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Rep. Fac. Sci., Kagoshima Univ. (Earth Sci. & Biol.),
No. 16, p. 1-20, 1983.

GEOCHEMICAL STUDY OF SOME VOLCANIC PRODUCTS FROM GALUNGGUNG VOLCANO, WEST JAVA, INDONESIA

By

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(Received July 1, 1983)

Abstract

Geochemical studies have been made of the volcanic products, i.e., pyroclastic flows, scorias and volcanic ashes, erupted out from Galunggung Volcano, West Java, Indonesia, during the period from April 5 to August 16, 1982.

The plots of almost all volcanic products fall in the field of MIYASHIRO's tholeiitic series on the SiO_2-total FeO/MgO diagram. Meanwhile, the plots of the volcanic products of April 5-8 and some of the volcanic products of April 25-May 6 fall in the field of the tholeiite series and others in the field of the high-alumina basalt series on KUNO's SiO_2-(Na_2O+K_2O) diagram.

The volcanic products range in chemical composition from basaltic andesite to basalt. In the silica-content, the volcanic products erupted out at the first stage, April 5-8 of 1982, are about 55 wt. %, while those at the successive stages, April 25-May 6, July 28 and August 16 of 1982, are about 49-50 wt.%, The former is high and the latter is low not only in the SiO_2-content, but in both the (Na_2O+K_2O)-content and the value of the total FeO/MgO ratio.

The value of the total FeO/MgO ratio and the (Na_2O+K_2O)-content decrease with a decrease of the SiO_2-content in the volcanic products during the processes from the first stage to the successive stages. Such a change in chemical composition of the volcanic products reflects the chemical change of a magma from which the volcanic products were formed. That is, it is possibly considered that at the first stage of explosion the volcanic products of basaltic andesite in chemical composition came from a magma which was contaminated with materials something rich in silica, at the magma chamber in which fractional crystallization was proceeding. The successive stages of eruptions were accompanied by the volcanic products which came from essentially basaltic magma.

Meanwhile, the fact that volcanic ashes, some of which look slightly reddish grey-colored, erupted out at the first stage from Galunggung Volcano have the high value of Fe_2O_3/FeO ratio against those erupted out at the successive stages will possibly be interpreted as foollows. Pre-existed materials or primary black-colored volcanic ashes, by those of which crater had been buried, were subjected to thermal alteration accompanied by chemical reaction due to volcanic gases and oxidation. Successively, the eruptions with plume or smoke at the crater have been accompanied by black-colored volcanic ash due to the upward-moving essential magma of basaltic composition with the low value of the Fe_2O_3/FeO ratio.

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Introduction

We attended at a meeting, chaired by General SOLICHIN G. P., Presidential Aide of Indonesian Government, and Ir. A. SUDRADJAT, Director of Volcanological Survey of Indonesia (VSI), held at Geological Research and Development Center, Bandung, on August 12, 1982, to discuss about monitoring by using of airplane for plume or flowing smoke erupted up from Galunggung Volcano, southeast of Bandung, West Java, Indonesia. Some comments for geochemical features of volcanic products from Galunggung Volcano were made by one of us at the meeting (ŌBA and others, 1982 a).

Geochemical and petrological research is required to make clear the physicochemical nature of volcanic products from Galunggung Volcano and the character of its volcanic activity. Genetical considerations for the nature of magma from which the volcanic products were provided will possibly be made through these processes.

The active volcanic zone, prevailing throughout over Java Island, comprises many active volcanoes such as Krakatau, Merapi and Galunggung and many sleeping volcanoes, and is located roughly parallel to the Java active subduction zone. Therefore, problem is not only for Galunggung Volcano, but the active volcanic zone itself is most important problem to be investigated. In this sense, a plan in a long-run view is desired for scientific research of volcanic activity within the zone.

A field observation for volcanic products and volcanostratigraphic succession was made at the southeastern foot of Galunggung Volcano (Fig. 12, A), on August 15, 1982 (ŌBA and others, 1982 b). Courses taken for the field survey are shown in Fig. 1. Petrographical and geochemical features of the volcanic products, in particular, of pyroclastic flows will be given in this paper.

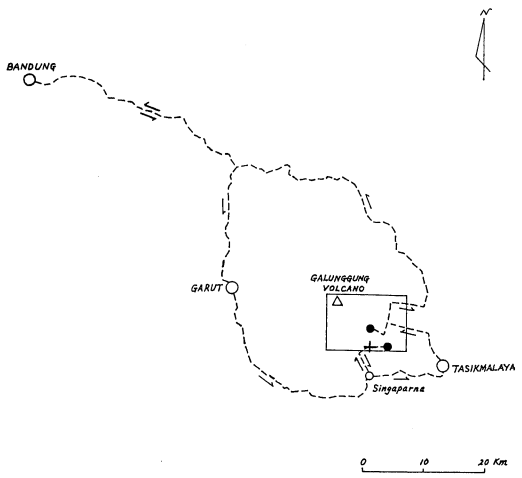

Fig. 1. Courses taken for a field survey for Galunggung Volcano, West Java, Indonesia, on August 15, 1982. Solid circules represent localities where samples were collected. Plus represents location of Observatory Station of Volcanological Survey of Indonesia.

Pyroclastic Elow Used in This Paper

Pyroclastic flow is used in a broad sense for volcanic products which imply the so-called "nuée ardente", i.e., "glowing avalanche", "glowing cloud" or "hot cloud (awan panas in Indonesia)", and pumice flow, ignimbrite and others. Meanwhile, pumice flow, characterized by abundant pumice and dacitic composition in both chemical and mineral compositions in many cases, is used in a narrow sense against the pyroclastic flow.

Referring to the suggested genetical classification for volcanic fragmental rocks proposed by Department of Geology, Gadjah Mada University, Indonesia (WIDIASMORO and others, 1977) (Table 1), pyroclastic flow will be used in this paper for lithificated rocks formed from "glowing avalanche" or "nuée ardente", those of which were erupted out from Galunggung Volcano.

Table 1. Suggested genetical classification for volcanic fragmental rocks with a pyroclastic component (WIDIASMORO and others, 1977)

Grain size (mm)	>256	256-64	64-2	2-1/16	1/16-1/256
Unconsolidated material	Coarse	Fine	Lapilli	Coarse ash	Fine ash
	Bombs, blocks				
Rocks formed by lithification of pyroclastic fall deposits. Type I. "Ash fall tuffs".	Agglomerate (Agglutinate) Pyroclastic breccia		Lapilli stone	Tuff	
			Lapilli tuff (ash>lapilli)		
	Tuff pyroclastic breccia (ash>blocks) Tuff agglomerate (ash>bombs)				
Rocks formed by lithification of pyroclastic flow deposits. Type II.					
Rocks formed from glowing avalanche deposits	Pyroclastic flow breccia		Lapilli stone	Tuff	
Rocks formed from ash flow deposits					
Rock unit consisting of welded and non welded rock types	Igninbrite				
Welded	Welded agglomerate			Welded tuff	
Non welded	Vitric agglomerate			Vitric tuff	

Stratigraphic Succession of Volcanic Products from Galunggung Volcano at Cihurip

A simplified map showing the distribution of pyroclastic flow, so-called "nuée ardente", and mud flow, "lahar" in Indonesia, is given in Fig. 2. The map was drawn on the basis of the hazard map, showing the distribution for "nuée ardente" and "lahar", of Volcanological Survey of Indonesia (VSI).

Pyroclastic flows erupted out in May of 1982 from Galunggung Vovcano crop out along river running southeast at Cihurip (Fig. 11), locating at the southeastern foot 4 km far from Galunggung crater. Many houses here were buried and destroyed by flowing down of mud flow (Fig. 12, C and D)

At an exposure of the same place, pyroclastic flow of 4 m (+) in thickness, a thin mud flow of about 50 cm in thickness, pyroclastic flow of 3 m in thickness and a thick mud flow of 1.5 m in thickness can be observed in ascending order (Fig. 12, B). The volcanostratigraphic succession is as shown in Fig. 3. Rock samples of nos. GA1505 and GA1506 were collected here from the surface exposures of the pyroclastic flows.

The thin mud flow is interculated between two pyroclastic flows. This fact shows that two times of pouring out of pyroclastic flow occurred by August 15, 1982. The thick mud flow at the upper most of the exposure is interculated by two thin beds of lapilli and ash,

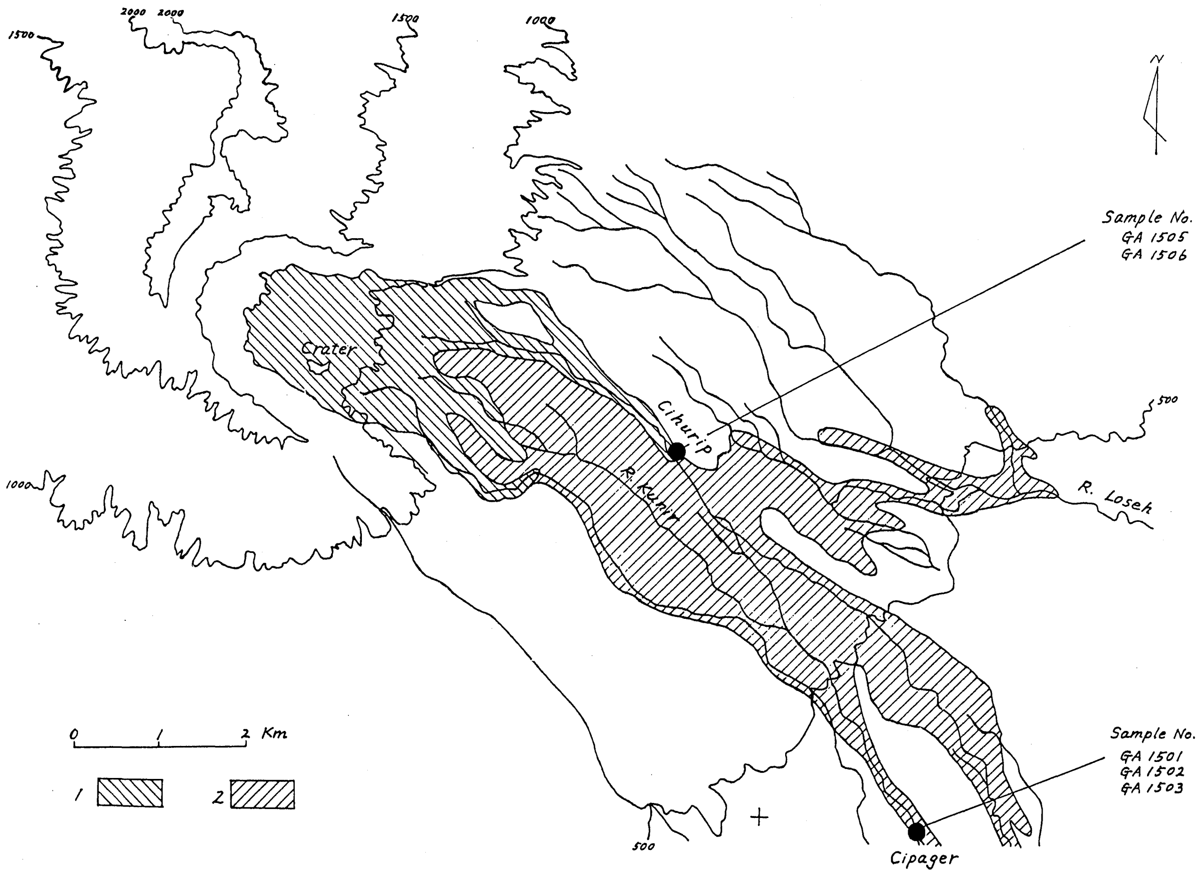

Fig. 2. Distribution of pyroclastic flow ("nuée ardente") erupted out in May of 1982 and mud flow ("lahar") in the southeastern foot of Galunggung Volcano, West Java, Indonesia. After
01 the hazard map by Volcanological Survey of Indonesia (VSI). Solid circles and attached numbers represent localities and collected samples. Plus represents location of Observatory Station, VSI. Stratigraphic sequence: 1. Pyroclastic flow ("nuée ardente"); 2. Mud flow ("lahar").

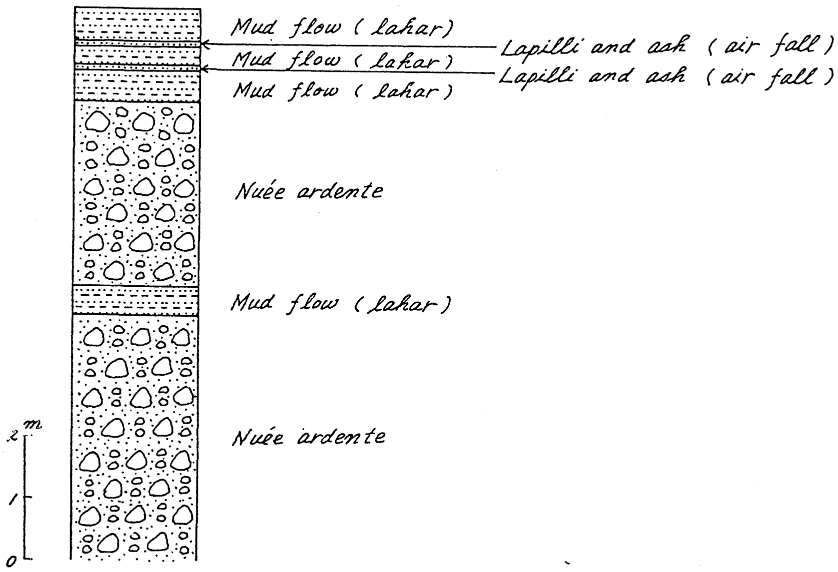

Fig. 3. Stratigraphic succession of volcanic products from Galunggung Volcano at the exposure where rock samples of Nos. GA1505 and GA1506 were collected at Cihurip, southeastern foot of the volcano.

those of which show to be air fall deposits.

As a result that groundwater is heated in the process pass through the pyroclastic flows keeping still high temperature, highly heated hot spring is pouring out through cracks at the exposure where the rock samples were collected (Fig. 11).

Petrography

Localities where samples were collected are given in Fig. 2. Samples collected at Galunggung Volcano, those received from Volcanological Survey of Indonesia (VSI) and one sample from Cihurip villagers are listed in Table 2.

Table 2. List of samples collected from Galunggung Volcano

SAMPLE NO.	LOCALITIES	ROCK TYPES	NOTE
26/LG/82	Maleganti	Stone (lithic fragment)	*
33/LG/82	Cikasasak	Lapilli	*
34/LG/82	Cikasasak	Volcanic ash	*
35/LG/82	Cikasasak	Volcanic ash	*
36/LG/82	Cikasasak	Volcanic sand	*
37/LG/82	Cikasasak	Volcanic sand	*
GA1501	Cipager	Mud flow ("lahar")	
GA1502	Cipager	Basaltic rock	Terrace rock
GA1503	Cipager	Basaltic rock	Terrace rock
GA1504	Crater	Basaltic rock	**
GA1505	Cihurip	Basaltic rock	Pyroclastic flow
GA1506	Cihurip	Basaltic rock	Pyroclastic flow
GA1601	Bandung	Volcanic ash	***

*From Volcanological Survey of Indonesia. **From Cihurip villagers. ***Collected from accumulated volcanic ash, which travelled from Galunggung Volcano, on the surface of car body at Bumi Asih Hotel, Bandung, August 16, 1982.

1. Pyroclastic Flows

Pyroclastic flows look dark yellow-, dark grey- and black-color in appearance, and are composed mainly of lapilli, block and interstitial matrix. The constituent materials are variable in size and incomplete in grading. It is noted that lithologically most of lapillis and blocks and even the interstitial matrices are scoriaceous. This fact shows that the pyroclastic flows were keeping still high temperature and erupted out in a molten state expanding and escaping gases at the time when the explosion took place. Pyroxene and a small amount of olivine are recognized as major mafic minerals in rock-hand specimens.

Considering from both chemical and mineral compositions, the pyroclastic flows are to be agglutinate of basaltic andesite. Meanwhile, they will be correlated to "welded agglomerate" according to the suggested genetical classification for volcanic fragmental rocks, proposed by Department of Geology, Gadjah Mada University (WIDIASMORO and

Table 3. Modal analyses of pyroclastic flow and volcanic ash from Galunggung Volcano

Sample no.	GA1505	GA1601
Name	Pyroclastic flow	Volcanic ash
Plagioclase	16.3 %	21.0 %
Augite	2.8	4.6
Hypersthene	3.5	3.9
Olivine	0.5	0.2
Hornblende	0.1	-
Opaque mineral	0.8	0.6
Groundmass	76.1	-
Volcanic glass	-	69.8
Total	100.1	100.1

Analyst. K. Ishii.

Table 4. Refractive indices of plagioclase and volcanic glass of pyroclastic flow and volcanic ash from Galunggung Volcano

Sample no.	GA1505	GA1601
Name	Pyroclastic flow	Volcanic ash
Plagioclase		
n_1	1.565	1.567
Volcanic glass		
Nmax	1.544	1.547
Nmin	1.529	1.542

Measured by S. Kiyosaki.

others, 1977).

Two rock samples, nos. GA1505 and GA1506, collected from surface exposures of pyroclastic flows at Cihurip, Galunggung Volcano, were examined under the microscope. Modal analysis was made of pyroclastic flow, sample no. GA1505 (Table 3), and refractive indices were measured of plagioclase and volcanic glass of the same sample (Table 4).

The pyroclastic flows are composed of phenocrystic plagioclase, augite, hypersthene and a small amount of phenocrystic olivine and hornblende, and accompanied by opaque mineral which occur in a form of both microphenocryst and inclusion. Apatite occurs as an accessory mineral. Microphotographs of the pyroclastic flow, sample no. GA1505, are shown in Fig. 13, A～E. The groundmass is assembled by plagioclase microlite, pyroxene, opaque mineral and a large amount of volcanic glass, and has the hyalopilitic～felted texture (Fig. 13, A).

Phenocrystic olivines are fresh (Fig. 13, E), but some of them show the corroded form with the reaction rim consisting of aggregates of micrograins of pyroxene and opaque mineral (Fig. 13, A). Almost all phenocrystic hornblendes show the corroded form (Fig. 13, B and D) and have strong pleochroism, X'=light yellow and Z'=brownish deep yellow. Many phenocrystic plagioclases contain light brown-colored volcanic glass-micrograins which are arranged parallel to cleavage and zonal structure (Fig. 13, C, D and E).

2. Volcanic Ashes

Two volcanic ashes from Galunggung Volcano, sample no. GA1606, dark grey-colored ash collected in Bandung, and sample no. 34/LG/82, slightly reddish grey-colored as received from Volcanological Survey of Indonesia, were examined under the microscope. Modal analysis was made of volcanic ash, sample no. GA1601 (Table 3), and refractive indices were measured of plagioclase and volcanic glass of the same sample (Table 4).

The volcanic ashes are composed of plagioclase, augite, hypersthene, a small amount of olivine and opaque mineral and a large amount of volcanic glass which corresponds to the groundmass of volcanic rock. Major mineral constituents of the volcanic ashes are essentially the same as those of the pyroclastic flow of Galunggung Volcano, though hornblende could not be taken account. The followings are characteristic: the presence of plagioclases in which micrograins of light brown-colored volcanic glass are arranged parallel to cleavage and zonal structure of host mineral; and the presence of volcanic glasses containing small bubbles which show that gases were expanding (Fig. 13, F).

Mineralogy

One specimen of pyroclastic flow was examined by the X-ray powder diffraction method. X-ray powder diffraction analysis and observation by the scanning electron microscope JEOL JSM-25SII were also made of three specimens of volcanic ash from Galunggung Volcano.

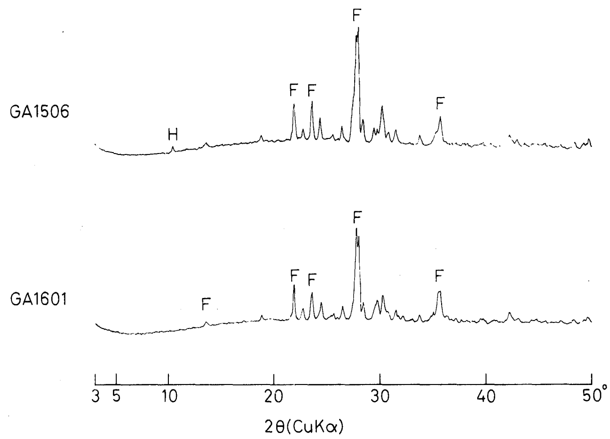

Fig. 4. X-ray powder diffraction patterns for pyroclastic flow, sample no. GA1505, and volcanic ash, sample no. GA1601, from Galunggung Volcano. F and H represent feldspars and hornblende, respectively.

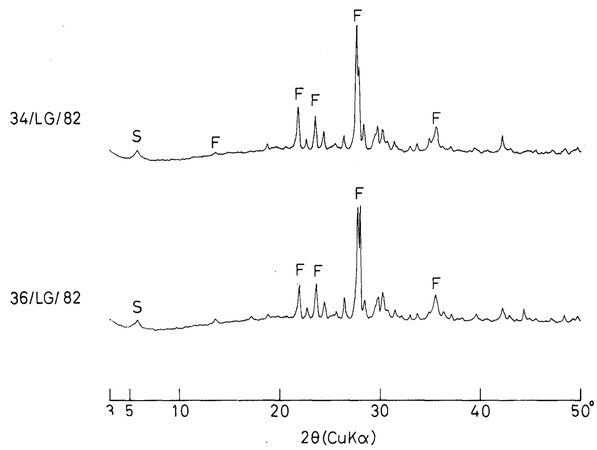

Fig. 5. X-ray powder diffraction patterns for volcanic ashes, sample nos. 34/LG/82 and 36/LG/82, from Galunggung Volcano. F and S represent feldspar and smectite, respectively.

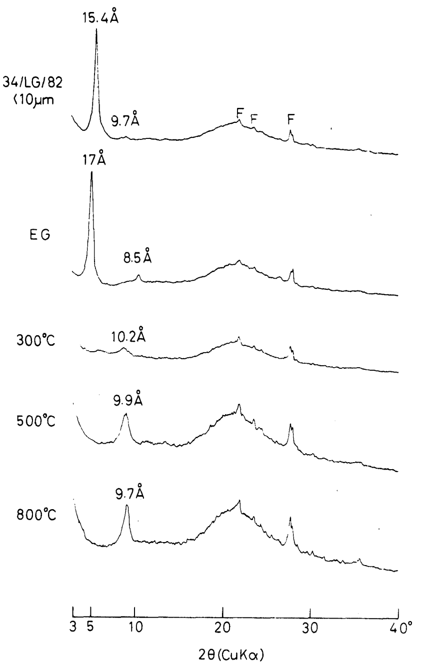

Fig. 6. X-ray powder diffraction patterns for a fraction less than 10 μm after various treatments of volcanic ash, sample no. 34/LG/82. EG: treated with ethylene glycol; 300℃: heated to 300℃ for 1 hr; 500℃: heated to 500℃ for 1 hr; 800℃: heated to 800℃ for 1 hr. F represents feldspar.

X-ray powder diffraction pattern for the pyroclastic flow, sample no. GA1506, is shown in Fig. 4. The powder pattern shows peaks indicating the presence of feldspars, mainly plagioclase, and hornblende. X-ray powder diffraction patterns for the volcanic ashes, sample nos. GA1601, 34/LG/82 and 36/LG/82, are shown in Figs. 4 and 5. These patterns show peaks indicating the presence of feldspars, mainly plagioclase, and smectite.

For examination of smectite, X-ray powder diffraction was made for a fraction less than 10 μm after various treatments of volcanic ash, sample no. 34/LG/82. The powder diffraction patterns are given in Fig. 6. The peak of 15.4 Å shows (001) reflection of smectite. It expanded to 17.0 Å by treatment with ethylene glycol. After heating to 800℃ for one hour, the peak shifted to 9.7 Å due to dehydration of interlayer water.

Shape, size and microstructure of grains of volcanic ashes, sample nos. GA1601, 34/LG/82 and 36/LG/82, were examined under the scanning electron microscope (SEM). The SEM photograph of the surfaces of grains of volcanic ash, sample no. GA1601, is shown in Fig. 14, A. The volcanic ash contains a large amount of grains less than 20 μm and those than over 100 μm. A number of hole where volcanic gases passed through, as shown in Fig. 14, B(sample no. GA1601) and Fig.14, C (sample no. 34/LG/82), can be observed within each grain materials, corresponding to the groundmass of volcanic rock, those which are composed mainly of volcanic glass.

Geochemistry

1. Bulk Chemistry

Two rock samples of pyroclastic flow (sample nos. GA1505 and GA1506) collected at Cihurip, and one sample of volcanic ash (sample no. GA1601), which travelled from Galunggung Volcano, collected in Bandung were chemically analyzed by a combination of

Table 5. Chemical analyses and CIPW norms of volcanic products from Galunggung Volcano

Sample no.	GA1506	GA1601	34/LG/82	36/LG/82	*	**
Volcanic products	Pyroclastic flow	Volcanic ash	Volcanic ash	Volcanic sand		
Date of eruption	May '82	Aug.16,'82	July 28,'82	July 28,'82		
SiO_2	56.02	50.02	50.24	49.16	51.16	53.41
TiO_2	0.81	0.95	0.88	0.87	0.88	0.79
Al_2O_3	18.23	19.21	18.64	18.04	17.37	17.75
Fe_2O_3	2.53	2.49	4.22	3.15	3.43	3.24
FeO	6.02	6.75	4.62	6.01	6.16	6.25
MnO	0.19	0.18	0.16	0.18	0.17	0.17
MgO	3.93	5.62	4.63	6.65	6.14	4.78
CaO	8.02	9.77	8.79	9.62	10.27	9.54
Na_2O	3.29	2.35	2.52	2.11	2.63	2.60
K_2O	0.74	0.44	0.50	0.42	0.84	0.68
H_2O+	0.16	1.14	3.04	1.70	0.19	0.48
H_2O-	0.02	0.16	1.08	1.16	0.55	0.23
P_2O_5	0.09	0.11	0.10	0.09	0.23	0.14
Total	99.73	99.94	99.93	99.83	100.02	100.06
Q	9.01	3.07	7.52	3.53		
Or	4.37	2.60	2.95	2.48		
Ab	27.84	19.89	21.32	17.86		
An	32.79	40.57	38.07	38.51		
Di Wo	2.68	3.00	2.04	3.60		
Di En	1.43	1.73	1.41	2.33		
Di Fs	1.16	1.13	0.47	1.03		
Hy En	8.36	12.26	10.13	14.24		
Hy Fs	6.82	7.98	3.37	6.30		
Mt	3.67	3.61	6.12	4.57		
Il	1.54	1.80	1.67	1.65		
Ap	0.21	0.25	0.23	0.21		
Fe_2O_3/FeO	0.42	0.37	0.91	0.52	0.56	0.52
T.FeO/MgO	2.11	1.60	1.82	1.33	1.51	1.92
Na_2O+K_2O	4.03	2.79	3.02	2.11	3.47	3.28

New analyses in this paper. Analyst. M. Yamamoto.
* and ** are arthmetic means of basalts and basaltic andesites of island arcs, respectively (EWART, 1976). T. FeO represents total iron oxide as FeO ($FeO+0.9\ Fe_2O_3$).

the gravimetric method for SiO_2 and $H_2O\pm$, the volumetric method for FeO, the atomic absorption method for Al_2O_3, total Fe, MnO, MgO, CaO, Na_2O and K_2O and the colorimetric method for TiO_2 and P_2O_5, accompanying with the ion exchange resin and chelate titration method. The rocks and volcanic ash were pulverized by a vibration mill in advance for analysis.

Chemical analyses are tabulated in Table 5, together with their CIPW normative compositions. Arithmetic means of basalts and basaltic andesites of island arcs by EWART (1976) are also given in the same table for comparison. Chemical analyses which have been made by Volcanological Survey of Indonesia (VSI) for scorias and volcanic ashes from Galunggung Volcano are given in Table 6.

Table 6. Chemical analyses of scorias and volcanic ashes from Galunggung Volcano

Sample no.	Date of eruption	Volcanic product	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	H_2O	P_2O_5	Total
01a/LG/82	Apr. 5, '82 (I)	Volcanic ash	55.71	0.81	20.90	4.35	2.92	0.14	3.15	6.11	2.82	0.63	1.17	0.06	98.77
01b/LG/82	"	"	55.71	0.82	20.51	4.55	2.74	0.14	2.92	6.44	2.79	0.61	0.10	0.06	97.39
01c/LG/82	Apr. 8, '82 (II)	Lapilli	55.61	0.74	20.51	3.78	3.59	0.12	3.30	7.16	2.93	0.64	0.21	0.06	98.65
01d/LG/82	"	Scoria	55.61	0.74	20.06	4.54	3.91	0.17	3.52	7.16	2.94	0.67	0.27	0.04	99.63
02/LG/82	Apr. 25, '82 (IV)	Lapilli	50.72	0.86	23.67	4.54	3.46	0.14	3.67	7.46	2.23	0.40	0.93	0.05	98.13
03/LG/82	"	Socria	53.34	0.86	19.89	4.39	3.95	0.14	5.58	6.97	2.93	0.63	0.11	0.01	98.80
04/LG/82	"	Lapilli	50.50	0.96	22.72	4.34	3.64	0.14	4.73	7.60	2.52	0.50	0.78	0.05	98.48
05/LG/82	"	Scoria	49.31	0.43	19.10	2.43	5.35	0.04	5.13	9.75	3.00	0.61	1.63	0.10	96.88
06/LG/82	May 6, '82 (V)	Volcanic ash	51.20	0.46	19.04	4.61	4.01	0.06	4.07	7.74	3.20	0.79	3.05	0.10	98.33
07/LG/82	"	"	51.12	0.46	19.11	4.61	4.01	0.06	4.19	8.00	3.13	0.70	2.09	0.10	97.58
08/LG/82	"	"Hot cloud" ash	51.08	0.89	21.11	3.84	3.82	0.15	4.24	9.38	2.50	0.58	0.59	0.12	98.30
09/LG/82	"	Lapilli	50.83	0.83	20.69	3.40	4.39	0.15	5.00	10.42	2.42	0.45	0.78	0.09	99.45
10/LG/82	"	Scoria	52.48	0.86	18.69	2.52	5.54	0.17	5.89	9.67	2.87	0.59	0.11	0.05	99.44
11/LG/82	"	Lapilli	50.97	0.83	20.50	3.51	4.34	0.17	5.30	10.27	2.47	0.49	0.73	0.09	99.67
33/LG/82	July 28, '82	"	47.53	0.81	19.01	4.57	4.69	0.16	9.80	10.54	2.09	0.28	0.01	0.15	99.64
34/LG/82	"	Volcanic ash	48.98	0.99	19.69	4.18	4.32	0.13	5.07	8.79	2.35	0.40	2.11	0.18	97.19
35/LG/82	"	"	48.71	0.81	19.48	3.33	5.26	0.14	6.38	9.37	2.36	0.36	1.55	0.13	97.88
36/LG/82	"	Volcanic sand	49.22	0.89	19.06	3.95	4.89	0.15	6.47	9.52	2.40	0.38	1.29	0.06	98.28
37/LG/82	"	"	49.51	0.70	20.14	4.07	4.51	0.15	6.38	9.37	2.34	0.38	0.98	0.08	98.61

Data from Volcanological Survey of Indonesia. Values of Fe_2O_3/FeO ratio, T. FeO/MgO ratio and (Na_2O+K_2O) were calculated in this paper.

2. Geochemical Nature of Volcanic Products

As seen from Tables 5 and 6, the Sio_2-content of volcanic ejecta, such as scoria and volcanic ash, erupted out during April 5-8 of 1982 is about 55 wt. %, while that of volcanic ejecta erupted out during April 25-May 6 of 1982 is about 50 wt. % and that of volcanic ejecta erupted out on July 28 of 1982 is about 49 wt.%. With respect to the SiO_2-content, the volcanic ejecta of April 5-8 are basaltic andesite, and those of April 25-May 6 and July 28 are basalt according to the classification of volcanic rocks from active volcanic arcs and continental margins in the world (CARMICHAEL and others, 1974).

Plotting of the volcanic ejecta on KUNO's (1966) SiO_2-(Na_2O+K_2O) diagram (Fig. 7) regarding the general boundaries between the tholeiite series, the high-alumina basalt series and the alkali olivine-basalt series for the late Cenzoic volcanic rocks of the Japanese Island arcs, the plots representing the volcanic ejecta of April 5-8 and some of April 25-May 6 fall within a field of the tholeiite series, while the plots representing the volcanic ejecta of July 28 and some of April 25-May 6 fall within a field of the high-alumina basalt series.

Table 6. (continued)

Sample no.	Fe_2O_3/FeO	T.FeO/MgO	Na_2O+K_2O
01a/LG/82	1.5	2.17	3.45
01b/LG/82	1.7	2.34	3.40
01c/LG/82	1.1	2.12	3.57
01d/LG/82	1.2	2.27	3.61
02/LG/82	1.3	2.06	2.63
03/LG/82	1.1	1.42	3.56
04/LG/82	1.2	1.60	3.02
05/LG/82	0.5	1.47	3.61
06/LG/82	1.1	2.00	3.99
07/LG/82	1.1	1.95	3.83
08/LG/82	1.0	1.72	3.08
09/LG/82	0.8	1.49	2.87
10/LG/82	0.5	1.33	3.46
11/LG/82	0.8	1.42	2.96
33/LG/82	1.0	0.90	2.37
34/LG/82	1.0	1.59	2.75
35/LG/82	0.6	1.29	2.72
36/LG/82	0.8	1.31	2.78
37/LG/82	0.9	1.28	2.72

It is remarked that the alkalies-content, as suggested from Fig. 7, slightly decreases with a decrease of the silica-content, and that in both of the alkalies-content and the silica-content the volcanic ejecta of April 5-8 are contrasted with those of July 28 ; the former is high, while the latter is low.

Taking account of the total FeO/MgO ratio against the SiO_2-content, the plots of the whole volcanic ejecta fall within a field of the tholeiitic series on MIYASHIRO's (1974) diagram (Fig. 8) regarding the general boundary between the calc-alkalic rock series and the tholeiitic series for western Pacific island arcs.

Meanwhile, it is noted that the value of the total FeO/MgO ratio, as is clear from Fig. 8, decreases with a decrease of the SiO_2-content, and that in both of the value of the total FeO/MgO ratio and the SiO_2-content the volcanic ejecta of April 5-8 are sharply contrasted with those of July 28 and August 16 ; the former is high, while the latter is low.

As seen from Table 5, the values of Fe_2O_3/FeO ratios for the average compositions of basaltic andesites and basalts of island arcs are about 0.5. In the volcanic products from Galunggung Volcano, however, many chemical analyses show that the content of ferric iron oxide is much more higher than that of ferrous iron oxide, that is, the values of the Fe_2O_3/FeO ratios are calculated out to be more 1.0 in many cases.

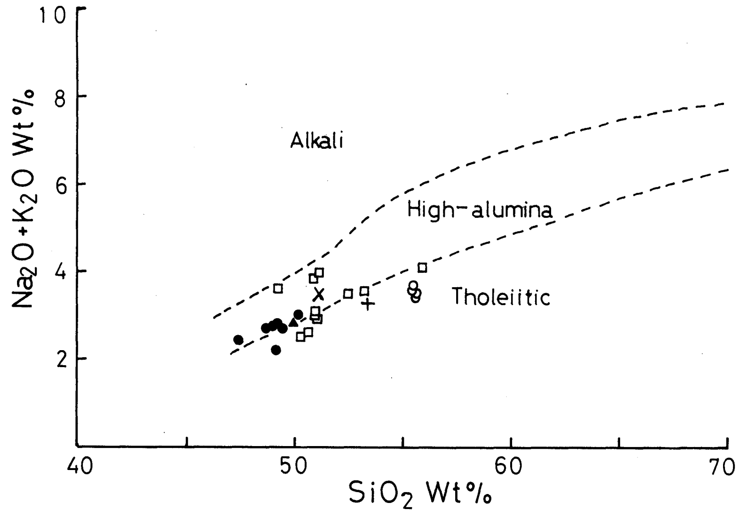

Fig. 7. Plots of the analyzed scorias and volcanic ashes from Galunggung Volcano on KUNO's (1966) SiO_2-(Na_2O+K_2O) diagram for the late Cenozoic volcanic rocks of the Japanese island arcs. The two dashed lines denote the general boundaries between the tholeiite series, the high-alumina series, and the alkali olivine-basalt series. Open circles, open rectangles, solid circles and solid triangles represent volcanic products of April 4-8, those of April 25-May 6, those of July 28, and volcanic ash of August 16, 1982, respectively. Plus and diagonal represent an average composition of basaltic andesites and that of basalts, respectively, of typical volcanoes of island arcs of western and northern Pacific and Carribean regions (EWART, 1976).

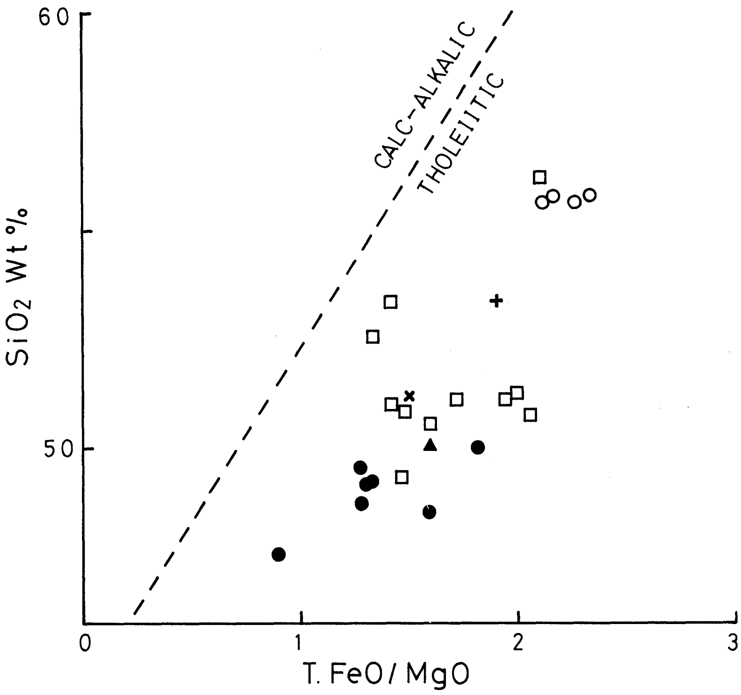

Fig. 8. Plots of the analyzed scorias and volcanic ashes from Galunggung Volcano on MIYASHIRO's (1974) SiO_2-total FeO/MgO diagram. The dashed line denotes the general boundary between the calc-alkalic rock series and the tholeiitic series for non-alkalic volcanic rocks of western Pacific island arcs. Symbols are the same as those in Fig. 7.

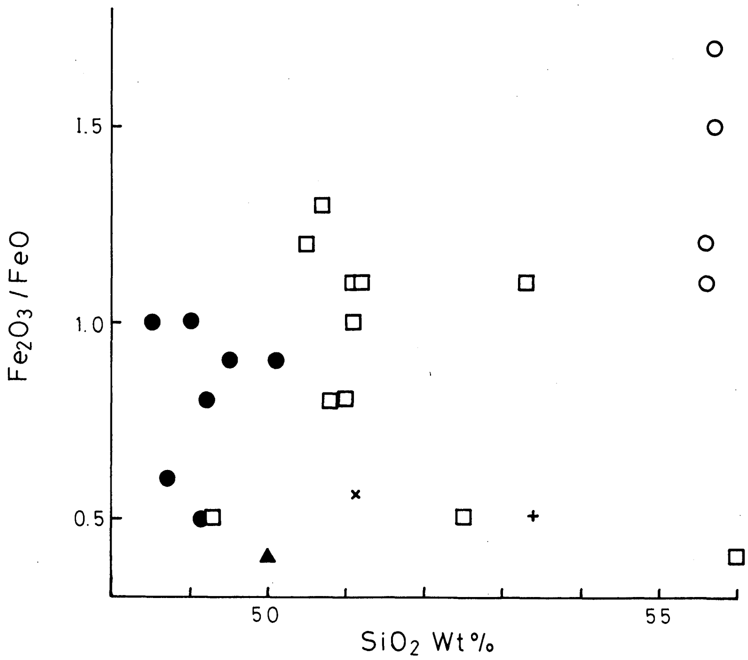

Fig. 9. Diagram showing a relationship between Fe_2O_3/FeO ratio and SiO_2-content for the analyzed scorias and volcanic ashes from Galunggung Volcano. Symbols are the same as those in Fig. 7.

Compared of the volcanic products of April 5-8 with those of July 28 and August 16, they are contrasted with each other in the value of the Fe_2O_3/FeO ratio; the former is characterized by high value over 1.0, while the latter by low value less 1.0 or of 1.0.

It is also noted that in both the relative proportion of ferric iron oxide to ferrous iron oxide and the silica-content the volcanic products of April 5-8 are contrasted with those of July 28 and August 16, that is, the former is higher than latter.

Taking account of the value of the Fe_2O_3/FeO ratio against the SiO_2-content, as shown in Fig. 9, the locations occupied by the plots of the volcanic products of April 5-8 are sharply contrasted with those occupied by the plots of the volcanic products of July 28 and August 16, that is, the volcanic products of April 5-8 are high, and, in contrast, those of July 28 and August 16 are low in both the value of the Fe_2O_3/FeO ratio and the SiO_2-content. The plots of the volcanic products of April 25-May 6 fall in a gradational area between the former two.

Such a fact as mentioned above shows that the volcanic products erupted out during April 5-8 had been much more affected by oxidation at crater before the eruption as compared to those erupted out later, and the volcanic products have gradually been changing into more basic in chemical composition.

Summary

1. Three Characteristic Features of Volcanic Products from Galunggung Volcano

Three characteristic features are recognized in the volcanic products from Galunggung Volcano: (a) chemical analyses of the volcanic products show that the silica-content of the volcanic products erupted out at the first stage, April 5-8, is about 55 wt. % and that of the volcanic products erupted out at the successive stages, April 25-May 6, July 28 and August 16, is about 49-50 wt. % ; (b) the volcanic products of the first stage are high, while those of the successive stages are low not only in the SiO_2-content, but in both of the (Na_2O+ K_2O)-content and the value of the total FeO/MgO ratio, and the (Na_2O+K_2O)-content and the value of the total FeO/MgO ratio decrease with a decrease of the SiO_2-content ; and (c) the value of the Fe_2O_3/FeO ratio of the volcanic products of the first stage is more 1. 0, while that of the volcanic products of the successive stages is less 1.0 or 1.0, and the volcanic products of April 5-8 are high and those of July 28 and August 16 are low in both the SiO_2-content and the value of the Fe_2O_3/FeO ratio.

2. Considerations for the Mechanism of Galunggung Volcano Explosion

It is significantly noted that the value of the total FeO/MgO ratio, as is clear from Fig. 8, decreases with a decrease of the SiO_2-content, and the (Na_2O+K_2O)-content, as Fig. 7 shows, decreases with a decrease of the SiO_2-content throughout over the whole chemical analyses of the volcanic products. Accordingly, the value of the total FeO/MgO ratio and the (Na_2O+K_2O)-content are correlative with each other as shown in Fig. 10, and both of them are also correlative with the SiO_2-content. Furthermore, it is noticed that in all of the value of the total FeO/MgO ratio, the (Na_2O+K_2O)-content and the SiO_2-content the volcanic products of the first stage are high, and, in contrast, those of the successive stages, in particular, of July 28, are low.

Such a fact clearly shows that the volcanic products from Galunggung Volcano have become change into basic in composition during the period from the first stage to the successive stages of eruption, and that magma of Galunggung Volcano is essentially basaltic in composition. Such a change in chemical composition of the volcanic products reflects the chemical change of a magma from which the volcanic products were provided. That is, it is possibly considered that at the first stage of explosion the volcanic products of basaltic andesite in chemical composition came from the magma which was contaminated with some materials, e. g., pre-erupted or pre-existed materials something more rich in silica, at the magma chamber in which fractional crystallization was proceeding. The successive stages of eruptions were accompanied by the volcanic products which came from essentially basaltic magma.

At the first stage of explosion, of course, it is certain that the presence of water, e. g., accumulated water at or nearby the present or pre-existed crater, played an important role to increase water vapor pressure underbeneath the cap rock by which the crater had been overlaid.

3. Genetical Consideration of the Galunggung Reddish Grey Ash

The volcanic products erupted out during April 5-8 of 1982 and those erupted out on July 28 and August 16 of 1982, as seen from Fig. 9, are contrasted with each other in the value of the Fe_2O_3/FeO ratio. This fact clearly shows that there were different conditions

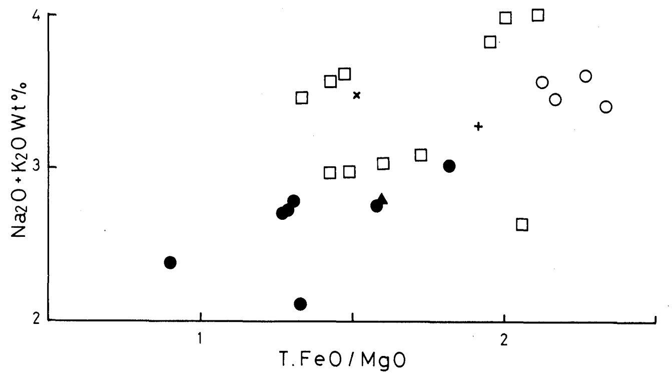

Fig. 10. Diagram showing a relationship between total FeO/MgO ratio and (Na_2O+K_2O)-content for the analyzed scorias and volcanic ashes from Galunggung Volcano. Symbols are the same as those in Fig. 7.

in the degree and state of oxidation by which materials at crater before the eruption were affected.

Such a characteristic feature that the volcanic products from Galunggung Volcano during April 5-8 are high in the value of the Fe_2O_3/FeO ratio is sometimes recognized in the so-called "red ash", termed by ŌBA and others (1980 a, b), from Sakurajima Volcano, Kagoshima, Kyushu, Japan. Actually, some of volcanic ashes from Galunggung Volcano look slightly reddish grey-color in appearance. That is, they are those analogous to the Sakurajima red ash.

The same genetical consideration for the mechanism of formation of the Sakurajima red ash will possibly be given to reddish grey-colored volcanic ashes from Galunggung Volcano, in short, Galunggung reddish grey ash.

That is, pre-existed materials or primary black ashes, by those of which crater had been buried, were subjected to thermal alteration accompanied by chemical reaction due to volcanic gases and oxidation. Thus, some amounts of ferrous iron oxide, which is one of major components of principal and accessory rock-forming silicate minerals in volcanic ash, were chemically converted into ferric iron oxide. Successively, the eruptions with plume or smoke at Galunggung crater have been accompanied by black-colored volcanic ash, i. e., black ash, and scoria, those of which appear to have been supplied from the upward-moving essential magma of basaltic composition with the relatively low value of the Fe_2O_3/FeO ratio.

Acknowledgements

Many thanks are given to General SOLICHIN G.P., Presidential Aide of Indonesian Government, who gave us an opportunity to present some comments at the meeting held in Bandung for discussion on Galunggung Volcano; and to Ir. L. PARDYANTO, Volcanological Survey of Indonesia (VSI), for his suggestions on volcanic activity at Observatory Station, Galunggung Volcano. Thanks are also given to Mr. H. SAIGO for his assistance in preparation of thin sections; and to Mr. S. KIYOSAKI and Mr. T. ISHII, Kagoshima

University, for their assistance in modal analysis and measurement of refrective index. Members of Japanese working group gratefully acknowledge for the Japan Society for the Promotion of Science (JSPS), from which the financial support in the 1982 fiscal year for the research of the Krakatau Group in Indonesia was provided, and wish to express their appreciation to Prof. Dr. D.S. SASTRAPRADJA and Dr. H. NAPITUPULU, Indonesian Institute of Sciences (LIPI) for their kind cooperation.

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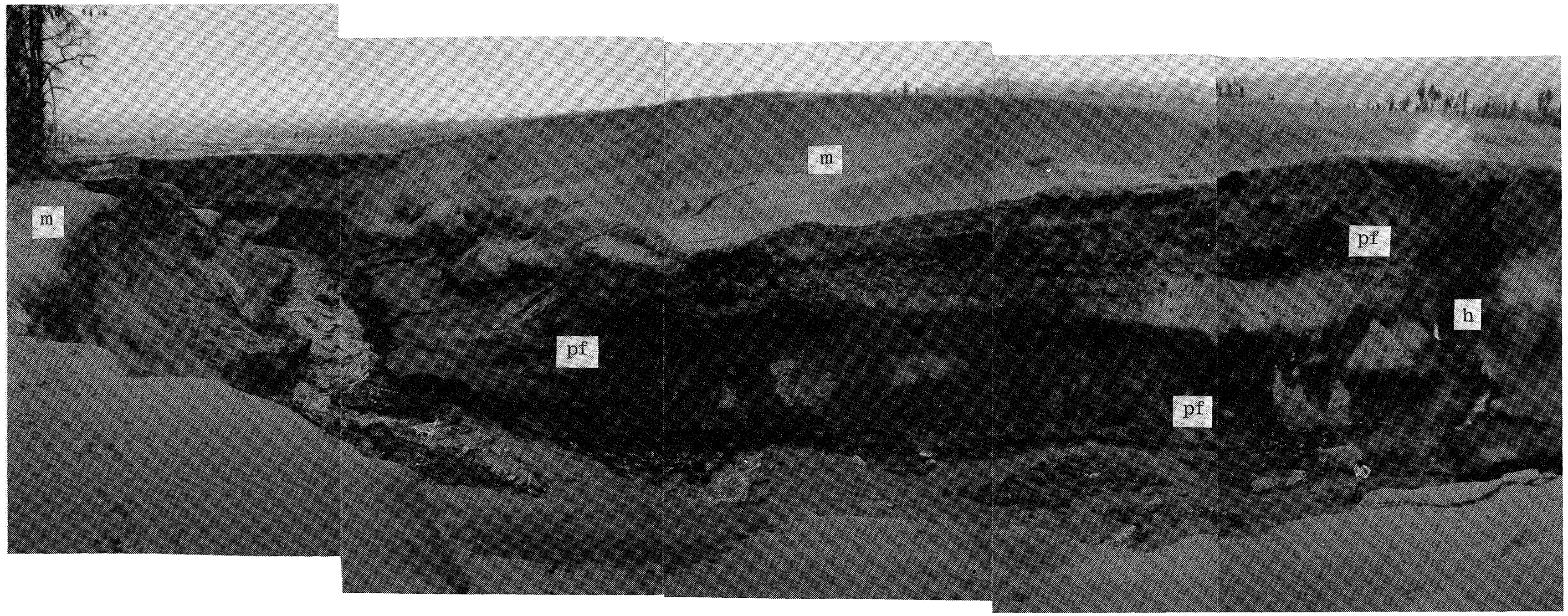

Fig. 11. Mode of occurrence of pyroclastic flow ("nuée ardente") and mud flow ("lahar") at the exposure along the river running southeast, Cihurip locating at the southeastern foot 4 km far from Galunggung Volcano, West Java, Indonesia (II-18~22). Abbreviations-pf, pyroclastic flow ; m, mud flow ; h, hot spring.

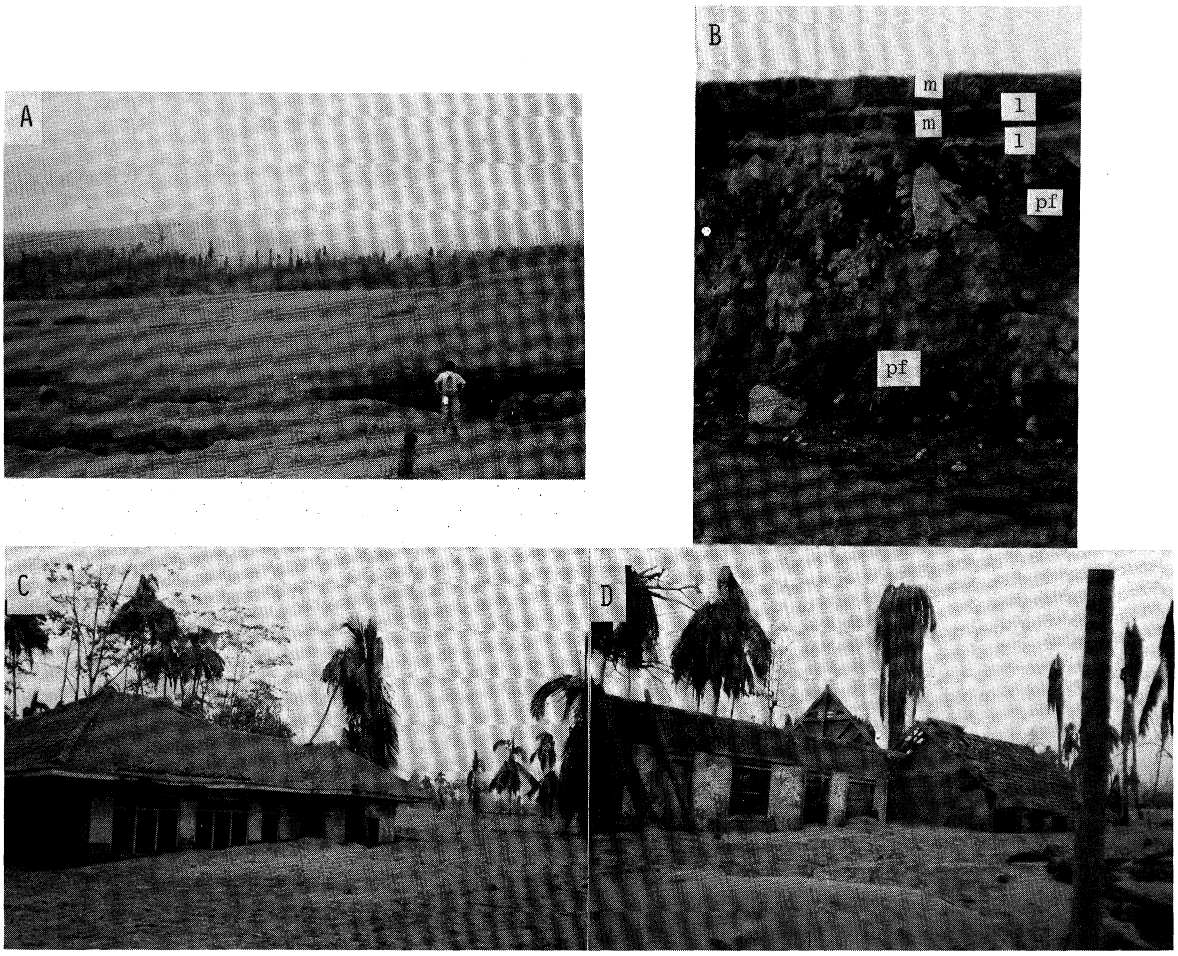

Fig. 12. Distance-view of Galunggung Volcano, exposure of pyroclastic flow, and houses which were destroyed owing to comming down of mud flow.

A. Distance-view of Galunggung Volcano. The whole land is covered by mud flow ("lahar"). Taken at Cihurip 4 km southeast of Galunggung crater (II-3).

B. The exposure showing the volcanostratigraphic succession on the shore of water at Cihurip (II-17). See Fig. 3.
Abbreviations-l, lapilli and ash (air fall). The others are the same as those in Fig. 11.

C & D. The villages here had a great damage due to flowing down of mud flow ("lahar"). Many houses were destroyed. Taken at Cihurip (I-33 & II-25).

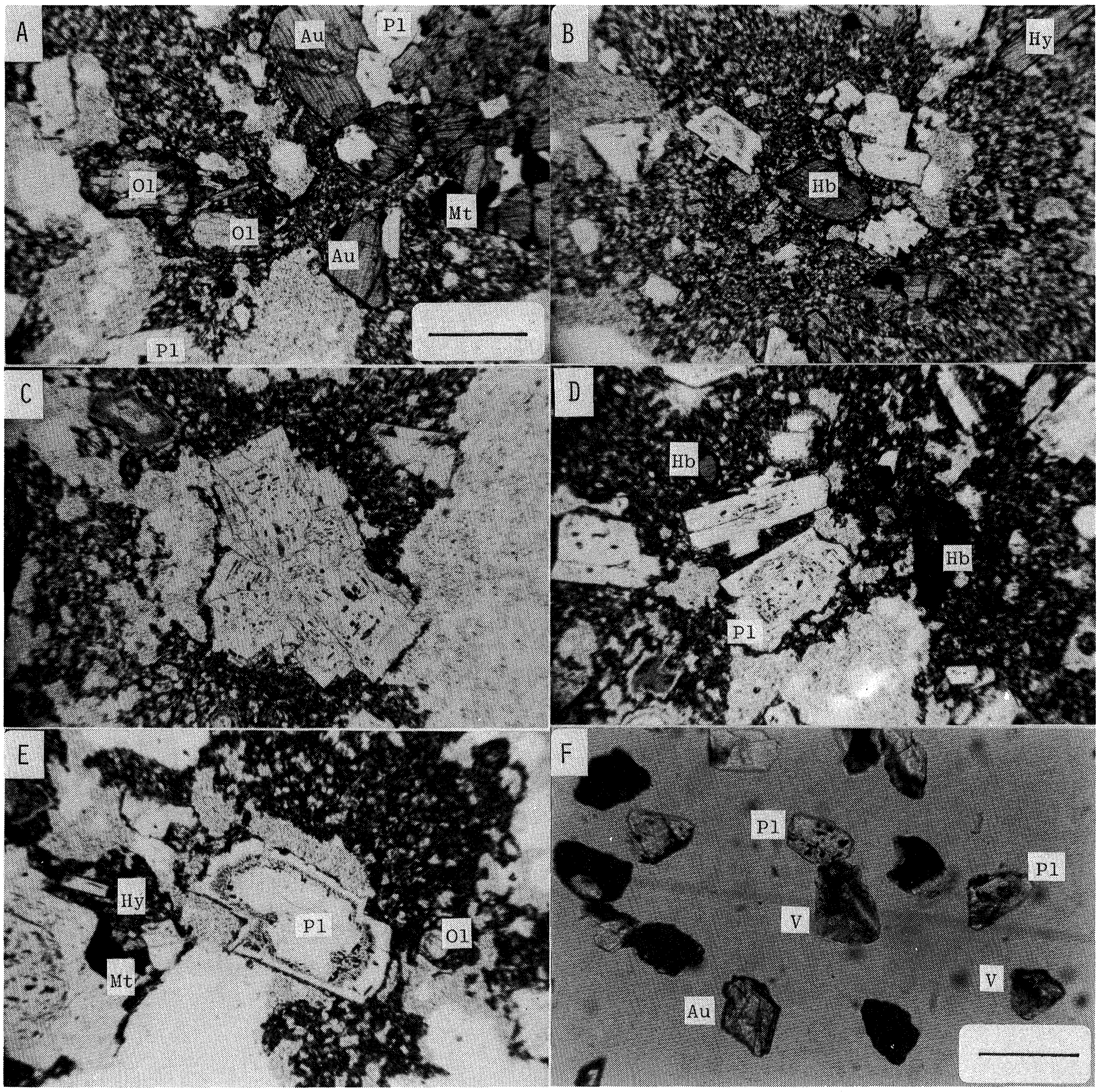

Fig. 13. Microphotographs of pyroclastic flow and volcanic ash from Galunggung Volcano. A ~C, pyroclastic flow, sample no. GA1505 ; D & E, pyroclastic flow, sample no. GA1506 ; F, volcanic ash, sample no. GA1601. The scale bar in A represents 0.5 mm ; the same scale for B~E. The scale bar in F represents 0.2 mm. Open nicol. Abbreviations-Pl, plagioclase ; Au, augite ; Hy, hypersthene ; Ol, olivine ; Hb, hornblende ; Mt, magnetite ; V, volcanic glass.

A. Phenocrystic olivines show the corroded form with the reaction rim consisting of pyroxene and opaque mineral (Photo I-3). The groundmass has the hyalopilitic~felted texture.
B. Phenocrystic hornblende has the corroded form (Photo I-11).
C. Phenocrystic plagioclases contain micrograins of light brown-colored volcanic glass those of which are arranged parallel to cleavage and zonal structure (Photo I-13).
D. Phenocrystic hornblendes show the corroded form (Photo I-15).
E. Phenocrystic plagioclases contain micrograins of volcanic glass those of which are arranged parallel to zonal structure and cleavage of host minerals (Photo I-19).
F. Many volcanic glasses contain small bubbles which show that gases were expanding (Photo II-21A).

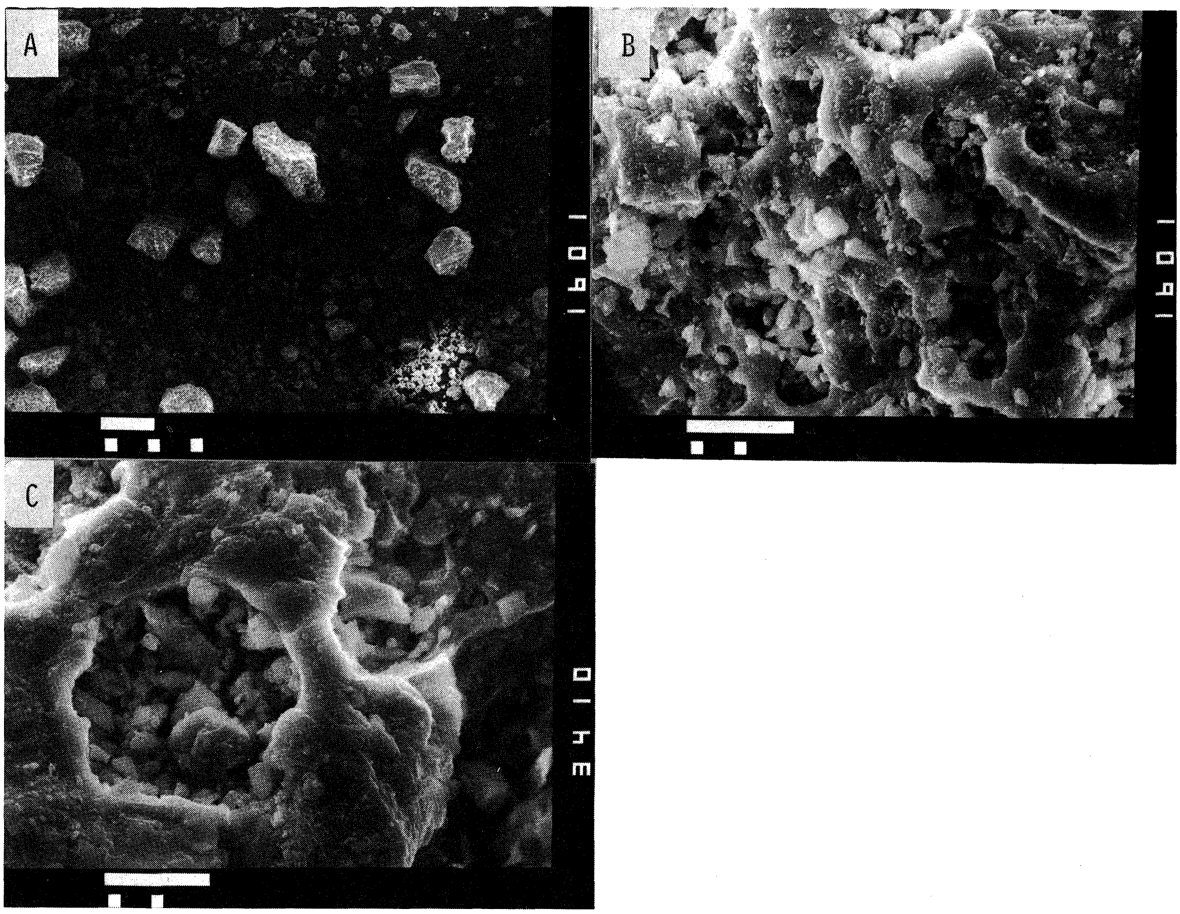

Fig. 14. Scanning electron microphotographs of grains of volcanic ashes from Galunggung Volcano.

A. Shape and size of grains of volcanic ash, sample no. GA1601. The scale bar is 100 μm.

B. A number of hole where volcanic gas passed through within the grain material composed mainly of volcanic glass. Volcanic ash, sample no. GA1601. The scale bar is 10 μm.

C. Same. Volcanic ash, sample no. 34/LG/82.