https://doi.org/10.20965/jdr.2021.p0556

Survey Report:

Landslide Process Revealed by Mineralogical Properties of Landslide Deposits in the Sa Pa District, Vietnam

Takanari Yamasaki*1, Go Sato*1,†, Takashi Kimura*2, Hoang Viet Hung*3, Nguyen Duc Manh*4, Takatsugu Ozaki*5, Osamu Yokoyama*6, Shinichi Tosa*6, and Akihiko Wakai*5

*1Graduate School of Environmental Informations, Teikyo Heisei University
4-21-2 Nakano, Nakano-ku, Tokyo 164-8530, Japan
†Corresponding author, E-mail: gsato@thu.ac.jp
*2Graduate School of Agriculture, Ehime University, Ehime, Japan
*3Faculty of Civil Engineering, Thuyloi University, Hanoi, Vietnam
*4Department of Geotechnical Engineering, University of Transport and Communications, Hanoi, Vietnam
*5Graduate School of Science and Technology, Gunma University, Gunma, Japan
*6Japan Conservation Engineers & Co., Ltd., Tokyo, Japan

[Received December 13, 2020; accepted March 6, 2021]

Hau Thao Village is located in Sa Pa Prefecture, in northern Vietnam. The village contains one of the most picturesque landscapes with terraced paddy fields located in landslide topography formed on a gentle slope. However, the creation of the topography has not been sufficiently clarified. In this study, samples of soil and stone are taken from two landslide areas in Hau Thao Village for mineral composition analysis, clarifying that the sauce rock of the deposits comprising the landslide areas is made up of granitoids, forming the upper slope above the fault located in the hinterland. The landslides occurring in Hau Thao Village are caused by the remobilization of the secondary deposits transported from the upper part of the slope by debris flow.

Keywords: weathered granitic rock, terraced paddy fields, XRD, clay mineral, Hau Thao Village

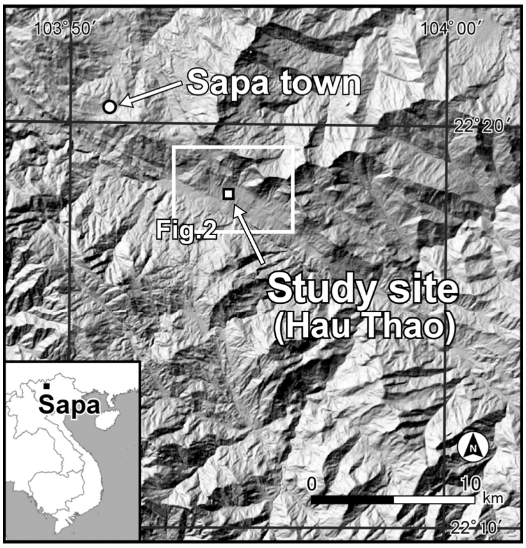

Fig. 1. Survey location map. Base map is created using DEM with the resolution of AW3D – 30 m.

1. Introduction

In Hau Thao Village, Sa Pa Prefecture, which is located in the northern part of Vietnam (**Fig. 1**), there are many ethnic minorities in the mountainous area, and the land on the slopes has long been used as terraced paddy fields that many tourists come to see. However, terraced paddy fields are mostly located in the landslide area, and damage is caused to both the infrastructure and farmland when a portion of that area slides away. For this reason, a survey has been conducted by geotechnical researchers by using slope stability analysis [1, 2]. However, there has been insufficient research from the geological and topographic viewpoints to provide important information in countermeasures against landslides. This study sought to determine the slope development process caused by landslides by conducting a geological survey in the landslide sites distributed across Hau Thao Village and performing a mineral composition analysis of the soil and stone taken from these sites.

2. Study Site

Hau Thao Village, the area to be surveyed (**Fig. 2(a)**), is located on the left bank of the basin of Muong Hoa River. It can be seen from the slope form on the left bank that the slope near Hau Thao Village is relatively gentle, while the slope above the village is steep. The geologic cross section shown in **Fig. 2(b)** indicates that this gradient change reflects the geological structure [3]. Taking the steep slope of the upper part as the upper slope and the gentle slope of the lower part as the lower slope,

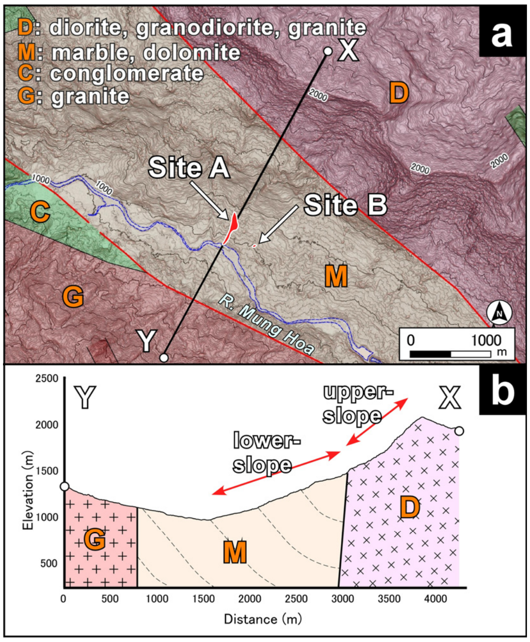

Fig. 2. (a) Geologic map around survey area. (b) Geologic cross section. The geological information shown in the geologic map and geologic cross section has been taken from the Vietnam Geological and Mineral Department [3]. The base map in **Fig. 2(a)** and cross section in **Fig. 2(b)** were created using DEM with the resolution of AW3D – 1 m. Site A and Site B indicate landslide areas where the field survey was conducted and correspond to the landslide areas of Site A and Site B in **Fig. 3**.

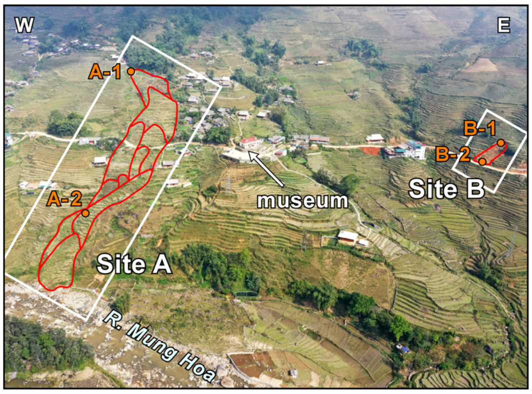

Fig. 3. Landslides and sampling locations for the survey (A-1, A-2, B-1, and B-2). Red solid lines indicate landslide blocks of landslides to be surveyed. Photograph was taken on December 1, 2019.

there exists a fault near the border between the upper slope and lower slope. The faults with the NW-SE strike parallel of the study site's fault are well developed around the study site. For example, the Red River Fault Zone, which stretches NE-SW direction, forms the borders between the southern part of China and the Indochina block located 20 km northeast of the study site [4, 5]. Additionally, the upper slope consists of diorite, granodiorite, and granite, which likely originated during the Cambrian to Ordovician of the Paleozoic Era, and belonging to Po Sen Complex. However, the lower slope where Hau Thao Village is located consists of marble and dolomite belonging to the Da Din Formation of the Proterozoic Era. Regarding land use, the upper slope is forest area and the lower slope is used as terraced paddy fields. Furthermore, many megalith relics with engraved patterns are distributed across Hau Thao Village. To introduce these relics, the Sa Pa Antique Engraved Rocks Museum has been established. The megaliths consist of granitic rocks different from the bedrock of Hau Thao Village.

3. Methods

The field surveys were conducted of two landslide sites in Hau Thao Village (**Fig. 3**). Site A is located in Ta Van District in the village. As seen from **Fig. 3**, the landslide body of the landslide is made up of multiple landslide blocks; its slope length is 400 m and the maximum width is 60 m. In the field survey, fresh cracks were confirmed on this landslide body. Site B is located about 350 m in the eastward direction from Site A and is made up of a single landslide, which occurred in 2019 along the road. Its scale includes a slope length of 50 m and a maximum width of 20 m. In the field survey, the deposits found in the landslide body at these sites were observed and samples were taken for the mineral composition analysis. Each sample was taken from the flank of the upper main scarp within the scarp located at the head of Site A (location A-1 of **Fig. 3**), the toe of the landslide body in Site A (location A-2 of **Fig. 3**), the main scarp in Site B (location B-1 of **Fig. 3**), and the toe of the landslide body in Site B (location B-2 of **Fig. 3**). The mineral composition analysis was conducted using desktop XRD MiniFlex of Rigaku Corporation, which is owned by Japan Conservation Engineers & Co., Ltd. In addition to powder X-ray diffraction using the random orientation method, and the preferred orientation analysis was also conducted to examine the clay mineral.

4. Results

4.1. Site A

The location of A-1 forms a scarp with a relative height of about 2.5 m. The scarp consists of unconsolidated soil containing gravel, and the gravel is composed of granitoids 6–15 cm in diameter and grayish-white limestone, which can be recognized only one at the outcrop. This portion of the matrix consists of ocherous weathered soil containing granule gravel, becoming red in an upward direction. The sample for X-ray diffraction was taken from the location 1.3 m below the top of the scarp. The results are shown in **Fig. 4**. Quartz (Qtz), amphibole (Amp), pyrophyllite (Prl), and kaolinite (Kln) were detected in the sample. The clay mineral sized 9.3 Å is classified as py-

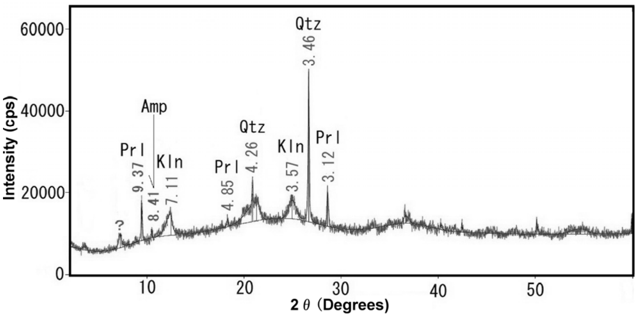

Fig. 4. Result of X-ray diffraction of sample at location A-1.

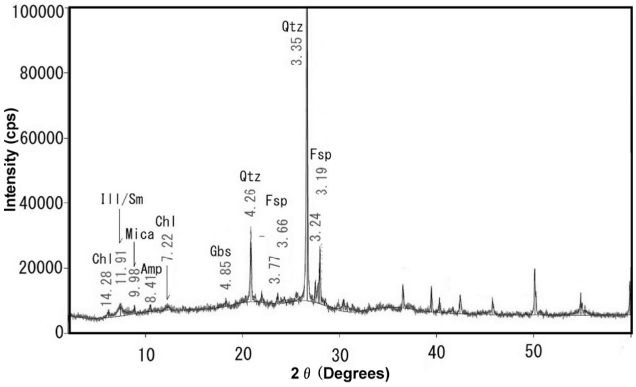

Fig. 5. Result of X-ray diffraction of sample at location A-2.

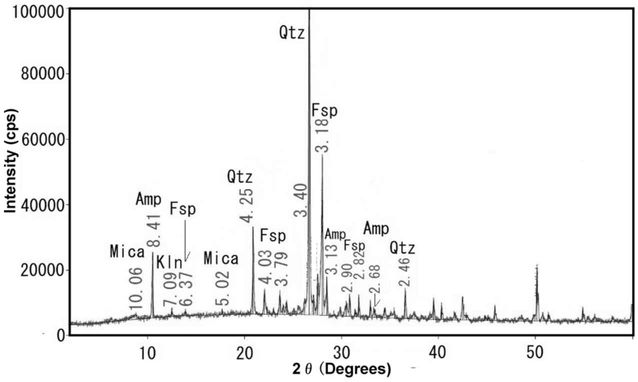

Fig. 6. Result of X-ray diffraction of sample at location B-1.

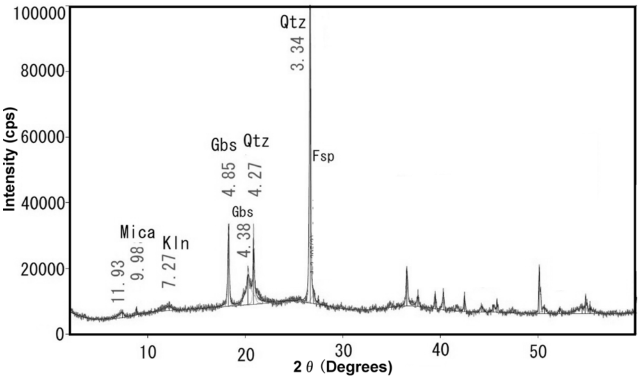

Fig. 7. Result of X-ray diffraction of sample at location B-2.

rophyllite, but might have been talc with the same value. However, because serpentine cannot be found on the site, it is determined as pyrophyllite.

A-2 is located at the toe of the landslide body. The terraced paddy fields are shaped in a way that complements the landslide body. The cultivated soil is composed of the soil mixed with granule gravel and its tone is grayish ocher. The X-ray diffraction sample was taken from 10 cm below the land surface by digging a hole. The results are shown in **Fig. 5**. Quartz (Qtz), amphibole (Amp), feldspar (Fsp), mica mineral (Mica), gibbsite (Gbs), and illite smectite mixed-layer mineral (Ill/Sm) are detected in the sample.

4.2. Site B

The location of B-1 forms a main scarp with a relative height of about 2.0 m. The main scarp consists of red unconsolidated soil containing granule gravel and sub-round gravel of granitoid with the maximum size of 25 cm near the surface of land. The sample for the X-ray diffraction is taken from 1.7 m below the top of the main scarp. The X-ray diffraction found quartz (Qtz), mica mineral (Mica), gibbsite (Gbs), and kaolinite (Kln) (**Fig. 6**). The location of B-2 is at the earth cut of the toe of landslide body and consists of reddened unconsolidated soil. At this location, a pebble of gneiss exposed on the surface was taken as a sample for X-ray diffraction and analyzed, finding quartz (Qtz), amphibole (Amp), feldspar (Fsp), mica mineral (Mica), and kaolinite (Kln) (**Fig. 7**).

5. Discussion

As mentioned above, the geological features of the lower slope where the landslide areas of Site A and Site B are located consist of marble and dolomite. However, in the X-ray diffraction results for all the samples taken from the landslide areas of Site A and Site B (**Table 1**), carbonate mineral contained in marble and dolomite was not detected, indicating that the materials comprising the landslide areas of Site A and Site B may not have originated from the site but may be regarded as a secondary deposit from another location. As shown in **Table 1**, rock-forming minerals typically obtained from both landslide areas include quartz (Qtz), amphibole (Amp), mica mineral (Mica), feldspar (Fsp), and kaolinite (Kln), formed by weathering feldspar. The characteristics of the minerals demonstrate that the sauce rock of the secondary deposits of the landslide areas would include diorite or granodiorite, which is the plutonic rock predicted from the combination of the rock-forming minerals.

As mentioned above, the upper slope comprises diorite, granodiorite, and granite. The sediment has deposited on the lower slope with a lower gradient below the fault. This

Table 1. Geological features recognized in the results of X-ray diffraction of samples taken from A-1, A-2, B-1, and B-2.

Location	Fsp	Qtz	Amp	Chl	Ill/Sm	Gbs	Mica	Kln	Prl
A-1		++	+					+	+
A-2	+	+++	+	+	+	+	+		
B-1		+++				++	+	+	
B-2	++	+++	++				+	+	

Estimated content: +++ large amount, ++ medium amount, + small amount,
(+) very small smount

Fsp: feldspar, Qtz: quartz, Amp: amphibole, Chl: chlorite, Ill/Sm: illite smectite mixed layer mineral, Gbs: gibbsite, Mica: mica mineral, Kln: kaolinite, Prl: pyrophyllite

sediment originated from a landslide on the upper slope and was moved during a landslide. A landslide of the unconsolidated deposits represented by Site A and Site B then occurred, with a series of slope formation processes. As mentioned above, the relics of the megaliths on which patterns are engraved are made of granitoids, considered to have been moved from the upper slope with a similar process and engraved after sedimentation.

The sample from the location A-1 contains pyrophyllite. Pyrophyllite is often generated by hydrothermal alternation with high temperatures [6]. Presumably, the hydrothermal solution would have occurred along the fault located on the border between the upper slope and the lower slope, or it would have originated from the lamprophyre intruding granitoids. However, it is also estimated that the weathering of the rocks generated by an increase of hydrothermal solution or intrusion into granitoids would contribute to the occurrence of landslides on the upper slope. This process on the upper slope should be clarified in the future, including the relationship with the failure landscape recognized at the upper slope where granitoids are distributed.

6. Conclusions

Samples of soil and stone were taken from two landslide-affected areas located in Hau Thao Village and subjected to X-ray diffraction analysis. The landslide areas are located in an area where marble and dolomite are distributed, but the carbonate mineral that these rocks are composed of was not found. However, quartz, amphibole, mica mineral, and feldspar, which are the rock-forming minerals of granitoids, were found in the results of X-ray diffraction. The landslides distributed in Hau Thao Village were possibly triggered by sliding of the granitoids on the upper slope and the secondary deposits delivered by debris flow and other movements.

Acknowledgements

A part of this study is supported by JST e-ASIA JRP "Construction of monitoring and prediction system of landslide (Grant Number: JPMJSC18E3)." The authors would also like to thank the members of the testing laboratory of Japan Conservation Engineers & Co., Ltd. cooperated in conducting the X-ray diffraction.

References:

[1] D. M. Nguyen and Q. H. Tran, "Features of large-scale landslide at Hau Thao Area, Sa Pa Town, Lao Cai Province," P. Duc Long and N. T. Dung (Eds.), "Geotechnics for sustainable infrastructure development (Lecture notes in civil engineering Vol.62)," pp. 917-922, Springer, doi: 10.1007/978-981-15-2184-3_119, 2020.

[2] T. V. Tran, V. H. Hoang, H. D. Pham, and G. Sato, "Use of Scoops3D and GIS for the assessment of slope stability in three-dimensional: A case study in Sapa, Vietnam," Proc. of the Int. Conf. on Innovations for Sustainable and Responsible Mining (ISRM 2020), Vol.2, pp. 210-229, doi: 10.1007/978-3-030-60269-7_11, 2020.

[3] Vietnam Geological and Mineral Department, "Geological and mineral map of Vietnam 1:200,000 Kim Binh-Lao Cai sheet," 2005.

[4] N. Q. Cuong and W. A. Zuchiewicz, "Morphotectonic properties of the Lo River Fault near Tam Dao in North Vietnam," Natural Hazard and Earth System Sciences, Vol.1, Nos.1-2, pp. 15-22, doi: 10.5194/nhess-1-15-2001, 2001.

[5] W. Zuchiewicz, N. Q. Cu'ò'ng, J. Zasadni, and N. T. Yêm, "Late Cenozoic tectonics of the Red River Fault Zone, Vietnam, in the light of geomorphic studies," J. of Geodynamics, Vol.69, pp. 11-30, doi: 10.1016/j.jog.2011.10.008, 2013.

[6] M. Utada, "Alteration of Rokko Granites: Mineralogical and magnetic susceptibility changes," J. of Geography, Vol.112, No.3, pp. 360-371, doi: 10.5026/jgeography.112.3_360, 2003 (in Japanese).

Name:
Takanari Yamasaki

Affiliation:
Visiting Professor, Graduate School of Environmental Informations, Teikyo Heisei University

Address:
4-21-2 Nakano, Nakano-ku, Tokyo 164-8530, Japan

Selected Publications:

- "Mechanism and shear strength of slip surface: Recent trends and emerging issues," J. of the Japan Landslide Society, Vol.48, No.3, pp. 125-138, 2011.
- "Ring shear characteristics of high purity clay minerals – Correlation with natural slip surface clay –," J. of the Japan Landslide Society, Vol.37, No.2, pp. 30-39, 2000.

Name:
Go Sato

Affiliation:
Professor, Graduate School of Environmental Informations, Teikyo Heisei University
Address:
4-21-2 Nakano, Nakano-ku, Tokyo 164-8530, Japan

Name:
Takashi Kimura

Affiliation:
Assistant Professor, Graduate School of Agriculture, Ehime University
Address:
3-5-7 Tarumi, Matsuyama, Ehime 790-8566, Japan

Name:
Hoang Viet Hung

Affiliation:
Associate Professor of Geotechnical Engineering, Thuyloi University
Address:
175 Tayson Street, Dong Da District, Hanoi, Vietnam

Name:
Nguyen Duc Manh

Affiliation:
Associate Professor of Geotechnical Engineering, University of Transport and Communications
Address:
No.3 Cau Giay Street, Lang Thuong Ward, Dong Da District, Hanoi, Vietnam

Name:
Takatsugu Ozaki

Affiliation:
Ph.D. Student, Graduate School of Science and Technology, Gunma University
Address:
1-5-1 Tenjincho, Kiryu, Gunma 376-8515, Japan

Name:
Osamu Yokoyama

Affiliation:
Section Manager, Engineering Promotion Department, Japan Conservation Engineers & Co., Ltd.
Address:
1-9-21 Esaka-cho, Suita, Osaka 564-0063, Japan

Name:
Shinichi Tosa

Affiliation:
Director, Engineering Promotion Department, Japan Conservation Engineers & Co., Ltd.
Address:
1-9-21 Esaka-cho, Suita, Osaka 564-0063, Japan

Name:
Akihiko Wakai

Affiliation:
Professor, Gunma University
Address:
1-5-1 Tenjincho, Kiryu, Gunma 376-8515, Japan