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Research Paper

Investigation of slopes on the Takanoobane lava dome using the resistivity imaging method

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A R T I C L E I N F O R M A T I O N

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A B S T R A C T

In the Kumamoto earthquake in 2016, landslides occurred in many place on moderately inclined slope in the Takanoobane lava dome. In this research, we focus on the orange-colored pumice layer (Kpfa), which is predisposed to the landslide, and show the distribution using the resistivity imaging method on a slope where no landslide has occurred. According to the survey results, the slope without the landslide was observed when the slope was hard to slip mechanically due to the Kpfa layer was distributed in a shallow place or paleogeography of the foundation layer surface (Takanoobane lava) .

1. Introduction

The north to south west slopes on the Takanoobane lava dome were hit by ground motions of a seismic intensity 6 upper during the main shock of the Kumamoto Earthquake of April 16, 2016. A landslide claimed five lives (Miyabuchi, 2016). The slope failure may have occurred because a liquefied tephra layer was liquefied by seismic ground motions (Kamai, 2016). Focus was placed on the following two points in relation to the landslide.

(i) The landslide occurred on a moderately inclined slope. The thickness of the landslide was small in relation to the width and length.

(ii) No landslide occurred in some areas on similar slopes on the same lava dome (**Photograph 1**).

These characteristics were attributed to geological structures. Then, slope investigations were conducted using the resistivity imaging method.

2. Geological characteristics

The authors investigated the slope on June 25 and 26, 2016 and identified the following characteristics of the landslide.

(i) The landslide occurred on a moderately inclined slope (inclination: 10 to 15 degrees).

(ii) Orange-colored pumice layers are distributed continuously near the slip surface.

(iii) Relatively consolidated tephra layers are distributed under the orange-colored pumice layers and have not been destroyed by the landslide.

(iv) Seepage occurs near the pumice layers on the scarp during rainfall (heavy rain fell during the field inspection).

Photograph 2 shows a landslide and the distributions of orange-colored pumice and consolidated tephra layers.

The relatively new stratigraphy near the Takanoobane lava dome including the tephra layer is shown in

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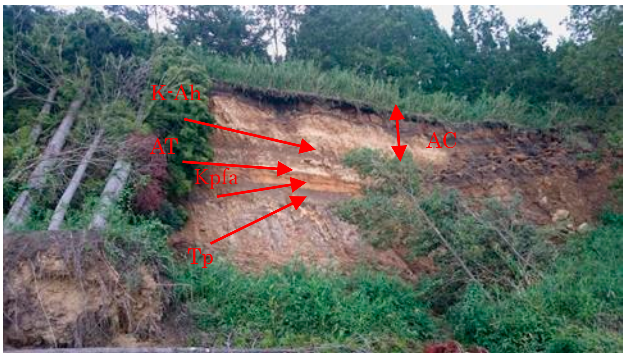
Note: Discussion on this paper is open until September 2018.

Photograph 1：Landslide that occurred on a slope of the Takanoobane lava dome.

Photograph 2：Landslide that occurred on a slope of the Takanoobane lava dome.



Photograph 3: Tephra layer observed on a scarp near the Hinotori hot spring.

Photograph 3 using the characteristic outcrop near the Hinotori hot spring where similar great debris flow occurred. The orange-colored pumice layer, or Kusasenrigahama pumice fall deposit (Kpfa: 31cal ka) was assumed to be related to the formation of the slip surface. A pumice volcanic ash layer generally known as Haiishi tuff that originates in the Takanoobane lava (Tp: 31cal ka) is distributed below the pumice fall deposit.

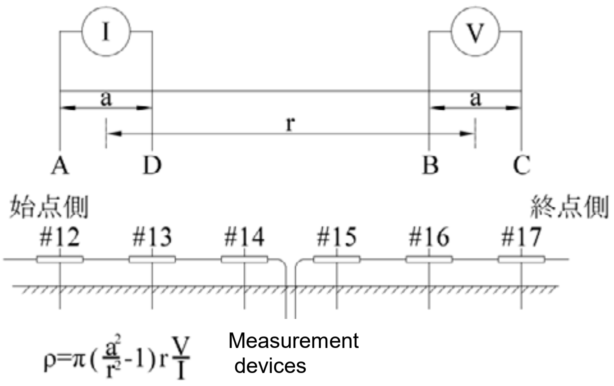


Fig. 1. Arrangements of electrodes in a dipole-dipole method used for observation.

3. Resistivity imaging

3.1 Reasons for finally selecting resistivity imaging

Electric prospecting is a classical technology that has been used for prospecting for oil and mineral resources since early 20th century. In the 1980s, the advancement of computers enabled high-speed and accurate switching between electrodes using multiple electrodes hardware-wise. In terms of software, increase that was achieved in data processing speed enabled prospecting and analysis in a relatively short time. With the development of a technology for obtaining resistivity profiles under a traverse line by inversion analysis to measured data (potential data), the accuracy of prospecting improved drastically. For grasping the structure at small depths in the ground, electrode arrangement in the dipole-dipole method was considered effective (Takeuchi,1985).

Resistivity imaging was found effective for prospecting for geological structure on the slope for the following reasons.

3.1.1 Electric resistivity of the tephra layer

The geological layers that are distributed on the slope have resistivity characteristics for the following reasons.

(i) The tephra layer is mainly composed of fine sand and clay and is expected to have low and homogeneity resistivity.

(ii) Kpfa (pumice fall deposit) is composed of coarse granule (diameter: 2 to 4 mm). It is in the weathered wet state and is considered to be a key bed with extremely low resistivity.

(iii) The consolidated Tp (tephra layer) on the slip surface and the lava proper that is expected to be distributed at great depths are considered to have high resistivity.

3.1.2 Elimination of elements affecting the topography

The slope is inclined relatively moderately. There is, therefore, no need to calibrate the observed resistivity (Loke,2000).

Based on the above, it was assumed that prospecting using the resistivity imaging method would be appropriate for determining the geological structure of slopes.

3.2 Resistivity imaging method used for observation

A resistivity measurement device manufactured by AGI (Advanced Geosciences Inc.) was used in the investigation. The dipole-dipole method was employed for observation. Fig. 1 shows the arrangement of electrodes. In analysis, profiles were drawn up using RE2DINV, resistivity two-dimensional investigation software (Loke,1996).

4. Results of observation using resistivity profiles

4.1 Arrangement of traverse lines

Fig.2 shows two traverse lines were arranged in the north-south and east-west directions in the area free from landsides on the west slope of the Takanoobane lava dome. At survey stations, a Trimble R4 GNSS GPS surveying instrument was used for measurement. The errors of accuracy are kinematic errors and 10 mm horizontally and 20 mm vertically.

4.2 Results of observation using the resistivity imaging method

Fig. 3 shows resistivity profiles along the A-B (north-south) and C (east-west) lines. Given below are an outline of resistivity distributions and the results of estimation for geological interpretation.

4.2.1 Takanoobane lava

Layers with resistivity exceeding 1,000 Ωm were observed at measurement point 100 m to the ending point along the A-B line, and at measurement points 25 through 75 m along the C line. They are assumed to be the Takanoobane lava proper. In the exploratory boring done on a plateau, the Takanoobane lava proper appeared at depths below elevations 520 to 530 m (Miyoshi, et al.,2007). Then, the layers with high resistivity were assumed to be the Takanoobane lava proper. It was assumed that the Takanoobane lava proper existed continuously in areas with resistivity of 600 or higher between measurement points 15 and 100 m along the A-B line and between measurement point 75 m

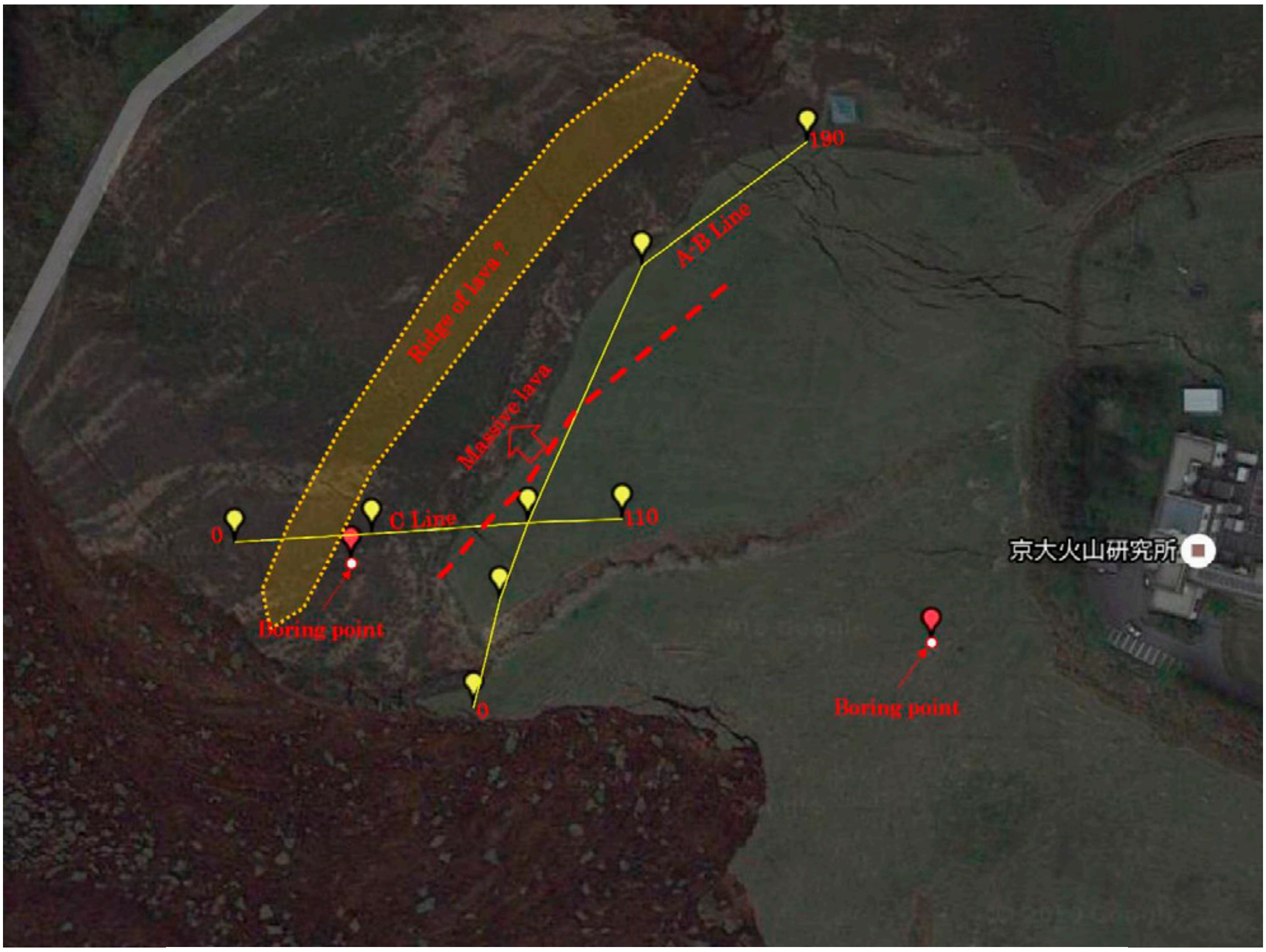


Fig. 2. West slope of the Takanoobane lava dome and arrangement of traverses

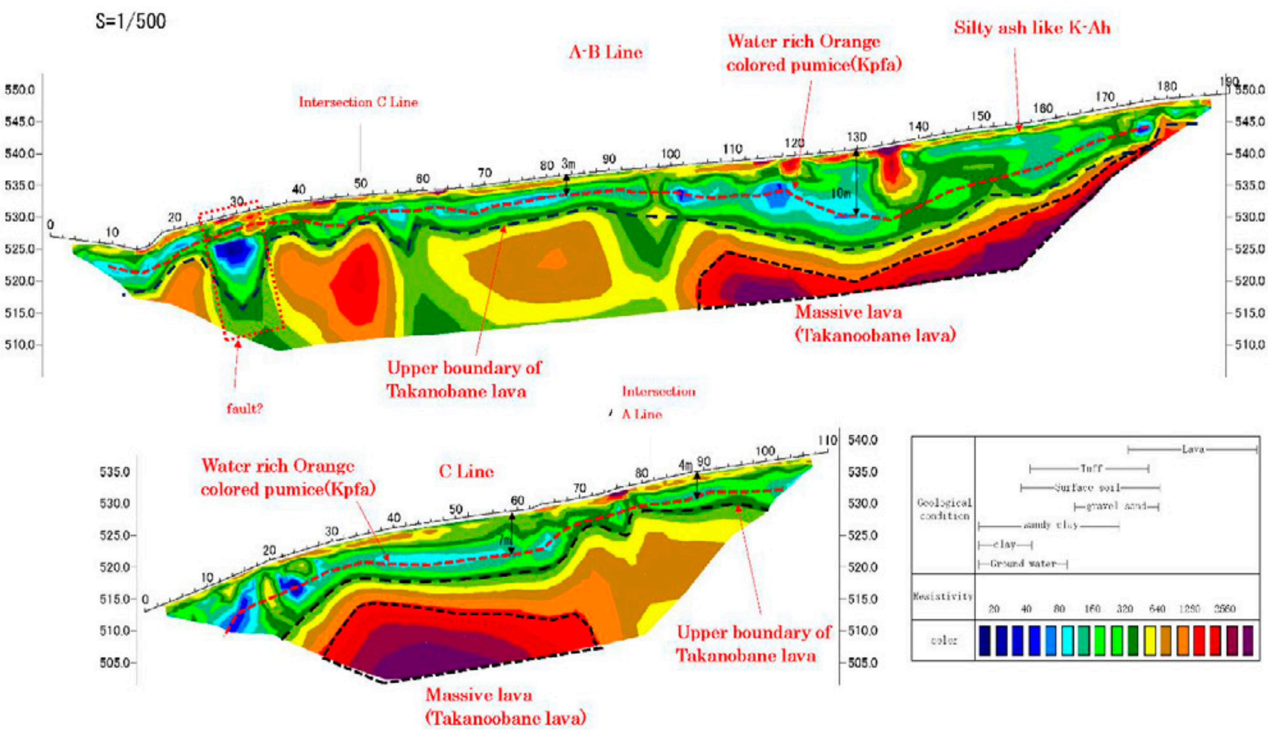


Fig. 3. Profiles of resistivity on the west slope of the Takanoobane lava dome.

and the ending point along the C line. Resistivity was, however, slightly low in these areas probably because of weathering.

4.2.2 Pumice fall deposit and volcanic ash layer above the Takanoobane lava:Tp

Areas with resistivity of 160 to 640 Ωm are observed above the area where high-resistivity zones are distributed in the Takanoobane lava. This is considered to be relatively consolidated pumice fall deposit and volcanic ash layer that serve as a base of slip surface (Photograph 2).

4.2.3 Kusasenrigahama pumice fall deposit: Kpfa

It was found that areas with resistivity 100 Ωm or lower are distributed in layers along both the A-B and C lines. The profiles show a thickness of 1 m or larger. Electrodes are placed at spacings of 2.0 m. Accuracy is basically considered to be low where thickness is smaller than the spacing between electrodes. The resistivity indicates clay layers or saturated sand and gravel layers. They are considered to be the Kusasenrigahama pumice fall deposit based on the geological conditions on the slope. The layer is distributed at an extremely small depth of approximately 3 m at the starting point to measurement point 100 m along the A-B line, and maximum depth of 10 m at measurement point 100 m to the ending point as the above surface of the Takanoobane lava is structured as a valley. In the direction of slope, the layer is distributed extremely low at a depth of 3 m at measurement point 75 m to the ending point along the C line, and relatively high at a depth of 7 m at measurement point 30 to 65 m. The layers are generally distributed horizontally governed by the fact that the Takanoobane lava is distributed at shallow depths near measurement point 30 m. The layer is distributed deeper at the ending point along the C line. Certainty is, however, reduced because resistivity imaging involves a risk of ghost images at outer edges.

4.2.4 New tephra layer: AT, K-Ah, AC etc.

Layers with resistivity of 160 to 320 Ωm were observed above the Kusasenrigahama pumice fall deposit to the ground surface. They are assumed to be new tephra layer (Aira, Kikai-Akahoya and Aso central cone volcanic ashes, etc.) Thin layers with resistivity 500 to 600 Ωm are continuously distributed nearly at a depth of 1.0 m. It is unknown to which horizon the thin layers correspond.

5. Consideration on the geology and causes of landslides on slopes of the Takanoobane lava dome

The results of above discussions are described below:

1 The profiles obtained the low-resistivity areas in new volcanic ash layers on the resistivity image is Kpfa can be estimated. The pumice deposit has low resistivity and is highly likely to be a groundwater aquifer.

2 The profiles also show high-resistivity zones. If other survey results are also taken into consideration, the profiles are highly likely to grasp the Takanoobane lava proper.

3 In the areas where no landslides occurred on the west slope, the Takanoobane lava is distributed at shallow depths or protruded at shallow depths on the slope. Thus, it was assumed that landslides were difficult to occur from a viewpoint of geological structure.

In the future, it is important to calibrate the survey results using the results of borings done in the vicinity. If it is verified that the results can be used, resistivity imaging can be applied to the estimation of three-dimensional geological structure on moderately inclined volcanic ash slopes. Then, the results can provide important data when developing hazard maps.

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