The Study on Comprehensive Disaster Prevention
Around Mayon Volcano

SUPPORTING REPORT (1)

(Part I: Master Plan)

VI : Disaster Mapping/Hazard Mapping

SUPPORTING REPORT (1) – VI
DISASTER MAPPING/HAZARD MAPPING

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1. TOPOGRAPHY AND GEOLOGY

1.1 Topography

(1) General Setting

Mayon Volcano is located on the Bicol Peninsula in the southern part of the Luzon Island. The Luzon Island, situated on the shear zone called circum Pacific island arcs, is centred at an active earthquake fault and volcanic zone between the Philippine Trench and the Philippine Fault Zone. Mayon Volcano is a part of the northwest trending eastern Bicol volcanic chain that results from subduction associated with the Philippine Trench (Ramos, et al. 1985).

Location map of Bicol volcanic chain is shown in Figure VI 1.1. The Bicol Peninsula consists generally of Upper Tertiary and Pleistcene sedimentary and volcanic rocks. Mayon Volcano, nine other major stratovolcanoes, and several smaller volcanic cones form the eastern Bicol volcanic chain (Datuin, 1982), associated with west-dipping subduction along the Philippine Trench.

(2) Mountain Slope Profile and Riverbed Slope

Topographical profile of Mayon Volcano has an extraordinary symmetry as a konide type. Its summit level is 2,469m above sea level and covers an area of 250km^2. Mountain slope has steep gradient (1/2.5) from the summit down to 500m above sea level. From 500m down to 200m above sea level, it becomes little gentle gradient (1/7.8) more than upper reaches. From 200m level down to the sea base, it has gently sloping sides (1/19.9). Landform units of Mayon Volcano slope are classified as lava flow, alluvial fan at volcanic foot and tertiary mountain at margin. The profiles and slope gradient classification of the slope are depicted and shown in Figure VI 1.2 and the table in the next page.

Meanwhile, Figure VI 1.3 present the profiles of the selected rivers. Most of the profiles show the gradual change in slope from steep to gentle in accordance with descending elevation. The profiles of the San Vicente and the Bulawan rivers in the northeast slope show a slightly sudden decrease in slopes at elevation 500 meter. This might be the effect of the deltas extending at the estuaries. The effect of the discharge backwater of the Quinali (A) river affected the riverbeds of its tributaries, the Nasisi and the Ogsong rivers. The riverbed slopes of both rivers show rather sudden decreases at 600 to 700 m in elevations.

Classification of Slope Gradient on Mayon Volcano

Elevational Classification by Slope Gradient (m)	Displacement of Elevation (m)	Horizontal Distance from Summit (m)	Horizontal Area (km^2)	Slope Gradient
2,469 - 1,000	1,469	2,330	17.05	1/1.6
1,000 - 500	500	4,000	50.24	1/3.3
500 - 200	300	6,330	125.82	1/7.8
200 - 10	190	8,000	200.96	1/16.7
10 - 0	10	10,300	333.12	1/23

(3) Geomorphological Classification Map

Mayon Volcano is classified as a strata volcano or composite cone. It consists of deposits formed basically by four major types of volcanoclastic material: lava flows, ashfall deposition, pyroclastic flows, lahar flows triggered by rainfall. Simplified geomorphic map is shown in Figure VI 1.4.

Volcanic lava are the dominant structural members of the Mayon edifice only from the summit to the 500m elevation near the crater, below which loose volcanoclastic debris predominates (Punongbayan and Ruelo, 1985). Ashfall and pyroclastic flow deposits are composed of unconsolidated materials varying in size from ash to small boulders. These deposits result from the eruption of fragmented rocks and are transported down slope under the influence of gravity, explosion blast and the prevailing wind. A large amount of rainfall during or after an eruption induces debris to flow down volcanic foot slope to form alluvial fan segment at about 300 to 200m of elevation or lower. The surface of the slope at this elevation covered by lahar material together with lava flow. These lahars are jumbled mixtures of rocks of loose sorting sizes in a matrix of sand, silt and clay. The area where is lower than 200 meters is composed of the deposited lahar. A few small mountain are, however, observed in the surrounding area of Mayon volcano like Lignon hill in Legazpi City. Those projections of terrain are considered to be the traces of eruption.

Submarine topographical counter map (NAMRIA. "Albay Gulf", scale 1:10,000, 1st Edition Dec.11/1961, Revised Feb.23/1976, Reprinted Feb/1989) is shown in Figure VI 1.5. According to the submarine map, the topographical features are that the gradient slope near shoreline is very steep and it become a flat bottom between 50 and 100 meters depth.

Mud and Debris Disaster Affected Area

on the Geomorphological Classification Map on 1999

River Basin	Disaster Affected Area (km^2)	Average Deposit Depth (m)	Lahar and Debris Deposit Volume (m^3)
Yawa	-	-	-
Pawa-Burabod	2.77	2.0	5,540,000
Budiao	0.76	2.0	1,520,000
Anoling	1.42	2.0	2,840,000
Quirangay	1.40	1.0	1,400,000
Tumpa	2.90	0.5	1,450,000
Maninila	1.98	0.5	990,000
Masarawag	1.86	1.2	2,230,000
Ogsong	2.62	1.2	3,140,000
Nasisi	1.16	2.0	2,320,000
Buang	-	2.2	-
Quinali (B)	-	-	-
San Vicente	-	1.0	-
Arimbay	2.43	1.0	2,430,000
Padang	0.95	1.5	1,430,000
Basud	2.63	1.0	2,630,000
Bulawan	-	0.5	-

(4) Volcanic fans

The schematic sketch of volcanic fan is shown in the attachment Figure VI 1.6. The schematic profile of volcanic fan is shown in the attachment Figure VI 1.7. The lower slopes of stratovolcanoes are generally composed of deposits of pyroclastic flows and debris avalanches. But in a considerable number of stratovolcanoes the lower slopes are mainly composed of piles of a number of beds of debris flow deposits of which the surface are called “volcanic fans”. Although most of the debris flows are secondarily generated by non-volcanic activity-heavy rains, the volcanic fans which the debris flow deposits make up are one of important units of the volcanic landforms.

The slopes of the volcanic fans 1/20 to 1/15 in gradient and about 6km in length around the Mayon Volcano are generally steep and smooth. In this area volcanic fans occupy considerable parts of the lower slopes of stratovolcanoes. In Mayon volcano three quarters of the lower slope are composed of volcanic fans.

The upper to middle parts of the initial steep slopes of stratovolcanoes are dissected by erosion to form deep radial valleys. And voluminous debris produced rush down the valleys of the continuous repetitions of this process, the volcanic fans are formed. The steep and smooth slopes of the volcanic fans are similar to those of the pyroclastic flow deposits.

Fan topography is formed by deposits from debris flow and also from tractive flow. Most of the large-scale fans, that is alluvial fans, are formed by tractive transportation and depositing. However, most of the small-scale fans are formed by debris flow and have a convex profile in the traverse section composed of large-sized boulders in the upper part of it and a concave or smooth surface formed fine-grained gravel in the lower part. The former part, having no bedding, indicates debris flow deposits. It can be estimated that the territory where the debris flow will extend by the morphological difference in the surface of a fan, using photo interpretation.

Deposit position of debris flow in the fan is gradually changed and conventionally called a "head-shaking phenomena" in Japan.

It can be estimated that the convex profile in the traverse section on the upper part of a fan is likely to affect the direct damage by debris flow. But a smooth or rather concave profile in the traverse section on the lower part of a fan almost guarantees safety from direct damage by the debris flow, though the water flow may reach there.

(5) Geomorphological Development Process of Volcano

Schematic sketch of geomorphological development process of volcano is shown in attachment Figure VI 1.8 (Moriya, 1981). Moriya has suggested that ordinary volcano have several stage in the development process of landform. This landform change is accompanied with volcanic activity. It is able to understand that the development process of volcanic landform resembles the life cycle of the human being. According to this theory, the longitudinal profile of the Mayon Volcano is consistent with stage No.2 or No.3 in Figure VI 1.8. It shows that stage No.2 and No.3 is the most active in this cycle, and is in frequent eruption. And also debris and mud flow will occur frequently. In the result of that, it is considered that Mayon Volcano is situated in the maximum stage of volcanic activity.

1st Period (Stage 1→2→3→): Stratovolcano, Symmetric profile
2nd Period (Stage 4→5)
3rd Period (Stage 6→7)
4th Period (Stage 8→9)

1.2 Geology

Pre-Mayon volcanic rocks are found in the hill located in the immediate vicinity of the volcano. Hills near Ligao, Sto.Domingo and Malilipot are found to consist of dacite and andesite with partly weathered.

Lava flows deposited on volcanic mountain slope consist of andesite and basaltic andesite lava. Riverbed material is also composed largely of hard rock (andesite, basaltic andesite) and porous rock. Pyroclastic flow deposit area is composed of soil, gray scoria fall deposit, scoria fall deposit, ash fall deposit, pyroclastic flow deposit, block and ash flow deposit and lava flow deposit in detail. Schematic Geological Profile of Pyroclastic Flow Deposit Area (Above) and Detail Geological Sketch of Pyroclastic Flow Deposit Area in the Anoling (B) River (Below) is shown in the Figure VI 1.9 to 1.11.

2. ERUPTION OF MAYON VOLCANO AND RELATED HAZARD

2.1 Ejection

Mayon volcano belongs to the Bicol Volcanic Chain which extend from north-west to southeast at about 150km west of the Philippines Deep. The Bicol Volcanic Chain comprises 16 volcanoes, of which 4 are active. The active volcanoes are Iriga, Malinao, Burusan, and Mayon. The activities of these volcanoes are closely related to the creeping of the Philippines Plate from the east.

Mayon volcano is a stratovolcano with a height of 2462 m and has kept a world noted conic shape. Accordingly, the steepness of the slope change gradually in general. Elevation 200m is the only point where the slope shows slightly large change. The mean steepness of the slope is 1:2.8 for the slope above elevation 200m. Meanwhile the slope lower than 200m becomes as gentle as 1:20. The volcano occupies around $250km^2$ and the volume thereof is estimated to be $100km^3$ (Newhall, 1977).

The volcano erupted 45 times during the period from 1616 to 1993 (the last eruption so far) according to the record. The record enunciates that the eruption in the latest two centuries was 43 times. The emitted materials by the eruption are andesitic lava, pyroclastic flow, ash fall and others. The physical and chemical features of magma are considered to be one of the significant factors, which controls the type of eruption together with the acquired energy of magma. According to the report prepared by Ramos and others in 1885, the most frequent type of eruption was Vulcanian, which occurred 20 times out of the adopted sample of 26 eruption or 76.9%. The Strombolian and the Plimnian eruptions were 5 and 1 times, respectively. The physical and chemical features might have affected the type of emission. The same report presents the occurrence frequencies of eruptive hazard, ash fall, pyroclastic flow and lava flow for the selected 21 eruptions as following Table:

Ratio of occurrence of Ash Fall, Pyroclastic Flow and Lava Flow at the First and during the eruption

Type of Emission	First Eruption	During Eruption
Ash Fall	16 (76.2%)	21 (100.0%)
Pyroclastic Flow	6 (28.6%)	19 (90.5%)
Lava Flow	2 (9.5%)	13 (61.9%)

The results of the study indicate that most of the eruption initiate with the emission of ash fall. And that an eruption not necessarily accompanies dangerous pyroclastic flow and lava flow from the first. However, both flows mostly arise before the eruption subside.

Ramos and others in 1985, Magalit & Ruelo in 1985 and Arboleda in 1998 published their study on the ejecta of eruption. The following table presents the ejected volume by major eruptions occurred in 20th century incorporating the estimations made by the Study. To be highlighted is the maximum ejecta of 150 million cubic meter in 1928. The previous eruption in 1900 was medium scale and since then no eruption is recorded until 1928. The storage of energy for 28 years might incur the large amount of ejecta in 1928. Eruptions with regular interval of around 10 years in 1938 and 1947 show decline of ejecta, from 150 in 1928, to 35 in 1938 and 25 million in 1947. The blank of 21 years from 1947 raised the ejecta to 35 million in 1968 but regular interval of 10 years reduces again the ejecta to 20 million in 1978. Magma might be activated by some reason and in 1984 the eruption of second largest of 70 million occurred although only 6 years passed since 1978. The regular interval of around 10 years, however, decreased the ejecta to 45 million cubic meters in 1993. The substantial types of volcanic ejecta are ash fall, pyroclatic flow, nuee ardente, lava flow and bomb for Mayon volcano. Table VI 2.1 summarises the main feature of recent eruption. The attachment Figures VI 2.1 to 2.4 show the recorded direction of each ejecta of major eruption in the last 2 centuries. Following sentences describe each hazard a little more in detail.

Volume of Ejecta of Substantial Eruption in 20th

Year of Eruption	Estimation Volume of Ejecta ($10^6 m^3$)
1928	150
1938	35
1947	25
1968	35
1978	20
1984	70
1993	45

Data: Ramos et al., 1985, Magalt & Ruelo, 1985 and Arboleda, 1998

2.2 Pyroclastic Flow

Pyroclasatic flow is frequent for the eruption of Mayon volcano. Pyroclastic flow accompanies 90.5% of the eruptions as previously mentioned. The frequencies of a slope visited by pyroclastic flow were studied on the basis of the event of which the pyroclastic flow direction from the crater is identified in the report prepared by Newhall. There are 15 eruptions, which were accompanied by the pyroclastic flow with identified direction. The distribution of the flow is shown in the following table:

Flowing direction and frequency of pyroclastic flow

Direction	Frequency	Rate (%)
North	2	13
Northeast	3	20
East	7	47
Southeast	9	60
South	6	40
Southwest	7	47
West	2	13
Northeast	2	13

The table shows that the north slope received pyroclastic flow 2 times out of 15 times or 13%.

The table enunciates that the southeast slope has received most frequent pyroclastic flow. It implies, however, the west and north slopes reserve the possibility to be affected by the flow as well. The Study Team interpreted aerial photo prepared in 1982 and developed Table VI 2.2. The table shows the travelling distance of pyroclastic flow on the basis of identified deposit. The elevation and slope angle of the site where the pyroclastic flow terminated its travel are also presented. Mostly travelling distances of pyroclastic flow is less than 6.0km. However, on the north and east slopes there are several traces of pyroclastic flow at 7.0 to 8.8km apart from the center of the volcano. Similar study was carried out by Punongbayan and Ruelo, on the pyroclastic fans formed by the eruption in 1986. The results of the study are summarized in Table VI 2.3.

2.3 Lava Flow

The variability of the lava flow directions might characterize the eruption Mayon volcano. The affected slopes differ from event to event. The frequencies of a slope visited by lava flow were studied similar to that of pyroclastic flow discussed above. There were 24 eruptions, which were accompanied by the lava flow with identified direction. As the result, no distinctive specific lava flow prone direction could be identified. Lava flow has arbitrarily visited any slope since 1616. The obtained frequency is shown in below:

Flowing direction and visited times of lava flow

Direction	Visited Times	Rate (%)
North	4	17
Northeast	2	8
East	11	46
Southeast	5	21
South	8	34
Southwest	9	38
West	7	29
Northwest	2	8

Table VI 2.4 present the maximum distance reached by lava flow quoted from the reports prepared by R.Punongbayan,1986 and Magalit & Ruelo,1986. The study based on the geologic analysis and adopted data include back dated ones far beyond 1616 but the difference between the figures in Table VI 2.4 and those in above table is negligible. Both the frequency and distance of southeast are the largest. The tendency may not be changed because of the prominent Bonga gully. Topographical feature of lava flow in Mayon is shown in the following figure.

Micro-Topography of Lava Flow Landform

2.4 Ash Fall

Ash fall tends to scatters all over the mountain slopes. However, there is a case that ash fall has a direction when it is drifted by a strong wind prevailing at the event. Especially during the northeast monsoon, the depth of fallen ash in southwest slope is deeper than other slopes. The volume of ash fall ejected is not estimated but deemed to share 10 to 100% of total ejecta. There is a case that eruption subside after the volcano eject ash and no ejection of others. In case the scale of eruption is medium or more, the share of ash fall might be as small as 10 to 30% because the material is andesitic with rather high viscosity. The historical record indicates that the depth of the ashes is from a few to thirty centimeter. And it has been seldom that ash fall itself caused significant disaster unless it is washed by a heavy rainfall and concentrate into a river channel to cause a mud flow.

2.5 Mud and Debris Flow

(1) Topography and Occurrence Record of Mud and Debris Flow

The slope of Mayon volcano is steep. Especially the slope between summit and the site with an elevation of 200m is as steep as 1: 2.8. The slope of less, from 200 to 0m elevation, becomes comparatively gentle, 1:20. Various gullies have developed on the mountain slope have their terminals at the sites with elevations from 400 to 200m. Mud and gravel with boulder carried by high flows triggered by heavy rainfall are deposited at these points and form fans. Pyroclastic flows travel mostly along gullies and terminates at fans to deposit debris thereon. Further gullies comprise older deposit loosely consolidated and liable to collapse by weathering and heavy rainfall. Thus, all the slopes are a rich source of mud and debris flow. Some rivers have their origins in the gully like the Basud river and the Pawa – Burabod river. And some are originated in these fans like the Anoling river and the Nasisi river after recurrent river piracy. The rivers of both types are subject to mud and debris flow. Table VI 2.5 present the traces of mud and debris flow in the existing river channels estimated through the interpretation of aerial photo shot in 1982. All the rivers except the Yawa River have suffered from mud and debris flow. Table VI 2.5 implies that an area with elevation 100 to 200m is a disaster prone area. Debris flow caused by the 1984 eruption deposited widely on the Pawa Burabod River. Deposit thickness of the debris flow is shown in Figure VI 2.6.

The precise mud and debris flow (lahar) record is not available because lahar usually occurs together with volcanic eruption or flooding and it might be hard to segregate lahar. However, some remarkable lahar are recorded. Table VI 2.6 presents such lahar, quoting the report prepared by Ramos and others. Most of those recorded were triggered by heavy rainfall attributable to the ascending air of eruption. The occurrence can be seen in any slope. Table VI 2.7 shows such mixed damages. The first column of the table presents the damages caused by eruption and adjacent lahar. Meanwhile second and third column present the damages caused by Lahar, flooding and strong wind. For instance, the fatal casualty of first column should be read 70 by pyroclastic flow and 7 by Lahar.

Table VI 2.8 present recorded damages caused typhoon and other heavy rainfall. The damage due to mud and debris flow and due to flooding or strong wind are summed up in this table. Table VI 2.9 shows the breakdown of the selected disaster. Table VI 2.10 shows the discriminated damage of typhoon Ditang. A method to segregate the damage into each cause should be developed referring each value. With this regard, the output of surveys on damage may provide some indications.

(2) Geomorphological Changes of Channels on the Mayon Volcanic Slope

The following description briefs the results of the comparative study on the aerial photographs shot in 1982 and 1999. Geomorphological changes and record of debris occurrences is summarized in the following table.

The Summit Crater

Figure VI 2.7 shows the summit crater in the aerial photographs shot in 1982 and 1999. As can be seen in the figure, the summit crater in 1999 has expanded. And the big gully, called "Bonga Gully," lying on southeastern side slope from the summit has expanded in 1999.

During the period from 1982 to 1999 the eruptions took place in 1984 and 1993. At that time soils were supplied in the form of lava flow, pyroclastic flow and air fall deposit. And in the bottom of Bonga gully, lava flow was deposited in 1993. It is considered that expansion of the crater and gullies was mainly caused by eruptions.

Maninila River

Figure VI 2.8 shows the geomorphological maps of Maninila River system in 1982 and 1999. As can be seen in the figure the stream network has changed. And geomophological change due to lava flow in 1984 has been taken place and a part of gully was buried. The tributary 1 has connected with streams near the summit and its catchment area expanded (refer to Figure VI 2.8).

Anoling (c) River and Budiao River

Figure VI 2.9 shows the geomorphological maps of Anoling (c) River and Budiao River system in 1982 and 1999. As can be seen in the figure the stream network has been changed. In 1982, halfway up to the mountain is the position of the valley head of Anoling (c) River. But in 1999, Anoling (c) has connected with stream near the summit and its catchment area expanded. And at the lower reach of the river the area of young lahar deposit expanded to the right tributary.

Basud River

Figure 2.10 shows the prepared geomorphological map of Budiao river system in 1982 and 1999. As can be seen in the figure the stream network has been changed.

In 1982, halfway up to the mountain is the position of the valley head of the tributary 1. But in 1999, the tributary 1 has connected with the stream near the summit and its catchment area expanded. And at the lower reach of the river the area of young lahar deposit expanded to the right tributary.

Disaster Record of Mud and Debris Flow on the Recent Eruption

River Basin	The Angle from the Crater Opening Direction	Changes of the drainage area by lava flowing and piracy	The 1984 Eruption	The 1993 Eruption	The 1998 Typhoon Loleng
Yawa					
Pawa-Burabod	10		Mud Flow	Mud Flow	
Budiao	30	Piracy (After 1984)	Mud Flow		
Anoling	60		Mud Flow		Downcutting of Riverbed
Quirangay	90				
Tumpa	95	Lava Flow (1984)			
Maninila	100	Lava Flow (1984)			
Masarawag	120		Mud Flow		Downcutting of Riverbed
Ogsong	130				
Nasisi	140				
Buang	170		Mud Flow		
Quinali (B)					
San Vicente	120		Mud Flow		
Arimbay	0	Lava Flow (1993)	Mud Flow	Mud Flow	
Padang	10		Mud Flow	Mud Flow	Debris Flow
Basud	20	Main channel shifted (after1984)	Mud Flow		Debris Flow
Bulawan	90		Mud Flow		Debris Flow

3. HAZARDS AND AFFECTED AREA

3.1 Review of Previous Disaster and Hazard Analysis

Disaster and hazard analysis has been published by the following study and organization.

- Re-study of Mayon Volcano Sabo and Flood Control Project by JICA Study on March 1983
- "Operation Mayon" by PHILVOLCS
- "Hazard Maps" revised by PHIVOLCS on 1999 version

(1) Re-study of Mayon Volcano Sabo and Flood Control Project by JICA Study on March 1983

Hazard zoning was analysed by using the air photograph survey and the field survey, and was presented on 1:50,000 contour maps. Danger Zone Map for Mud/Debris Flow by the 1983 JICA Study is shown in Figure VI 3.1 and VI 3.2. The legend which is classified in the map is as the below:

- Danger zone 1 (1979, 1981 devastated area)
- Danger zone 2 (other topographical danger zone)
- Safety zone

(2) "Operation Mayon" by PHILVOLCS

"Operation Mayon" is a disaster preparedness plan, which provides a framework and systematic guidelines for smooth and effective disaster management in the event that Mayon Volcano erupts. Hazards from the Mayon Volcano in "Operation Mayon" could be classified into the following four- (4) type:

- Lava flows
- Pyroclastic flows
- Lahars
- Ashfall

Hazards from Mayon in "Operation Mayon" can be classified into two broad types:

Flowage hazards (ground-huggers)
Lava flow
Pyroclastic flow
Lahars

Non-flowage Hazards (Airfall)
Ashfall

Hazard Maps in "Operation Mayon" is shown in Figure VI 3.3.

The hazard zonings for each disaster are described by PHIVOLCS as follows:

<u>The Lava Flow Hazard Zone:</u>

The lava flow hazard zone is an array of narrow zone radiating outwards from the summit crater. These areas define the gullies and crevices radiating from the volcano's summit crater and extend from to 6 - 7km downwards. There are at least 23 of these gullies around Mayon, the 3 largest of which had been recently emplaced in 1984 and subsequently enlarged by constant erosion thereafter, making these areas potentially prone to lava encroachment. The biggest and deepest is the Bonga gully, facing the southern flank of the volcano. Presently a notch at the southern rim of the summit crater, compounded tilt of the crater lip to the southward direction, will most likely funnel the next lava flow towards the Bonga gally.

If the next flow would be poured out towards the Bonga gully, then the extent and the possible effects would depend on the volume of lava material extruded. The present estimated volume of the gully is 15 x $10^6 m^3$. The 1928 lava flow was 60 x $10^6 m^3$ in volume. In each of the 1968 and the 1984 eruptions, lava flow amounted to 20 x $10^6 m^3$. Thus, gully overflowing is expected if the same lava volume would come out. However, the Bonga gully connects with the upper Pawa-burabod channel at elevation 600m, just right next to the apex of the big Bonga pyroclastic deposit.

If the next lava flow would be "fluid" enough to flow downstream, then the upper Mabinit channel would accommodate excess lava materials and therefore would be susceptible to the advancing hazard. The villages of Mabinit and Bonga lie downstream of the channel. On the other hand, if an overflow would occur at the Bonga gully, lava materials are expected to follow gullies leading to barangays of Matang and Buyuan. The flow, however, would most likely stop before reaching the village proper.

The Pyroclastic Flow Hazard Zone:

The pyroclastic hazard flow hazard zone is the outward extension of the lava flow hazard zone. Occupying a total of 1,800 square km, this zone extends downward to an elevation of 200m. the general slope of the topography varies from 8.5 to 3.0 degree. The narrow zone known to have been severely affected by historic eruptions situated in the Basud River near Sto.Domingo is also a hazard zone. This zone extends to the seashore about 12km from the summit.

The area with the greatest hazard lies along the southern slopes, mainly because of the presence of a deepened crevice (the Bonga gully) slicing the upper cone's surface. This gully faces the villages of Mabinit, Bonga, Matanag and Buyuan – all of Legazpi City. The vulnarability of this area is compounded by the present tilt of the crater lip towards the southern portion. Pyroclastic flows could therefore be channeled along the Bonga gully. Other likely paths of deadly pyroclastic flows are the Sto. Domingo gully, facing the eastern flank, and the Daraga-Camalig Gully, facing the southwestern sector.

The Ash Fall Hazard Zone:

The ash fall hazard zone defines places that will likely receive heavy ash fall of at least 20 cm in thickness. This zonation is modeled from eruptions similar to the 1984 and 1968 Vulucanian type activities. Ideally, this zone forms an overlapping elliptical-shaped pattern with prominent northeast-southwest elongation, concordant with the prevailing windstream around Albay province.

A word of caution, however, should be kept in mind regarding future hazard areas from future ash fallout. Firstly, dispersion of airborne fine ash from eruption column is dependent on the prevailing wind apeed and direction at different altitude, at the surface heights of 25km or more. Data from upper-air observations in Legazpi City show that wind direction and velocity vary considerably at different heights above the surface. In general, winds blow most often in the northeast and southwest directions.

The volume of ash fall on specific sites around the volcano will also depend on the height of the eruption column, the rate at which the ash components leave the vent (intensity), the relative amount of ash contained in the eruption column, and the duration of the eruption. This factor is a consequence of the style of the eruption (Plinian, Vulcanian or Strombolian) and its magnitude (minor, moderate, violent or catastrophic). Thus, Vulucanian eruptions will produce more ash-size components compared to Strombolian eruptions. Likewise, Plinian eruptions will disperse more ash farther and widely more than would Vulcanian and Strombolian events.

The Lahar Hazard Zone:

Lahars (an Indonesian term), sometimes called mudflows or volcanic debris flows, are flowing mixtures of volcanic debris and debris and water. Lahars from Mayon originate not from its summit crater but from the upper and middle slopes of the volcano. Lava and pyroclastic materials perched on the steep slopes are eroded and then mobilized by heavy rains, thus causing a debris-water mixture (like the consistency of wet concrete) to cascade and flow downslope of the volcano. Lahars usually follow pre-existing gullies and ravines. Upon reaching the lower slopes, they spread out and leave thick and widespread deposits.

Lahars and accompanying floods are expected to constitute immediate as well as long-term major hazards for downstream areas located from 7 – 13km around Mayon.

High danger areas are restricted to drainage basins that have frequently been recently affected by lahars and floods. Places along which lahars frequently pass are those areas in the southern flanks primarily because of the presence of three big gullies and large recent deposits of pyriclastic flows. These areas also include most active rivers, streams, gullies, and terraces a few meters high adjacent to these depressions. These places should always be avoided during intense and long periods of rainfall. Low- lying areas, especially along and near the mouth of rivers, are very prone to frequent flooding.

Moderate danger areas include those, which appear to have apparently been affected by lahars during pre-historic times. These areas may probably be affected again by very large but infrequent lahar events. These include areas adjacent (a few hundred meters) to rivers and gullies that are highly vulnerable to lahar encroachment and flooding.

Low danger zones are topographically elevated high grounds in the vicinity of the two aforementioned hazard zones or places that are too far from the main lahar inundation area. Although these areas are believed to have been affected by lahars during the last few thousand years, they are much less likely to be affected by lahars and floods in the near future.

(3) "Hazard Maps" revised by PHIVOLCS on 1999 version

"Hazards Maps" revised by PHIVOLCS on 1999 version is considered of the disaster condition caused in the 1984 and 1993 eruption. After the 1984 eruption, only Debris and Hazard Map was revised from the "Operation Mayon". Permanent danger and high susceptibility areas map was newly set up after the 1993 eruption deposits. This new hazard map considered distribution of the 1993 eruption deposits. Legend of the 1993 eruption deposits are divided as follows; Pyroclastic Flow Deposit, Pyroclastic Surge Deposit, Fall-out Deposit, Lava Flow Deposit and Singed Zone. Also hazard zones are classified in the Hazard map as follows;

- 6 km Radius Permanent Danger Zone (PDZ)
- Additional Areas Highly Susceptible to Pyroclastic Flow-Generating Events (6 km from the summit extended to 7 km in the SE sector)

On the other hands, PHIVOLCS describes hazard zones as follows in their official home page (www.philonline.com/seismo/Volcanoes/Mayon/MayonAbout.html).

But definition of hazardous grade is not clear and does not coincide with hazard maps which are published also by PHIVOLCS.

Hazard zones;

- Permanent Danger Zone- 6 km radius
- High Danger Zone- 6 km from the summit extended to 11 km in the SE sector
- Moderate Danger Zone- 8 km from the summit extended to 15 km in the SE sector

3.2 Disaster Affected Area

Mud and Debris Disaster Affected Area on the Geomorphological Classification Map on 1999 is shown in Table VI 3.1. Disaster affected area means a devastated area of debris flow, which is covered with poor pine tree. Deposit depth data was obtained by the field survey.

Disaster Record of Mud and Debris Flow on the Recent Eruption, 1984, 1993 and 1998 typhoon is shown in Table VI 3.2. Mud and debris flow disaster occurred immediately after the eruption on 1984 and 1993. The 1998 typhoon “Loleng” occurred in accompany with the two-year probable rainfall.

3.3 Hazard Zoning

In order to identify the hazard area of sedimentation, a bed change calculation was carried. As the results of these studies, the range of sedimentation area is estimated and is shown in Table VI 3.3. Characteristic sedimentation areas in 17 rivers can be retrieved in this table, and are indicated as the value in round brackets.

Boundary condition will be changed by the ejecta after the volcanic eruption. In order to plan countermeasures in the sabo area in the alluvial fan topography developed on the slope of Mayon volcano, feature to grasp the possibility of watercourse change after deliberation about the sediment transportation feature and the sediment yield potential from upper river basin are indispensable. Therefore, countermeasures should be selected in accordance with assumed sediment transportation scenario.

In Table VI 3.3, objective 17 rivers basin around Mayon Volcano mostly have the problem of sedimentation in the range portions located 4.0 to 8.0km from the center of the volcano. There are hazards of overflow due to the aggravation by sedimentation deposit and the variable river course in the fan top part. The point where the possibility of watercourse changes is anticipated, must be considered in the sabo facility planning.

Hazard maps in this study is compiled about the following phenomena.

- Lava flow
- Pyroclastic flow
- Mud flow and Debris flow

(1) Lava Flow

Table VI 3.4 present the maximum distance reached by lava flow quoted from the reports prepared by R.Punongbayan, 1986 and Magalit & Ruelo, 1986. Maximum distances reached by lava flow units are almost all within 6km. But there might be varied lava flow longer than visible lava landform. Lava flow hazard zoning will follow the result of "Operation Mayon".

(2) Pyroclastic Flow

The Study Team interpreted aerial photo prepared in 1982 and developed Table VI 3.5. The table shows the travelling distance of pyroclastic flow on the basis of identified deposit. The elevation and slope angle of the site where the pyroclastic flow terminated its travel are also presented. Mostly travelling distances of pyroclastic flow is less than 6.0km. However, on the north and east slopes there are several traces of pyroclastic flow 7.0 to 8.8km apart from the centre of the volcano. Pyroclastic flow hazard zoning will follow the result of "Operation Mayon".

(3) Mud Flow and Debris Flow

Mud flow and debris flow hazard area is based on the run off volume, which is calculated by using the probable one day rainfall for 20 years. The boundary of hazard area is enclosed by consideration with the topographical undulation. Lahar and debris flow hazard area in this study is summarised in the following table. The simplified hazard maps is shown in Figure VI 3.8 and VI 3.9. Mud flows may, in some cases, continue to advance even the gradient is as low as 1/30. The margin of mud and debris flow zoning adopted the maximum advanced reaches on 1/30 of gradient.

In the JICA Study, the extents of hazards by mud/debris flows are classified into three levels; high, moderate and low. The definition of each danger zone is as follows.

- High danger area: This area is located at the steep slopes under the Volcano's opened crater.
- Moderate danger area: Mostly situated on and along the rivers heavily silted with mud and debris flows. This area is identified on the basis of the following assumptions:
  a. Mud and debris is to generate in a gully and flow along the channel.
  b. The flow direction of mud and debris has possibility to fluctuate 25 to 30 degree at the intersection point according to the topographic conditions of the fan.
  c. The results of preliminary mud and debris flow analysis and interpretation of geography indicate that a mud and debris flow with a scale of 20-year return period flows down the fan to area which has the slope gradient of less than 1/35.
- Low danger area: Generally having places at the intermediate zones between the respective moderate danger zone

Lahar and Debris Flow Hazard Area in This Study

River Basin	Hazard Area (m^2)	Maximum Distance from Crater (km)
Yawa River System	26,585,500	12.3
Padang	8,358,800	10.2
Basud	6,480,000	10.2
Bulawan	3,739,300	11.4
Quinali (A) River System	14,000,000	11.8
San Vicente	10,364,000	11.5
Buang	1,187,000	7.0