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Nuées ardentes of the 1948-1953 eruption of Hibok-Hibok *)

(With 10 figs.)

Introduction

With the first description of nuées ardentes, during the 1902 eruption of Mont Pelée and the Soufrière of St. Vincent, controversy immediately arose concerning the nature of the explosions that initiated them. LACROIX (1904, 1908) believed that many resulted from blasts directed laterally at low angles; whereas ANDERSON and FLETT (1903) believed they resulted entirely from vertically directed explosions, gravity alone driving them down slope. There appears never to have been any doubt that nuées ardentes can result from the voluminous fall of vertically projected debris onto the outer slopes of the volcano, as concluded by ANDERSON and FLETT at St. Vincent in 1902, and by many investigators since then; but their formation by explosions directed at low angles continued to be a matter of debate. The uncertainty has been largely removed by PERRET's (1935) observations at Mont Pelée in 1929, and MACGREGOR's (1952, pp. 50-62) reanalysis of the observations on the 1902 eruption.

There is little doubt that low angle blasts from the sides of domes do initiate some nuées ardentes. It seems worthwhile, however, to record some additional evidence for their existence during the recent eruption of Hibok-Hibok volcano, in the Philippines, as well as some data concerning the composition

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of the deposits and other features of the nuées ardentes at Hibok-Hibok.

The information was obtained during a study of Hibok-Hibok in December 1953 and January 1954, to ascertain whether the people evacuated from the area around the base of the volcano could be allowed to return in safety (MACDONALD and ALCARAZ, 1954). We wish to express our appreciation to Eugenio OMAHOY, volcanological observer of the Philippine Commission on Volcanology in Mambajao, and to Mrs. OMAHOY, for their kind hospitality during our stays on the island; and to acknowledge the aid of Messrs. OMAHOY, Gregorio ANDAL, and Benigno YAMBAO, our associates during the investigation. Special mention should be made of Rev. Arthur SHEA, S. J., parish priest at Mambajao during the eruption, who contributed much valuable information, and whose tremendous personal efforts during the eruption did so much to alleviate the physical and mental suffering to his stricken parishioners.

Description of Hibok-Hibok

Hibok-Hibok forms the northwestern end of Camiguin Island, a small island lying 15 kilometers north of the major island of Mindanao. An older name for the mountain is Mount Catarman. South of Hibok-Hibok lies Mt. Mambajao, a geologically young volcano which, however, has not been active during historic times. Still farther south Mounts Butay and Guinsiliban probably are the dissected remnants of strato-volcanoes. The broad low cone south of Binone (fig. 1) appears to be a cinder cone. The volcanoes composing the island lie roughly along a north-northwest trending line, probably a zone of fracturing, on the extension of which also lie several eroded volcanoes near Balingoan and inland to the southeast of that town, on the north side of Mindanao. Volcanic activity along this zone appears in general to have progressed from south to north.

Hibok-Hibok is a composite volcano, composed partly of pyroclastic deposits, and partly of thick stubby lava flows and

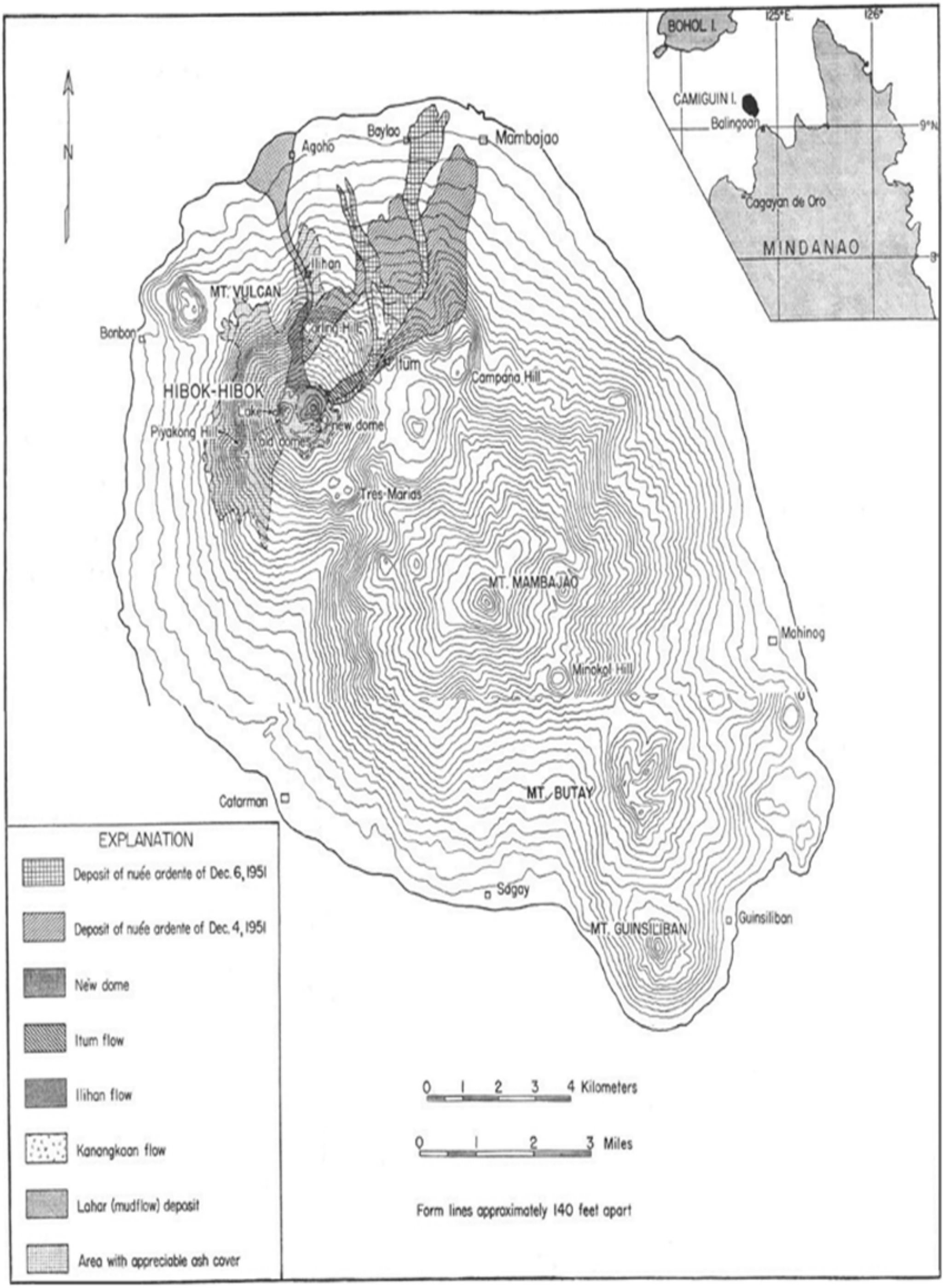

Fig. 1. - Map of Camiguin Island showing the location of Hibok-Hibok volcano, and the course of the nuées ardentes of December 4 and 6, 1951. Modified after Alcaraz, Abad, and Quema, 1952.

domes. Carling Hill, Piyakong Hill, and the Tres Marias hills, on the flanks of the volcano, almost certainly are domes. Deposits of prehistoric nuées ardentes are exposed in shallow gulches eroded into the mountain slope. Previous to the last eruption the summit crater was partly occupied by two prehistoric domes. North and northeast of them a portion of the crater was enclosed by a low arcuate wall. The lowest part of the wall appears to have been on the northeast side, toward the town of Mambajao. In a depression west of the domes lay a small lake. This lake does not appear to have been affected by the recent eruption.

Mt. Mambajao is a composite volcano very similar in construction to Hibok-Hibok. The summit peak appears to be a dome, as also do Minokol and Campana hills, on the flanks of the mountain.

The last eruption of Hibok-Hibok occurred in 1871, when a dome (Mt. Vulcan) was built on the lower west-northwest flank of the mountain (fig. 1) and a thick lava flow from the edge of the dome entered the sea (MASO, 1904, p. 33-40). Activity lasted about 4 years. After that the volcano was quiet until 1897, when a new solfatara appeared in the summit crater northeast of the old domes. Another solfatara appeared nearby in 1902, accompanied by hollow rumbling sounds from within the mountain. The solfataras continued mildly active, and some sulfur was collected from them, but there were no other volcanic manifestations during the ensuing 45 years.

The eruption of 1948-1953

The recent eruption of Hibok-Hibok has been described elsewhere (ALCARAZ, ABAD, and QUEMA, 1952), and only a brief summary of events is given here.

Numerous earthquakes during the last week of August, 1948, were followed on September 1 by an explosion in the summit crater at or near the solfataras of 1897 and 1902. A cauliflower-type cloud quickly developed; and nuées ardentes and a lahar swept down the north-east side of the mountain. devastating an area of about 8 square kilometers. Because of the earthquakes most persons had left the area around the base of the mountain, and the only casualities were two persons caught at the edge of the affected area who suffered second- and third-degree burns, but survived.

Other weaker blasts occurred during the rest of 1948, 1949, and 1950. On September 15, 1950, another blast similar to that of September 1, 1948, devastated the Ilihan area on the northern slope of the mountain, and claimed several victims. This is believed to have been a « nuée ardente d'avalanche » (ALCARAZ, ABAD, and QUEMA, 1952, pt. 2, p. 1), probably of the « Pelée directed lateral type » of MACGREGOR (1952, table 2), as also were most of the other nuées ardentes of 1948-1950. It is noteworthy that they were not only smaller, but of lower temperature than the great blasts of December 1951, described later. Neither clothing of victims nor houses within the devastated areas caught fire.

Following the explosion of September 1, 1948, lava extrusion began on the northeast side of the mountain. The vent of the flow was below the crater lip, probably on a northeast-trending lateral fissure. Extrusion continued into 1949, and formed a thick flow of block lava known as the Kanangkaan flow (fig. 1). Another smaller flow (the Itum flow) was formed a little farther south during the interval from June 1949 to September 1950; and a third (the Ilihan flow) formed on the north side of the mountain in late 1950 and 1951. Extrusion shifted back to the Itum area in December, 1951.

In May, 1949, a dome started to build in the crater northeast of the old domes, at approximately the site of the solfataras of 1897 and 1902, and the explosion of September 1, 1948. During the next two years it continued to grow slowly, until by late 1951 it was a prominent feature filling nearly all of the crateral depression and overlapping onto the northeast slope of the mountain. The dome continued active until early 1953, but since that time there has been no appreciable further growth, and crumbling of the dome has reduced its slopes essentially to stability. The last large avalanche resulting from collapse of part of the dome, occurred in May, 1953; and the last observed eruptive activity was a small ash explosion on

July 14 of that year (E. OMAHOY, unpublished reports to the Commission on Volcanology).

The nuées ardentes of December, 1951

The most violent and destructive nuées ardentes took place in December, 1951. During the morning of December 4 a nuée ardente swept down the northeast side of the mountain into the outskirts of Mambajao, killing 500 persons. Trees were blown down and aligned along the course of the blast. Others left standing nearer the edge of the devastated area were charred on the side toward the volcano, but not on the side away from it. Houses were burned. Bodies of persons and animals were charred and mummufied. The force of the blast is attested by the fact that a coconut tree 25 centimeters in diameter was wrapped in the form of a U around a mango tree 5 kilometers from the source of the blast. Another, smaller blast occurred at 6:40 p. m. on the same day.

Before daylight on December 6 another similar cloud descended the mountainside, reaching nearly to the sea 1.5 kilometers west of Mambajao. In the pre-dawn darkness the entire segment from the summit of the mountain to the coast was aglow from the deposit of incandescent ash. The bright red incandescence indicates that the material had a temperature of at least 700° C. The deposits of both the December 4 and December 6 nuées ardentes remained unbearably hot beneath the surface for many days.

The nuées ardentes originated at the active dome at the summit of the mountain. At the northeastern foot of the mountain they encountered the slopes of Mt. Mambajao, and were deflected northward. Their major portions followed the valley of the stream crossed by the road 0.8 kilometer east of Baylao. The valley was too small to confine the cloud of December 4, which spread laterally both east and west of the valley (figs. 1 and 2). The cloud of December 6 was more nearly confined to the valley, but spilled over to the northwest north of Itum (fig. 2). The strong effect of topography in guiding the nuées ardentes clearly indicates the importance of gravity in their movement and their essential similarity to lava flows. Indeed, we regard a nuée ardente as essentially an unusually mobile auto-expansive lava flow.

Each nuée ardente consisted of a lower principal avalanche portion composed of a relatively dense emulsion of incandescent ash and gas bearing a suspended load of partly active and partly inert blocks of rock derived for the most part from the summit dome, overlain by a spectacular billowing and rapidly expanding, but relatively diffuse cloud of fine ash. The relatively dense lower avalanche portion produces the principal deposits of the nuées ardentes, though the great cloud above it also produces relatively thin deposits of fine ash that may extend over much larger areas than the deposit of the avalanche portion. The lower portion of the nuée ardente also is responsible for most of the serious damage, though for a variable distance beyond the edge of the avalanche portion the overlying cloud may be hot enough to kill animals and persons.

In the region northeast of Itum the deposits of the nuées ardentes filled the valley to an estimated depth of 100 meters (fig. 3).. The level of the top of the lower avalanche portion of the active nuée ardente was about 150 meters above the former valley bottom near Itum . Along the southeast side of the valley there are small discontinuous deposits and signs of scouring of the valley walls to that height. However, the surface of the principal permanent deposit in the valley bottom is about 50 meters below that highest level, partly because of compaction of the avalanche material as it lost its gas, but perhaps also partly owing to a recession of the flow during its later stages from an earlier flood stage of maximum depth. On the northwest side of the valley the nuée ardente of December 6 spilled over the Kanangkaan flow, leaving deposits on its surface about the same distance above the top of the principal valley-filling deposit as are the minor deposits along the side of the valley northeast of Itum.

Toward the coast the deposits become much thinner. One to two kilometers southwest of Mambajao the ash of the December 4 nuée ardente is only a few centimeters thick. The deposit of the December 6 nuée ardente at the road just east of Baylao averages about 60 centimeters thick. In the latter area trunks of standing coconut trees are charred to a height of about 5 meters above the ground.

The deposits in the upper part of the valley are unstratified, and consist of a heterogeneous assemblage of fragments of pumice grading into sand-size ash, containing breadcrust bombs and angular fragments of glassy banded dacite. The latter closely resemble the rock of the dome, and undoubtedly were derived from it. As far down stream as the road near Baylao blocks of dacite 5 meters across are fairly common, and some are as much as 10 meters across.

The material on the higher ground east of the valley southwest of Mambajao, is entirely fine ash without bombs or large blocks, as might be expected if the denser lower portion of the nuée ardente was confined to the valley axis.

One large block, with dimensions originally about 10 by 8 by 5 meters, exploded after coming to rest on the surface of the December 6 deposit about 600 meters south of the road (2.5 kilometers from its source at the dome). The explosion caused a loud detonation heard by people nearby, and threw angular fragments of the block to a considerable distance with sufficient force to imbed some of them in coconut trees 20 meters away. The block was torn into three large fragments (fig. 4) and many smaller ones. The interior of the block was still plastic at the time of the explosion, and the surfaces of the large fragments formerly in contact are very rough and spinose where the plastic material was pulled apart. The explosion of this block clearly illustrates the active character of the material of the nuée ardente, which continues to evolve gas during the emplacement of the flow.

The early stages of the nuée ardente on the morning of December 4 were not accompanied by any vertical vulcanian cloud. Photographs taken during the first few minutes show the sky above the mountain top to be clear (figs. 5 and 7). On that morning Father Arthur SHEA was on Mindanao, just starting back to Camiguin Island. Driving along the north shore of Mindanao he observed a black cloud rushing down the slope of Hibok-Hibok toward Mambajao. The cloud swept down close to the ground, and was not accompanied at first by any cloud above the mountain. Father SHEA lost sight of Hibok-Hibok temporarily as the vehicle in which he was riding rounded a turn in the road. When he saw it again, a few minutes later, a high cauliflower cloud was developing above the mountain (figs. 8-10). Photographs appear to indicate that this cloud rose largely from the mountain slope covered by the nuée ardente, rather than from the summit of the mountain (figs. 6 and 7).

Thus it is clear from the sequence of development of the explosion cloud, as well as the abundance of big blocks of dome debris, that the blast of the morning of December 4 was not a vertically initiated crateral nuée ardente (nuée ardente vulcanienne of Lacroix, 1930; St. Vincent vertical type of MACGREGOR, 1952). It was either a nuée ardente d'avalanche, or a nuée ardente d'explosion dirigée (LACROIX, 1930). Its higher temperature, larger size, and great force distinguishes it clearly from the earlier blasts of the eruption, and make it decidedly unlikely that it was a nuée ardente d'avalanche.

The large proportion of pumice and pumiceous ash in the deposits also indicates clearly that the nuées ardentes of December 4 and 6 were formed fundamentally by explosion of new magma, not simply by crumbling of the dense glassy dacite of the dome. We climbed the dome to its top in January, 1954, and paid special attention to the nature of the rocks composing it. Nowhere was more than a very small amount of pumice observed. No doubt the explosion undermined part of the carapace of the dome, with concomitant crumbling of the overlying portion providing the many blocks of glassy dacite transported seaward by the flow, but the mechanism supplying the basic initial impulsion was an explosion of new magma directed outward at a low angle.

At about 6:40 p. m. on December 4 an explosion threw a large number of blocks, some of them as much as 2 meters across, into a narrow sector just south of Itum. The area was examined in detail a few days later by Father SHEA and Eugenio OMAHOY. The blocks produced hundreds of impact craters, many of wich were still clearly visible in January, 1954. The largest crater observed was about 6 meters across and 2.5 meters deep. Some of the craters were on nearly flat ground; others were on a steep slope facing the summit of Hibok-Hibok. Only a relatively small amount of fine debris was associated with the blocks. The blocks had descended through heavy vegetation, breaking and scarring the trees before striking the ground. Study of these marks on the trees in relation to the craters indicated that the blocks had been traveling along paths that projected back to a point a little below the summit of the mountain. Allowing for the steepening of trajectory that certainly occurred during their flight, it is apparent that the blocks must have originated well below the summit of the dome. Just below the impact area of the blocks the major portion of the nuée ardente of December 4 was confined and somewhat deflected by the preexisting topography. If this deflection had not taken place the major portion of the cloud would have swept over the area covered by the blocks.

The distribution and impact pattern of the blocks indicate a considerable horizontal component of momentum. It appears unlikely that this could have resulted wholly from the impulsion of gravity driving the mobile cloud down the valley, particularly since the finer and more mobile upper part of the cloud (which is less controlled by gravity than the lower, denser part) did not sweep over the area to any extent. It seems clear that the blocks were hurled into the impact area by an explosion directed at a low angle. This explosion may have occurred within the descending nuée ardente itself, though in that case more fine debris would be expected to have accompanied the blocks. However, it appears much more probable that the explosion took place low on the flank of the dome. The explosion was associated with the generation of the nuée ardente, though it was not necessarily the cause of the latter. The fact that it did occur, together with the distinctly hotter and more mobile character of the nuées ardentes of December 4 and 6 as compared with the known nuées ardentes d'avalanche, suggests strongly that similar explosions directed outward at a low angle from points on the lower slopes of the dome were the cause of the major nuées ardentes.

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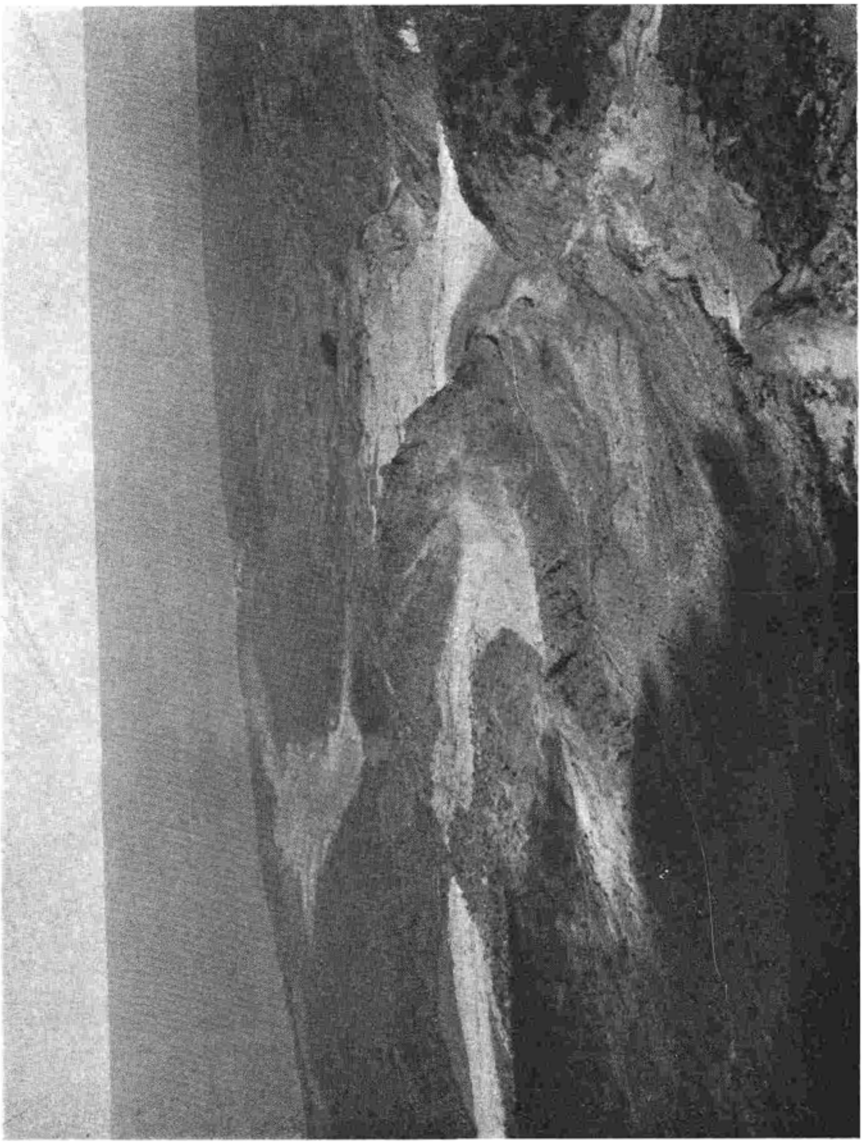

Fig. 2. - View down the avalanche valley from near the summit of Hibok-Hibok, in December 1953. The light areas are the nuée ardente deposits. Mambajao lies at the coast in the center of the picture. In the middle ground, the nuée ardente of December 6 spilled over the top of the Kanangkaan lava flow.

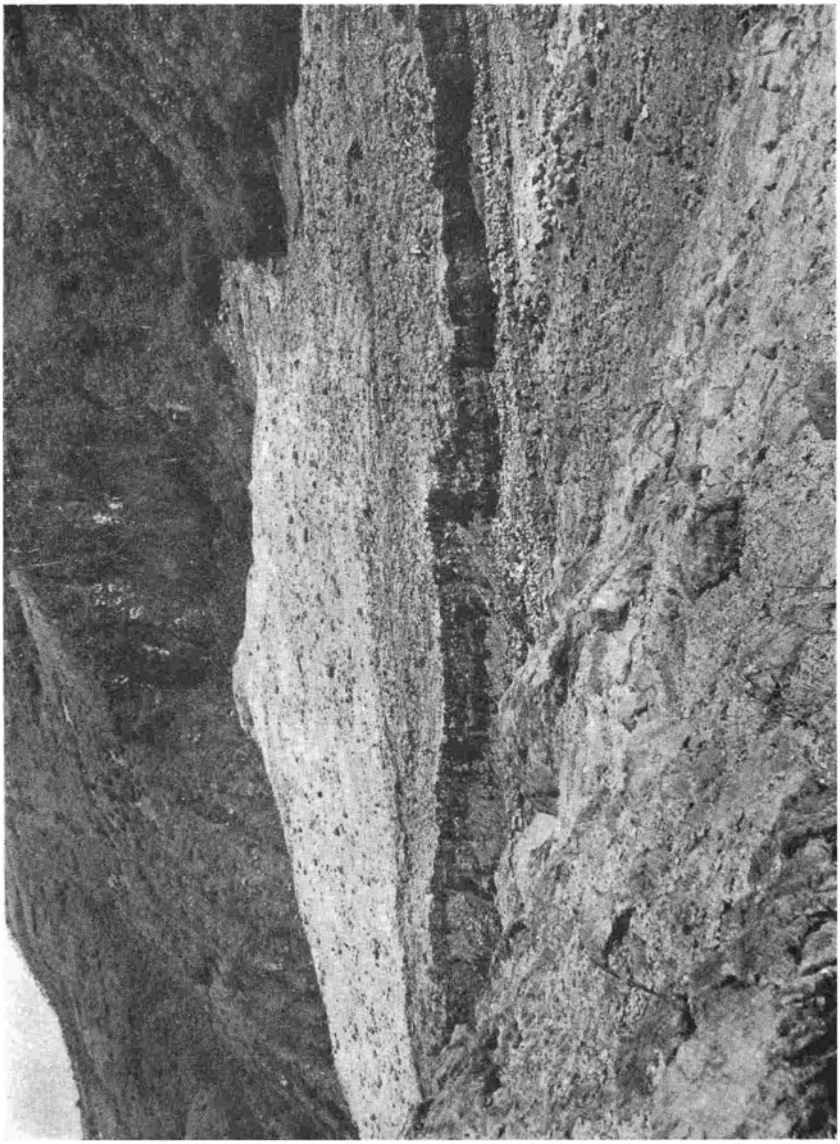

Fig. 3. - The deposits of the nuées ardentes of December, 1951, filling the bottom of the valley near Itum. The barranca has been cut into the flat surface of the deposits by stream erosion.

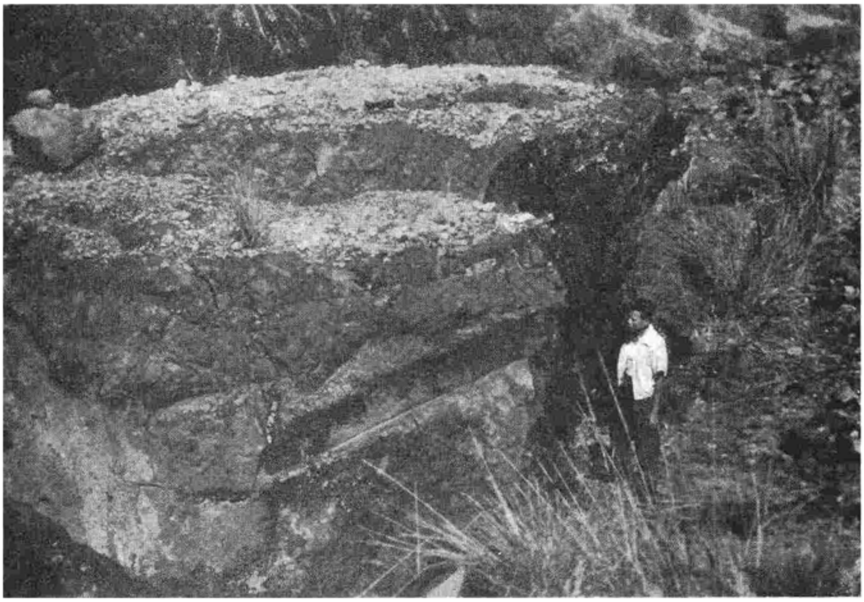

Fig. 4. - Part of the large block on the deposit of the nuée ardente of December 6 that was torn apart by explosion after its emplacement.

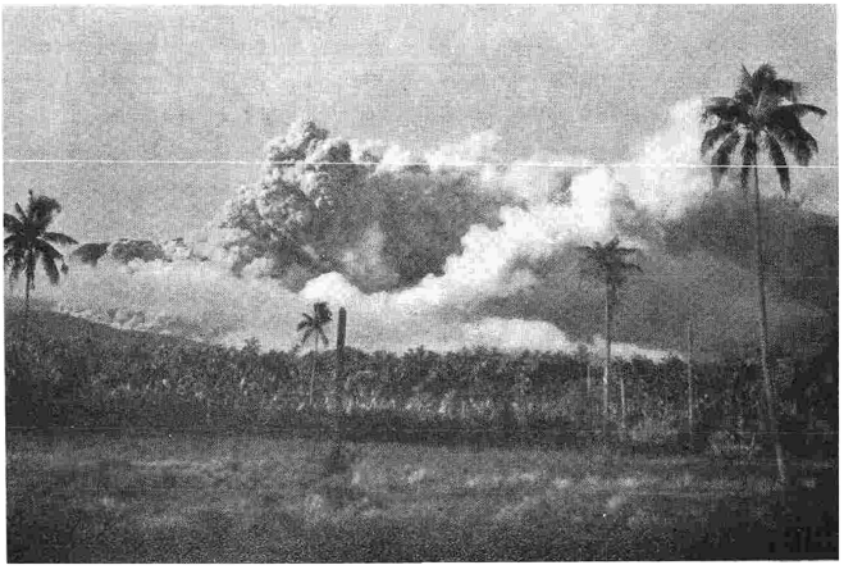

Fig. 5. - Early stage of the nuée ardente on the morning of December 4, 1951, seen from near Mambajao. Note the absence of any vertical vulcanian explosion cloud over the summit of the mountain. Photo by Hibok-Hibok Studio.

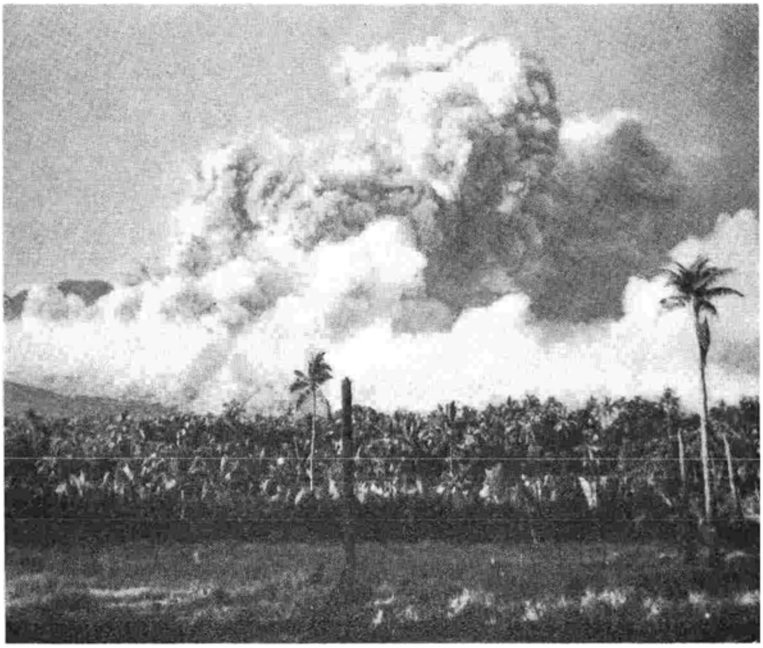

Fig. 6. - Dark cauliflower cloud rising over the course of the nuée ardente on the slope of the mountain. Photo taken a few minutes after that in fig. 5, by Hibok-Hibok Studio.

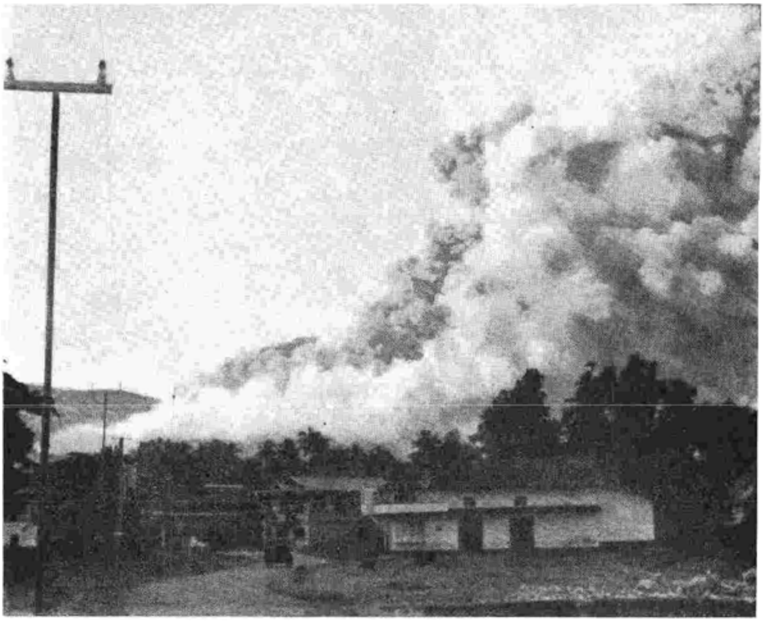

Fig. 7. - Early stage of the nuée ardente of December 4, 1951, seen from Mambajao. Photo by Hibok-Hibok Studio.

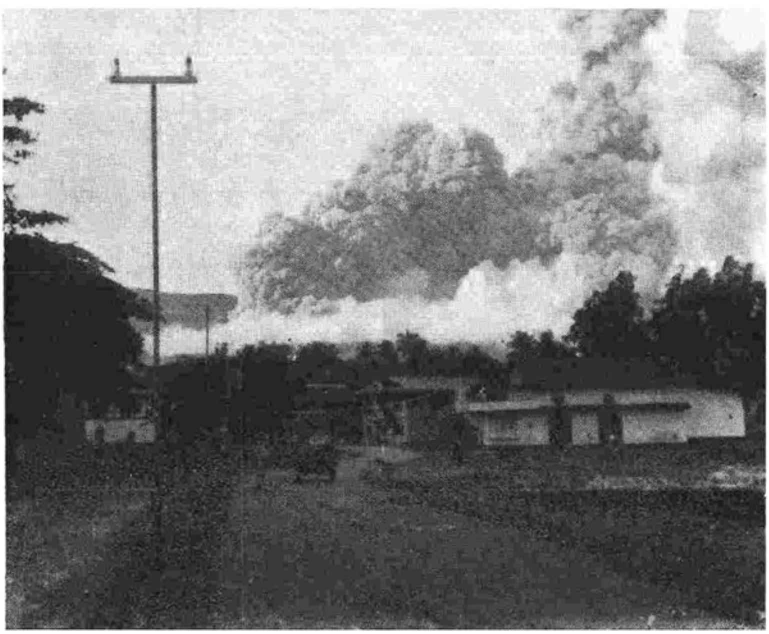

Fig. 8. - The nuée ardente of December 4, 1941, a minute or two after the stage shown in fig. 7.

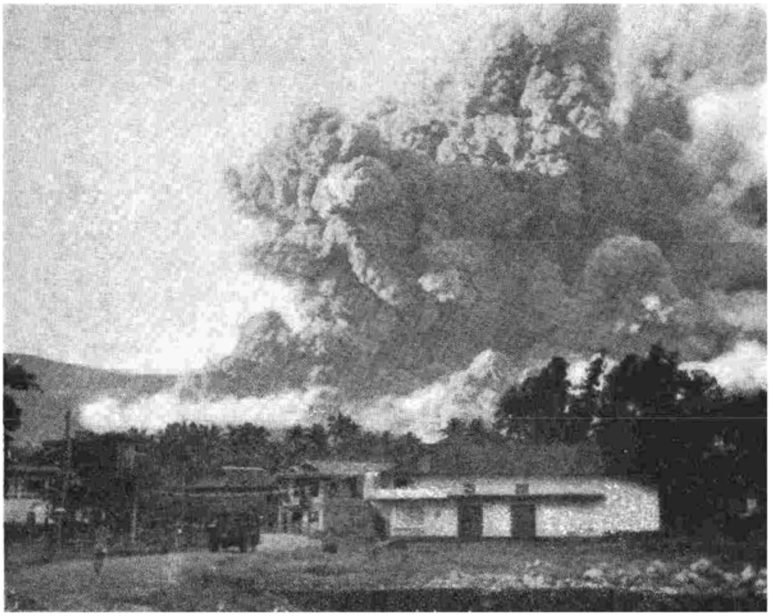

Fig. 9. - The nuée ardente of December 4, 1951, a few minutes after the view in fig. 8.

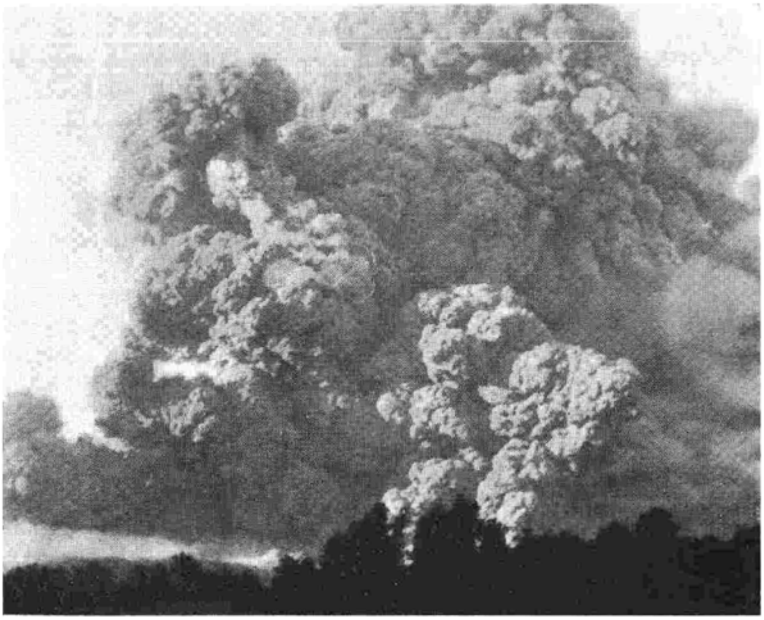

Fig. 10. - The nuée ardente of December 4, 1951, a few minutes after the view in fig. 9.