Nuées Ardentes of the 1968 Eruption of Mayon Volcano, Philippines *

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Abstract

Mayon Volcano, southeastern Luzon, began a series of explosive eruptions at 0900 April 21, 1968, and by May 15 more than 100 explosions had occurred, at least 6 people had been killed, and roughly 100 square km had been covered by more than 5 cm of airfall ash, blocky ash flows, and a lava flow. All material erupted was porphyritic augite-hypersthene andesite.

Explosions from the summit crater (elevation 2460 m) ejected large quantities of ash and incandescent blocks to a height exceeding 600 m and produced ash-laden clouds which rose to heights of 3 to 10 km. Backfall of the coarser material fed nuées ardentes which repeatedly swept down ravines on all sides of the volcanic cone. The velocity of one nuée ardente ranged from 9 to 63 m per sec. The largest nuées descended to the southwest and reached as far as 7 km from the summit. An aa lava flow also descended 3 1/2 km down this flank.

The nuées ardentes deposited pyroclastic flows that contained large breadcrust-surfaced blocks averaging about 30 cm across, but occasionally reaching 25 m in greatest dimension. These blocks were still very hot in their interiors several days later. Surrounding the pyroclastic flows is a seared zone as much as 2 km wide, but averaging a few hundred meters, in which vegetation is charred and splintered, but over which only a thin layer of airfall ash was deposited.

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Introduction

Mayon Volcano is located on the southeastern peninsula of the Island of Luzon, Philippines (Fig. 1), about 300 km ESE of Taal Volcano. Taal began a period of activity in September 1965 (MOORE,

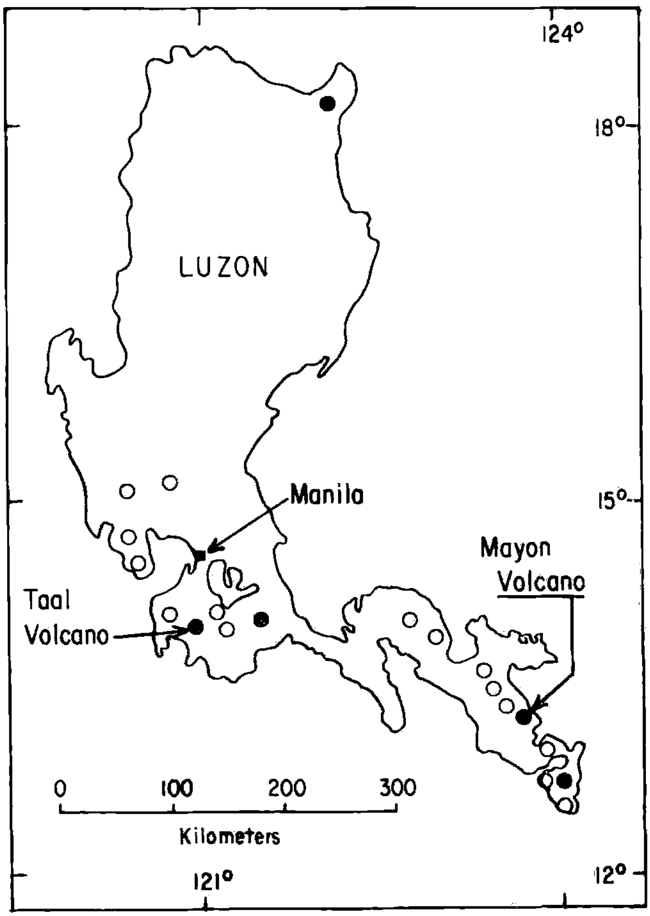

FIG. 1 - Map of the island of Luzon, Philippines, showing location of Mayon and Taal Volcanoes. Other active volcanoes are shown by solid circles, and inactive volcanoes by open circles.

et al., 1966). The eruption of Mayon Volcano began at 2200 April 20, 1968, and the activity which followed consisted of more than 100 explosive eruptions which covered several square kilometers with block-and-ash or pyroclastic flows and a lava flow, and hundreds of square kilometers with a millimeter or more of airfall ash. At least 6 people had been killed by the direct effects of the volcano as of May 15, 1968.

Mayon Volcano ranks as one of the most perfectly symmetrical composite volcanic cones in the world (Fig. 2). It rises 2462 m from

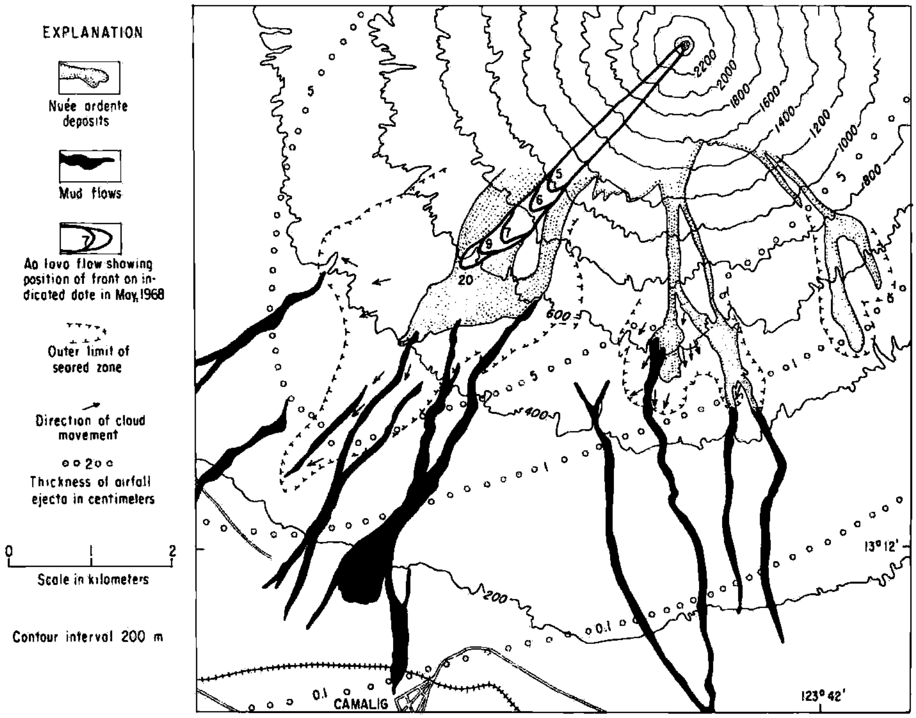

FIG. 2 - Reconnaissance geologic map of the south flank of Mayon Volcano showing deposits of the 1968 eruption.

the sea coast. The smoothly regular concave slopes are progressively steeper toward the summit and attain a maximum slope of 35°. Three km from the summit the slope is 19°. The summit crater is small, less than 200 m in diameter.

Mayon Volcano has had a long history of destructive eruptions (VAN PADANG, 1953). The first recorded eruption occurred in 1616, and since that time about 40 eruptions, which have claimed more than 1500 lives, have occurred. Judging by the records of previous eruptions, the present one seems to be rather typical and moderate in intensity. The eruptions of 1766, 1814, and 1897 were of much greater intensity.

The efficient action of the Philippine Commission on Volcanology, which delimited danger area; and of Gov. Jose S. Estevez of Albay Province, who ordered immediate evacuation and who organized care for the refugees, greatly minimized the loss of life.

Field work reported here was done from May 1 to May 9. The authors made flights over the volcano on April 29, May 1, May 9, and May 11.

Acknowledgments

We are deeply grateful for the logistic support provided by Father Ramon SALINIS, director of Aquinas University, Legazpi City, and by Dr. W. T. T. WARD of Clark Air Force Base, Angeles City. The U. S. 13th Air Force provided air and ground support, and obtained both aerial and ground photographs. We thank R. CITRON, Administrative Officer of the Smithsonian Institution Center for Short-Lived Phenomena for his assistance at all stages of this investigation. Bulletins released by the Philippine Commission on Volcanology have been used freely in this report.

Eruption

The first indication of a revival of activity on Mayon Volcano after the eruption of January-February, 1947, was the appearance of a glow from the summit crater at 2200 hours, April, 20, 1968, local time. At 0900 April 21, the seismometer operated by the Commission of Volcanology 8 km east of the summit began recording harmonic tremor, and a small eruption cloud appeared above the summit crater. Four explosive eruptions occurred on April 21 and 22, and early on April 23 the tempo of these explosions increased one occurring every few hours. The explosions were characterized by deep rumbling from the volcano followed by vertical ejection of ash and blocks commonly 300 and sometimes 600 m into the air, indicating their maximum velocity was about 100 m per sec (Figs. 3 and 4). Much of the ejected material was faintly incandescent, though its red glow could only be seen at night (Plates 1 and 2). The ejection

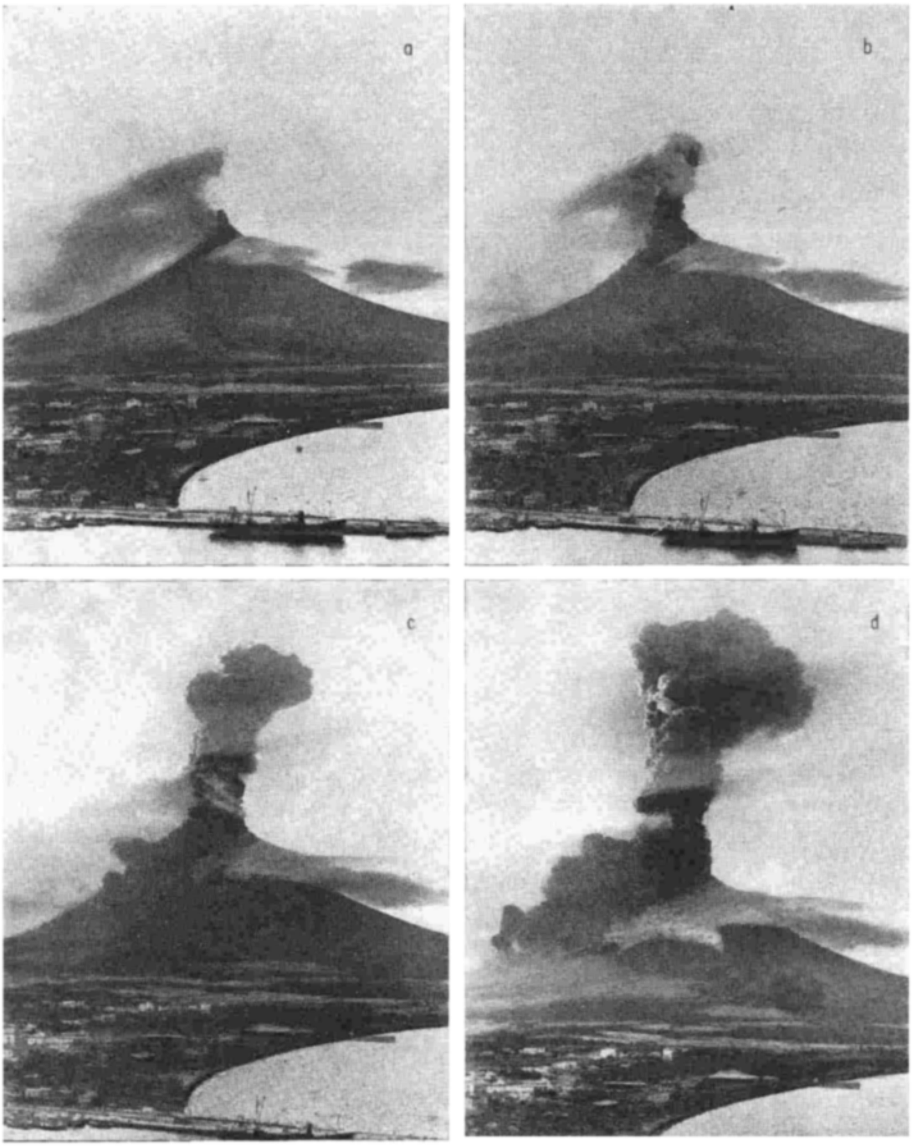

FIG. 3 - Sequence of photographs taken from Legazpi Port showing explosive eruption on morning of April 24, 1968. Approximate time intervals between photographs (based on motion pictures of other eruptions and assumption that small sailboat in bay is traveling at 2 knots) are: a to b 34 sec, b to c 58 sec, and c to d 24 sec. Nuée ardente on left skyline which emerges from the vertical explosion cloud is descending at a rate of approximately 30-50 m per sec. Photos by *Hollywood Photographic Studio*, Legazpi City.

4 - Aerial photograph of approximately the upper 500 m of Mayon Volcano on May 1, 1968. Large blocks are ejected several hundred meters above the vent, and small nuées ardentes are confined to ravines on upper slopes. Photo by *U. S. Air Force*.

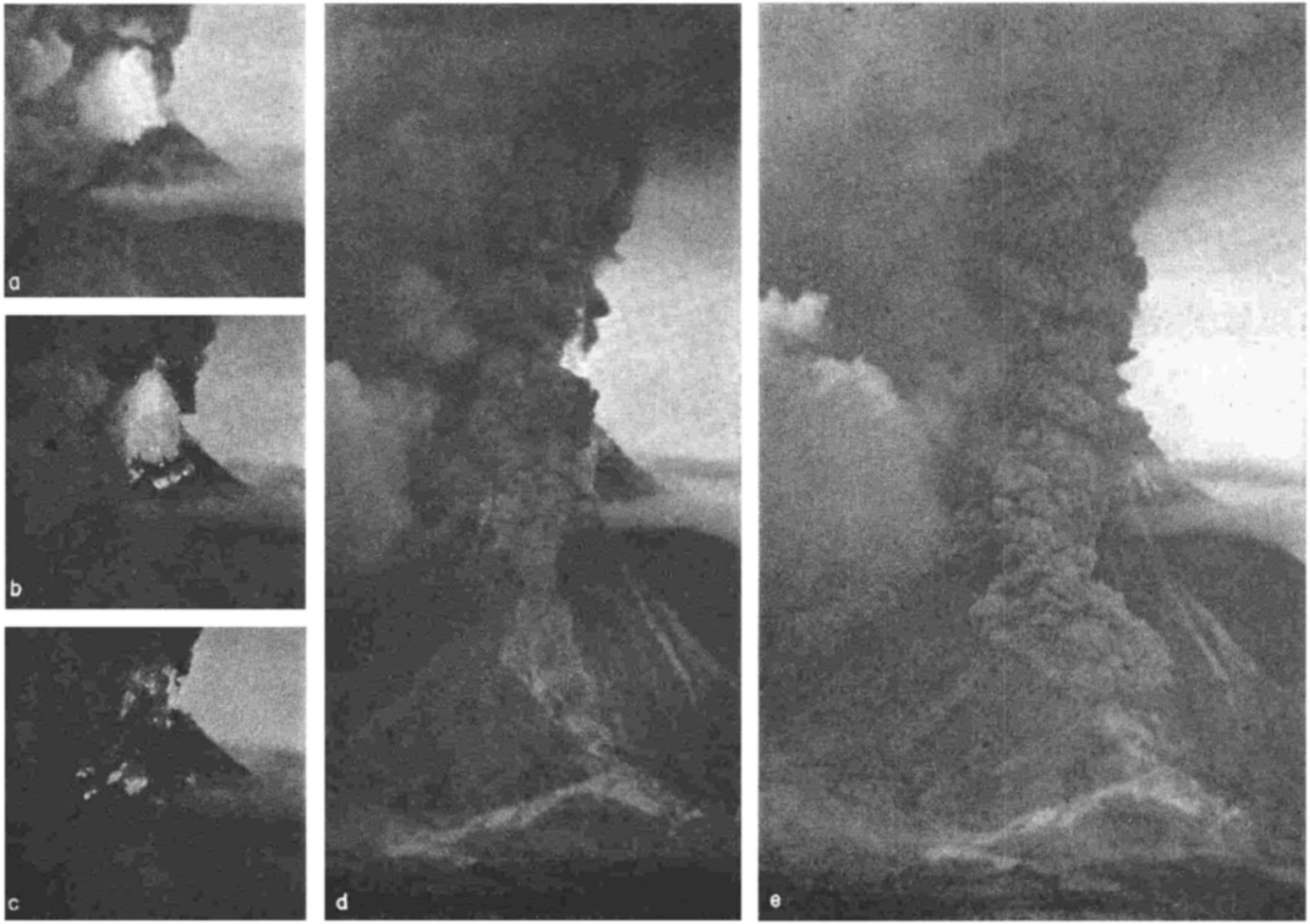

PLATE 1 - Sequence of photographs, all at same scale, of the south flank of Mayon Volcano showing development of nuées ardentes beginning at 0519 May 2, 1968. Photos were not timed, but comparison with motion pictures of later, similar eruptions indicates the time between d and e was 24 sec and e and Pl. 2 was 32 sec. Time between other photos was similar or somewhat shorter. Note vertical ejection of incandescent material to ∾ 600 m above vent, downfall and accumulation around vent, and downflow to feed nuées ardentes.

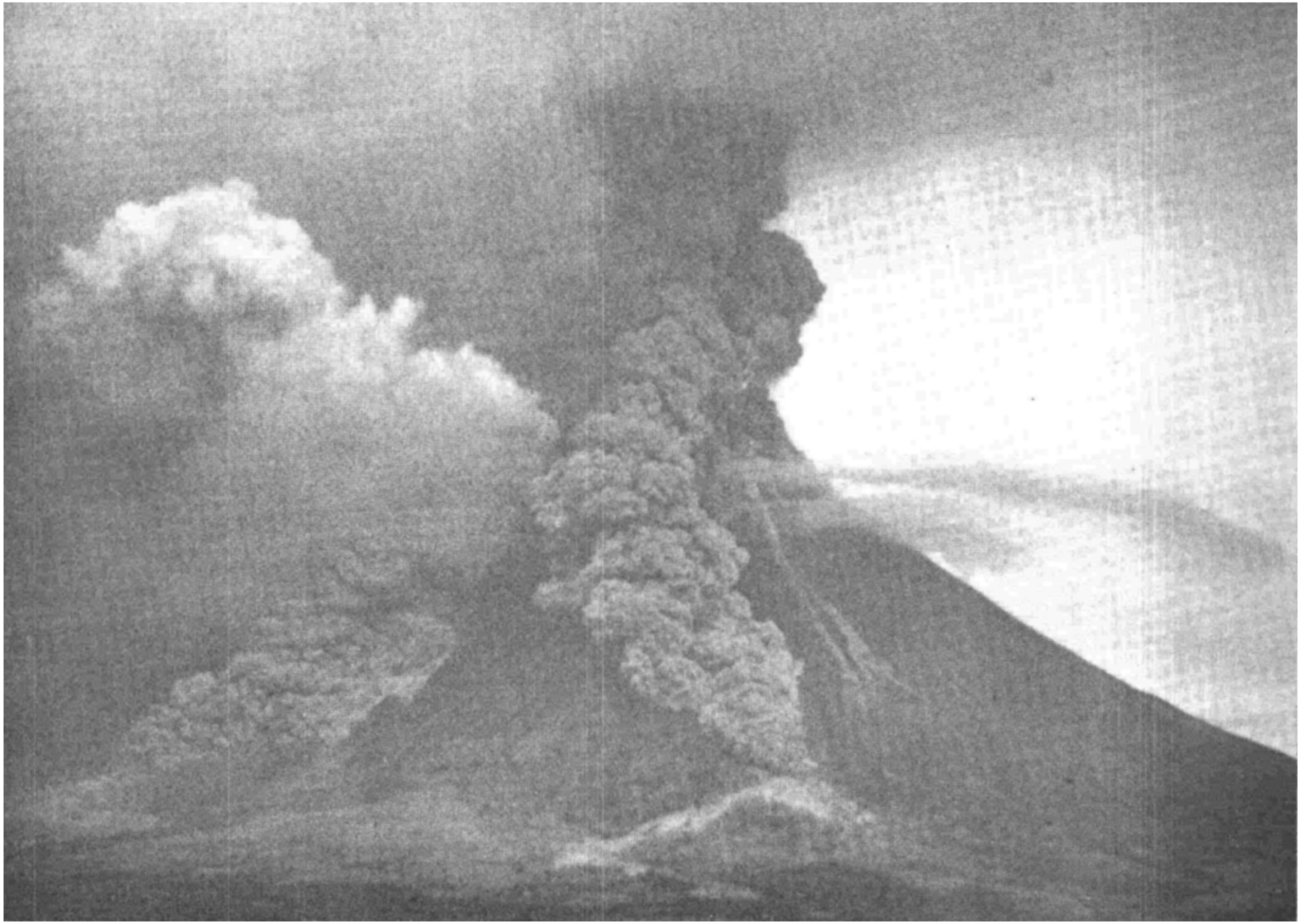

PLATE 2 - Final photograph of same eruptive sequence as shown in Plate 1. Terminus of nuée ardente in center has reached an elevation of about 650 m. Incandescence is visible in ravines on right where it is not obscured by dust and gas clouds from nuées ardentes.

was accompanied by development of a vertical ash-laden explosion cloud which rapidly reached a height of 3 to 10 km. From the base of this vertical cloud, tongue-like clouds emerged and swept down the flank of the mountain, generally within the deeper ravines. These downward-moving hot clouds or nuées ardentes continued to billow hot gases and ash all along their path. Lightning was common within

FIG. 5 - Aerial view of terminus of aa lava flow on the southwest flank of Mayon Volcano on May 10, 1968. Lava flow (partly obscured by dust and gas clouds) is moving over light-colored nuée ardente deposit on which many large blocks are visible. Two dark colored mudflows are visible on nuée ardente deposit at bottom. Photo by *U. S. Air Force*.

both the vertical explosion column and the downward-moving tongue-like clouds. The larger nuées ardentes also appeared to generate torrential rainstorms which eroded the loose ash and caused destructive mudflows on the lower flanks.

Such explosive eruptions continued from early on April 23 to May 4, separated by periods of only a few minutes or a few hours.

They reached their greatest intensity on April 25, but were most frequent, though of lesser intensity, on May 2.

On April 27 a large explosion breached the southwest crater rim and shortly afterwards a viscous aa lava flow began moving slowly down the southwest flank (Fig. 5). On May 7 its lower terminus was at an elevation of 520 m, on May 9, 460 m, and on May 11, 400 m. By May 15 activity was confined to the quiet extrusion of lava and only occasional weak blasts from the summit crater. Downslope movement of the lava flow had virtually stopped by May 20, but infrared images taken by the U. S. Air Force on August 6 show that the lava flow and the southwest nuée ardente deposit were still hot. At the time of this writing (October, 1968) moderate seismic activity still accompanied steaming from the crater, and heavy rains intermittently triggered mudflows.

Volcanic Products

Materials erupted from the volcano include airfall ash nuée ardente deposits, and an aa lava flow. Only the roughest sort of estimates can be made of the volume of the erupted materials because of incomplete data on distribution and thickness. Preliminary estimates indicate that the total volume approximates 35×10^6 m^3, of which 5×10^6 m^3 is airfall ash, 15×10^6 m^3 is nuées ardente deposit, and 15×10^6 m^3 is contained in the aa lava flow on the southwest flank. These materials are all composed of a rather uniform porphyritic hypersthene-augite andesite (Table 1). Plagioclase and pyroxene phenocrysts constitute more than half the rock and range from 1 to 4 mm in size.

Airfall ash was deposited in measurable quantities over an area of several hundred square kilometers; it is more than 5 cm thick over an area of about 50 sq. km (Fig. 2). Winds spread the ash cover farther from the vent toward the southwest and northeast, making an elongate pattern.

At a distance from the vent, airfall ash is very fine. At the resthouse on the north slope, 4 km from the crater, the maximum diameter of airfall material is 3 mm and most is less than half a millimeter. However, near San Rogue, 7 km northeast of the crater, stronger winds deposited pumiceous fragments more than 1 cm across.

TABLE 1 - Chemical, modal, and mineral analyses of rocks from Mayon Volcano.

	1	2	3
	Chemical analyses (weight percent)		
SiO_2	55.09	54.90	50.25
Al_2O_3	18.90	19.04	18.95
Fe_2O_3	3.40	2.96	4.90
FeO	4.62	4.81	4.19
MnO	0.15	0.15	0.14
MgO	4.03	4.05	4.00
CaO	8.56	8.62	9.60
Na_2O	3.42	3.40	5.19
K_2O	1.11	1.13	1.38
H_2O^+	0.00	0.00	n.d.
H_2O^-	0.04	0.04	n.d.
TiO_2	0.63	0.64	0.89
P_2O_5	0.26	0.26	0.34
Total	100.21	100.00	99.83

Modal analyses * (volume percent)

Composition	1	2
Pore space (vesicles, primary cracks, etc.)	22	42
Microlite-rich, glass matrix	44	41
Plagioclase (oscillatory zoning, An_{56}-An_{69})	36	45
Hypersthene ($Fs_{25}\,Wo_3\,En_{72}$, slightly zoned) and subcalcic augite ($Fs_{15}\,Wo_{41}\,En_{44}$, slightly zoned)	17	13
Olivine	none noted	trace
Opaques	3.2	1.4

1. USNM111124. Hypersthene andesite collected from the advancing terminus of aa lava flow on the southwest flank of Mayon Volcano (elevation, 870 m) on May 7, 1968. Chemical analysis by E. JAROSEWICH, Smithsonian Institution. Modal and mineral (microprobe) analyses by W. G. MELSON.
2. USNM111125. Hypersthene andesite from 8 centimeters within a breadcrust-textured block with a diameter of one meter. Block is from the nuée ardente deposit (elevation 500 meters), on the southwest flank of Mayon Volcano (13° 13.60′ N), (123° 42.15′ E). Chemical analysis by E. JAROSEWICH, Smithsonian Institution. Modal and mineral (microprobe) analyses by W. G. MELSON.
3. Olivine augite hypersthene andesite from the 1928 eruption of Mayon Volcano (FAUSTINO, 1929).

* Constituents other than pore space are recalculated to 100 percent.

Accretionary lapilli, formed when torrential rains fall through an ash-laden atmosphere, are particularly abundant in the thicker deposits of airfall material. Two distinct layers of accretionary lapilli

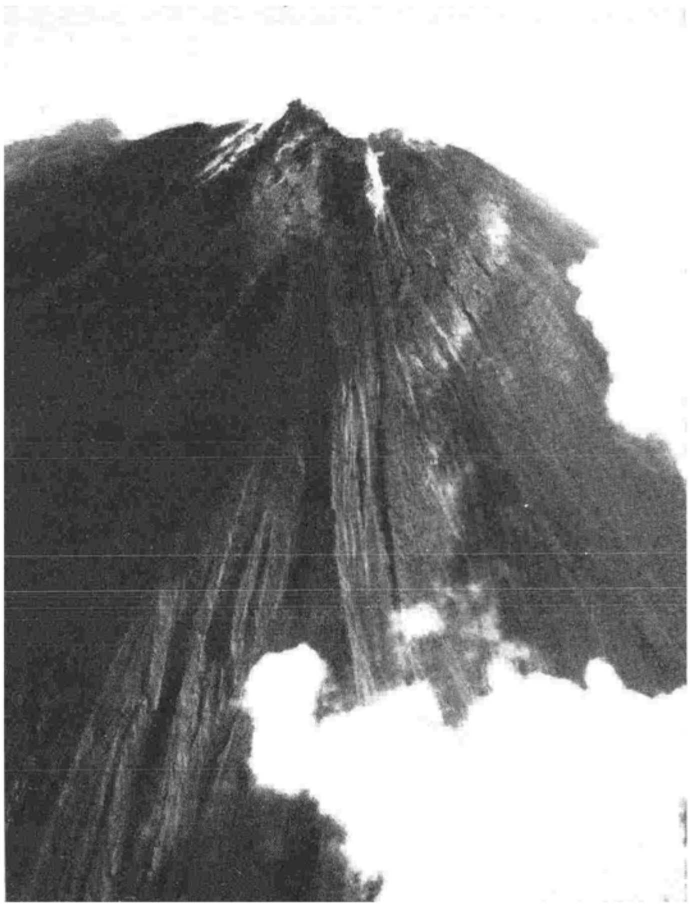

FIG. 6 - View of summit and northeast flank of Mayon Volcano on May 16, 1968 showing chutes deeply eroded by descent of nuées ardentes. Summit area appears to be covered by welded ejecta which has moved downslope plastically producing viscous flow lobes. Smaller lobate masses appear on the sides of the main chute in center of photograph and were apparently produced by overflow from the chute and welding of plastic material. Photograph by *U. S. Air Force.*

are present in a deposit of airfall ash 5.8 cm thick on the southwest flank of the volcano at an elevation of 300 m. Generally accretionary lapilli are present where the airfall ash is thicker than 2 cm.

Each of the three main areas of nuées ardente deposits on the southern part of the volcano (Fig. 2) was examined briefly in the field. Observations were limited to the lower part of the deposits — below 670 m. At this elevation the pyroclastic flow deposits are composed of a totally unconsolidated mixture of crystal-rich ash, lapilli, and blocks. Some blocks are angular and some have a characteristic rounded breadcrust surface. The texture of the deposits, as seen on areal photographs (Fig. 6) within about 1 km of the vent (in the zone where abundant incandescent material was observed during the eruption), indicates that much of the ejected material was plastic and welded into a carapace capping the volcano. This material formed short lobes as it flowed down the slopes.

Where observed near their lower ends, the deposits are poorly sorted and unbedded, blocks of all sizes being scattered at random through lapilli and ash. One block more than 25 m long was observed at an elevation of 600 m on the southwest slope. Fragments of shattered and abraded wood are common in the deposits.

A total of 60 blocks, including all those more than 4 cm in diameter, were measured at an elevation of 560 m on the pyroclastic flow deposit on the south flank of the volcano. The median size was 28 cm; 42 were breadcrust blocks, 12 were angular blocks, and 6 were crushed and splintered wood fragments ranging from 5 to 70 cm in length.

The median size of six samples of ash flow material containing lapilli less than 16 mm was found to range from 0.4 to 1.1 mm. These data indicate that the deposits are particularly coarse and poorly sorted as compared to other pyroclastic flows (SMITH, 1960, p. 822). Such coarseness probably results from the high crystal-to-glass ratio, the short transport distance, and the extremely steep slopes of the volcano.

The lower part of the pyroclastic flow on the south flank was emplaced during the night of May 1. On May 6, the temperature was 98° C in a pit 60 cm deep. The temperature of a large breadcrust-surfaced block 8 m long that projected 3 m above the ash surface was 240° C in a crack 8 cm deep.

The thickness of the nuées ardente deposits is incompletely known since no good sections have been exposed by erosion and since only the lower parts of the deposits were studied. However, in a gully on the southern deposit, the pyroclastic flow is 4 m thick. It shows no pronounced layering or bedding, and contains blocks scattered at random through the finer ash. There seems to be a slight tendency for blocks to bc concentrated on top. At another place, the relationship of the forward lobe of the deposit to nearby trees suggests that the deposit is about 7 m thick.

Most of the blocks in the pyroclastic flow deposits have a characteristic lobate breadcrust-textured surface (Fig. 7). Even though

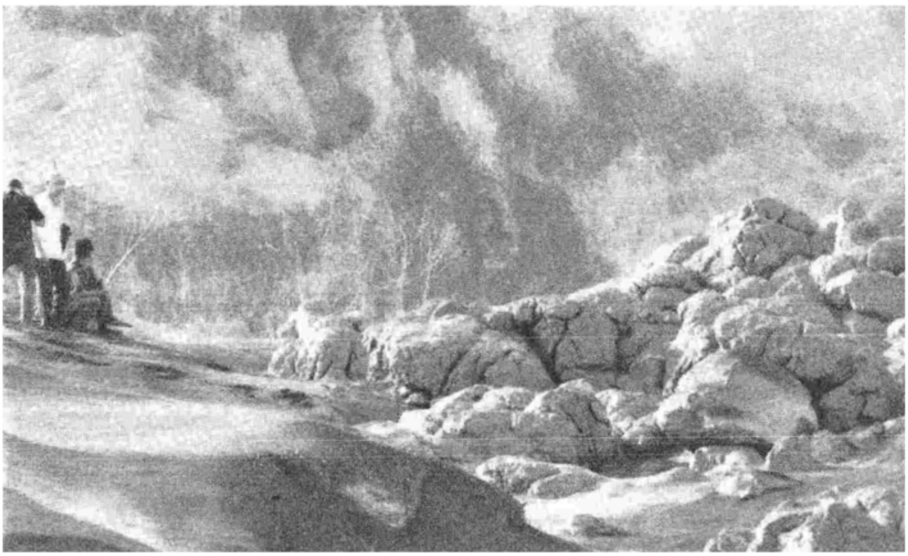

FIG. 7 - View near lower end of nuée ardente deposit on south flank of Mayon Volcano during week of 20 April, 1968. Breadcrust surfaced blocks are particularly abundant. Photograph by *Manila Times*.

many broken blocks are present, the abundance of these rather fragile surface features indicates that the breadcrust cracking occurred late in the period of flow. Probably many of the blocks puffed up and cracked open on their outer cooler surface after the deposit came to rest.

On their outer surfaces the breadcrust blocks are scoriaceous, rarely pumiceous. The vesicles are generally angular and irregular, shaped in part by the abundant phenocrysts. Some blocks show a uniform increase in porosity from center to margin. Others have a denser margin with an irregularly scoriaceous core.

Lava from the aa flow is similar to that of the pyroclastic deposits except that it has a lower porosity and contains flow-aligned phenocrysts.

Bulk chemical analyses, modal analyses, and microprobe mineral analyses were carried out on two samples of 1968 lava. These data are shown in Table 1 and are compared with one previously published analysis of Mayon lava. One sample is from the nuée ardente deposit on the southeast flank that was emplaced about May 2. The other was taken from the active front of the aa flow on the southwest flank on May 7, 1968.

These two new analyses show a remarkable similarity in bulk composition as well as in mineral composition for materials that were emplaced in different ways and at different times.

Plagioclase (An_{56}-An_{69}) is the most abundant phenocryst. The crystals are oscillatory zoned and commonly contain numerous fine glass inclusions in the inner zones. Both hypersthene ($Fs_{25}Wo_3En_{72}$) and subcalcic augite ($Fs_{15}Wo_{41}En_{44}$) occur as slightly zoned phenocrysts containing many large inclusions of titanmagnetite. Hypersthene is considerably more abundant than augite. Olivine is rare; one grain, jacketed by granules of hypersthene, was noted in a search of eight thin sections.

The matrix of the andesite, in the airfall ash, ash flows, and the lava flow, is a nearly opaque brown glass containing numerous microlites and dusty opaque inclusions. In the pyroclastic rocks, the ash fragments are irregular and angular; curved shardlike shapes are rare.

Chemically, the rock is a somewhat calcic andesite with a high alumina content, represented in the mode by the abundant plagioclase phenocrysts. The two analyzed samples of 1968 material contain 6 percent normative quartz, whereas the analysis of 1928 material (Table 1) contains an abnormally high Na_2O content and normative olivine-markedly different from the present eruptives. A lava of this composition should have a lower viscosity than that typical of the Mayon lavas, and this early analysis may be erroneous.

Nuées Ardentes

During the period of explosive ejection of ash and blocks from the summit, hot flows of blocky pyroclastic material with admixed gas swept down the major ravines to an elevation as low as 200 m.

Formation of the nuées ardentes was clearly seen during the night of May 1-2 under favorable cloud conditions (Plates 1 and 2). Explosions occurred every few minutes, hurling incandescent blocks and finer ejecta as high as 600 m above the summit. This material fell back and produced a glowing collar on the surface around the summit crater. As this material flowed down the slope, it produced a rapidly moving pinkish mass with bright moving particles speckling its surface. From a distance of 12 km, these glowing blocks could be clearly seen through binoculars; many of them must have been several tens of meters across. Commonly the downward-moving blocks changed direction abruptly and simultaneously divided into several brighter particles, apparently as a result of bouncing or striking ravine walls, breaking into smaller pieces, and exposing the hotter brighter interiors.

The downward flowing blocks rapidly cooled and faded in color, but incandescence could commonly be seen at an elevation of 1000 m down from the summit. However, the continuous mantle of glowing material generally divided about 500 m from the summit, and glowing material was confined to narrow tongues, probably in ravines, below that elevation.

Careful observations of the nuées ardentes indicated that many of then were formed by the vertical discharge of incandescent ash and blocks from an open crater, and their subsequent downfall and avalanching. This type of nuée has been termed the St. Vincent type by Escher (1933) (or *d'éxplosion vulcanienne* type of Lacroix, 1904). They are different from those produced by a directed lateral explosion, by the disintegration of a lava dome, or by the avalanching of a lava flow.

Several minutes after the descent of a nuée ardente, spots of light, which persisted for more than half an hour, were visible near its lower terminus. Some of these were burning fragments of trees that had been ignited by the hot ash flows.

Clouds billowing up from the nuées ardentes obscured incandescence along most of their course, but lightning occurred both above the main vent, and within the nuée itself. Following a strong explosion at 0200, May 2, lightning bursts occurred at a rate of 1-3 per second forming horizontal strikes within a single nuée ardente cloud.

During the daytime, no incandescence was visible and the nuées ardentes appeared as rapidly moving tongue-shaped light-gray clouds confined to ravines on the slopes. The clouds rapidly expanded outward and upward and became darker gray (Fig. 3). They maintained their pointed shape as long as the forward downhill motion was slightly faster than the expansion. About the time that the nuée stopped, or even before doing so, the great cauliflower cloud masses generated by it expanded and sometimes obscured the major part of the volcano. Commonly 5 or 6 minutes elapsed between the first appearance of the nuées and its disappearance into a disorganized mass of expanding clouds. Although the nuées were never observed from a distance of less than about 4 km, no noise of their descent was audible.

The great speed and mobility, the soundlessness, the continual generation of upward and outward billowing clouds, and the peripheral wind and heat damage all indicate that the active nuées ardentes consist of an admixture of hot gas, blocks, and ash. Much of the gas originated by exsolution from the still hot and plastic particles during flow. The breadcrust surface structure of the blocks shows that they puffed up repeatedly by expansion of the included gases after they were broken in pieces during flow. However, part of the hot gas was produced by the heating of infolded air. The continual breaking down of blocks during flow exposed their hot interiors — a process which not only aided further exsolution of included gases, but also heated air and other gases mixed with the blocks.

The lower parts of the nuée deposits were commonly, but not always, eroded by torrential rains; the rain in part was triggered by nucleation by dust rising from the nuées ardentes and fell minutes after the descent of the nuées. Loose airfall ash and unconsolidated material on the lower parts of the deposit were eroded and formed destructive mudflows which swept down from the terminus of the nuée ardente deposit (Fig. 2). These mudflows caused considerable damage to roads, the Manila-Legazpi railroad, pipelines, and broad areas of farmland. We observed a boulder-carrying mudflow near Camalig during the late afternoon of May 3. This mudflow formed after the beginning, and continued during the descent, of four separate nuées ardentes. This mudflow was not hot, but local residents reported that a mudflow observed on May 4 at an elevation of 190 m on the southwest flank was hot and that large boulders in it were steaming.

Surrounding the lower part of the nuée ardente deposits is a mappable « seared zone » (Fig. 2). This zone ranges from a few hundred meters to more than 2 km in width. In the inner part of this zone all vegetation was charred on the side facing the crater. Field measurements of the azimuth of charring (Fig. 2) indicates the direction of cloud movement. Most of the fronds of coconut palms were blown off on the blast side. Houses were swept away and the remaining fragments were charred and splintered.

A group of coconut palm trees at an elevation of 330 m in the seared zone surrounding the southwestern nuée ardente deposit was uprooted and blown down. The uprooted palms were not charred on the trunk as were nearby, though slightly more distant, upright trees. This suggests that the first blast from the nuée, which knocked down the palms, was not hot. Furthermore such uprooting of coconut palms requires winds in excess of 60 m per sec, — a figure based on the fact that typhoons with winds in excess of this velocity have failed to uproot such trees (Mr. Othello H. ESTAREIA, Philippine Weather Bureau Station At Legazpi Airport, personal communication, May, 1968).

The initial cold air blast is perhaps similar to the air blast associated with the approach of a rapidly moving rock or snow avalanche (MELLOR, 1968, p. 73). Such blasts are believed to be formed by displacement of air in front of the moving avalanche.

In the outer part of the seared zone plant leaves were shriveled and browned but not turned to charcoal. All animals in the seared zone were killed. A farmer, caught within the seared zone northwest of Camalig on the morning of May 2, died shortly afterwards of burns. He suffered second degree burns on the upper body and third degree on the lower body, but was otherwise believed to have been uninjured, although no autopsy was performed. It was reported that he ran 1 km after being burned, and told those who met him that he was caught in a blast of hot gas (air?) (Dr. Prurificion ORENSE, Albay Provincial Hospital, personal communication, May 3, 1968).

The velocity of the nuées ardentes varies considerably; the larger seemed to travel with a greater velocity than the smaller. Determination of velocity by field measurements was difficult because of the scarcity of visible landmarks along the path of the nuées. However, a study of timed photographs, particularly motion pictures, has provided reliable velocities for some of the nuées.

Sixteen millimeter motion pictures of the eruption of 0620, May 2, were taken of a nuée ardente descending the south flank from an elevation of 1360 m to 600 m. Measured velocities (Table 2) varied from 9 to 63 m per sec and averaged 31 m per sec for the 2.03-km path that was photographed.

TABLE 2 - Velocity of nuée ardente of 0620 hours May 2, 1968, on the south flank of Mayon Volcano. Data from 16 mm motion pictures taken at 24 frames per second.

Elapsed time in seconds	Time interval in seconds	Elevation of nuée front in meters	Slope distance traveled in meters	Velocity meters per second
0		1360		
	3.2		200	63
3.2		1260		
	4.7		220	47
7.9		1150		
	16.1		460	29
24.0		980		
	9.2		350	38
33.2		830		
	8.3		420	51
41.5		690		
	17.0		160	9
58.5		650		
	7.3		220	30
65.8		600		
Total	65.8	760	2030	Average for entire path 31

The front of the moving pyroclastic flow was commonly obscured because it was traveling down gullies and drainage channels. Suddenly it would reappear at a lower elevation as it spilled out of a channel or as topography permitted a view into the channel. This fact accounts for some of the variation in the measured velocities of Table 2.

Velocities of a large nuée ardente which descended the southwest flank have been calculated from an excellent series of photographs taken from Legazpi Port by the Hollywood Photographic Store (Fig. 3). The photographs were not timed, but an attempt has been made to determine the time interval between them by relating them to the speed of a sail-powered fishing boat in the foreground. If this fishing boat was moving at a speed of 2 knots (1.03 m/sec), the velocity of the nuée ardente ranged from 52 to 35 m per sec. If the boat speed was 1 knot, the calculated velocities would also be halved. It is unlikely that the boat was moving slower than 1 knot because it left a distinct wake.

These photos also show that in the first minute after an explosion (assuming boat speed of 2 knots), a vertical explosion cloud developed faster than the nuées ardentes; the vertical cloud rose as fast as 64 m per sec. After one minute, however, the travel distance and velocity of the nuée exceeded that of the vertical explosion cloud.

Aerial photographs of the summit region of the volcano (Figs. 4 and 6) show broad straight ravines along the upper courses of the nuées ardentes. These ravines were presumably formed by the nuées ardentes. Here, where their velocity was high and the gradient was steep, the nuées eroded their courses. ARAMAKI (1956, p. 217) has described similar, though larger scale, erosion by the 1783 Kambara nuée ardente on the north slope of Asama Volcano, Japan.

Much of the summit area of the volcano appears to be covered by a mass of welded ejecta which moved downslope producing viscous flow lobes (Fig. 6). On the sides of the eroded chutes, smaller lobate masses were apparently produced by overflow and welding of plastic material (Fig. 6). Lower down, the nuées ardentes traveled in steep narrow gorges and locally cut cirquelike enlargements where the flowing mass accelerated as it passed over particularly steep areas. Only on the lower half of their courses did the nuées ardentes deposit rather than erode.

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