Geology and Clay Mineralogy of the Landslide Area in Guinsaugon, Southern Leyte Island, Philippines.

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Barangay Guinsaugon, a village, in southern Leyte Island, Philippines was buried by landslide debris in February, 2006. Geological survey of the landslide area was performed in 2006 and 2007. The cause of the landslide was determined with the survey and laboratory analysis of samples collected during the survey thereon. The most important factor detected was the occurrence of smectite, a kind of clay mineral. Smectite expands or swells at wet conditions, and is already known as the material sharing the resposibility of landslides. Apparently, smectite was formed at the late stage of volcanic activity in the area. The second factor was the fault system of the Philippine Fault Zone. The faults cut the area in many directions, and loosen the volcanic rocks. There were some observations indicating that many landslides occurred prior to the February 2006 landslide. Another factor acting as a trigger is the heavy rainfall; over 700 mm for two weeks prior to the landslide.

1. Introduction.

Landslide in southern Leyte Island, Philippines occurred on February 17, 2006. The geological surveys were done on March 23 to 30, 2006, and March 6 to 13, 2007 by survey teams from Chiba Institute of Science. The laboratory works were done using equipments of Chiba Institute of Science. Partial analyses were reported in Japanese as a report (Ueno and Jige, 2006b), a paper (Ueno and Jige, 2006a) and speaking papers (e.g. Sakamoto et al., 2007). In this paper, results based mainly on the field survey of 2006 and on new laboratory results are described.

Immediately after the landslide, Dimalanta et al.(2006) reported the relation between the geological features of the area and the landslide. Sakurai et al. (2006) and Suwa (2006) have described the landslide as deep landslide and debris avalanche, respectively. Gravity measurements and analyses were conducted by Makino et al. (2007). Araiba et al. (2007) have reported the rescue activities and assistance techniques in detail.

Although there are many opinions about the cause of the Guinsaugon landslide, we maintain that the occurrence of smectite is an important factor.

2. Outline of the disaster.

At 10:30 AM (Local Time) on February 17, 2006, a landslide triggered by heavy rainfalls occurred at Barangay Guinsaugon in Municipality St. Bernard, Southern Leyte Province, Republic of the Philippines (Fig.1). The slope failure had started from the mountain crest with elevation of 780 m. The crest is part of a sharp slanting surface in the north-west ridge which includes Mt. Kan-Abag with altitude of 805 m (10º 20.13' N , 125º 04.83' E). An alluvium plain of 50 to 60 m above sea level was covered by the thick debris. The covered area extends to 2.6 km² and the volume of collapsed slope is 2.9×10^7 m^3 (Araiba et al., 2007). The whole aspect of the Guinsaugon landslide is seen in Figures 2 and 3. A software of ArcGIS mediated by

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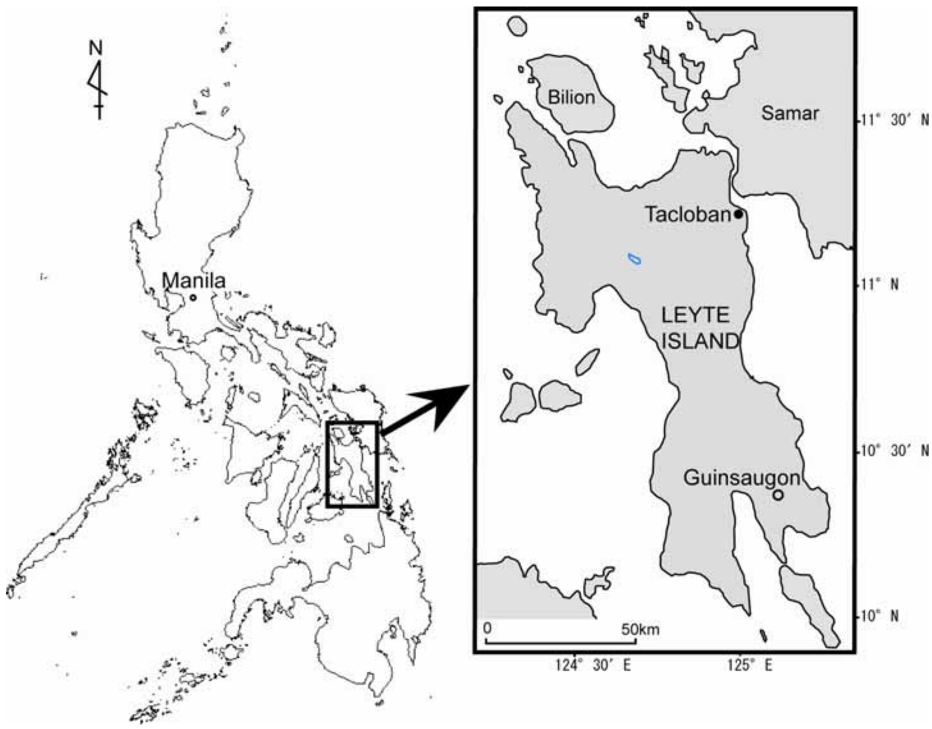

Figure 1. Location of Barangay Guinsaugon, Municipality St. Bernard, Southern Leyte Province, Republic of the Philippines.

PASCO Co. Ltd was used for drafting Figure 3. A stereograph of the Guinsaugon landslide is shown in Figure 4. Palm trees and other plants on the mid-slope seen in Figure 5 stand on the old colluvium. Houses destroyed in Barangay Guinsaugon are 357. The numbers of fatality and missing are 156 and 968, respectively.

3. Geology and clay minerals.

Geological basement rocks in southern Leyte Island are Cretaceous ultrabasic rocks in Mesozoic Era. These are covered by Paleocene sedimentary rocks and Eocene igneous rocks in Paleogene Tertiary age. Miocene igneous rocks in Neogene Tertiary age are distributed in the eastern area. The Miocene sedimentary rocks are mainly sandstone, mudstone and limestone (Fig. 6).

Barangay Guinsaugon had been located on Alluvium deposits. On the other hand, the western mountain side where the slope failure occurred consists of Miocene volcanic complex. The original rocks crop out well in the site of the slope failure. As shown in the geological column of Figure 7, the stratigraphy of the area is composed of volcanic breccia, dacitic tuff and hornblende dacite in ascending order (Fig. 8).

Volcanic breccia is massive, and its constituent fragments are dacite, dacitic tuff, andesite, basalt and sedimentary rocks.

Dacitic tuff, having slightly layered structures and vertical columnar joints, is gray in color. Thickness is 30 meters and its density is 2.0. Under the microscope it consists of plagioclase, hornblende and clinopyroxene with minor amounts of orthpyroxene. Whole rock X-ray analysis of weakly altered specimens of dacitic tuff reveals the existence of smectite, a kind of clay mineral.

Hornblende dacite is the constituent of the top sliding surface. It is grayish white in color and slightly porous. The density of fresh hornblende dacite is 2.3. Plagioclase and hornblende are phenocrysts in a holocrystalline groundmass of the same minerals (Fig. 9). In some rock specimens, clinopyroxene and othopyroxene are present together with plagioclase and hornblende. It is proved by the whole rock X-ray diffraction analysis that altered parts of hornblende dacite include smectite (Fig. 10). The density of the altered rocks is 2.2. A typical example of whole rock chemical compositions of hornblende dacite examined by the X-ray florescence equipment (Rigaku-ZSX100e) is shown in Table 1. SiO_2, K_2O and Na_2O of fresh hornblende dacite

Fig2

Figure 2. Landslide at Barangay Guinsaugon in southern Leyte Island.
A photograph taken from GPS point 17 on March 28, 2006. The width of the top mouth opened is 550 to 600 m.

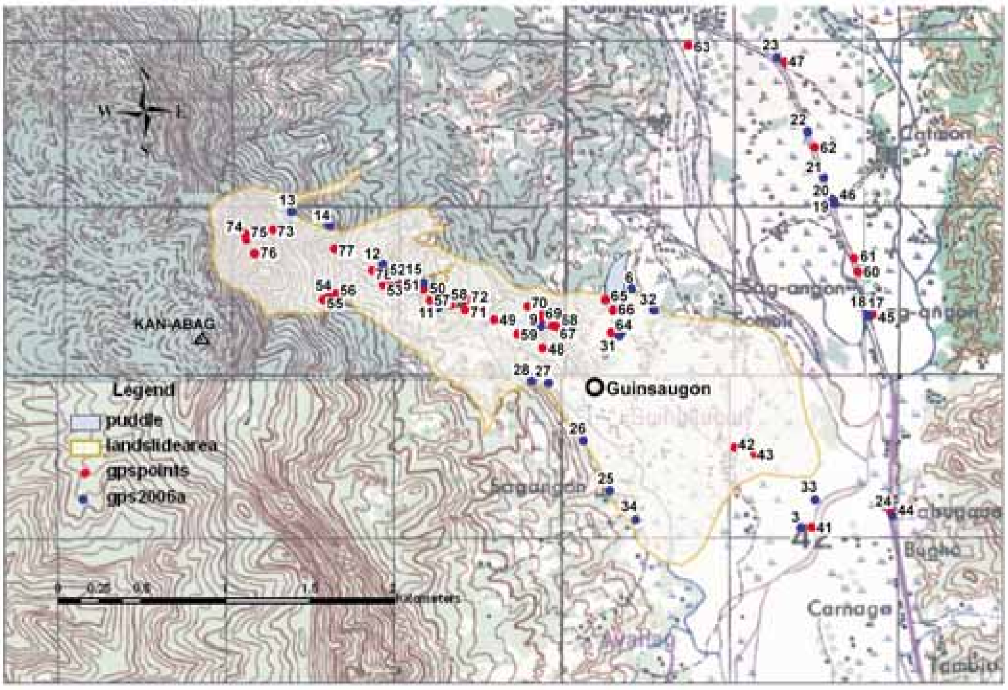

Figure 3. Guinsagon landslide area. A GPS Model EMPEX 38EX was used.

Fig4

Figure 4. Stereophotograph of the Guinsaugon landslide area.
Adjusted for the simple stereoscope of 11 cm high.

Fig5

Figure 5. North end porton of the Guinsaugon landslide area.
A photograph towards east taken on March 27, 2006. At GPS point 15, 70 m above sea level.

coincide with those of typical dacite.

Collected clay minerals were examined by the rotating X-ray powder diffractometer. A used X-ray diffractometer is Rigaku-RINT2500H/PC of the rotating anode type. Analytical conditions are as follows: CuKα, 40KV, 200mA. Results of powder X-ray analyses of clay mineral on the slickenside are shown in Figure 11. Only smectite is found as clay minerals on the slickenside and around failure surface. This fact is proved by the analyses after treatments of heating and ethylene glycol-solvation (EG)

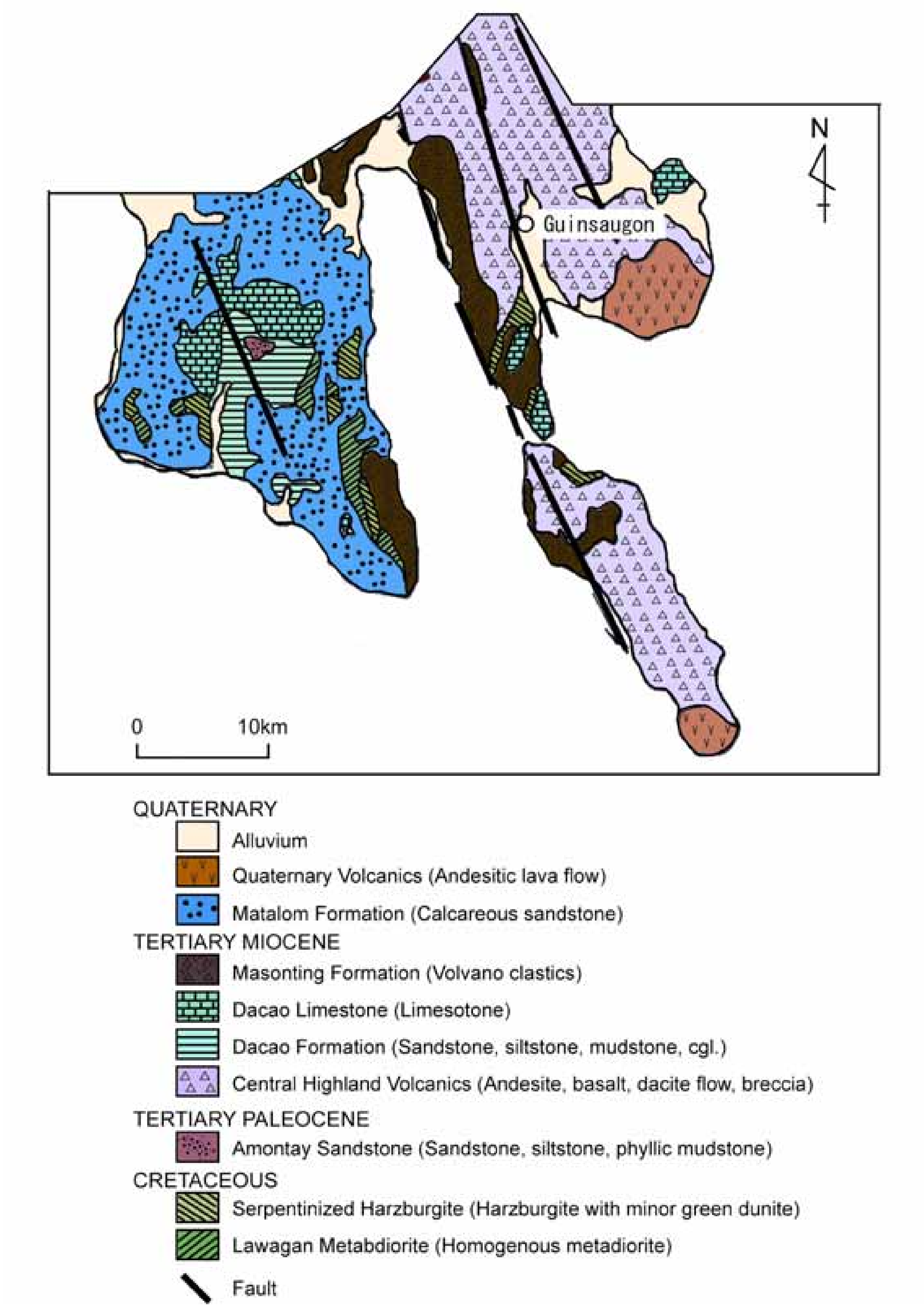

Figure 6. Geological map of southern Leyte Island.

Compiled from JICA(1990), Dimalanta et al.(2006)., Aurelio and Pena (2004) and Balce (Unpublished data).

for clay minerals (Fig. 11). As mentioned above, it must be emphasized the altered rock itself also contains smectite.

4. Precipitation.

Mindanao, Leyte and Samar Islands suffer from heavy rains due to the trade wind in late autumn to early spring every year. On November 5, 1911, Ormoc City (10º 58' N, 124º 38' E) in the northern part of Leyte Island, the heavy rains and floods affected over 7,900 victims (Kato, 1998).

Since December, 2005, it has looked rainy condition (Japan Meteorological Agency, 2006a). The data of precipitation in the central and south parts of Philippines in February of 2006, when the landslide happened, are taken from Philippine Atmospheric, Geophysical and Astromonical Administration, and shown in Figure 12. In the east side of the area, such as at Samar, Leyte and Mindanao Islands, precipitation was heavy, whereas in the west side such as at Cebu and Panay Islands, precipitation was light. Also, the heavy rain portion is limited between the north end of Samar Island and the south end of North Mindanao Island.

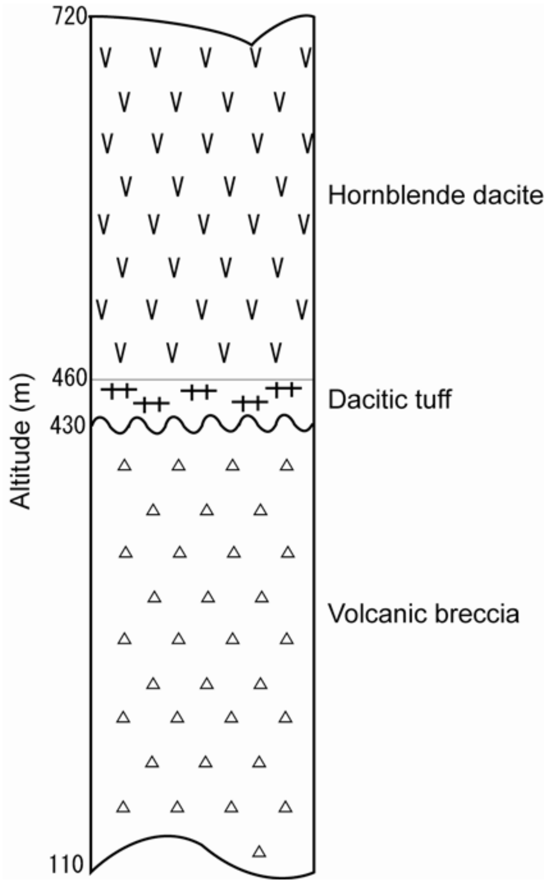

Figure 7. Geological column of the Gunsaugon landslide area

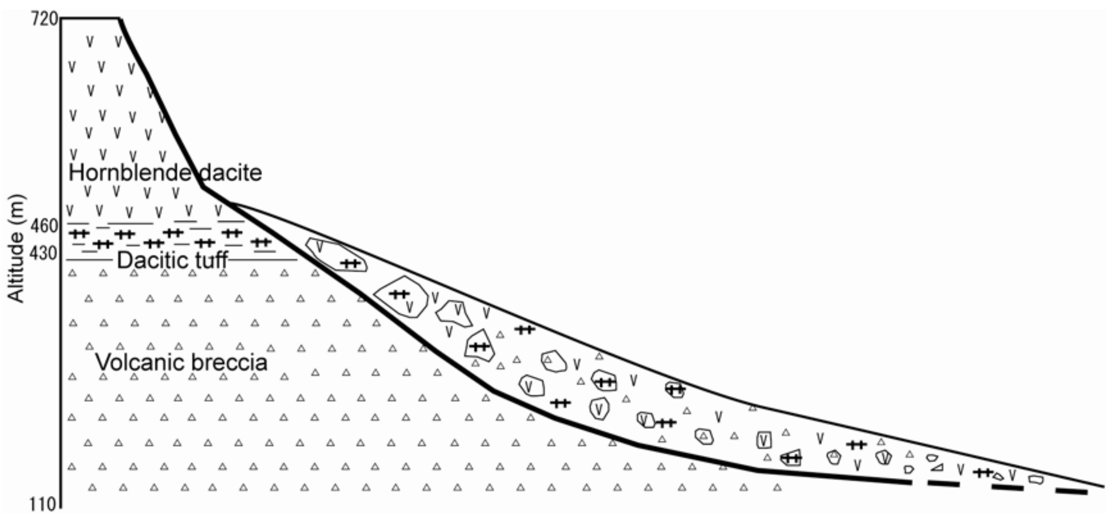

Figure 8. Geological cross section of the Guinsaugon landslide area.

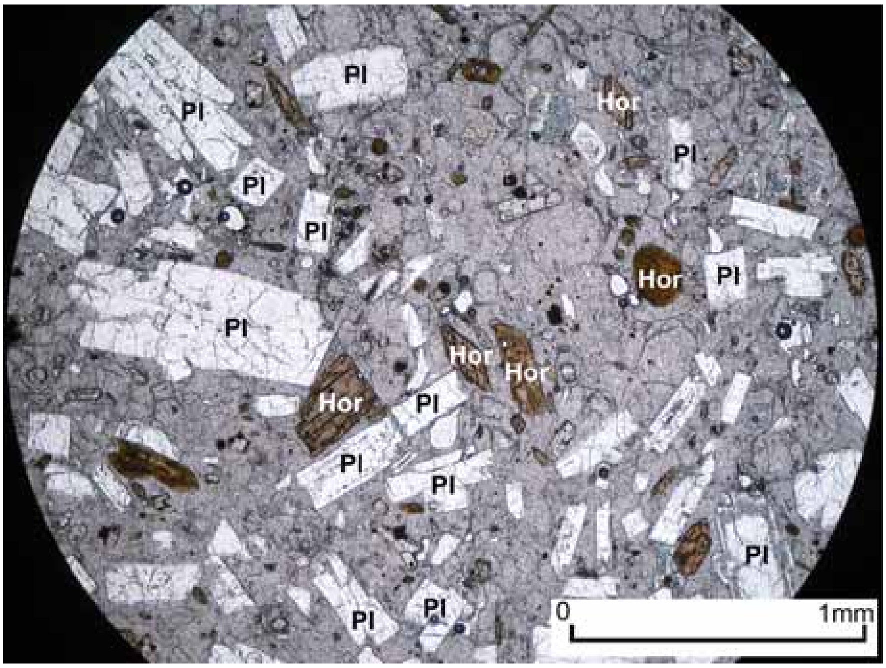

Figure 9. Photomicrograph of honblende dacite..
Pl; plagioclase. Hor; hornblende. Open nicol.

Every observation point in Leyte Island have heavy rainfall on 10th to 13th of February, 2006 (Fig. 13). At Oticon/Libagon, the nearest observation point 8 km west-southeast of Guinsaugon, total precipitation from 8th to 15th of February is 635 mm, and this value is three times more than the general year one, 211 mm. The trade wind from the east hits a chain of mountains from north to south including Mt. Kan-Abag, and may bring heavier rains in the Guinsaugon landslide area than at Oticon/Libagon (Japan Meteorological Agency, 2006b).

5. Discussion.

The approach from many viewpoints is important to find the cause of the Guinsaugon landslide. First is the geological standpoint, stressing the existence of the Philippine Fault System. The Philippine Fault extends from Luzon Island in the north to eastern Mindanao in the south over 1,200 km in length parallel to the Philippine Trench. It displaces still at the rate of 3 cm per year in left-handed strike slip direction of N30º～40º W. The Philippine Fault traverses the central portion of Leyte Island from north to south. The Guinsaugon landslide area is located along the fault zone. The sliding surface showing N30º W, 55º E of the slope failure coincides with the fault plane (Fig. 2). The front portion of the sliding surface composed of hornblende dacite has disappeared, but broken pieces of this portion are scattered on the slope between 300 to 100 m above sea level.

The south extension of this fault is recognized as landslide landforms, and its north extension is found as triangular facets indicating the landscape of landslides. Colluvial deposits caused by a small-scale landslide on the 17th of December, 2005 (Personal communication by field guides) are recognized during this survey. A small mountain (170 m above sea level) within the slope failure consists of old colluvial deposits, and palm trees stand on

Table 1. Chemical composition of hornblende dacite.

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total
Hornblende dacite	64.05	0.33	16.86	2.74	0.06	2.04	3.93	7.58	2.69	0.16	97.44

(wt%)

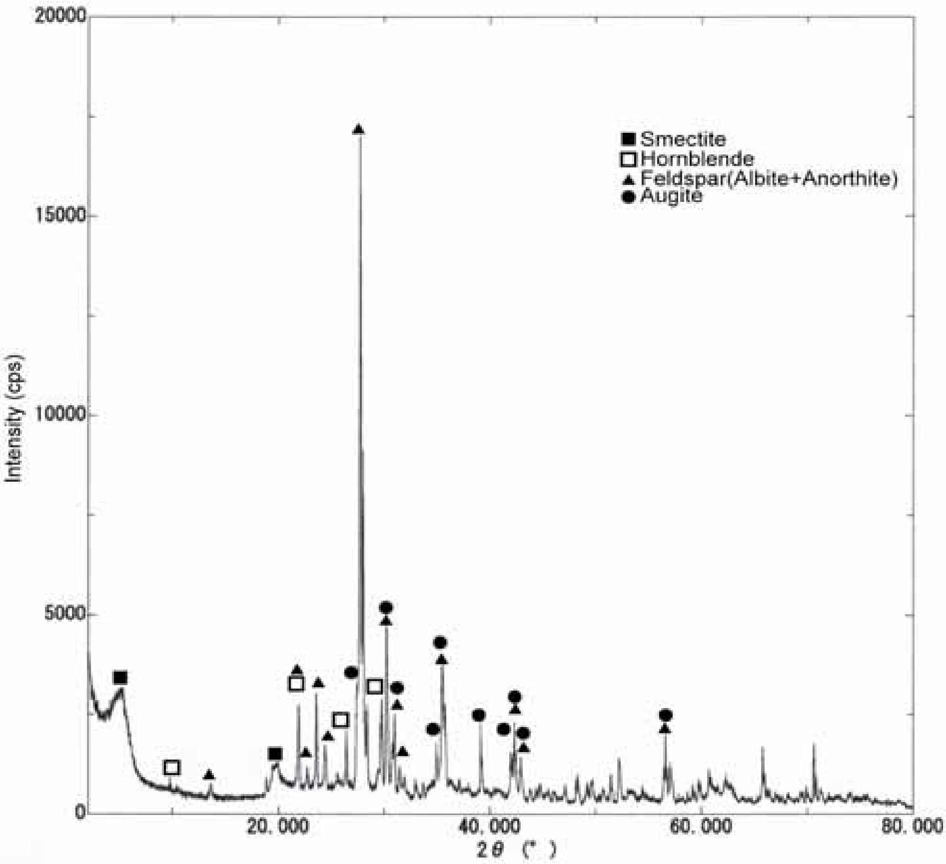

Figure 10. Whole rock powder X-ray chart of altered hornblende dacite.

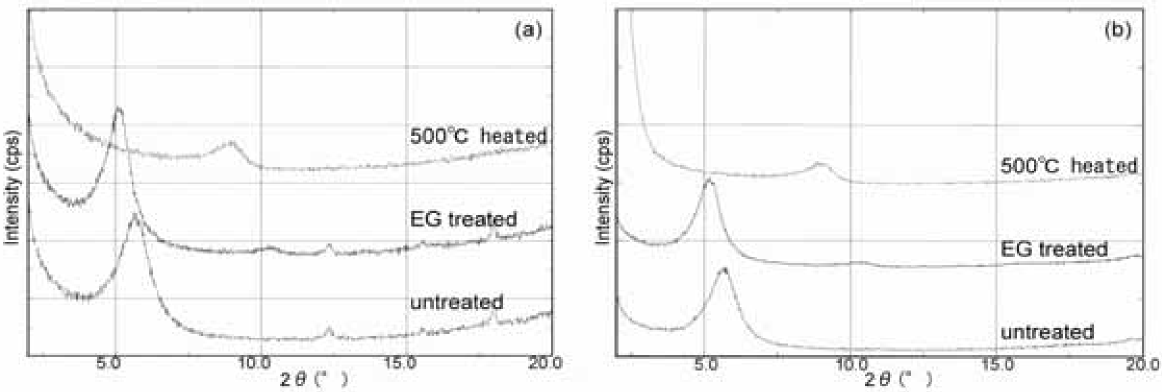

Figure 11. Powder X-ray charts of clay minerals.
(a) Milky white clay on the sliding surface of dacite at the slope failure.
(b) Yellowish brown clay at the same slope failure.

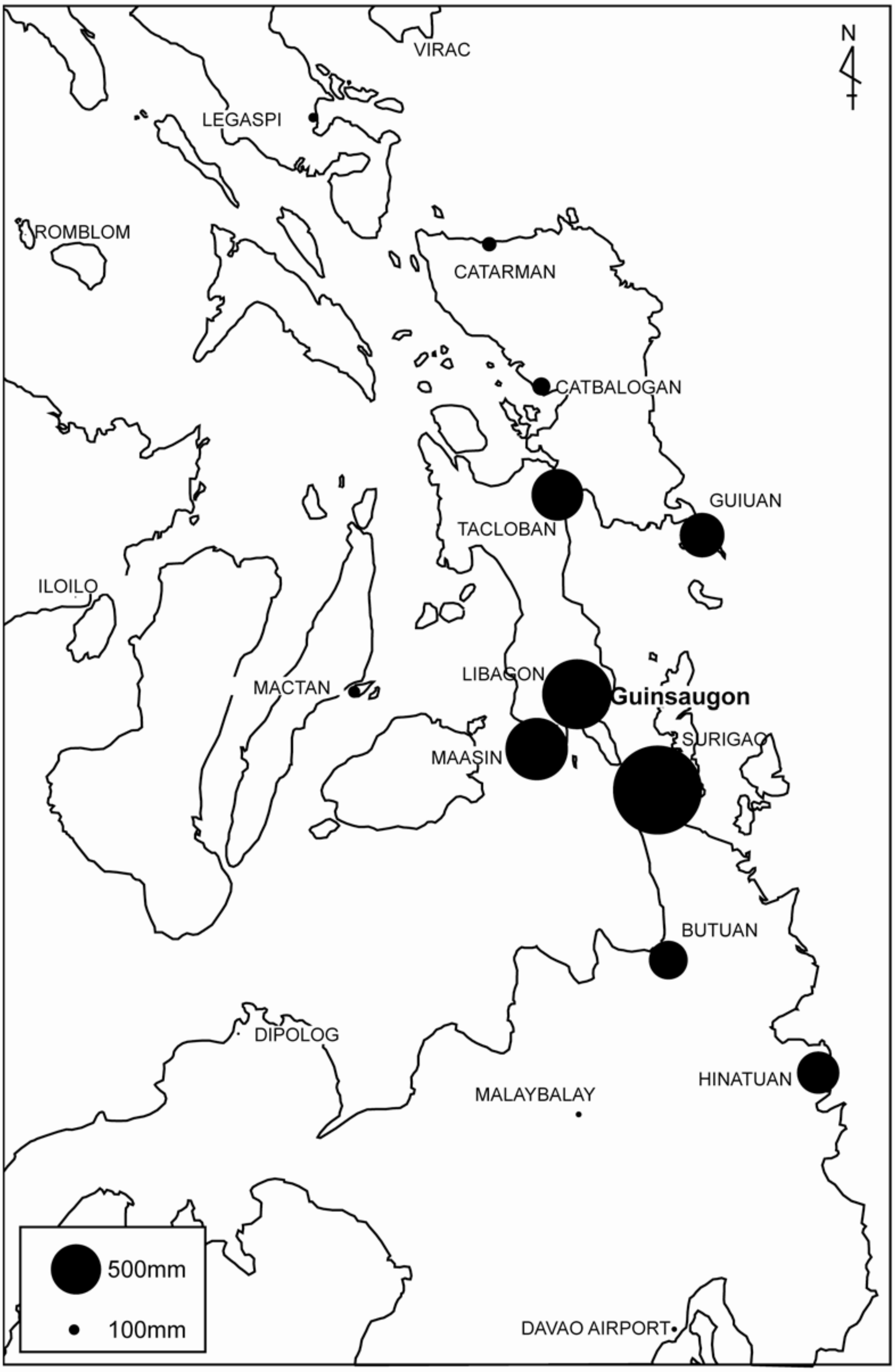

Figure 12. Records of the precipitation at observations facing the Pacific Ocean from 8th to 20th of February, 2006

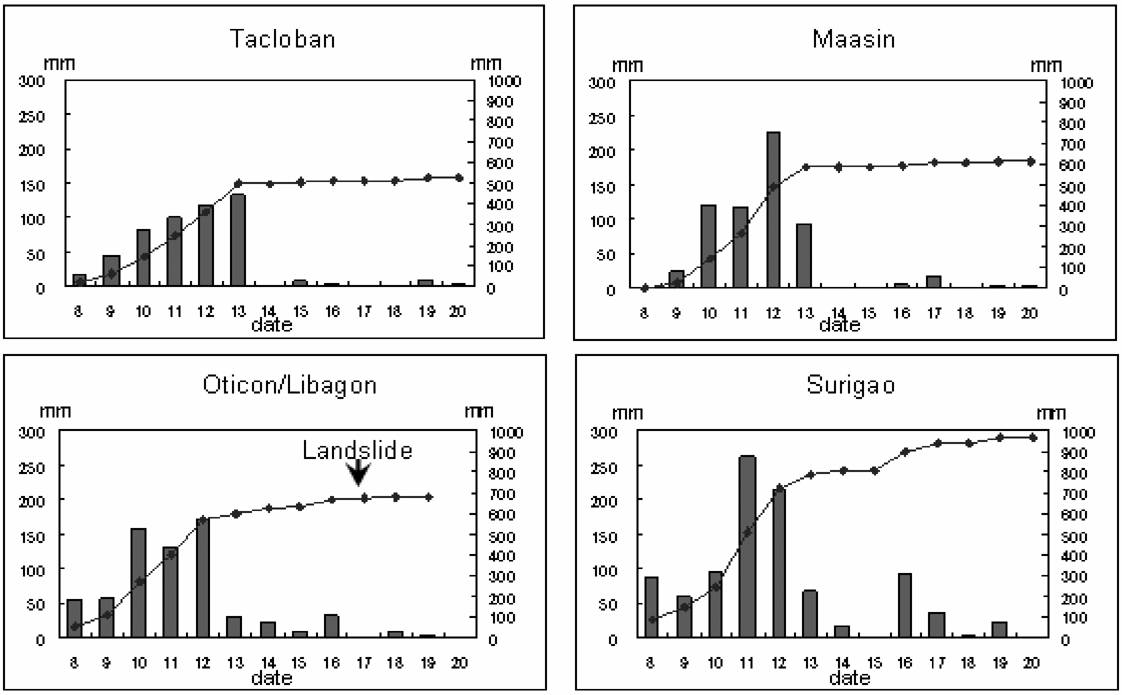

Figure 13. Records of the precipitation at near observations from Guinsaugon from 8th to 20th of February, 2006.
Curves indicate the total precipitation (Right side scale).

the weathered surface of these deposits. Many small or medium scale landslides have occurred in this area, and a phenomenon recognized in other slope failure regions (Imura et al.,2004).

A second standpoint is on clay minerals. Smectite, a type of clay mineral, occur on the sliding surface. This surface recognized as a fault plane, where smectite is held. Smectite expands or swells when it absorbs water. The existence of smectite can be considered as one of the factors that cotributed to the landslide.

A third standpoint is hydrothermal alteration. Large portions of dacitic tuff and some parts of hornblende dacite in the area have undergone hydrothermal alteration. Whole rock X-ray diffraction analysis reveals the existence of smectite as the only clay mineral. Generally, smectite is formed in a neutral or alkaline hydrothermal solution at moderate temperatures (Yoshimura, 2001). Dimalanta et al.(2006) cited hydrothermal alteration and clay formation as factors contributing to this landslide. There are many geothermal fields which usually have hydrothermal alteration zones in southern Leyte Island. One example is the Tongonan geothermal field acting as a power plant of 800 MW. Another is the Cabalian geothermal field in which a new power plant of 40 MW is in the process of costruction. The mountain side, west of the disaster area, has undergone hydrothermal alteration, and weak smectite mineralization has occurred during the hydrothermal alteration. Contemporary, smectite are concentrated partly along faults and cracks. The rocks subjected to hydrothermal alteration become lose and slightly light (Ueno et al., 2003). Jige and Kitagawa (2003) have reported smectite formation by hydrothermal alteration in the landslide area. Thus, the Guinsaugon landslide has close relationship with hydrothermal alteration. Landslides in other places should be examined from the view point of hydrothermal alteration.

There exists an opinion that an earthquake has acted as the trigger for the landslide. The mild earthquake of magnitude 2.6, depth 6 km had hit just moments before the landslide. However, a seismologist in Japan said it is not enough as a trigger for the landslide and a Philippine government geological expert confirmed that it had not appeared strong enough to trigger the landslide.

The disaster area is situated in the portion which repeatedly suffered by many landslides before, and also in the fault zone of the Philippine Fault. The hydrothermal alteration made the rocks loose, and produced smectite. The factor of the heavy rain overlapped many geological factors. The combination of these factors led to the Guinsaugon landslide.

6. Conclusion.

Field surveys and laboratory works on the landslide in southern Leyte Island yielded to following results.

1) The lithologic sequence at the landslide area consists of the volcanic breccia mass, thin dacitic tufff layer and hornblende dacite flow in ascending order. These facies are exposed on the sliding surface.

2) The Philippine Fault traverses north to south through the central part of Leyte Island. The landslide area is located in the fault zone. The sliding surface of the slope failure coincides with one of the fault planes.

3) Smectite, a kind of clay mineral, occurs on the sliding surface and small cracks nearby. The occurrence of smectite is considered as one of factors that caused the landslide, because smectite has the property of expanding or swelling at wet conditions.

4). Dacitic tuff and hornblende dacite were subjected to hydrothermal alteration widely. Smectite is an alteration product. Hydrothermally altered rocks become loose.

5) Heavy rainfalls recorded at every observation point in Leyte Island for two weeks prior to the Guinsaugon landslide. Total precipitation at that time in Oticon/Libagon, the nearest observation point, is 787 mm, three times that of normal year.

6) The factor of heavy rains overlaps many geological factors. The combination of these factors led to the landslide.

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