Research on a method of estimating the potential depth of slope failure using the Airborne Electromagnetic Survey

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At Ontake volcano in 1984 and Kurikoma volcano in 2008, areas of the volcanoes collapsed and large-scale sediment disasters occurred. These events were unrelated to volcanic eruption. We conducted case studies using airborne electromagnetic surveys to investigate slopes likely to induce landslides on such volcanoes.
Airborne electromagnetic surveys are effective for rapidly investigating wide-ranging extreme environments that persons cannot enter. The surveys were conducted by a helicopter carrying survey instruments; this method of non-contact investigation acquires resistivity data by electromagnetic induction. The surveys were conducted on 15 active volcanoes where volcanic events could have serious social implications. These case studies extracted data showing only areas likely to be at risk of collapse. This is the first time that such data on slopes likely to induce landslides and on estimated collapse depths have been obtained. It remains necessary to find a method of extracting precise data on slopes likely to induce landslides on each volcano.
Firstly, we categorized the properties of the collapsed slopes as cap rock type, extended collapse type, or landslide type on the basis of collapse case and paid attention to the slope of the cap rock type and defined the collapse range based mainly on the topography and geological properties.
Secondly, we analyzed the resistivity structures of collapse cases with a differential filter and found that collapse occurred at a depth at which resistivity suddenly changes. In other volcanoes, we could estimate collapse depth by extracting areas where resistivity suddenly changes.
Several cases, including Hokkaido Komagatake, Asama volcano, and Ontake volcano, will be introduced in this presentation.

Keywords: Airborne Electromagnetic Survey, resistivity, volcano, collapse depth, differential filter

Study on the depth information of resistivity using frequency-domain airborne electromagnetic survey

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Airborne electromagnetic survey is a method to investigate the electrical resistivity distribution of the subsurface from the air using electromagnetic induction. And this method can be subdivided into the time domain type and frequency domain type.
Frequency domain type is a system using several combinations of the transmitter coil and receiver coil. And the survey is towing a sensor that contains the coils by the aircraft. In general, the depth of investigation of the frequency domain type is less than the time domain type. However, near-surface resolution of the frequency domain type is better.
The procedure of cross-sectional analysis of the frequency domain type shown below. First, create an apparent resistivity map for each frequency using the measured data. The next is to calculate the plot depth of apparent resistivity for each frequency. This depth is a function of frequency and apparent resistivity. Inversion has been studied in order to obtain accurate depth information. However, case study using a numerical model are many, but almost no study from the perspective of disaster prevention work.
This study is a report of the cross-sectional analysis using the actual data of airborne electromagnetic survey of the frequency domain type. We compared the apparent resistivity cross-section and the one-dimensional inverted cross section on the basis of the actual geological and groundwater information.
First, we were collected survey data of wide area slopes, including a large-scale collapse and landslides in the distribution areas of accretionary complex and volcanics. And, we were classified depth information of the apparent resistivity in a large-scale collapse of slopes and landslide slope. As a result, large-scale collapsed slopes and landslide slope(including the slope of the neighborhood) can be classified into two types. Type(1) is upper layer is high resistivity, and lower layer is low resistivity, and resistivity contrast between two layers is large. Type(2) is upper layer is low resistivity, and lower layer is high resistivity, and resistivity contrast between two layers is small. Focusing on moving scale of soil, we have found that there are many type(1) slopes near the large-scale collapsed.
So, we create the apparent resistivity cross section by Sengpiel(2000) using the actual measurement data at the type(1), and we applied a one-dimensional inversion to it. Next, we compared the each cross section and geological information and groundwater by the drill hole, and understand the accuracy of the resistivity distribution in the depth direction. As a result, the depth of the layer boundary of type(1) was almost the same in the apparent resistivity cross-section and the one-dimensional inversion analysis. From this, there is no accuracy problems in using the apparent resistivity cross section by Sengpiel(2000) in the preliminary investigation of the large-scale collapse of the type(1) slope.
On the other hand, the resistivity contrast of apparent resistivity cross-section of the type(2) is usually small. Therefore, quantitative analysis may be difficult.
The next, in order to increase the accuracy of depth information of resistivity cross-section of the type(2), we're intend to apply the one-dimensional inversion. Also, we want to continue the study using real data in disaster prevention work because there is almost no example of application of two-dimensional and three-dimensional inversion in the frequency domain airborne electromagnetic

survey.

Keywords: frequency-domain airborne EM, resistivity section, inversion

A case study of aerial time domain helicopter EM survey

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Aerial source (Tx) and receiver (Rx) time domain electromagnetic (EM) survey systems have been developed and used in many countries from the past. Recently, some survey companies are carrying out airborne time domain EM survey in Japan by bringing a whole system from overseas. Meanwhile, grounded Electrical Source Airborne Transient EM (GREATEM) system has been in operation in Japan since about 10 years.
Last year, aerial Tx and Rx Time domain EM system (P-THEM) was introduced in Japan for the first time. In this report, we introduce the case study and result of the survey carried out with the new P-THEM system.

Keywords: time domain EM, airborne survey

Influence of ground clearance on airborne gravity gradiometry survey

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In geophysical surveys, increase in the distance between the sensors and the survey targets generally causes deterioration of resolution. Higher altitude above the ground level leads to degraded resolution in airborne surveys. While low-level flight is desirable for high resolution measurements, the ground clearance in actual surveys can increase to avoid rugged terrains, tall trees and high-rise structures including power lines. While the influence of higher clearance can be estimated by upward-continuing the gravity data to the flight surface, only a few case studies based on actual surveys are found.

Japan Oil, Gas and Metals National Corporation has been conducting airborne gravity gradiometer (AGG) surveys at the nominal terrain clearance of 120 m in the geothermal potential evaluation projects by using heliborne geophysical methods. We collected AGG data by varying the ground altitude at 120 m, 250 m, 500 m and 750m for the purpose of directly evaluating the influence of flight height on the vertical gravity gradient component (GDD) and vertical gravity (gD).

In the survey results, we observed a significant loss in the resolution of GDD due to the increased flight height, compared with that of gD. We plan to compare the measured results at each altitude with the calculated values by upward continuation of GDD and gD at 120m.

Keywords: Airbornne Gravity Gradiometry, Vertical gravity gradient, Flight height

3D magnetization structure of Aogashima Volcano by aero-, sea-surface and deep-sea magnetic vector surveys

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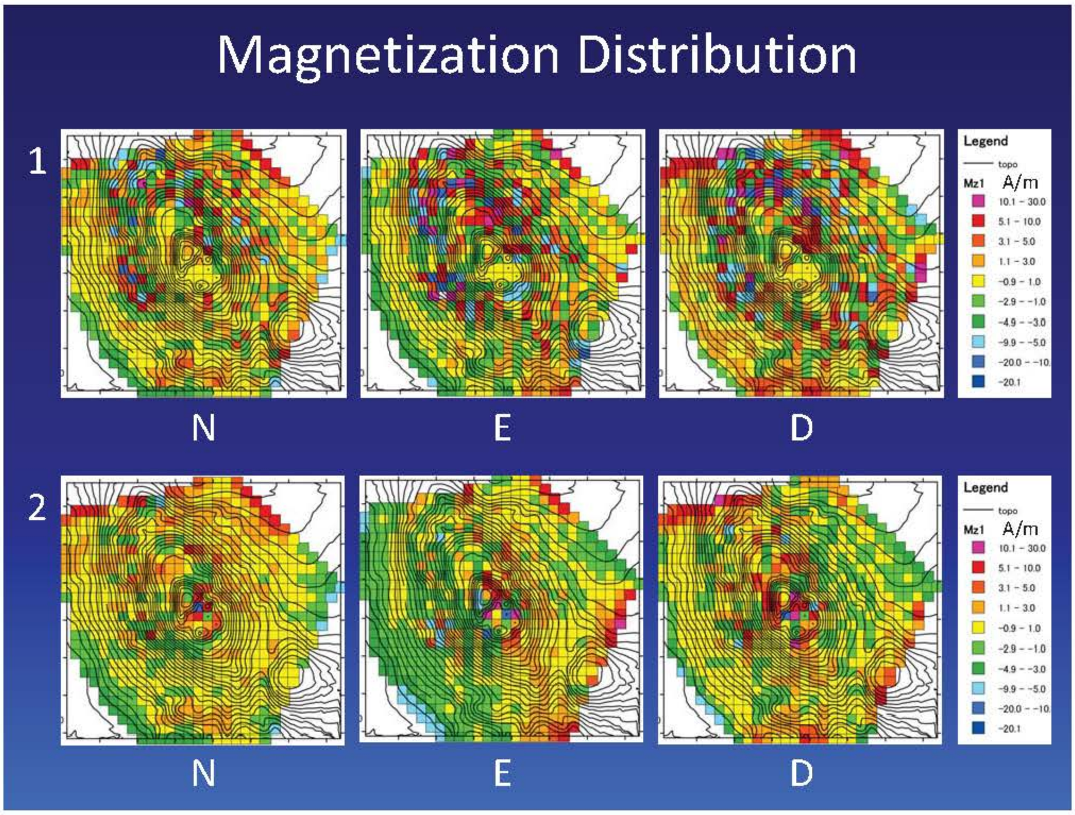
Measurement of magnetic anomaly vectors is absolutely essential to obtain a magnetization structure of the magnetized body. We have developed a new magnetometer for measurement of the vector magnetic field, called High Precision Magnetic survey System (HPMS), which can be used in various situations, for instance, in the air, on the sea surface and in the deep-sea. We have applied the HPMS as Heliborne Three Component Magnetometer (HTCM), Deep-tow Three Component Magnetometer (DTCM) and Shipboard Three Component Magnetometer (STCM) for airborne surveys (2006 and 2009) and marine magnetic surveys (2014) over and around the volcanic island, Aogashima. A helicopter of Nakanihon air service and Tokai University Vessel 'Bousei-Maru' were used for the HTCM surveys and for the STCM and DTCM surveys, respectively. The Aogashima Island is an active volcanic island included in the Izu-Ogasawara volcanic arc. The objectives of this study were to obtain magnetic anomaly vectors on Aogashima volcano by aero-, sea surface and deep-sea magnetic surveys, and to clarify 3 dimensional spaced 3 component magnetization structure of the volcano.
In the HTCM surveys, a towing frame mounted with the HPMS, GPS and wireless LAN devices was towed using a fiber rope below the helicopter. In the DTCM survey, the towing frame mounted with the HPMS, acoustic positioning (SSBL) and acoustic communication devices was towed near the sea bottom using a wire rope. In the STCM survey, the towing frame mounted with the HPMS and GPS devices was fixed on the after-deck of the ship. Three components of the observed geomagnetic field, F = (Hh, Hs, Hv), and gyro data (yaw, pitch, roll) are sampled in 10Hz. SSBL positions are fixed every 10 seconds. F, the vector in ship's coordinate (heading, starboard, vertical) is rotated to the vector in Earth's coordinate (X, Y, Z: north, east, vertical down) using the gyro data. From the rotated vector (X, Y, Z), the IGRF field is subtracted to get three components of a magnetic anomaly (dX, dY, dZ).
3D spaced 3 component magnetizations of the Aogashima volcano are analyzed by solving the linear least square equation for the obtained magnetic anomaly vectors. We tried 4 layer block model which consists of blocks with width of 500m, depth of 500m, and thickness of 250 m, 500 m, 750 m and 1000 m. The total number of the blocks is 2,492. The upper surface of Layer 1 approximates topographic surface. 25,536 data of three components of magnetic anomalies were inputted, and 7,476 data of three components of magnetization of 3D magnetized body were obtained by magnetization inversion with least square method using a dumping factor.
The figure shows three components of magnetization of each layer. Thin contour lines show the topography. The Aogashima Island is located at the center of each map. The shallower layers have complicated magnetization distribution, especially in Layer 1. There are larger magnetization to the north of the island as seen in Layers 1 and 2. The deeper layers such as Layers 3 and 4 have smooth magnetization distribution comparing with Layers 1 and 2. Layers 3 and 4 show the following characteristic distributions: relatively large positive north component of magnetization to the north of the island, contours of east component of that elongated along the ridge, and small downward component of that along the ridge in Layer 3 and under the island in Layer 4.
In conclusion, we have developed the versatile and useful equipment corresponding to a multiplatform that can survey the vector magnetic fields in the air, on the sea surface and in the deep-sea. That enables us to calculate the 3 dimensional and 3 components magnetization. The HPMS should make a contribution for more detailed and reliable magnetic geophysical surveys.

Keywords: three components of geomagnetic anomaly, magnetization vector, 3D magnetization structure, vector magnetometer for multi-platform, Shipboard Three Component Magnetometer (STCM), Deep-tow Three Component Magnetometer (DTCM)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-2.9 - -1.0
-4.9 - -3.0
-9.9 - -5.0
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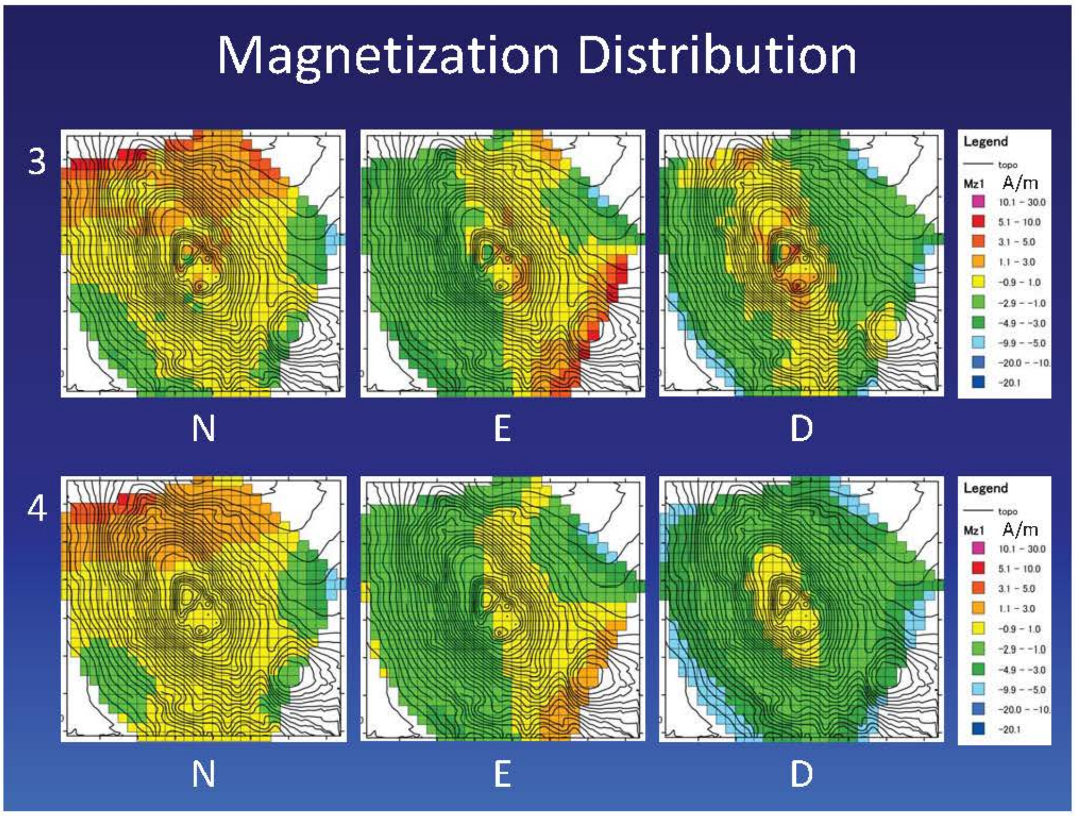
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Repeated aeromagnetic surveys at Kuchi-erabu-jima volcano by using unmanned helicopter

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Kuchi-erabu-jima island is an active volcanic island in Kyushu, and some volcanic events happened in the last century. Very recently, a phreatic eruption occurred on Aug. 23rd 2014, and a phreatomagmatic explosion followed it on May 29th 2015. At the latter eruption, a pyroclastic flow attacked a village, and all the residents in the island have evacuated out of the island. The eruptive activity never happens after a tiny Vulcanian eruption on 18th June 2015.
We conducted repeated aeromagnetic surveys in April and September 2015 by using unmanned helicopter. The altitude of the flight was kept to about 100 m above the ground and geomagnetic total intensity data at an almost whole area above the volcanoes were obtained. A total measurement length of flight was about 60 km.
The first survey in April 2015 revealed that the average magnetization is so small as about 1.8 A/m, which is typical value for andesite. Also the crater areas show very low magnetization, while surrounding areas of the crater have relatively strong magnetization as much as 3 A/m. The second survey in September detected small changes of the geomagnetic field. It reveals that the demagnetization in the crater and the magnetization around the crater. It may indicate that the magmatic products erupted out of the crater and showed the demagnetized features, while some ashes and pyroclastic flow remain at the volcanic surface around the crater and got some magnetization.

Keywords: aeromagnetic survey, unmanned helicopter, volcano

Validation flights of the Airborne Radiative Transfer spectral Scanner for a Single-Engine aircraft (ARTS-SE)

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We developed an airborne imaging system, the Airborne Radiative Transfer Spectral Scanner for a single-engine aircraft (ARTS-SE) for volcano observations in June of 2015. The platform for ARTS-SE is a single-engine Cessna 208 aircraft.
ARTS-SE consists of two imaging units. These imaging units are a push-broom imaging spectrometer and a camera system. The ARTS-SE push-broom imaging spectrometer unit covers the wavelengths from 380 to 1,100nm and 8,000 to 11,500nm with 320 bands. This unit consists of two sensor head units (SHUs). These SHUs are the visible-near infrared (VNIR) SHU and the long-wave infrared (LWIR) SHU. These sensor head units are the modified system of our conventional airborne hyperspectral scanner (ARTS). The ARTS-SE camera system unit consists of four cameras. These cameras are the two visible cameras and the two thermal infrared cameras.
Before beginning the operational use of ARTS-SE, it is important to validate its in-flight performance. Therefore, we conducted ARTS-SE instrument validation overflight of the bundle test site (Aichi prefecture), and the volcano observation test flight over an active volcano (Asamayama volcano and Hakoneyama (Owakudani)) in the late autumn of 2015. At the Asamayama volcano and Owakudani district, we could detect the geothermal activities. We are conducting validation for the rectification accuracy using the image data from bundle test site.

Keywords: airborne hyperspectral imager, volcano observations, infrared remote sensing

Characteristics of magnetic anomalies on a high-resolution aeromagnetic anomaly map of Fuji Volcano

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Geological Survey of Japan, AIST has complied a high-resolution aeromagnetic anomaly map of Fuji Volcano (in press), based on the data by two aeromagnetic surveys in 2003 and 2007 through latest data processing. The magnetic anomalies of the volcano are affected by terrain magnetized strongly in the present Earth’s magnetic field as expressed on previous regional maps but more detailed information can be seen. For instance, apparent magnetic anomalies are dominant on the northwest and southeast slopes of the volcano, corresponding to chains of lateral craters and some lava flows. Some magnetic high chains are also apparent over the northeastern middle slope, corresponding to the Takamarubi lava flow but long-wavelength ones close to Lake Yamanaka can be treated as an extension of regional magnetic highs from the Tanzawa Mountains. The most significant characteristic is conspicuous magnetic anomalies with a pair of highs and lows elongated in an east-west direction resides over the eastern flank of the volcano as far as the altitude approximately 1,300 m above sea level, suggesting a buried volcanic structure exists there.

Keywords: Fuji Volcano, aeromagnetic anomaly map, magnetic anomaly

High resolution three-dimensional magnetization mapping in Tokachidake Volcano using low altitude airborne magnetic survey data

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Tokachidake Volcano, central Hokkaido erupted in 1926, 1962 and 1988-1989 from the central part, in the 20th century. In recent years, the volcano is getting active at the 62-2 crater and the Taisho crater. A low altitude airborne magnetic survey was conducted in 2014 mainly over the active area of the volcano by the Ministry of Land, Infrastructure, Transport and Tourism to manage land slide risk in the volcano. We have re-analyzed the aeromagnetic data to delineate three-dimensional magnetic structure of the volcano.

The survey was flown at an altitude of 60 m above ground by a helicopter with a Cesium magnetometer in the towed-bird 30m below the helicopter. The low altitude survey enables us to delineate the detailed magnetic structure. We calculated magnetic anomaly distribution on a smooth surface assuming equivalent anomalies below the observation surface. Then the 3D magnetic imaging method (Nakatsuka and Okuma, 2014) was applied to the magnetic anomalies to reveal the three-dimensional magnetic structure. In this analysis, the magnetic structure with a thickness of 3,000 m was assumed as the initial model. As a result, magnetization highs were seen beneath the Ground crater and other craters around the summit of Tokachidake (62-2 crater, Ground crater, Nokogiridake crater, Suribachi crater and Kitamuki crater). This implies that magmatic activity occurred in the past at these craters. These magma should have already solidified and acquired strong magnetization. Relative magnetization lows were seen directly under the 62-2 crater and beneath the Ansei crater. This implies that these areas are still hot since the magma activity continues.

As described above, the distribution of magnetization can help us to better understand the subsurface structure of Tokachidake Volcano. However, its intensity seems to be more or less low overall compared to previous rock magnetic studies (i.e. Uesawa, 2008). This disagreement might be improved by more appropriate assumptions especially about the thickness of the magnetic model. This point should be further studied in detail.

Acknowledgement

We would like to thank the Asahikawa Development and Construction Department, Ministry of Land, Infrastructure, Transport and Tourism for providing the airborne magnetic survey data of Tokachidake Volcano.

Keywords: Tokachidake, magnetic anomaly, aeromagnetic survey

Three-dimensional Inversion of Grounded Electrical-source Airborne Transient Electromagnetic (GREATEM) Survey Data

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Studies have shown that Grounded Electrical-Source Airborne Transient ElectroMagnetics (GREATEM) is a promising method for resistivity structures investigating in coastal areas, in addition to inaccessible areas such as volcanoes, mountains and deep forest cover. To expand the application of the GREATEM system, a three-dimensional (3-D) resistivity model that considers large lateral resistivity variations is required. In this paper, we present a frequency- domain 3-D electromagnetic (EM) inversion approach that can be applied to time domain data from GREATEM. In the frequency-domain approach, TEM data were Fourier-transformed using a smooth-spectrum inversion method, and the recovered frequency response was then inverted. To deal with a huge number of grids and a wide range of frequencies in airborne datasets, a method for approximating sensitivities is introduced for efficient 3-D inversion. Approximate sensitivities are derived by replacing adjoint secondary electric fields with those computed in the previous iteration. These sensitivities can reduce the computation time without significant loss of accuracy. Firstly, we verified both of our forwarding and inversion solutions. We then applied this approach to the GREATEM survey data from Kujukuri beach, central Japan. The inverted results of the field data are well fit with the previous study results at Kujukuri area, suggesting the applicability of this inversion approach for constructing 3D resistivity models from the GREATEM field survey data in the future.

Keywords: Airborne EM, , GREATEM, 3-D inversion, Frequency-domain inversion., 3-D forward modeling

Relationship between Resistivity Distributions by Airborne Electromagnetic Method and Underground Structure

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Frequency of Deep-seated catastrophic landslide is less. However, this phenomena have potential to add serious damage by a lot of sediment. Therefore, it is important to develop extraction method of scale and areas tending to cause deep-seated catastrophic landslide. In previous studies, they studied about how to estimate depth of collapse in the areas tending of cause deep-seated catastrophic landslide using airborne electromagnetic method. As these results, in the areas of past deep-seated catastrophic landslide, it confirmed that there were values of high resistivity at shallow layer. However, there are lack of further studies that how resistivity is affected by geology and groundwater. Therefore, purpose of this study is to understand relationship between resistivity distributions and underground structure.First, we created figures of resistivity distributions of airborne electromagnetic method in pluvial period and not pluvial period. Then, we compared these figures. Next, we estimated groundwater level in studies areas using results of borehole surveys. Last, we compared figures of resistivity distributions and estimated water level. Then, we considered about relationship resistivity distributions and groundwater level.In this study, it was found that the following. In pluvial period, ground plan of resistivity distributions have many low resistivity than not pluvial period. Then, in pluvial period, it confirmed that changes zone of resistivity were unclear. Therefore, it confirmed that there was difference in distribution of resistivity between pluvial period and not pluvial period. It is assumed that groundwater distribution are affected. Then, it confirmed that changes zone of resistivity were generally consistent with ground water level by results of compared with cross section of resistivity and borehole.

Keywords: Deep-seated Catastrophic Landslide, Airborne Electromagnetic Method, Resistivity

Relationship between the average depth of a causative layer and the power spectrum of the vertical gradient component of a gravity gradient tensor

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In recent decades, six components of the gravity gradient tensor have been observed by gravity gradient exploration, and techniques for estimating the subsurface structure using these data have been studied and developed (e.g., Zhang et al., 2000; Beiki and Pedersen, 2010; Barnes and Barraud, 2012; Martinetz et al., 2013). In such research, filtering to extract the specified wavelength from the total gravity gradient tensors is not conducted frequently for subsurface estimations. One reason for this omission is that the wavelength characteristics differ among the components of the gravity gradient tensor. Filtering is an important data processing method for estimating subsurface structures. When this technique is applied, it is necessary to determine the relationships among the components of the gravity gradient tensor and subsurface structures. In the case of a gravity anomaly, the well-known relationship between the power spectrum and the average depth of the subsurface layer plays an important role in the filtering. Such relationships for the gravity gradient tensor have not been shown thus far. Therefore, we attempted to derive the relationship between the average depth of the causative subsurface layer and the power spectrum of the vertical gradient component of the gravity gradient tensor. Although the gravity gradient tensor has six components, we employed only the vertical gradient component because it has often been used for interpreting data and for estimating subsurface structures. We derived an equation for this relationship, which is shown to be nonlinear in the semi-logarithmic scale. We applied the equation obtained in this study to the vertical gradient component of the gravity gradient tensor observed in the Kuju geothermal area of central Kyushu, Japan, and we obtained results that are consistent with the average depth estimated by spectrum analysis of the gravity anomaly. However, we determined that the equation cannot estimate the average depth of the subsurface layer at the longest wavelength range. In addition, the wavenumber range giving the same average depth as that given by spectrum analysis of the gravity anomaly shifts to a higher and wider wavenumber range.
[Acknowledgment] We are grateful to JOGMEC which permits us to use gravity gradient tensor data obtained in Kuju geothermal area, Kyushu, Japan. A part of this study is supported partially by JSPS Kakenhi 15K14274.
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Keywords: Gravity gradient tensor, Spectrum analysis, Average depth of causative layer

Gravitation exploration as an estimation procedure of a causative potision

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In this study, we propose a new method for estimating the location of a causative body based on the relationship between the body and its three gravitational vector components. The relationship was derived based on the fact that the angle between the observation points of gravitation and the causative body is equal to the angle between the horizontal and vertical vectors of gravitation, and a non-linear equation was obtained. Accordingly, the location of a causative body can be estimated by using a non-linear least square method such as the Gauss-Newton method. Our proposed method is not an inversion method but belongs to the category of semi-automatic interpretation methods such as Euler deconvolution. However, additional information such as the structural index in Euler deconvolution is not required for the calculations in this method, and the location of the causative body can be estimated by providing only the window size for the analysis. In order to confirm the efficacy of this method, we conducted numerical tests using a simple sphere model and a rectangular model. While according to the tests in the sphere model, the 3-D location of the body was estimated correctly, the rectangular model showed the shape to have been estimated correctly. A comparison of the results by this method with those by Euler deconvolution showed the depth estimated by the former to be higher than that obtained by the latter.
[Acknowledgment] This study was supported by JSPS KAKENHI Grant NUmber 15K14274.

Keywords: Gravitation exploration, Euler deconvolution

