Identification of slip surfaces in shallow landslides at Aso volcano, Japan based on the fine fraction-plasticity index relationship

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Research

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Abstract

Shallow landslides have frequently occurred in the Aso volcano, Kyushu island, Japan. Yet, observations of the effects of the physical properties of the soil on the landslide stratigraphy have not been explained. In this study, we conducted field observations—at two landslide sites in the Takadake mountain (Aso volcano) area—to identify the slip surfaces. We found that slip surfaces (at both sites) were located in the lower part of the N3-4 Kuroboku soil layer. This was determined by characteristics of the physical properties of the soil, including particle size distribution and plasticity index. Furthermore, we identified the relationship between plasticity index and the fine fraction of the soil to help explain the identification of slip surfaces. Results showed that Kuroboku and Scoria layers have different characteristics according to the plasticity chart (liquid limit-plasticity index relationship) as well as plasticity index-fine fraction relationship.

Introduction

On July 12th, 2012, heavy cumulative rainfall (up to 508 mm) triggered sediment-disasters at Aso volcano, Kyushu island, Japan (Fig. 1). These shallow-landslides have been identified as being similar to the sediment-disasters that occurred in June 1953, July 1990, and June 2001 (Miyabuchi et al., 2004). The soil materials in research area were a tephra layers which formed from volcanic activity. Miyabuchi et al. (2004) Ono and Watanabe (1985) investigated pyroclastic in Aso volcano and found that tephra formation was more than 6,300 years old (^{14}C age) and had 13 active periods from N1 to N13 (N being the symbol for Nakadake) (Fig. 2). OJS Scoria originated in the N4 period (around 3.6 ka), and the lower and upper Scoria beds are believed to have erupted from the Kishimadake and Ojodake volcanoes, which are located in the northwestern part of the central cones. Afterward, N2 Scoria formed during N2 period (around 1.5 ka).

Miyabuchi and Daimaru (2004) reported that for sediment-disasters events, the slip surfaces of the landslides were formed near the boundary between Kuroboku and Scoria layers that differ in grain size and soil hardness (Shimizu and Ono, 2016). Moreover, the effect of the hydraulic conductivity of tephra layers with the slip surface was investigated by Shimizu and Ono (2016); they found that the difference in hydraulic conductivity was the dominant control on the slip surface layer. Shimizu et al. (1992) determined that the layer below the slip surface had a lower conductivity, thus acting as a hydraulic aquiclude (Shimizu and Ono, 2016).

Based on these previous research, our study aimed to address the uncertainties around how the physical soil properties may be related to being able to confirm the identity of slip surface layers in Aso volcano.

Material And Methods

To characterize the effects of the soil physical properties of the slip surface on tephra layers, we carried out a field-based stratigraphy investigation (soil hardness test) combined with laboratory analysis of soil properties including liquid limit and plastic limit, particle size distribution, density of soil particles, ignition loss and organic matter content.

• Field Investigation

Two locations featuring shallow landslides in Takadake were selected as field observation areas. Takadake 1 is located at N 32° 53’ 54.06”,E 131° 7’ 33.48” with landslide dimensions of 34 meters in length by 10 meters in width. Here, the main soil layer was divided into six sub-layers from the surface down to 1.39 m below ground. Takadake 2 is at N 32° 54’ 8.22”,E 131° 7’ 13.74” with landslide dimensions of 18 meters in length by 39 meters in width. The main soil layer in Takadake 2 was divided into seven sub-layers from the surface down to 1.37 m below ground. The main soil layer in both areas were defined from the surface down to 1.3 m because the lowest sub-layer (OJS scoria) was hard to be exposed.

At each landslide, we exposed the tephra layers and measured the soil hardness value with a device of Yamanaka-type soil hardness meter. Yamanaka-type soil hardness meter can easily measure the strength by press the device vertically into the soil layer at the site. The hardness of the soil layers is shown commonly by the mm unit in the case of a Yamanaka-type soil hardness tester. In this study, we measured the soil hardness value on each sub-layer at Takadake 1 and on several sub-layer at Takadake 2 area.

• Laboratory Analyses

Physical properties of the soil in this research, such as the liquid limit and plastic limit, particle size distribution, density of soil particles, and ignition loss were obtained by referring to the laboratory testing standards of Geomaterials Vol. 1, Japanese Geotechnical Society Standards (2015). These analyses were performed to obtain the characteristics of physical properties in the soil materials. The liquid limit and plastic limit methods obtained the water content of a soil in the different condition, transition from the plastic state to the liquid state (liquid limit) and transition from the plastic state to the semi-solid state (plastic limit). Furthermore, the particle size distribution method obtained the distribution of particle sizes in soils as a mass percentage. The density of soil particles obtained the mass per unit volume of the solid part of soil. The last analysis from Japanese Geotechnical Society Standards (2015), ignition loss obtained the reduction in mass of soil when heated (750 ± 50) °C relative to the mass of the soil when oven dried to a constant mass (110 ± 5) °C, expressed as a percentage.

The Kuroboku layers in research area have a black color and had an assumption that contains a high organic matter. Because of that reason, in this study, the organic matter analysis was obtained carried out referring to Condie (1993) where the organic matter was determined by using oven-dried samples on the ceramic crucibles with a capacity of 50 mL at a temperature of 550 °C for 4 hours.

Results And Discussion

• Stratigraphy analysis of the field

Table 1 shows the observation of the soil samples in the field. At both landslide sites, the color of Kuroboku was darker than that of Scoria. We found that in Takadake 1, the soil hardness for N2 Scoria was the highest i.e., 18.55 mm average and of topsoil layer was 12.6 mm. Contrastingly, in Takadake 2, the soil hardness for OJS Scoria was the highest i.e., 23.9 mm average, whereas for N2 Scoria and N3-4 Kuroboku, it reached an average of 19.6 mm and 18.1 mm, respectively. The hardness of the soil layers in the field may be reflective of the observations of particle size; both the landslide sites showed that in general, particle size in Scoria layers appeared larger than Kuroboku layers.

• Physical Properties Of Soil Materials

Figure 3 shows the results of physical properties in soil layers. Generally, the results of Kuroboku were different from those of Scoria. Scoria layers contain a lower fine fraction and plasticity index, a higher density of soil particles, and a lower ignition loss with low organic matter content. Oppositely, Kuroboku layers contain a higher fine fraction, higher plasticity index, a lower density of soil particles, and a higher ignition loss, but also feature low organic matter (except for the lower part of N3-4 Kuroboku at Takadake 1—which has a higher organic matter content).

In the field, slip surfaces located in the lower part of N3-4 Kuroboku were observed at each landslide sites. Characteristics of these slip surfaces include a higher fine fraction, higher plasticity index, lower density of soil particle, high ignition loss and occasionally higher organic matter content. Not like other physical properties (plasticity index, fine fraction and density of soil particles), the values of ignition loss and organic matter were not clearly showed the differences between Kuroboku and Scoria layers. Therefore, in this study, the ignition loss and organic matter values were difficult to be used as the parameters of the characteristics for the slip surface.

Same with those analyses, the identification of the slip surface using particle size distribution and soil texture classification scheme were not specified. The particle size distribution (Fig. 4) confirmed that Kuroboku layers contain a higher fine-fraction than Scoria layers. However, the soil classification scheme (Fig. 5) in which almost all soil layers are located in the same group (SF to S-F). SF to S-F group showed that soil layers were dominated by sand and fine fraction. Therefore, it was difficult to be used as the parameters of the characteristics for slip surface because the results between Kuroboku and Scoria layers showed the similarity on this method.

However, the identification of the slip surface with a plasticity chart (Fig. 6) showed an interesting result. The plasticity chart showed that almost all soil layers are inorganic silts of high compressibility and organic clays. N2 Scoria layers are inorganic silts of medium compressibility and organic silts. The plasticity index values for Kuroboku layers are higher than for Scoria. The range of Kuroboku layers on the liquid limit started from 50–120% and its plasticity index from 10 to 35. Moreover, the liquid limit for Scoria ranges from 30–55% and its plasticity index is from 0 to 20.

The Casagrande plasticity chart shows that Kuroboku and Scoria generally have different values. Even though the upper part of the N3-4 Kuroboku at Takadake 2 were plotted between Kuroboku and Scoria, it is still evident that the Kuroboku layers and Scoria layers have different characteristics. Figure 6 shows that the slip surface layers (located in the lower part of N3-4 Kuroboku) have a high value of plasticity index and high liquid limit, whereas the range between the layers was excessively wide for liquid limit value. Therefore, from Fig. 6, we infer that the plasticity index may be a useful parameter to help identify the slip surface.

Furthermore, the plasticity index and fine fraction were combined into one chart (Fig. 7), and show clearly that Kuroboku layers and Scoria layers plot in two distinct groups. Scoria layers have low plasticity index (0–20) and a low fine fraction (10–30%), while Kuroboku layers have a high plasticity index (10–35) and a high fine fraction (20–45%). This relationship shows that the plasticity index is directly proportional to the fine fraction.

Figure 7 shows that soil layers from each landslide site were fitted with trend lines and were separated in Kuroboku and Scoria layers group. The Scoria layers plotted outside the trend lines, whereas almost all the Kuroboku layers were plotted within the trend lines. The slip surface layers also plotted within the trend lines and have the highest values of fine fraction and plasticity index (Fig. 7). This chart showed clearly the different characteristics between Kuroboku and Scoria layers, further, the characteristics of slip surface layers also was obvious on this chart. Therefore, this chart enabled to help identify the slip surface layers on Takadake at Aso volcano.

Conclusion

On the grassy hill slopes of post-caldera central cones of Aso volcano, many shallow landslides have occurred, most of them caused by heavy rainfall. The soil materials in research area were a tephra layers which formed from volcanic activity. The previous research was mentioned about different characteristics between tephra layers (Kuroboku and Scoria layers) on the grain size, soil hardness and hydraulic conductivity analyses.

On this research, the different characteristics between tephra layers (Kuroboku and Scoria layers) more obvious on physical properties analyses. Scoria layers contain a lower fine fraction and plasticity index, a higher density of soil particles, and a lower ignition loss with low organic matter content. Oppositely, Kuroboku layers contain a higher fine fraction, higher plasticity index, a lower density of soil particles, and a higher ignition loss, but also feature low organic matter (except for the lower part of N3-4 Kuroboku at Takadake 1—which has a higher organic matter content).

Furthermore, the fine fraction and plasticity index is strongly related with the identification of the slip surface in landslide sites. This study conclude that plasticity index is directly proportional to fine fraction.

Our method of correlating the plasticity index with fine fraction could ultimately be used to help identify the slip surface in a landslide area.

Declarations

- Availability of Data and Materials:

The datasets used and/or analysed during the current study area available from the corresponding author on reasonable request.

- Competing Interests:

Authors have no competing interests on this study.

- Funding:

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- Authors’ contributions:

All authors went to the landslide sites, took a samples and did the field investigation. MLI analysed and interpreted the physical properties analyses regarding the soil layers at the landslide sites. All authors read and approved the final manuscript.

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References

1. Condie KC (1993) Chemical composition and evolution of the upper continental crust: Contrasting results from surface samples and shales. Chemical Geology 104(1–4):1–37. doi:10.1016/0009-2541(93)90140-E.
2. Map of research area. https://gbank.gsj.jp/seamless/seamless2015/2d/. Accessed September 2010.
3. Miyabuchi Y, Daimaru H (2004) The June 2001 rainfall-induced landslides and associated lahars at Aso Volcano, southwestern Japan: implication for hazard assessment. Acta Vulcanol 16(1–2):21–36.
4. Miyabuchi Y, Daimaru H, Komatsu Y (2004) Landslides and lahars triggered by the rainstorm of June 29, 2001, at Aso Volcano, Southwestern Japan. Transactions, Japanese Geomorphological Union

25–1:23–43. (in Japanese with English abstract)

5. Ono K, Watanabe K (1985) Geological map of Aso Volcano (1:50,000), Geological map of volcanoes 4. Geological survey of Japan. (in Japanese with English abstract)
6. Shimizu O, Ono M (2016) Relationship of tephra stratigraphy and hydraulic conductivity with slide depth in rainfall–induced shallow landslides in Aso Volcano, Japan. Landslides 13(3):577–582. doi:10.1007/s10346-015-0666-2.
7. Shimizu A, Takeshita M, Mizutani K (1992) Research on the shallow landslide of the 7.2 Aso disaster. Trans Kyushu Branch Japan Forest Society 45:177–178. (in Japanese)
8. The Japanese Geotechnical Society (2015) Japanese geotechnical society standards laboratory testing standards of geomaterials, vol 1.

Table

Due to technical limitations, the table is only available for download from the Supplementary Files section.

Figures

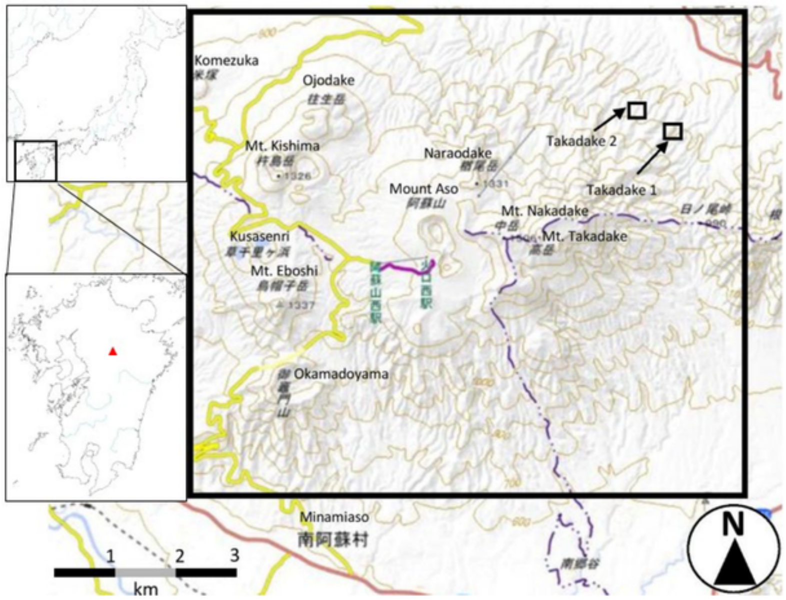

Figure 1. Map of the shallow landslides; Takadake 1 and Takadake 2 are in caldera rim area (https://gbank.gsj.jp/seamless/seamless2015/2d/)

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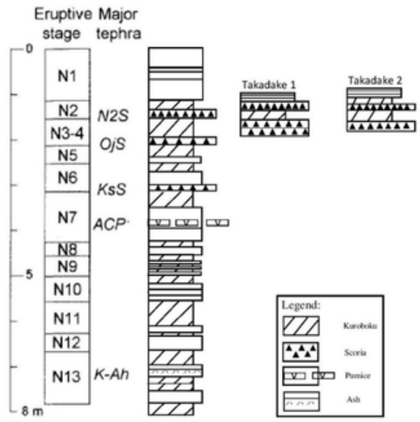

Figure 2. Schematic of tephra stratigraphy (Miyabuchi et al., 2004)

Figure 2

Schematic of tephra stratigraphy (Miyabuchi et al., 2004)

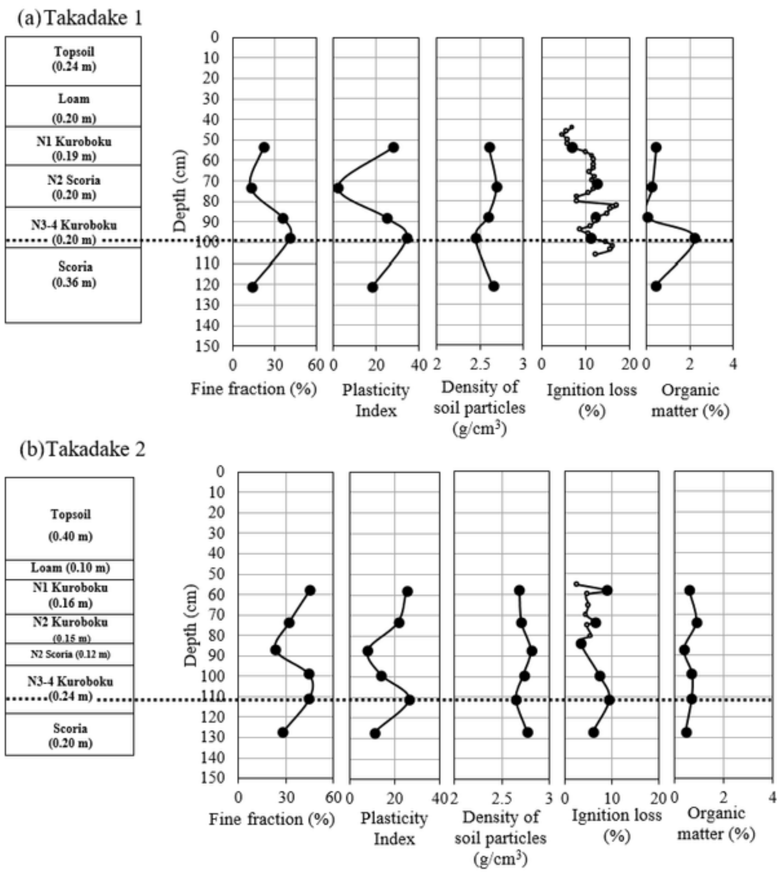

Figure 3. Physical properties and slip surface; dotted lines indicate slip surface by field observation

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Physical properties and slip surface; dotted lines indicate slip surface by field observation

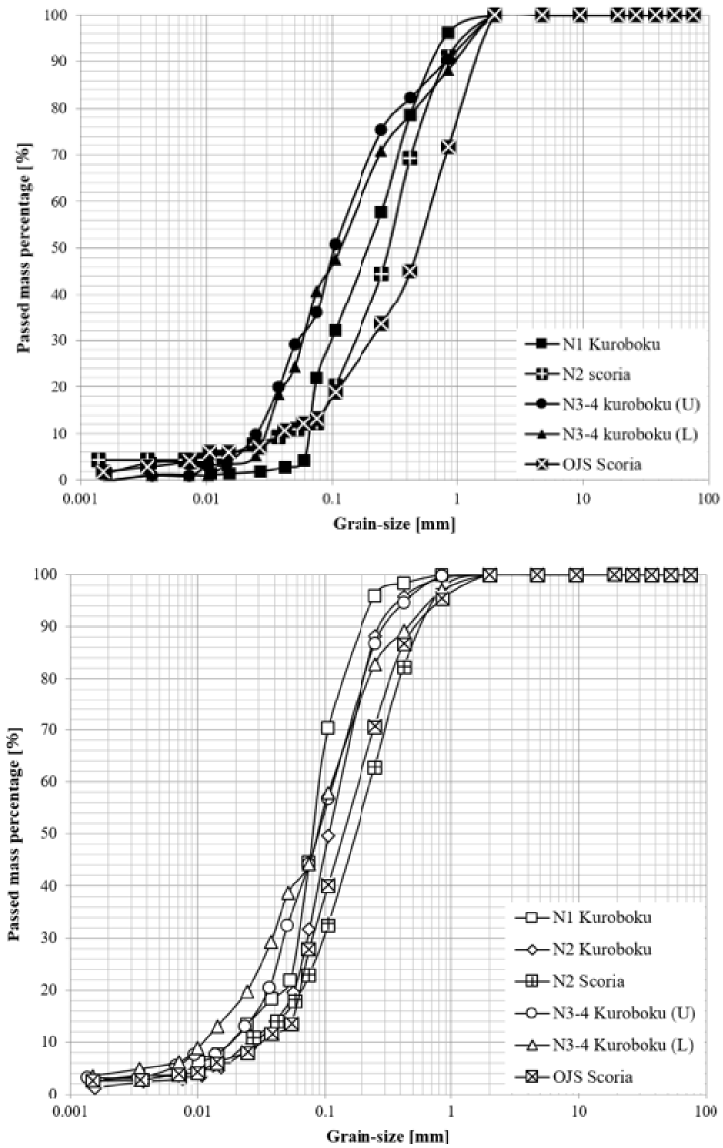

Figure 4. Particle size distributions

Figure 4

Particle size distributions

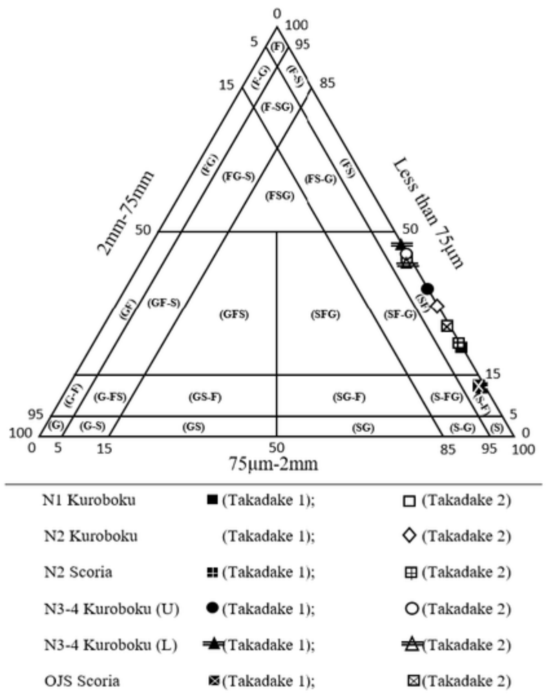

Figure 5. Soil classification triangle of soil materials in research area

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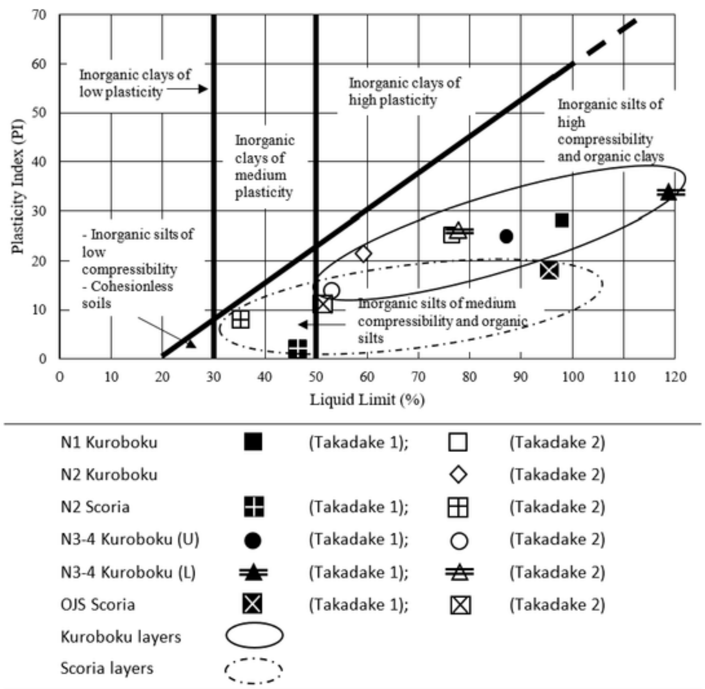

Figure 6. Plasticity index showing the differences among Kuroboku and Scoria soil layers

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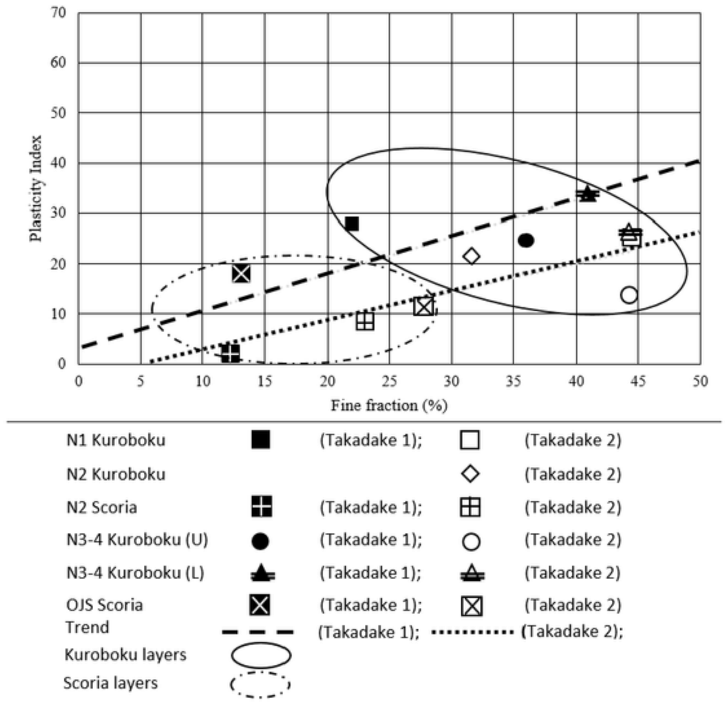

Figure 7. Fine fraction-plasticity index relationship between Kuroboku, Scoria, and slip surfaces

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Supplementary Files

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