its source magmas

(1) Significance of the presence of the vesiculated matrix volcanic glass

Grains of the vesiculated matrix volcanic glass can frequently be observed in most common volcanic ashes represented by the black ash. Such a fact shows that at the time when magma which was under the relatively higher temperatures and pressures at depths moved up to the summit crater of the relatively lower temperatures and pressures through a volcanic vent, and was abruptly pushed out and explosively ejected out as volcanic ash into the atmosphere, the adiabatic expansion took place and vesiculation phenomenon occurred at least in part.

(2) Significance of the presence of the brown-colored transparent volcanic glass contained in major rock-forming minerals

Regarding to microstructure in major constituent minerals of volcanic ashes under the microscope, the fact that the brown-colored transparent volcanic glass is contained in a regular arrangement within phenocrystic minerals such as plagioclase and pyroxene, suggests that pre-crystallized major rock-forming minerals had been subjected to remelting in part at magma chambers at depths, and, as a result, the brown-colored transparent volcanic glass had been formed under the condition controlled by crystal structure of the rock-forming minerals (Ōba and others, 1981) before the time when magmas, from which volcanic ashes were originated, attained at the summit crater.

(3) Discontinuity in time and space in crystal growth of plagioclases

Plagioclases, composing of a core plagioclase with many inclusions of the brown-colored transparent volcanic glass and a fresh and clear margin of plagioclase without the same kind of inclusion, are recognized in volcanic ashes (Ōba and others,1981). Such a fact shows that clearly there was discontinuity in time and space, as well as in composition, during the processes of crystallization of plagioclase; and, at the same time, it suggests that there was discontinuity in time and space at the magma environment where plagioclase was crystallizing out.

Influences of volcanic ash to the environments

1. Influences due to volcanic ash to the natural and socical environments

Major two factors, i. e., physical factor and chemical factor, are deeply concerned to the influences due to volcanic ash, as represented by dying down of fluits and atrophy die of silkworm, giving to the natural and social environments, e. g., plants, industries and civic life.

(1) Physical factor due to volcanic ash by which the environments are affected

(a) Physical factor due to volcanic ash

Physical foctor due to volcanic ash by which the environments are affected is attributed to the substantial nature and grain size of volcanic ash. If components of volcanic gases adhered to or accompanied with volcanic ash are ignored, volcanic ash erupted out from Sakurajima Volcano is that which is composed of grains, essentially, of silicates. Micrograins ranging in grain size from 5 to 2 μm those which correspond in size to epidermal stoma of plants or pulmonary alveolus of animals are contained in volcanic ash. When such the micrograins are adhered to and fill epidermal stomata of plants, pulmonary alveoli of animals, etc., as a result, respiration is stopped or hypofunction occurs. Furthermore, volcanic ash-grains in micron unit are possible to invade into every environments, where every kinds of materials and goods, such as various precision instruments and machines, are subjected to undesirable influence.

(b) Amount of micrograins ranging in grain size from 5.0 to 0.5 μm in volcanic ash

The result of the measurements of grain-size distribution those of which were made of three black ashes erupted out in 1974–1978, shows that grains less than 10 μm in grain size occupy about 3–4 wt. % in the accumulative ratio in the whole grains less than 300 μm at maximum (ŌBA and others, 1980). The result of the measurement of grain-size distribution that of which was made of the range in grain size from 180 to 0 μm for the black ash analogous to the red ash erupted out in 1979, consisting of grains less than 250 μm at maximum, shows that grains less than 10 μm in grain size occupy 7.4 wt. % in the accumulative ratio. The result of the measurement for the range in grain size from 10 to 0 μm of the same sample, shows that micrograins ranging in grain size from 5 to 0 μm occupy about 58 wt. % in the accumulative ratio. From these, it may possibly be said that micrograins, ranging in size from 5.0 to 0.5 μm, those which correspond to epidermal stoma of plants or pulmonary alveolus of animals in cell unit, occupy approximately 2.0–1.5 wt. % in the accumulative ratio in volcanic ash consisting of grains less than 250 μm at maximum.

(2) Chemical factor due to volcanic ash by which the environments are affected

(a) Chemical factor due to volcanic ash

Chemical factor due to volcanic ash by which the environments are affected is attributed to the presence of and action by volcanic gases accompanied with volcanic ash. Volcanic gases, such as SO_2, H_2S, Cl, F, etc., are always accompanied by native volcanic ash just after the eruption. They are adhered to surfaces of grains of volcanic ash and readily combined with the coexisting water while they are floating and falling down in the air, and immediately converted into acids such as sulfric acid, hydrochloric acid, etc. They also form acids on moisturized epidermis of plants and respiratory organs of animals. Thus, the functions as to be the organisms are lowered or disordered by action of acids. In addition to this, volcanic gases and its accompanying volcanic ash-grains in micron unit invade into every environments, and, as a result, every kinds of materials and goods, such as metals and plastics, are subjected to the depletion and decaying. That is, it must be said that volcanic gases play just the same role as the so-called "acid rain" which accelerates the depletion and decaying in materials.

(b) Volcanic gases adhered to volcanic ash-grains

An accompanying of volcanic gases to native volcanic ash-grains just after the eruption is apparent from the fact that the presence of microcrystals of calcium hydrosulfate, i. e., gypsum, those of which are formed on surfaces of volcanic ash-grains, was identified by differential thermal analysis and scanning electron microscopy in most common volcanic ashes represented by the black ash.

OSSAKA and OZAWA (1975) showed that fresh volcanic ash-grains are accompanied by unexpectedly abundant volcanic gases, that is, the content of SO_4^{2-} soluble in water attains to 208 mg/kg at the lowest and 13,000 mg/Kg at the highest, and the content of

Cl^- to 18.4 mg/Kg at the lowest and 2,800 mg/Kg at the highest in regard to volcanic ashes erupted out in 1975 from Sakurajima Volcano.

The amount of components of volcanic gases adhered to the surfaces of volcanic ash-grains is acceleratedly increased at the square of the radius of grain. The fact that the farm products were subjected to much more serious damge by the red ash than by the black ash, will possibly be illustrated to depend on the grain size of volcanic ash-grains, that is, on the reason that constituent-grains of the red ash are smaller in grain size as compared to those of the black ash, and, accordingly, components of volcanic gases accompanied with the red ash had been much more abundant in amount.

2. Influences due to volcanic ash to farm products and human body

(1) Influences due to volcanic ash to farm products

When micrograins ranging in grain size from 5 to 2 μm in volcanic ash are adhered to and fill epidermal stomata of plants, the respiratory organs are lost. At the same time, when acid volcanic gases, such as sulfer oxides and hydrogen chloride, accompanied with native volcanic ash-grains just after the eruption, are combined with the coexisting water during floating and falling down in the air or with water on the moisturized epidermis of plants and converted into acids, the respiratory organs of epidermal stomata are lowered or disordered. Thus, farm products are resulted into killing down by a composite factor of the physical factor in the former and the chemical factor in the latter.

(2) Influences due to volcanic ash to human body

Native volcanic ash just after the eruption is essentially a mixture of silicate grains and acid volcanic gases such as sulfer oxides and hydrogen chloride. Accordingly, most simply speaking, it will possibly be said that it is a mixture of microfragments of silicate glass and acids such as sulfric acid and hydrochloric acid.

When the fact that a certain amount of grains in micron unit as almost the same as about 5 μm of the pulmonary alveolus is contained in volcanic ash is taken account, and if it is supposed that man inspires uninterruptedly a considerable amount of volcanic ash every day for many years, man showing respiratory deceases such as silicosis and/or pneumoconiosis or their analogous deceases will certainly come out, while man showing a condition symptoma of a decease caused by acid volcanic gases may also possibly come out, though an influence caused by volcanic ash on the human body has basically been uncertain. The former depends on the physical factor, while the latter on the chemical factor, due to volcanic ash. In general, however, man will be affected by a composite factor of the physical factor and the chemical factor due to volcanic ash.

Acknowledgements

Many thanks are given to Mr. T. SAKURAI and Mr. S. KIJIMA for their presentation of unusual volcanic ashes; and to Dr. S. NAWATA, Emeritus Prof. of Kagoshima University, for his useful suggestions from the point of view of medical science. Thanks are also given to Prof. K. YUNOKI, Prof. H. TAGAWA, Dr. J. YUKAWA and Dr. T. HIGASHI, Kagoshima University, for their suggestions in improvemens of terms in medical, botanical and zoological sciences. This work was finacially supported in part by the Conference for Scientific Research of Sakurajima Volcano, organized by Kagoshima Prefectural Government.

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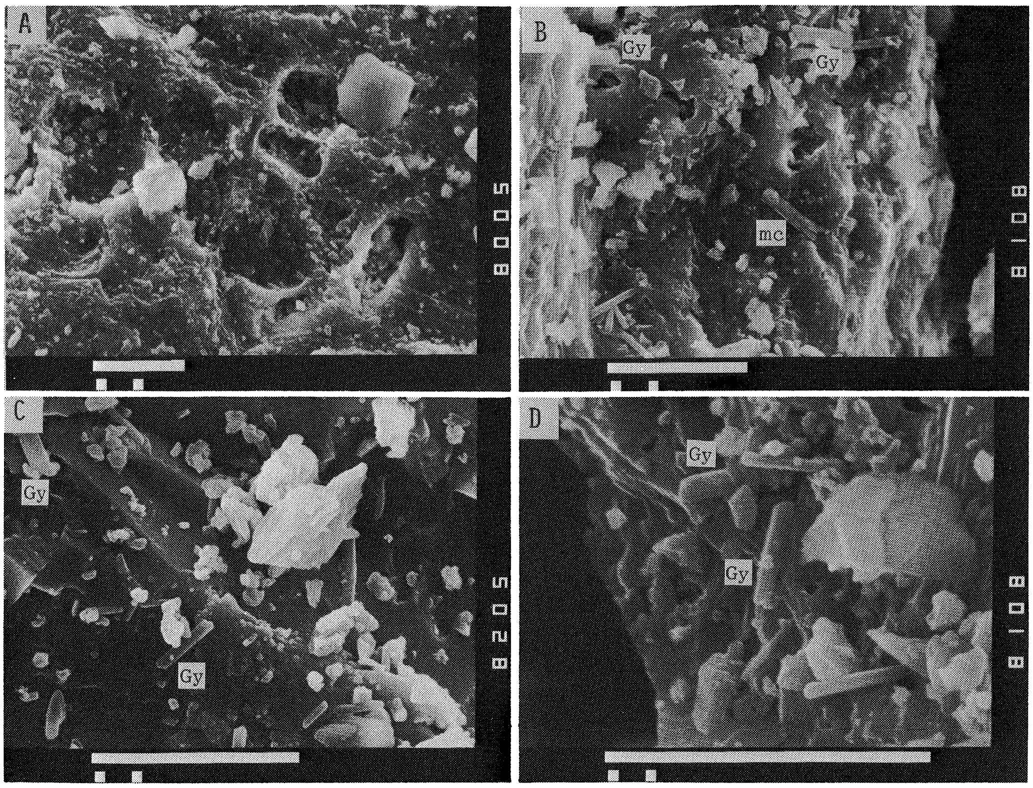

Fig. 12. Scanning electron microphotographs of microstructure and gypsum crystals on the surfaces of grains of black ashes from Sakurajima Volcano. Bars represent 10 μm. Taken by K. TOMITA.

A. Cavities, showing that volcanic gases passed through out, in the matrix volcanic glass. Sample no. 80051101.

B. The presence of gypsum crystals (Gy) less than 5 μm in size of elongation adhered to the surface of the matrix volcanic glass with cavities, which show that volcanic gases passed through out, is noted. Microlites (mc) are also observed. Sample no. 81081901.

C. Gypsum crystals (Gy), showing a long prismatic form with oblique cut at both edges, less than 3 μm in size of elongation are recognized on the surface of the matrix volcanic glass with cavities which show that volcanic gases passed through out. Sample no. 820524.

D. Close up of gypsum crystals (Gy) on the surface of the matrix volcanic glass with cavities. Sample no. 81081901.