Estimation of depth profile of radiocesium in soil based on characteristics of gamma-ray spectra obtained by airborne radiation monitoring

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A large amount of radiocesium (^{134}Cs and ^{137}Cs) were released into the atmosphere as a result of 2011 Fukushima Daiichi Nuclear Power Plant (FDNPP) accident. To estimate the impact of the accident to the environment, dose rate around FDNPP have been measured by Ministry of Education, Culture, Sports, Science and Technology of Japan. However six years passed since then, dose rate nearby FDNPP have been high in spite of decontamination work. The result means that it is necessary to propose of effective decontamination method as soon as possible. Information of depth profile of radiocesium in soil is important for effective decontamination method. In many cases, general measurement method of depth profile of radiocesium is troublesome due to collection and measurement of soil samples. In our previous studies, we have developed the radiation measurement techniques using unmanned aerial vehicle such as helicopter and unmanned multi rotor helicopter for rapid measurement of dose rate distribution over wide areas. In this paper, we attempt to establish the estimation method of depth profile of radiocesium in soil based on characteristics of gamma-ray spectra obtained by airborne radiation monitoring. This method expects to be useful for effective selection of area that is needed to decontaminate with high priority.
The extended farm land of National Livestock Breeding Center in Fukushima Prefecture was selected for verifying this method. This farm is located on approximately 100km south west of FDNPP in Nishigo-village. Dose rate in the farm was measured with three $LaBr_3$:Ce scintillators (3.8cmΦ×3.8cmH) using unmanned helicopter, R MAX G1 (YAMAHA Co., Ltd) at 6-10, Jun. 2016. The Spectra of $LaBr_3$:Ce scintillators showed the best resolution of the three systems, able to clearly distinguish the 605keV energy peaks of ^{134}Cs from the 662keV energy peak of ^{137}Cs. However, background of spectra of $LaBr_3$ were highly affected by self-contamination of the nuclides such as daughter nuclide of ^{227}Ac and ^{138}La in the detecter. Self-localization of the helicopter was controlled by flight programs based on differential GPS (Gloval position system). When used for monitoring, the flight altitude(altitude above grand level) of the helicopter was 20-30m and its velocity was approximately 8.0m/s. The distance from one measurement line to the other was 20-30m. The γ-ray spectra were measured per 1s continuously with position data. In addition, ratio of peak-compton (RPC) was defined by the ROI (region of interest) ratio of scattered area (50-450keV) and photo peak area (450-760keV) on γ-ray spectrum for evaluating of influence with the depth profile of radiocesium in soil. The deeper radiocesium exist in soils, the more γ-ray was scattered by soil particles compared with direct γ-ray. Thus, value of RPC changes by depth profile of the radiocesium in the soil.
Soils were sampled by liner soil sampler (0-30cm) and root auger (30-60cm) for measurement of depth profile of radiocesium. Quantitative analyses of radiocesium in the samples in the containers were conducted at the Institute for University of Tokyo using NaI(Tl) scintillators. In addition, the parameters (Depth: $D_{20\text{-}90}$) about depth profile of radiocesium were calculated for evaluating of influence with scattered γ-ray. For examples, D_{90} at that the soil contains 90% of the inventory of radiocesium. It is estimated that the higher value of the parameters, the deeper radiocesium exist in soils.

Result of aerial monitoring indicated that relationship between RPC and D_{90} has good correlation. It is suggested that feature on gamma-ray spectra of $LaBr_3$:Ce scintillators were affected by depth profile of radiocesium. Thus, it supported the hypothesis that the deeper radiocesium exist in soils, the more γ-ray was scattered by soil particles compared with direct γ-ray. Furthermore, result of quantitative analyses suggested that the depth profile of radiocesium in the farm were irregular. The irregular profiles of radiocesium in soil were result in the decontamination called reversal tillage. It was expected that the depth profile of radiocesium will show an exponential distribution with depth in many cases. However, the maximum concentration progressively moved from the surface layer to deeper ground layers when the decontamination was performed. In summary, it is hoped that this method will help in rapidly selecting of area that is needed decontamination with high priority by focusing on the feature on gamma-ray spectra.
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Keywords: Fukushima Daiichi Nuclear Power Plant accident, radiocesium, airborne radiation monitoring, depth profile, decontamination

Airborne Geophysical Survey for the Evaluation of Geothermal Potential in Japan

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Airborne survey is one of the most effective methods which can investigate subsurface structures in areas where are difficult to access and/or exploration activities are restricted by surface conditions. Most of geothermal areas in Japan are located in mountainous regions. Furthermore, about 80% of geothermal resources are situated within areas designated as a national park, where geothermal development activities causing big impacts on environment are limited. In recent years, regulations on geothermal development in the natural parks are gradually relaxed because accelerating renewable energy is required to mitigate global warming. However, geothermal development movements by private companies are not active in those areas due to huge risk of subsurface uncertainty caused by lack of geological information. Therefore, since 2013, according to a government policy, Japan Oil, Gas and Metals National Corporation (JOGMEC) has been conducting airborne geophysical surveys to provide regional basic information for evaluation of geothermal potential, which leads to promote the geothermal development.
Airborne Gravity Gradiometry (AGG) method and time domain electromagnetic and magnetic method using a helicopter (HELITEM) are applied in the surveys. AGG survey is suitable for delineating geological structures in detail. HELITEM survey has an advantage over frequency domain electromagnetic survey as it has deeper penetration. A helicopter can fly at lower altitude with lower velocity than a fixed wing, which provides higher resolution and higher signal intensity data. Adopting the helicopter is beneficial especially for topography with steep slopes such as the mountain regions in Japan.
We are studying analysis methodologies for the acquired geophysical data. For example, we tried a variety of filtering to extract structural features such as lineaments from AGG data. Ground truth surveys with outcrop sampling are also conducted to ascertain the analysis results of the airborne geophysical surveys. We have completed the airborne geophysical surveys in more than 10 areas in Japan, so far. In this presentation, we will introduce results and our experience from the surveys recently acquired.
The authors acknowledge local municipalities and related organizations for their understanding and cooperation with us to conduct the airborne survey.

Keywords: airborne geophysical survey, geothermal resources, gravity survey, electromagnetic survey

CONTRIBUTION OF THE INTERPRETATION OF AERO-GEOPHYSICAL DATA IN THE INCREASE OF GEOLOGICAL AND STRUCTURAL KNOWLEDGE, IN THE PROVINCE OF CABO DELGADO, MOZAMBIQUE.

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Abstract:
The evolution of geosciences, with the appearance of new techniques of data collection and analysis, and the implementation of new technologies in its various fields of action have led to the development of more realistic geological maps, thus contributing to the growing discovery of new mineral deposits.
In 1970, the first aero-geophysical surveys were carried out by Italian company CGG with a view to boosting geological research work and contributing to the increase of geological knowledge at the country level. But it was in 2004/5 that the geophysics in Mozambique witnessed a major evolution, with the performance of aero-geophysical surveys by FUGRO, of high resolution, with flight lines spacing of 300 m, flight height of 100 m, and comprises data from Total magnetic field and gamma-spatter.
The integration of the high-density aero-geophysical data interpretation as a tool to support the geological mapping allowed an easy discrimination of the geological complexes, structural and kinematic interpretation and identification of intrusive bodies. The examples presented here refer to the province of Cabo Delgado, an area with potential for research of several mineral resources, but which has few publications of geological mapping works.
In this region, the aero-geophysical surveys conducted by FUGRO in 2004/5 were of fundamental importance in assisting the geological mapping for the project to compile the Geological Map of Mozambique, carried out by Norconsult in the periods of 2002 to 2007, and financed by several national and foreign institutions.
In addition, some dissertation work was carried out in the Province of Cabo de Delgado, being (Danta, 2009) the most relevant on processing and interpretation of aero-geophysical data, in the province of Cabo Delgado.
As an example, the interpretation of radiometric data of high resolution added to field observations revealed the existence of folded and mylonitic contact between the geological complexes of Xixano and Marrupa, in the province of Cabo de Delgado.
In addition, Nipepe Klippe is a geological structure whose discovery was made possible by combining ternary images of radioelements (K, Th, U) resulting from high-density aero-geophysical data and field observations. The image of the first vertical derivative superimposed on the satellite image revealed the existence of dikes inside the complex of Marrupa.
This information, based on the data processing related to high-density aero-geophysical surveys and field observations, contributed significantly to the increase of geological and structural knowledge for the improvement of the geological map of the province of Cabo Delgado.

Keywords: Importance, aerogeophysic, geological mapping

Development of frequency domain electromagnetic exploration system using unmanned aerial vehicle (UAV/drone)

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In recent years, industrial activities using unmanned vehicles, especially small unmanned aerial vehicles (UAVs, drones), have become extremely common globally in various fields (environment, infrastructure, agriculture, logistics, security, etc.). There has also been rapidly growing interest in the development of the geophysical exploration method for subsurface visualization by UAV. However, the necessary technology for geophysical exploration has yet to be established compared with optical measurement from the air to acquire surface information, which has already been advanced in terms of technology. This is mainly due to size and weight of geophysical equipments, measured signal strength, data quality and difficulty of stable flight.

Traditionally, for efficient exploration of a wide area and of inaccessible areas, conventional gravity/magnetic and electromagnetic (EM) exploration using a helicopter or a fixed-wing aircraft have been developed and used. However, applicable targets have been limited because of the difficulty of operations to meet regulations such as airframe remodeling and flight altitude control, particularly in a densely inhabited district (DID), and limitations and restrictions of exploration specifications (depth and resolution of investigation).
On the other hand, the existing traditional ground survey method using manpower has faced various problems such as a reduction in exploration efficiency for surface conditions (topography, vegetation, accessibility, etc.), survey costs, and others. Therefore, as a new exploration method for filling the gap between conventional airborne and ground surveys, there are high expectations for geophysical exploration using UAVs (drones).

In addition, considering the current situation of Japan, where there have been natural disasters such as the landslide disaster caused by heavy rain in Hiroshima, the Ontake volcanic disaster in 2014, and the 2016 Kumamoto earthquake, there is an urgent need to establish not only UAV techniques to obtain information about the surface but also methods for conducting underground surveying quickly, safely, and more accurately in inaccessible areas.

Therefore, in this research, we have been working to develop a new method that uses existing portable EM survey equipment with frequency domain electromagnetic methods, suspended by drone, to obtain geo-electrical information. In this presentation, we introduce the progress and details of the development of the drone-suspended electromagnetic survey system, including results of field experiments.

Keywords: exploration geophysics, applied geophysics, electromagnetic exploration, airborne geophysics, unmanned aerial vehicle, UAV, drone

Penetration depth of the GREATEM survey

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The grounded electrical source airborne transient electromagnetic (GREATEM) system uses a grounded electrical transmitter and an aircraft equipped with a receiver. Numerical forward modelling, using a finite-difference staggered-grid method, is performed to generate a three-dimensional (3D) resistivity structure model. A 3D electromagnetic forward-modelling scheme is modified and used to calculate the response of the study model in which a conductor is suited under ground surface at different depths. The sizes of conductor are 100 x 100 x 100 m, 200 x 200 x 200 m, 400 x 400 x 400 m. Depths of conductor are set to 50, 100, 200, 400, 600 m under ground surface. The bedrock has a resistivity of 100 Ω·m, and the resistivity of conductor is 1 Ω·m, 10 Ω·m. The vertical magnetic (Hz) field response decay curves for the different depths are compared. The results showed some differences between the Hz of different depths, so it is possible to detect that conductor in cases of different depths at flight altitude Z = 50 m. We used the relative difference (RD), defined as $|(Hz^{stand}-Hz^{case})/Hz^{stand}|$, of Hz field response for different depths to estimate responses difference quantitatively. When the size of conductor is bigger, it is easier to be detected. For low-resistivity conductor, the detection depth of GREATEM is up to 600m at flight altitude Z= 50 m.
The Ogiri geothermal area is located in southwestern Japan, a southern part of Kyushu Island. The arrangement of the geological structures is Quaternary volcanic rocks and Mesozoic metamorphic formation from the top down. Synthetic numerical models was used to construct 3D resistivity structure model of GREATEM system data in the study area. A 3D model of $3.7\times4.2\times2.3$ km^3 was designed, and discredited into 52×38×41 cells using the grids coordinates that are modelled to the geothermal area. The 3D resistivity model has been based on layered earth resistivity structures. In order to estimate the penetration depth of GREATEM in a geothermal field, we set the resistive basement rock layer at various depth and investigated change of GREATEM responses. There are some differences between the Hz of different depths. The RD of Hz field response is also calculated. The results showed that, the GREATEM can detect structure of a cap rock layer and top of geothermal reservoir, and the penetration depth is up to 1600 m below the ground surface.

Keywords: GREATEM, 3D resistivity structure model, penetration depth, geothermal survey

Can magnetic survey estimate locations of intrusions?

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The Geological Survey of Japan (GSJ), AIST conducted various magnetic surveys such as stinger-mounted helicopter-borne magnetics, helicopter-borne EM and magnetics and ground magnetics in the Usu Volcano area, Hokkaido Japan after its 2000 eruption to better understand the subsurface structure of the volcano (i.e. Okuma et al., 2010). Recently, 3D imaging method was developed (Nakatsuka and Okuma, 2014) and applied (Okuma et al., 2014) to the aeromagnetic anomalies of the volcano observed by the stinger-mounted helicopter-borne magnetics flown at an altitude of 150 m above terrain. The result revealed the subsurface distribution of basaltic somma lava but no information about magmas intruded during the recent eruptions in 1977-1978 and 2000 was obtained. This implies a difficulty to estimate locations of intrusions by a single magnetic survey and instead we proposed an alternative repeat survey (Okuma et al., 2013).
This time, we took a different approach to overcome the problem. We thoroughly reexamined the aeromagnetic anomalies observed by helicopter-borne EM and magnetics flown at an altitude of 70 m above terrain. Since the flight altitude of this survey is lower than that of the former one, a dipole of magnetic anomalies with a reverse polarity was found on the southwestern flank of the main edifice of volcano. To confirm the magnetic anomaly, we, then, conducted a ground magnetic survey along some profiles. As a result, a comparable magnetic anomaly was observed on ground. Whereas, the survey area is underlain by basaltic somma lava which shows high NRM intensities (6-10A/m) (Okuma et al., 2014). This suggests the existence of an intrusive body with a magnetization intensity lower than that of the somma lava. There are two possibilities which account for the magnetic anomaly. A hot magma of the recent eruptions might have intruded in the somma lava since some fumarolic activities were observed nearby during the ground magnetic survey. A cooled magma intruded during older eruptions is another possibility. Volcanic activities of the volcano changed from basaltic to dacitic after the formation of the main edifice. Since the NRM intensities of dacite is lower than that of soma lava (Nemoto et al., 1957), an old dacitic intrusion can account for the magnetic anomaly as well. Consequently, a repeat magnetic survey might play a role of judging if which hypothesis is more suitable by observing temporal magnetic changes.

Keywords: intrusion, magma, magnetic survey, 3D imaging, Usu Volcano, Usu 2000 Eruption

