Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

U02-01 会場:419 時間:4 月 28 日 10:00-10:15

薩摩硫黄島のミュオグラフィ観測
Muographic observations in Satsuma Iwojima, Japan

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Satsuma-Iwojima volcano continuously discharges large amounts of volcanic gasses without significant magma discharge. One of the proposed mechanisms of this continuous gas discharge is conduit magma convection. In this hypothesis, a magma conduit is connected to a deep magma chamber and a ”degassing” phenomenon drives convection. Once the volatile component is released (by degassing) at the top of the magma conduit, the degassed magma sinks through the non-degassed magma occupying the pathway. A continuous supply of non-degassed magma from the magma chamber ensures that there is compensation for the degassed magma and the cycle continues. In 2008, a muography detector was placed at the foot of Satsuma-Iwojima volcano, and it captured an image of a large, shallow depth, low-density region existing beneath the crater floor. Degassing magma, with its high proportion of bubbles, has been interpreted as being the low-density region, and its dimension (location and size) was compared to the results from other field measurements, laboratory and theoretical studies. In 2013, an improved muography detector was developed and placed at the same location as the 2008 observation to exploit advanced muographic images in Satsuma-Iwojima. The recent progress in muographic observations will be reported.

キーワード: ミュオグラフィ, ミュオン, 火道, イメージング
Keywords: Muography, Muon, Volcanic Conduit, Imaging

U02-02　会場:419　時間:4 月 28 日 10:15-10:30

火道内マグマ対流：Muon 観測からの制約
Conduit magma convection: Constraints from Muography

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Muographic imaging is a powerful tool to radiographically reveal density structure of a shallow volcanic edifice with high energy muons and was applied to the rhyolitic dome of Iwodake, Satsuma-Iwojima in order to understand the conduit magma convection in this volcano. In this paper, we will discuss the constraints obtained by the muographic measurements performed in 2008 and their implication to the conduit magma convection model.

Conduit magma convection is a model to explain persistent degassing, that is continuous emission of large amount of volcanic gases without eruption and is driven by the density contrast between the ascending non-degassed magma and the descending degassed magma that is created by outgassing at the top of a magma column (Kazahaya et al., 1994). This model is commonly applied to less viscous basaltic magma systems but the application to andesitic or rhyolitic magma system is a matter of debate, because the large viscosity of these magmas can slow down the magma flows in the conduit. Although theoretical evaluation indicated that a larger diameter of a conduit can compensate the larger magma viscosity and can cause the rapid magma flows in the conduit, it is difficult to prove its occurrence under the ground, as the conduit magma convection is a steady state process with few seismic signals nor deformation. In contrast, the conduit magma convection suggests that intensive degassing occurs at top of a magma column, which is likely detectable as a low density zone in a shallow magma conduit system. Therefore the density structure survey the muon-radiography is an ideal method to reveal the size, shape and magnitude of density anomaly at the shallow volcanic edifice.

Quantitative re-evaluation of the muon radiography data at the Iwodake rhyolitic cone obtained by Tanaka et al. (2009) confirms the existence of a low-density body of 300 m in diameter and with 0.9-1.0 g cm^{-3} at depths of 135-190 m from the summit crater floor. The low-density material is interpreted as rhyolitic magma with 60% vesicularity on average, and existence of this unstable highly vesiculated magma at shallow depth without any recent eruptive or intrusive activity is considered evidence of conduit magma convection. The structure of the convecting magma column top was modeled based on density calculations of vesiculated ascending and outgassed descending magmas, compared with the observed density anomaly. The existence of the low-density anomaly was confirmed by comparison with published gravity measurements, and the predicted degassing at the shallow magma conduit top agrees with observed heat discharge anomaly distribution localized at the summit area. This study confirms that high viscosity of silicic magmas can be compensated by a large size conduit to cause the conduit magma convection phenomena. The rare occurrence of conduit magma convection in a rhyolitic magma system at Iwodake is suggested to be due to its specific magma features of low H_2O content and high temperature.

キーワード: 火道内マグマ対流, ミュオン, 火山体浅部構造, 密度構造
Keywords: Conduit magma convection, muon-radiography, shallow volcanic edifice, density structure

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U02-03 会場:419 時間:4 月 28 日 10:30-10:45

高粘度混相流コードの開発：マグマダイナミクスシミュレーションにむけて
Development of coupled Stokes–DEM simulation scheme for geodynamical magmatic studies

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For geodynamical magmatic studies such as crystal settling at the melting roof of a magma chamber, we develop a robust and efficient simulation scheme for solving high-viscosity fluid and particle dynamics in a coupled computational fluid dynamics and discrete element method (CFD–DEM) framework. The high-viscosity fluid is treated by the Stokes-flow approximation, where the fluid interacts with particles via the drag force in a cell-averaged manner. The particles are tracked with contact forces by DEM. To efficiently solve such Stokes–DEM coupled equations, we propose two key techniques. One is formulation of particle motion without the inertial term, allowing a larger time step at higher viscosities. The other is a semi-implicit treatment of the cell-averaged particle velocity in the fluid equation to stabilize the calculation. We will explain some details of our model developments in the presentation. A series of numerical experiments shows that our proposed scheme can handle sinking particles in a high-viscosity fluid; such problems are difficult for the conventional CFD–DEM method. Then we will discuss our targeting geodynamical problems tackled with this simulation method.

キーワード: マグマ, 固液混相流, ストークス流れ, 個別要素法, メルトルーフ, 数値手法
Keywords: Magma, Particle-Laden flow, Stokes flow, Discrete element method, Melt roof, Numerical simulation

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U02-04 会場:419 時間:4 月 28 日 11:00-11:15

Recent updates on the DIAPHANE project of muon tomography
Recent updates on the DIAPHANE project of muon tomography

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Density radiography with atmospheric muons aims at determining the density variations or the absolute densities of geological or large volume bodies. The density is measured through the screening effect on the incident muons flux induced by the presence of matter, like for the X rays in a standard medical radiography. We will present recent updates on the DIAPHANE project which studies volcanoes with this technique since many years and is now deployed in the Lesser Antilles (Guadeloupe, Montserrat), Italy (Etna), the Philippines (Mayon) and in underground sites (France and Switzerland). Time-of-flight techniques have been developed to improve the data analysis and provide significant results.

キーワード: Volcanology, Muon tomography, Particles detector, Inverse problem
Keywords: Volcanology, Muon tomography, Particles detector, Inverse problem

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Muon radiography by nuclear emulsions - Report on activity in Italy
Muon radiography by nuclear emulsions - Report on activity in Italy

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The nuclear emulsions technology has entered the field of muon radiography of volcanic edifices and faults in the last decade, and progressively attracted the interest of nuclear emulsion laboratories and experts from various countries. The historical first muographic image of a volcano was indeed generated by using this nuclear emulsion technology. In earlier times, large-scale application was limited by the readout time and manpower needs as the emulsion films had to be scanned by eye; modern fast automatic microscopes solved both issues with limited cost, and the readout and analysis speed increased by several orders of magnitude, opening the door to access muography that requires large statistics. The Italian nuclear emulsion groups of the Universities of Salerno, Napoli and Padova and the Laboratori Nazionali del Gran Sasso (INFN) have built an Italian network of scientists working on muography, establishing tight collaboration links with the Tokyo University Earthquake Research Institute; more Italian groups could join in the near future. The network performs many activities, from the preparation of emulsion film exposure, on-site data taking campaigns, to readout and data analysis.

Nuclear emulsions are usually cast in the shape of thin films (thickness in the range of 20-100 micrometers) coating transparent plastic bases. Even a single film can provide 3D tracks marking the passage path of ionizing particles, when observed by a dedicated microscope. Normally emulsions films are exposed in stacks, piling several sheets, so that a single particle, after development, leaves several aligned tracks, one in each film.

Automatic emulsion readout systems allow track detection and measuring on several m^2 of surface in few weeks, collecting large statistics, which is needed to investigate regions of high cosmic muon absorption. Angular resolution of the order of a few milliradians is commonly achieved, which gives the ability to discriminate relatively small details, depending on the distance between the detector and the observed volume. Currently, one line of research aims at developing faster and cheap film readout systems, based on commercial hardware, to increase the current data-taking speed by a factor 10 or better.

Emulsions are continuously sensitive, since the time of their production: while this is an advantage because they need no power supply, the lack of time discrimination makes data analysis for such detectors a delicate task. The high combinatorial background of 3D tracks, due to many months' pile-up, can be greatly reduced by exploiting the micrometric alignment precision of emulsion tracks. Application of nuclear emulsion data to muon radiography requires also particle identification. Multi-film stacks with interleaved slabs of dense scatterers (such as iron or lead), allow distinguishing soft particles, typically electrons/positrons from electromagnetic showers, from hard muons with 1 GeV/c momentum or higher. Dedicated simulation of the passage of hard muons through rock and in the emulsion-instrumented volume allows optimizing selection criteria and estimating purity and efficiency of the selection. Systematic errors on the predicted integrated flux, which is compared to the measured integrated flux, should be kept as small as possible; in turn, this requires proper modelling of the expected cosmic-ray muon flux, which demands specific efforts in some regions of the angular and energy spectrum, where the statistics is intrinsically lower. Simulation and modelling activities require specific software and sizeable computing resources and are shared amoung the collaborating groups.

Accounts are given of the status of muon radiography campaigns in which the Italian groups are mostly involved. The cases covered are Stromboli, Teide and the La Palma fault. For each case, the present situation, possible developments and future plans are also envisaged.

キーワード: nuclear, emulsion, muography, Italy, volcano, fault
Keywords: nuclear, emulsion, muography, Italy, volcano, fault

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U02-06 会場:419 時間:4 月 28 日 11:30-11:45

宇宙線ミューオンラジオグラフィのための原子核乾板検出器の開発とその応用
Development of Nuclear Emulsion Detector for Cosmic-ray Muon Radiography and Its Applications

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We are developing nuclear emulsion and its automatic analysis system for cosmic-ray muon radiography (muography). Nuclear emulsion is very high-sensitive photographic film for detecting 3-demensional trajectories of charged particles like muon in its volume with the very high position resolution (sub-micron), which gives us the very high angular resolution (a few mrad). In addition, nuclear emulsion does not require electronic power, the size is very compact and the weight is very light. And also, it is easy to perform the tomographic analysis using multiple detectors placed around the target. These features have advantages in the field observation for the measurement of geoscience object, archeological object, or in the disaster area like Fukushima Dai-ichi nuclear power plant.

In the case of Fukushima Dai-ichi nuclear power plant, high radioactivity shielding and lack of electronic power supplies should be taken into account. Nuclear emulsion is the powerful candidate used in such area. We have conducted the basic study of muon radiography of reactor core at fast reactor Joyo, which belongs to Japan Atomic Energy Agency (JAEA), in order to demonstrate the imaging of the reactor core. The result validates the observation of the reactor core with high resolution.

We will present technical developments of nuclear emulsion, latest scientific results including other observed objects and future prospects.

キーワード: 宇宙線ミューオンラジオグラフィ, 原子核乾板, 非破壊観測, 福島第一原子力発電所
Keywords: cosmic-ray muon radiography, nuclear emulsion, non-destructive observation, Fukushima Dai-ichi nuclear power plant

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U02-07 会場:419 時間:4 月 28 日 11:54-12:09

素粒子探査による世界遺産プランバナン寺院の構造調査
Muon radiography Monitoring for Structural Survey of the Prambanan World Heritage Temple

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Muon cosmic-ray can penetrate rocks and soils and give us projection of the path' density, therefore, muography technology has been successfully developed in the geological field for disaster prevention of volcano explosion 1). Furthermore, it was utilized to survey the inner condition of a blast furnace in a steel mill during its operation time. On the other hand, non-destructive tests are required, in general, to conduct structural survey of heritage structures with cultural and historical values. In particular, when World Heritage Monuments are surveyed, we have to follow this principle strictly. There are a number of World Cultural Heritages of masonry in seismic regions in the World. When their seismic safety is assessed, seismic structural survey is conducted by employing non-destructive tests. Considering that muography technology can be useful for structural survey of massive masonry structures as a non-destructive test, we installed the muon detecting system at the Prambanan Temples, World Cultural Heritage in Indonesia and monitored the muon cosmic-ray for 5 months. Here, the Prambanan Temples of stone masonry structures were severely damaged by Central Java Earthquake of 2006. We have been successfully involved in architectural and structural survey project conducted by an international and interdisciplinary team. The damaged masonry monuments have been restored after the earthquake, however, restoration work of Candi Siva, the oldest and highest monument of the Prambanan Temples, was not started yet, as its inner structural condition was unknown. If the inner structural conditions are revealed, 3-D finite element model is available for seismic structural diagnosis of such massive masonry structures. The scope of the present paper is to describe this challenge of non-destructive test utilizing muography technology for the Prambanan restoration project and to demonstrate applicability of this advanced technology to structural survey of World Cultural Heritages of masonry. The muon data obtained at the site indicated that the monument must have inner chambers that had been unknown. The date also indicated their sizes and locations. This information will be useful to provide analysis model for seismic evaluation.

References

1)Tanaka,H.K.M.,Taira,H.,Uchida,T.,Tanaka,M.,Takeo,M.,Ohiminato,T.,Aoki,R.,Nishiyama,et al. :
Three-dimensional computational axial tomography scan of a volcano with cosmic ray muon radiograph,
J. Geophys., Res.,115, B12332, 2010

Keywords: muon, structural survey, masonry, World Heritage, seismic safety

Japan Geoscience Union Meeting 2014
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U02-08 会場:419 時間:4 月 28 日 12:09-12:24

巨大石造建造物探査へのミュオグラフィの応用：エジプトのピラミッドに対する建築技術の発展過程
An Application of Muography to Exploring Gigantic Masonry Architectures: Evolution in Pyramid ConstructionTechnique

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Since the technique of Muography was used for the pyramid of Khafre (second pyramid of Giza) by L. W. Alvarez in 1970, academic researches using non-destructive testing methods have been applied to some huge stone structures (ex. the Pyramid of the Sun in Teotihuacan, Mexico, by A. Menchaca-Rocha). Although Alvarez and his team attempted to find a new chamber in the pyramid, they couldn't find any hidden chambers. However, now it is thought that the result was unreliable because their muon detector was an old type. After Alvarez the muon detector was developed and contributed to the elucidation of mechanism of a volcanic eruption in recent years (e.g. Asama volcano and Satsuma-Iwojima Volcano by H. Tanaka et al). Applying this technique, the internal structures of the Shiva temple in the Prambanan temple compounds (Indonesia) and the Parthenon (Greece) is explorable. On the basis of those results, we are going to go back to the roots of Muography by Alvarez by revisiting the pyramid.

It is assumed that if it is possible to use Muography for the pyramids in Egypt (the oldest huge stone building in the world), in terms of the usage and volume of differing density of the stone (limestone and granite), it would make clear the developmental sequence and construction way of pyramids which has been impossible to know until now. Therefore, we can confirm the human ingenuity of earthquake-proof structures by ancient Egyptians. Most of the pyramids were made of limestone. Harder granite was sometimes used to encase the pyramids. If it can be made clear where two different kinds of stones were used and how much stone were used for the pyramids, we can take possession of previously-unattainable new information in the study of earthquake-proof structures of pyramids.

The developmental sequence of burial of ancient Egyptian kings and the transition of the outer shape are as follows:1.Simple graves, 2.Mastabas, 3.Step Pyramids, 4.Bent Pyramid, 5.Red Pyramid (true pyramid), 6.Pyramid of Khufu (true pyramid), 7.Pyramid of Khafre (true pyramid), 8.Pyramid of Menkaure (true pyramid).

Judging from the above-mentioned process, it is assumed that there were further stages in the development of pyramids. However, it is still not clear. If we have the opportunity to use muongraphy to the above pyramids (from the step pyramid of Netjerykhet to three true pyramids in Giza), we can put an end to speculation as to the evolution theory of the pyramid from the viewpoint of earthquake-proof structures and advancement of civilization.

References

(1) L. W. Alvarez et al, Search for Hidden Chambers in the Pyramids: The Structure of the Second Pyramid of Giza is Determined by Cosmic-ray Absorption, Science 167 (1970), pp.832-839.

(2) A. Dodson, The Pyramids of Ancient Egypt (London, 2003).

(3) M. C. Gonzalez-Garcia, Francis Halzen, Michele Maltoni, and Hiroyuki K. M. Tanaka, Radiography of Earth's Core and Mantle with Atmospheric Neutrinos, Physical Review Letters, 100, 061802, 2008.

(4) Hiroyuki K.M. Tanaka, Tomohisa Uchida, Manobu Tanaka, Minoru Takeo, Jun Oikawa, Takao Ohminato, Yosuke Aoki, Etsuro Koyama and Hiroshi Tsuji, Detecting a mass change inside a volcano by cosmic-ray muon radiography (muography): First results from measurements at Asama volcano, Japan, Geophysical Research Letters, 36, L17302, 2009.

(5) Hiroyuki K.M. Tanaka, Tomohisa Uchida, Manobu Tanaka, Hiroshi Shinohara, Cosmic-ray muon imaging of magma in a conduit: Degassing process of Satsuma-Iwojima Volcano, Japan, Geophysical Research Letters, 36, L01304, 2009.

キーワード: ミュオグラフィ, ピラミッド, 文明, 耐震構造
Keywords: muongraphy, pyramid, civilization, earthquake-proof structures

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U02-09 会場:419 時間:4 月 28 日 12:27-12:42

Overview of Neutrino Geoscience
Overview of Neutrino Geoscience

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Radiogenic heating is a key component of the energy balance and thermal evolution of the Earth. Geo-neutrino observations from Japan and Italy are now measuring the radiogenic power of our planet. Although the error on the present measurement is too large to significantly constrain geological models, the potential of geo-neutrino observations is clearly demonstrated. This contribution traces the development of neutrino geosciences and discusses the prospects for geo-neutrino observations to inform geology.

キーワード: neutrino geoscience, radiogenic heat
Keywords: neutrino geoscience, radiogenic heat

U02-10　会場:419　時間:4 月 28 日 14:15-14:30

KamLAND: 地球ニュートリノの観測結果
KamLAND: geo-neutrino result

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Geo-neutrinos are anti-neutrinos (elementary particles) produced in radioactive decays within the Earth. Those anti-neutrinos can be detected in a terrestrial experiment using interaction via weak force, however, due to extremely low reaction probabilities, there were no feasible experiments for a long time. Owing to the development of large-size anti-neutrino detectors, the observation of geo-neutrinos has been finally made, and then composition models of the Earth are constrained from the radiogenic heat estimate. In this talk, a precise measurement of geo-neutrino flux from the Kamioka Liquid-scintillator Anti-Neutrino Detector (KamLAND) in Japan will be presented. In addition, the recent situation of KamLAND anti-neutrino data will be reviewed. Following the Fukushima nuclear accident in 2011, the most of Japanese nuclear reactors has been subjected to a protracted shutdown, resulting in the low reactor anti-neutrino background. It provides a unique opportunity to measure the geo-neutrinos with an improved sensitivity. Based on this low background data, prospects of geo-neutrino sensitivity with KamLAND data in the near future will be shown, and discuss the ability of discriminating between Earth models.

キーワード: 地球ニュートリノ
Keywords: geo-neutrino

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U02-11 会場:419 時間:4 月 28 日 14:30-14:45

Borexino: geo-neutrino results
Borexino: geo-neutrino results

SUVOROV, Yury[1*]
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[1]Yury Suvorov
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Geo-neutrinos are the electron anti-neutrinos produced by long-lived radioactive isotopes (such as U, Th and K) in the earth crust and mantle. Geo-neutrinos can be detected in kiloton scale organic liquid scintillator detectors located in underground laboratories. The detection reaction is the inverse-beta decay, which has a particular signature given by two correlated in space and time prompt and delayed signals.

In spite of the strong signature geo-neutrino can only be detected in massive low background set-ups designed for low energy (1 MeV) neutrinos.

Borexino at the GranSasso underground laboratory in Italy has been in operation since 2007 to search for sub-MeV solar neutrinos.

At present experimental studies of geo-neutrinos are carried out with Kamland at the Kamioka mine in Japan and with Borexino at GranSasso. The first attempt of a geo-neutrino measurement was done in Kamland in 2005. Only in 2010 and 2011 both Borexino and Kamland observed at more the 4sigma C.L. a signal from geo-neutrinos. The search of geo-neutrinos likewise the one of solar neutrinos for the sun provides a unique tool to probe the interior of the earth. Uranium and thorium from the crust and the mantle make the geo-neutrino flux on surface. The energy spectrum of the detected geo-neutrinos depends on the abundance of uranium and thorium and on the different beta decays in the two radioactive chains. A spectroscopy determination of the geo-neutrino signal can be done. This has been recently shown by Borexino. By means of this analysis the ultimate goal of the geo-neutrino search will be the determination of the uranium and thorium content in the mantle. For this purpose a combined analysis of more than one experiment results will be necessary. In this talk we will review the present status of geo-neutrino research. We elaborate on the recent results from Borexino and Kamland. The experimental difficulties and background sources will be discussed.

キーワード: neutrinos, geo neutrinos, Earth, crust, mantle
Keywords: neutrinos, geo neutrinos, Earth, crust, mantle

U02-12 会場:419 時間:4 月 28 日 14:45-15:00

A reference Earth model for geoneutrinos
A reference Earth model for geoneutrinos

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Geoneutrino data from the KamLAND and Borexino experiments provide insights into Earth's energetics and global radiogenic heat production. In 2014, SNO+ will begin to collect data; the era of the exploration of our planet through geoneutrinos is definitely open.

Detection of geoneutrinos provides quantitative information about the total amounts of U and Th in the Earth and their distribution within the different reservoirs (crust, mantle and possibly core). One of the greatest potentials of geoneutrino is to discriminate among the different models for the bulk composition of the Earth, which are based on cosmochemical arguments and geochemical and geophysical observations. In order to determine the U and Th concentration of the deep Earth from the geoneutrino signal, the regional and crustal contribution to the geoneutrino flux needs to be determined from detailed geological studies.

We developed a geophysically based, three-dimensional global reference model for the abundances and distributions of U and Th in a Bulk Silicate Earth (BSE) model. The structure and composition of the outermost portion of the Earth, the crust and underlying lithospheric mantle, are detailed in the reference model; this portion of the Earth has the greatest influence on the geoneutrino fluxes. The structure of the crust is based on 1^{o} x1^{o} surface map of the Earth discriminating layers of sediments, upper, middle and lower crust. For the first time three geophysical global crustal models based on reflection and refraction seismic body wave (CRUST 2.0), surface wave dispersion (CUB 2.0), and gravimetric anomalies (GEMMA) are studied with the aim to estimate the contribution of geophysical uncertainties to the reference crustal model.

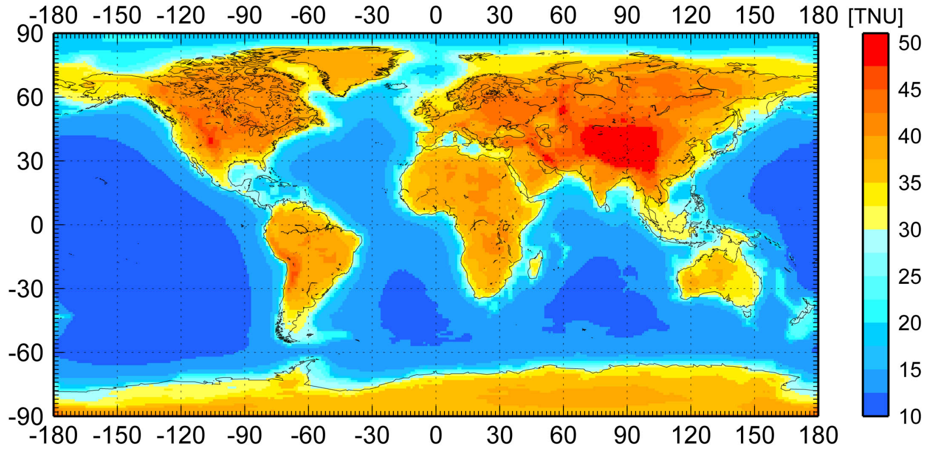
On the base of new compilations of geochemical data for sediments, oceanic and continental crust, we estimate the expected geoneutrino signal and its uncertainties for the crust of the Earth. Evaluating the U and Th abundances and their uncertainties in middle and lower crust are a focus of this model, along with using seismic velocity data to determine the lithological nature of these layers. The fraction of felsic and mafic rocks in the deep portions of the continental crust has been estimated by comparing the velocities of longitudinal and transverse seismic waves reported in the crustal model with the laboratory values obtained for ultrasonic velocities of different rock types.

An updated xenolithic peridotite database is used to represent the average composition of continental lithospheric mantle. The geoneutrino signal from this reservoir is calculated for the first time and it exceeds that from the oceanic crust at all three existing detectors.

Geoneutrino signal at Earth's surface is calculated in TNU (Terrestrial Neutrino Unit) (see figure) and Monte Carlo simulation is used to track the asymmetrical uncertainties of different crustal inputs. The combination of the global crust model, detailed local crust models, and the measured signal for each detector provides the critical inputs needed to assess the global mantle signal and its uncertainty. Thus, the mantle signal at each detector and its uncertainty can be independently combined to place limits on acceptable models for the mantle's radiogenic power.

キーワード: geoneutrino flux, heat producing element, radiogenic heat power, reference crustal model, deep crust composition, bulk silicate Earth composition
Keywords: geoneutrino flux, heat producing element, radiogenic heat power, reference crustal model, deep crust composition, bulk silicate Earth composition

U02-12　　会場:419　　時間:4 月 28 日 14:45-15:00



U02-13 会場:419 時間:4 月 28 日 15:00-15:15

マントル中の希ガス貯蔵庫を地球ニュートリノ観測から特定できるか？
Can noble gas reservoirs in Earth's mantle be identified from the geoneutrino distribution?

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Noble gas isotopes in mantle-derived samples are key tracers of chemical heterogeneity in the Earth's mantle and of the origin of the atmosphere. Samples of mid-ocean ridge basalt (MORB) and ocean island basalt (OIB) provide a comprehensive understanding of mantle noble gases. MORBs show relatively uniform ^{3}He/^{4}He ratios and in a ^{21}Ne/^{22}Ne-^{20}Ne/^{22}Ne diagram form a mixing line between the atmospheric composition and the MORB-source endmember. The latter is formed by the addition of nucleogenic ^{21}Ne to the primordial Ne ("solar" or "Ne-B" composition, Ballentine et al., 2005; Honda et al., 1991; Trieloff et al., 2000; Mukhopadhyay, 2012). In contrast, OIB samples, which are derived from a deeper region of the mantle, can exhibit higher ^{3}He/^{4}He ratios and less nucleogenic Ne isotope compositions. The OIB characteristics provide evidence for a mantle source in which primordial He and Ne has been less diluted by addition of radiogenic ^{4}He and nucleogenic ^{21}Ne produced by the decay of U- and Th-series elements. Therefore, noble gas isotopic evolution in the mantle is directly related to the U and Th contents in their reservoirs. However, the reasons for the less-radiogenic/nucleogenic character of the plume source are under debate; it may be less degassed (e.g., Allegre et al. 1983; Kaneoka, 1983; Kurz et al. 1982; Porcelli and Ballentine, 2002; Porcelli and Elliott, 2008), re-gassed through volatile recycling (Holland and Ballentine 2006; Ballentine and Holland 2008), or depleted in U and Th by ancient melt extraction events (Parman, 2007; Albarede, 2008). Recent finding of different ^{129}Xe/^{130}Xe ratios (^{129}Xe is a product of extinct isotope ^{129}I, while ^{130}Xe is primordial) in the MORB and Icelandic plume source requires that a portion of the latter has been isolated from the MORB-source mantle over geological timescales (Mukhopadhyay, 2012). This finding is consistent with that the less degassed nature is essential for the high ^{3}He/^{4}He ratio of the plume source because high noble gas concentrations in the plume source is required to preserve Xe isotope heterogeneity against dilution by depleted or surface-recycled material with atmospheric or MORB-like ^{129}Xe/^{130}Xe. If the plume source corresponds to the large low-shear-wave-velocity provinces (LLSVPs) or D" layer at the base of the mantle, it may indeed have existed since the formation of the Earth and cannot exclusively be composed of subducted slabs (Mukhopadhyay, 2012). This is consistent with high ^{3}He/^{4}He (primordial) and low ^{3}He/^{4}He (recycled) components in Polynesian OIBs (Parai et al., 2009). The geoneutrino distribution will shed light on this issue; the less degassed (i.e., primordial) plume source is expected to contain 30-40% of the total mantle U and Th and if the LLSVPs is dominated by undiluted primordial material this feature will generate a significantly higher geoneutrino flux than a LLSVPs dominated by ancient subducted slabs with U and Th contents most likely lower than the convecting mantle.

Subcontinental lithospheric mantle (SCLM) exhibits slightly lower ^{3}He/^{4}He ratio and more nucleogenic Ne feature (Gautheron and Moreira, 2002; Buikin et al., 2005), indicating it is enriched in U and Th relative to noble gases. Although U and Th concentrations in SCLM is estimated as 10-30 times those in the convecting mantle, its small volume fraction (ca. 1.5%) results in insignificant contribution to global geoneutrino flux. However, it may be significant for existing detectors located in or close to continental region such as KamLAND (Japan) and Borexino (Italy). An ocean-based or transportable detector like Hanohano (Sramek et al., 2013) is therefore expected to have a great advantage to reveal geoneutrino flux from the deep mantle.

キーワード: 希ガス, マントル, ウラン・トリウム, 地球ニュートリノ, LLSVP, D"層
Keywords: Noble gas, Mantle, Uranium and Thorium, Geoneutrino, LLSVP, D" layer

U02-14 会場:419 時間:4 月 28 日 15:15-15:30

On the origin of large-scale heterogeneity in the deep mantle: Thermo-chemical mantle convection in a spherical geometry

On the origin of large-scale heterogeneity in the deep mantle: Thermo-chemical mantle convection in a spherical geometry

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The origin of large-scale heterogeneous structure in the deep mantle, that is, large low shear velocity provinces (LLSVP) is still debated, which is between thermo-chemical [e.g. Nakagawa et al., 2012] and purely thermal [e.g. Davies et al., 2012]. If the large-scale heterogeneous anomalies in the deep mantle are generated by basaltic piles, the large-scale anomalies such as LLSVP may be enhanced for huge amount of heat source compared to the ambient mantle. Current efforts of geoneutrino observations attempt to detect the large-scale anomalous region of radioactive elements in the deep mantle [personal communication with H. Tanaka], which may have large-scale enhanced region of radioactive element in the deep mantle beneath the southern Pacific from test simulations of geoneutrino detectors. In addition, this approach could give an answer for the origin of large-scale heterogeneous structure in the deep mantle. Here we introduce our current numerical modeling of thermo-chemical mantle convection in a spherical geometry with self-consistently calculated mineralogy. The advantage of this approach is to include all phase transitions in the mantle without any linearization of physics of phase transition in mantle minerals and calculate seismic anomalies from thermo-chemical structure obtained from numerical modeling directly. In this presentation, we will show several important information on resolving this issue.

キーワード: thermo-chemical convection, large-scale heterogeneity, mineral physics, radioactive heat source
Keywords: thermo-chemical mantle convection, large-scale heterogeneity, mineral physics, radioactive heat source

U02-15 会場:419 時間:4 月 28 日 15:30-15:45

KamLANDによける反ニュートリノ方向性
Anti-Neutrino Directionality with KamLAND

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KamLAND holds its novelty in the observation of reactor anti-neutrino disappearance. After the great Tohoku earthquake in 2011, almost all nuclear power plants of Japan are closed for safety inspection. This Reactor-Off period offers a unique opportunity to study the directionality of anti-neutrinos from the earth and the remaining nuclear reactors with the liquid scintillator detector.

キーワード: ニュートリノ
Keywords: neutrino

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

U02-16 会場:419 時間:4 月 28 日 15:45-16:00

地球ニュートリノグラフィを目指した地球ニュートリノの到来方向観測
Tracking geo-neutrinos towards the future geo-neutrinography

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Directional sensitive neutrino detectors contributed to astronomy and particle physics. The solar neutrino problem was firmly believed by the directional measurement of solar neutrinos, and the atmospheric neutrino oscillation was confirmed by the zenith angle distribution for two types of neutrinos. Liquid scintillator detectors are marked by the ability to detect low energy neutrino signals, such as reactor, geo, and extraterrestrial neutrinos. On the other hand, liquid scintillator detectors do not have sensitivity of neutrino direction.

KamLAND (Kamioka, Japan) and Borexino (Gran Sasso, Italy) have showed the geo anti-neutrino detection realized by the event rate and energy spectra. We have begun to use neutrinos as “probe” to observe the Earth’s interior. Geo-neutrino measurement does not have the sensitivity of its direction, so we can not distinguish the crust and mantle contribution.

It is hoped the development of new measurement technology to measure neutrino direction. Lithium-loaded liquid scintillator has the potential to have the high sensitivity of coming anti-neutrino direction. Directional sensitive detectors will contribute to the better understanding of the earth interior using geo anti-neutrino flux information. Other motivations are the earlier determination of supernova direction and improvement of oscillation sensitivity for reactor anti-neutrinos.

キーワード: 地球ニュートリノ
Keywords: geo-neutrino

Japan Geoscience Union Meeting 2014
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U02-17 会場:419 時間:4 月 28 日 16:15-16:30

地球ニュートリノデータの地球物理学的インバージョン：地球の化学構造を制約するための定式化
Geophysical Inversion of Geo-Neutrino Flux Data: Formulation for Reveling Chemical Structure in the Earth

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Observation of geo-neutrino flux enables us to constrain distribution of radiogenic heat sources in the Earth (e.g., Enomoto et al. 2007, EPSL). Although the data provides unique information, resolution was limited because the observed data has been just one scalar quantity (geo-neutrino flux at the observational site). However, recent challenge to directional measurements by the RCNS group will greatly improve the resolution, because the observed data becomes a vector quantity with large dimension (geo-neutrino flux as a function of incident angle and azimuth).

In this study, I will formulate geophysical inverse problem to effectively constrain where and how much we have radiogenic heat sources in the Earth. Following procedures by Enomoto et al. (2007), we first categorize reservoirs of radiogenic elements (e.g., crust, bulk mantle, slab and LLSVP) and develop a reference distribution model of radiogenic elements in the Earth. We then compute a synthetic geo-neutrino flux pattern (as a function of incident direction) for each reservoir category. We assume that the observed flux can be expressed by linear combination of synthetic patterns and define their coefficients as model parameters.

The optimal coefficients can be obtained by solving an inverse problem. If the reference model is perfect, every coefficients should be equal to one. If the optimal coefficient deviates from one, it suggests that the assumed concentration was not appropriate for that reservoir category. This formulation should be useful for geophysical interpretation. For example, if the coefficient for LLSVP is large, we can suggest that a large amount of crustal material is accumulated in the LLSVP.

At the time of presentation, besides the details of the above formulation, I plan to show expected resolution when we use data obtained by the ongoing KamLAND experiment.

キーワード: geo-neutrino, KamLAND, geophysical inversion
Keywords: geo-neutrino, KamLAND, geophysical inversion

Japan Geoscience Union Meeting 2014
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U02-18 会場:419 時間:4 月 28 日 16:30-16:45

Hanohano: Future deep ocean geo-neutrino measurement
Hanohano: Future deep ocean geo-neutrino measurement

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Neutrinos from the decay chains of Uranium and Thorium from within the Earth's mantle constitute a vital signature of the origin of most of the heat thought to be driving all of geodynamics. The only means conceived as yet to study the magnitude and geographical distribution of the flux of mantle geo-neutrinos is from a large and mobile deep ocean detector. This study cannot be done from crustal locations due to the ovewhelming flux of neutrinos from local rocks. We present a description of the Hanohano Project, aimed at opening this new discipline.

キーワード: neutrino, uranium, thorium, geoneutrino, tomography
Keywords: neutrino, uranium, thorium, geoneutrino, tomography

Japan Geoscience Union Meeting 2014
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U02-19 会場:419 時間:4 月 28 日 17:03-17:18

Prospects of Earth Composition Measurements via Neutrino Tomography at Next-generation Neutrino Detectors

Prospects of Earth Composition Measurements via Neutrino Tomography at Next-generation Neutrino Detectors

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The Earth matter density is well determined through seismological measurements, however the chemical composition of the Earth has not yet been measured and only been inferred from meteorite samples. The Earth interior composition could be determined using neutrino tomography. Neutrinos are naturally produced in the Earth atmosphere and can be detected at neutrino telescopes. Neutrinos are elementary particles that are extremely light and only rarely interact, so that they can traverse the entire Earth without being absorbed. For the measurement, one can utilize a unique property of neutrinos, which is known as matter induced neutrino oscillations. This effect changes the neutrino properties based on the electron density of the medium through which the neutrino travels.

The dependence on electron density is what allows us to get a handle on the composition of the Earth. While seismological measurements determine the matter density, so to speak the average mass of nuclei, the oscillation effects depend on the electron density. In combination we can determine the average Z/A, where Z is the proton number (number of protons per nucleus) and A is the atomic mass (number of protons and neutrons per nucleus). The talk will introduce the measurement and discuss prospects at next-generation neutrino detectors like PINGU and Hyper-K, that could perform it.

キーワード: Neutrino, Tomography, IceCube, PINGU, Hyper-K, Earth Composition
Keywords: Neutrino, Tomography, IceCube, PINGU, Hyper-K, Earth Composition

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U02-20 会場:419 時間:4 月 28 日 17:18-17:33

The Hyper-Kamiokande Project
The Hyper-Kamiokande Project

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In this paper, we present the baseline design and expected performance of the Hyper-Kamiokande detector (Hyper-K)[1,2], a next generation underground water Cherenkov detector proposed in Japan. Hyper-Kamiokande is a successor of Super-Kamiokande (Super-K), which has been producing epoch-making results in particle physics and astrophysics, most notably the discovery of neutrino oscillation, since 1996. A water Cherenkov detector measures properties of elementary particles by detecting Cherenkov light, which is emitted when a charged particle travels faster than the velocity of light in water. Although neutrino itself does not emit Cherenkov light, it can be detected via particles produced in interaction with matter. Because the interaction probability is very small, a gigantic detector is necessary for the study of neutrinos. Water Cherenkov technique is the only solution to realize a Megaton scale detector with currently available technology. The design of Hyper-K is based on the highly successful Super-K, taking full advantage of a well-proven technology. The science goals of Hyper-K include not only the study of neutrino properties, but also broad topics in particle physics, astrophysics and geophysics.

Hyper-K consists of two cylindrical tanks lying side-by-side, the outer dimensions of each tank being 48 (W) 54 (H) 250 (L) m^3. The total (fiducial) mass of the detector is 0.99 (0.56) million metric tons, which is about 20 (25) times larger than that of Super-K. The inner detector region is viewed by 99,000 20-inch PMTs, corresponding to the PMT density of 20% photo-cathode coverage (one half of that of Super-K). In order to enhance the performance of the detector and to reduce the construction cost, new types of photosensors are under development. The design of critical components such as excavation of large caverns, mechanical structure of the tank, and water purification system is established. Further R&D towards detailed technical design, together with study of science cases, is ongoing by an international working group consisting of more than hundred scientists from eleven countries over the world.

Hyper-K presents unprecedented potential for precision measurements of neutrino oscillation parameters and discovery reach for CP violation in the lepton sector. Hyper-K can extend the sensitivity to nucleon decays beyond what was achieved by Super-K by an order of magnitude or more. The scope of studies at Hyper-K also covers high precision measurements of solar neutrinos, observation of both supernova burst neutrinos and supernova relic neutrinos, and dark matter searches.

Although the main motivation of the Hyper-K project arises from particle physics and astrophysics, thanks to its large volume and excellent performance, Hyper-K will be also able to contribute to geophysics by detection of neutrinos coming through the inside of the earth as discussed in [1]. The prospects for geophysics using Hyper-K will be discussed.

References
[1] K. Abe, T. Abe, H. Aihara, Y. Fukuda, Y. Hayato, K. Huang, A. K. Ichikawa and M. Ikeda et al., Letter of Intent: The Hyper-Kamiokande Experiment — Detector Design and Physics Potential —, arXiv:1109.3262 [hep-ex].
[2] Hyper-Kamiokande Working Group, Hyper-Kamiokande Physics Opportunities, arXiv:1309.0184 [hep-ex].

キーワード: neutrino, radiography
Keywords: neutrino, radiography

U02-21 会場:419 時間:4 月 28 日 17:33-17:48

Testing Geological Hypotheses Using Particle Physics
Testing Geological Hypotheses Using Particle Physics

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Installations of muon and neutrino observatories are yielding an increasing spirit of collaboration between particle physicists and Earth scientists interested in leveraging their resources and techniques and to apply them to major outstanding scientific problems in both fields. This comes at a very good time, as experimental methods and seismological analysis has increasingly illuminated the frontier of Earth's deep geological structure, leading to new ideas and hypotheses regarding the evolution of Earth since its formation. Particle geophysics offers unique new tools to test hypotheses regarding the geological evolution of the entire Earth, some of which should help to break through non-uniqueness hurdles that arise using more traditional approaches. Here we discuss some of the frontier problems in Earth science, and describe some potentially novel approaches that may lead to breakthroughs in our understanding of our planet. One already well-known application involves detection of anti-neutrinos generated by naturally occurring radioactive decay processes in Earth's interior, the strength and distribution of which is sensitive to different hypotheses regarding Earth's origin and evolution. Other approaches, which will be made possible using the high energy detectors in Antarctica, is the determination of the electron density inside the Earth. This is especially useful, since the electron density is sensitive to the molar fraction of elements in solution inside bodies like the core, while seismology is only sensitive to the weight percent of those solutes. Here we show how combining this independent information will help to solve major questions such as the composition of the core.

キーワード: Thermal Evolution, Chemical Evolution, Composition of Earth, Earth Formation, Hadean Geology, Deep Earth
Keywords: Thermal Evolution, Chemical Evolution, Composition of Earth, Earth Formation, Hadean Geology, Deep Earth

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U02-P01 会場:3 階ポスター会場 時間:4 月 28 日 18:15-19:30

Review of the recent muon radiography observations by using nuclear emulsion detector
Review of the recent muon radiography observations by using nuclear emulsion detector

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Nuclear emulsion is one of three dimensional particle tracker which have micron position resolution and the feature that no electricity so we can put this detector everywhere easily and also this is suitable for non-fixed point observation.

Several observations for volcanoes were done and will be done from 2011 to 2014. The imaging the of Unzen lava dome, which was formed from 1991 to 1995, was done by Miyamoto et al and they found the detector got many back ground particles and the amount is more than several times than expected muon signal. this implies that we are on the stage of background particle study.

The emulsion cloud chamber (ECC) is a modular structure made of a sandwich of passive material plates such as lead interleaved with emulsion film layers. Nishiyama et al studied the source of background noise in cosmic-ray muon radiography using ECC. They found that the origin of background is expected to be electromagnetic components of air-showers or cosmic-ray muons scattered in topographic material whith momentums is less than 2GeV/c.

The shallow conduit shape of Stromboli will provide the important information for eruption dynamics modeling by Tioukov et al. Hernandez et al put the emulsion detector near the top of summit of Teide volcano to investigate the past eruption histroy of Teide. Teide volcano is located in Teferife, Canary Islands, Spain. They are also under observation of the fault appeared in La Palma, Canary Island, in 1949, which is the sign of huge land collapse or not. The width of the fault is expected to be 1 meter or less, so high position resolution of emulsion detector is suitable for this observation. They will measure the width, delth and the porosity of this fault.

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

U02-P02 会場:3 階ポスター会場 時間:4 月 28 日 18:15-19:30

宇宙線ミューオンラジオグラフィーと重力異常データの同時インバージョンによる溶岩ドームの３次元密度構造解析
Simultaneous inversion of muon radiography and gravity anomaly data for 3-D density structural analysis of lava domes

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Cosmic-ray muon radiography (muography) has been utilized for obtaining the density profiles of volcanoes (eg. Tanaka et al., 2007; Lesparre et al., 2010; Cârloganu et al., 2013). Since gravity measurement is also sensitive to the internal density of the Earth, a combination of muography and gravimetry is expected to provide density profiles with fine resolutions (Okubo and Tanaka, 2012). Nishiyama et al. (2014) has developed a simultaneous inversion method of both two data for determining the 3-D density structures of volcanoes and has presented the feasibility of the hybrid measurement through a case study of a small (500 m in diameter) lava dome, Showa-Shinzan, Hokkaido, Japan. This study revealed that a vent extends downward beneath the dome.

We are now planning another hybrid measurement at Tarumai Lava Dome on the Shikotsu caldera, Hokkaido, Japan, in order to perform a comparative study on the internal structures of lava domes. The Tarumai lava dome has formed at the top of Mt. Tarumai during the 1909 eruption. We conducted gravity measurements at 23 stations spanning 1.5 km (NS) x 1.5 km (EW). We are preparing the muography detector for the coming measurement. We report the possible detector sites and the result of the resolution test of this new hybrid measurement.

References:
Tanaka et al., Earth Planet. Sci. Lett., 263, 104-113 (2007).
Lesparre et al., Geophys. J. Int., 183, 1348-61 (2010).
Cârloganu et al., Geosci. Instrum. Method. Data Syst., 2, 55?60 (2013).
Nishiyama et al., J. Geophys. Res. Solid Earth, 119, doi:10.1002/2013JB010234 (2014, in press).

キーワード: 宇宙線ミューオンラジオグラフィー, 重力異常, 密度, 溶岩ドーム
Keywords: cosmic-ray muon radiography, gravity anomaly, density, lava dome

U02-P03 会場:3 階ポスター会場 時間:4 月 28 日 18:15-19:30

ミュオンを用いた地下水状態把握のテスト計測の紹介（いくつかの観測結果を含めて）
Introduction about test measurement of the muon detection system for monitoring a groundwater (With some observations)

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The technique to radiographically image the internal structure of gigantic objects by utilizing muon's significant penetration power (muography) enabled us to investigate the internal structure of volcanoes and the city foundation with higher spatial resolution than possible with the conventional techniques.

This observation technique is applicable to exploring a large-scale civil engineering structure, the internal state of a base rock, etc. However, feasibility of muographic application to monitoring inside the large-scale civil engineering structure has not confirmed yet. Therefore, we decided to carry out test measurements in order to explore the possibility of muography for monitoring groundwater levels.

We are currently investigating the response of the groundwater levels to major rainfall events in the landslide area. We selected this area as an observation area. The measurement was carried out from the inside of a scupper tunnel in the base rock. Our muon detection system consists of plastic scintillator, photomultipliers (PMTs), and a high voltage (HV) power supply.

The muography detector was installed to the observation site in August, 2012 and measurement was started on the same date.

The result will be compared with the independent measurement results of groundwater levels and soil resistivity in order to quantitatively assess the technological limit of muography.

So far, we obtained the preliminary result that showed variations in the penetrating muon intensity; hence the density as a response of major rain fall events by plotting a moving average of the 48-hour observation time at different time intervals of one hour, two hours, three hours, and six hours. It showed a clear rainfall effect when the time interval is 6 hours. The future prospect includes further case studies for different rainfall-underground water coupling scenarios.

キーワード: ミュオグラフィー, ミュオン観測装置, 地下水位, テスト計測, 地すべり
Keywords: muography, muon detection system, groundwater, test measurement, landslide

U02-P04 会場:3 階ポスター会場 時間:4 月 28 日 18:15-19:30

歴史的考察から得られるギリシア・パルテノン神殿の耐震性能低下の可能性とミュオグラフィによるその評価について
A Historical View on the Degradation on Seismic Performance of The Parthenon, Greece and Muography as the Potential Eval

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To reinforce the Parthenon against earthquakes, the process of disassembling and reassembling Doric columns is obligatory. For this, the column strength and durability is required to withstand the reconstruction process. Wooden rods in the dowels of each drum provide the mechanical strength of each column, however some of these rods may have been damaged during the Venetian bombardment of the Acropolis on September 26, 1687. Due to the size of the Parthenon's Doric columns, muography is more appropriate to image the internal structure than conventional radiographic techniques. Muography may be utilized as a non-destructive technique targeting the inside composition of the Parthenon's Doric columns, potentially providing the following information: (1) the durability of the columns against future earthquakes, and (2) the magnitude of the internal damage sustained during the Venetian bombardment. The results of this muographic survey would aid conservator's efforts to protect the Parthenon along with the possibly of applying to other cultural properties. Secondly, the state of the wooden rod inside the column will provide evidence for the time and temperature around the column (based on the geometrical structure and thermal conductivity of the column) which would contribute further evidence to historical discussions particular to the Parthenon, such as estimates of the amount of gun powder stored in the Parthenon by the Ottoman Empire and information on the aforementioned siege. Muography may supplement efforts to preserve and protect the Parthenon as well as contributing to our understanding of the historical events that have occurred in this ancient structure.

キーワード: 歴史的考察, 耐震性能低下, パルテノン神殿, ミュオグラフィ
Keywords: a Historical View, the Degradation on Seismic Performance, the Parthenon, Muography

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Geo-neutrinos and reactor anti-neutrinos expected in Daya Bay II and in LENA
Geo-neutrinos and reactor anti-neutrinos expected in Daya Bay II and in LENA

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BALDONCINI, Marica[1*] ; ESPOSITO, Juan[2] ; LUDHOVA, Livia[3] ; MANTOVANI, Fabio[1] ; RICCI, Barbara[1] ; XHIXHA, Gerti[1] ; ZAVATARELLI, Sandra[4]

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Geo-neutrinos produced by beta decays occurring in ^{238}U and ^{232}Th decay chains are presently detected via inverse beta reaction in liquid scintillation detectors (KamLAND and Borexino). Geo-neutrinos are a unique direct probe of our planet's interior since they instantaneously bring to the Earth's surface information concerning the total amount and distribution of U and Th in the crust and in the mantle, which are thought to be the main reservoirs of these elements. The geo-neutrino spectrum allows to discriminate the different Th and U components. Measuring geo-neutrino fluxes and spectra can shed light on the radiogenic contribution to the terrestrial heat power and on the Earth's nowadays composition, providing a direct test of the Bulk Silicate Earth models and giving additional constraints on the Earth's evolution models.

A better discrimination among different Earth's global models can be reached combining the results from several sites: new measurements of geo-neutrino fluxes are highly awaited from experiments entering operation, such as SNO+, or proposed to the scientific community, as LENA or Daya Bay II. In particular, LENA and Daya Bay II would provide a substantial increase of the detection sensitivity and of the event rate thanks to their large target masses (50 kton and 20 kton, respectively) compared to the 1 kton mass of KamLAND and SNO+ and to the 0.3 kton of Borexino.

The main background in geo-neutrino measurements is due to the electron anti-neutrinos produced by nuclear power plants, which are the strongest man-made anti-neutrino sources. Many fission products decay through beta processes with the consequent emission of electron anti-neutrinos, the so called reactor anti-neutrinos. The reactor anti-neutrino spectrum covers an energy range extending up to about 8 MeV, which results in a significant overlap between geo-neutrino and reactor anti-neutrino signals in the geo-neutrino energy window (1.8 － 3.3 MeV). The events of reactor anti-neutrinos are strongly dependent on the distance of the closeby commercial nuclear power plants. Therefore, a careful analysis of the expected reactor anti-neutrino event rate at a given experimental site is mandatory.

In this framework, we estimate the expected reactor anti-neutrino signals at ongoing geo-neutrino experiments sites, in particular at Pyhasalmi and JUNO (Jiangmen Underground Neutrino Observatory), which are the candidate sites for hosting the LENA and Daya Bay II experiments, respectively. The inputs required to evaluate the reactor anti-neutrino flux come from neutrino properties, nuclear physics in the reactors and features of nuclear power plants. In our calculation we take into account the three neutrino oscillation mechanisms in vacuum, the most updated reactor anti-neutrino spectra and standard fuel compositions. According to the International Atomic Energy Agency (IAEA) database, we use detailed information on the locations and on the monthly time profiles of the thermal power for each nuclear core.

In Table 1 we report the expected geo-neutrino and reactor anti-neutrino signals for different locations, expressed in TNU (Terrestrial Neutrino Units). Nuclear power plants data refer to IAEA database reporting information of year 2012, when all of the Japanese nuclear power plants were still switched off. The ratio between the expected reactor anti-neutrino signal in the geo-neutrino energy window (R_G) and the expected geo-neutrino signal (G) is calculated all over the world in order to produce a R_G/G map. The values of R_G/G for future sites (Phyasalmi and JUNO) are almost comparable to the operating ones (LNGS and Kamioka), with a slight preference for the Finnish location. The total uncertainty on the reactor signal predictions is on the order of 5%: among all the accounted sources of uncertainties, the ones giving the main contributions originate from the θ_{12} mixing angle, the anti-neutrino spectrum, the fuel composition and the thermal power.

キーワード: geo-neutrino, anti-neutrino from reactor, neutrino detector
Keywords: geo-neutrino, anti-neutrino from reactor, neutrino detector

Sites	R [TNU]	R_G [TNU]	G [TNU]	R_G/G
LNGS	85.8 ± 4.6	22.8 ± 1.1	$40.3^{+7.3}_{-5.8}$	0.6
KAMIOKA	70.1 ± 3.7	18.7 ± 1.1	$31.5^{+4.9}_{-4.1}$	0.6
SUDBURY	174.6 ± 9.0	43.1 ± 2.1	$45.4^{+7.5}_{-6.3}$	0.9
PHYASALMI	69.2 ± 3.7	17.5 ± 0.8	$45.3^{+7.0}_{-5.9}$	0.4
FREJUS	587.9 ± 31.0	134.0 ± 7.1	$42.4^{+7.6}_{-6.2}$	3.2
HOMESTAKE	27.7 ± 1.5	7.3 ± 0.3	$48.7^{+8.4}_{-6.9}$	0.1
HAWAII	3.4 ± 0.2	0.9 ± 0.04	$12.0^{+0.7}_{-0.6}$	0.1
CURACAO	9.5 ± 0.5	2.5 ± 0.1	$29.3^{+4.2}_{-3.3}$	0.1
JUNO	99.0 ± 5.1	27.4 ± 1.4	$39.7^{+6.5}_{-5.1}$	0.7

Table 1: Comparison between expected reactor (R) and geo (G) antineutrino signal. R_G indicates the reactor signal expected in the geo neutrino energy window ($E_{\bar{\nu}} < 3.26$ MeV). 1 TNU = 1event/year/10^{32} protons.

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Towards a refined regional geological model for predicting geoneutrinos flux at Sudbury Neutrino Observatory (SNO+)

Towards a refined regional geological model for predicting geoneutrinos flux at Sudbury Neutrino Observatory (SNO+)

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The SNO+ detector is the redeployment of the illustrious Sudbury Neutrino Observatory (SNO) at SNOLAB in Ontario (Canada). After the substitution of heavy water (D_2O) with liquid scintillator (CH_2) inside the inner vessel, in 2014 the 1 kton detector will come on-line and together with KamLAND in Japan and Borexino in Italy will accumulate geoneutrino events. Geoneutrinos are electron antineutrinos originating from beta decays of natural radioactive nuclides in the Earth interior. A fraction of them, generated from ^{214}Bi and ^{234}Pa of ^{238}U decay chain and from ^{228}Ac and ^{212}Bi of ^{232}Th decay chain, are above the threshold for inverse beta reaction on free protons and can be detected by SNO+. Geoneutrinos are a real time probe of Earth interior, because the flux at the terrestrial surface depends on the amount and distributions of U and Th in the Earth's reservoirs. To extract global information such as terrestrial radiogenic heat power or to test compositional models of the Bulk Silicate Earth (BSE), the regional contribution to the geoneutrino signal has to be controlled by study of regional geology.

We present the 3-D refined geological model of the main reservoirs of U and Th in the regional crust extended for approximately 2×10^5 km^2 around SNOLAB, including estimates of the volumes and masses of Upper, Middle and Lower crust, together with their uncertainties. According to the existing global reference model (Huang et al., 2013), this portion of the crust contributes for 43% of the total expected signal at SNO+. The remaining contributions come from the far field crust (34%), from continental lithospheric mantle (5%) and from the mantle (18%). Since SNO+ will accumulate statistically significant amounts of geoneutrino data in the coming years, the calculated signal that is predicted to be derived from the lithosphere can be subtracted from the experimentally determined total geoneutrino signal to estimate the mantle contribution.

The main crustal reservoirs are modeled by identifying three main surfaces: the Moho discontinuity, the top of the Lower Crust and the top of the Middle Crust. About 400 depth-controlling data points obtained from deep crustal refraction surveys and from teleseismic receivers are the inputs for the spatial interpolation performed with the Ordinary Kriging estimator. This method takes into account the spatial continuity of the depths and it provides the uncertainties of the crustal volumes. The Upper Crust is further modeled in detail combining information from vertical crustal cross sections and Geological Map of North America at 1:5,000,000 scale. Seven sub-reservoirs with distinctive characteristics lithologies, metamorphism, tectonic events and chemical composition are identified. The density and the abundances of U and Th in the seven sub-reservoirs are evaluated from the published litho-geochemical databases, including analyses of representative outcrop samples. The Middle and Lower Crust densities and radioactivity contents are evaluated from seismic constraints.

The numerical 3D model consists of about 9×10^8 cells of 1 km $\times$ 1 km $\times$ 0.1 km dimensions. For each of them geophysical information, such as latitude, longitude, depth and reservoir type, are combined with estimates of the U and Th abundances to predict the geoneutrino signal at SNO+ originated from the regional crust. The total geoneutrino signal at SNO+ is about 12% less than that calculated using the global reference model (Huang et al., 2013).

キーワード: geoneutrinos, SNO+, uranium, thorium, geological modeling
Keywords: geoneutrinos, SNO+, uranium, thorium, geological modeling

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地球ニュートリノの測定精度向上に向けたカムランドのアップグレード計画
Upgrade plan of the KamLAND detector for improvement of sensitivity to geo-neutrino

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素粒子の一種であるニュートリノは、弱い相互作用を通してのみ他の粒子と反応する。東北大 RCNS は、大型ニュートリノ検出器 KamLAND を用いてニュートリノ科学について研究している。 地球内部の放射性熱源の推定や地球モデルの構成元素への制限をするには、地球内部で起こるベータ崩壊によって生じる地球ニュートリノを測定することが唯一の方法である。

KamLAND 検出器は低エネルギーの反電子ニュートリノを検出することが可能な点が特徴である。^{238}U や ^{232}Th などの放射性元素は以下の様に崩壊し、（反）電子ニュートリノ（地球ニュートリノ）を放出する。

^{238}U→ ^{206}Pb+8 ^{4}He+6e^{-}+6$\nu^{bar}{}_{e}$+51.7[MeV]

^{232}Th→ ^{208}Pb+6^{4}He+4e^{-}+4$\nu^{bar}{}_{e}$+42.7[MeV]

地球ニュートリノを測定することで、放射性熱源について直接知ることができる。実際に KamLAND は過去に地球ニュートリノの測定を通して結果を出していて、^{238}U や ^{232}Th による放射性熱源が $20.1_{-9.1}{}^{+9.1}$ TW であるとの推定を行った。これは地球の全熱流量である 44 ± 1TW よりも明らかに小さい結果である。

KamLAND 検出器の感度上昇を目標として、アップグレード計画（KamLAND2）が進行中である。例えば、大光量液体シンチレータ、集光ミラー、高量子効率の光電子増倍管（PMT）、カメラ、光るフィルムなどが挙げられる。

KamLAND2 実験においてはエネルギー及び位置分解能の向上が見込まれていて、これによって地球ニュートリノがより高い精度で、かつ多くの統計を得ることが可能となる。すなわち、モデルの検証や ^{238}U と ^{232}Th 比を求めるための精度があがる。

本講演では将来計画とその R&D に関して発表する。

Keywords: geo-neutrino

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カムランドにおける次期エレクトロニクス
The next-generation KamLAND electronics

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KamLAND was constructed to detect the low energy anti-neutrinos. And then, KamLAND detected reactor neutrinos and solved solar neutrino problem on 2003. And furthermore, KamLAND detected geo-neutrinos for the first time in the world on 2005. Currently, KamLAND has already been beginning to search several new physics. However, searching new physics in the detector of 10 years ago is difficult. So, it is necessary to update the detector. We are planning to update the KamLAND. As this updating, KamLAND electronics will be renewed using the latest technologies. The next-generation KamLAND electronics will certainly contribute to geoscience.
Keywords: Neutrino detector, Data taking, electronics

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イメージング検出器
Imaging detector

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地球ニュートリノは、地球の熱源の約半分を占める放射性元素（ウラン、トリウムなど）から放出され、ニュートリノの透過力の高さから、マントル内部の寄与も観測できる可能性がある。2005 年に、1 キロトン液体シンチレータ検出器「カムランド」（岐阜県飛騨市）で地球ニュートリノが初めて観測されて以来、地球の熱源を探る新たな観測手段として注目されている。現在では、イタリアの液体シンチレータ検出器「ボレキシーノ」も加わり、「２点観測」を行っているが、観測点がまだ不足していることに加え、ニュートリノの到来方向を測定できていないことが、データの精密化の障壁となっている。我々は、地球ニュートリノの到来方向測定のための新たな検出器開発を進めており、カムランドへの実装を目指している。地球ニュートリノ検出の際に放出される中性子の放出方向を検出するため、中性子捕獲断面積の大きいリチウム６を溶かし込んだ液体シンチレータの開発、中性子捕獲位置を精密測定するため、液体シンチレータを撮影するイメージング検出器の開発などを行い、それらを組み合わせて地球ニュートリノの方向検出を目指している。本ポスターでは、イメージング検出器について解説する。シンチレータの微弱な発光を 1 光子単位で検出し、発光点を精度よく決定するため、受講面積が大きく収差が小さい光学系、量子効率が高く、位置分解能にすぐれた光検出器を組み合わせる必要がある。現在、もっとも有望な設計として、直径 50 cm のミラーを用いた光学系と、256 チャンネル・マルチアノード光電子増倍管を組み合わせたデザインを中心に、開発状況、実装計画、期待される成果を述べる。

キーワード: ニュートリノ, 地球ニュートリノ, 放射性熱源
Keywords: neutrino, geo-neutrino, radiogenic heat source

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方向検出のためのリチウム液体シンチレーターの開発
Li loaded liquid scintillator for directional measurement

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現在の液体シンチレータを用いた電子型反ニュートリノの検出では、陽子による逆 β 崩壊反応により放出される陽電子と中性子の遅延同時計測によって強力なバックグラウンド除去を行うことが出来る。そしてそれによって低エネルギー領域での電子型反ニュートリノの観測を行うことが可能となっている。

その反面現存する検出器では水チェレンコフ法のように電子型反ニュートリノの飛来方向を知ることが出来ない。しかし、陽電子の反応点と中性子の捕獲点を観測することによって電子型反ニュートリノの飛来方向を知ることは可能である。低エネルギーにおけるニュートリノの飛来方向の観測が可能になればニュートリノを観測対象ごとに区別することができるようになり、従来の観測よりもさらに高い精度での観測が出来ると期待される。

液体シンチレータによって電子型反ニュートリノの飛来方向を検出するためには、次の三つの問題を解決することが重要である。それは方向情報を失う前に中性子を捕獲すること、中性子捕獲反応点で発光現象を起こすこと、そしてその発光点を高い位置分解能で検出する装置を作ることである。

現在の液体シンチレータでは逆 β 崩壊により放出される熱中性子が陽電子により捕獲されるまでに平均 200 μs かかり、陽電子によって捕獲された際に放出されるエネルギーは 2.2MeV の γ 線となってしまう。これでは、放出される熱中性子は十数 cm 拡散し位置情報はぼやけてしまい、2.2MeV の γ 線は約 40cm も移動するために中性子吸収点を特定することが出来なくなってしまう。今回、この問題を解決するために中性子捕獲断面積が 940barn で陽子の 0.3barn に比べて非常に大きく、中性子捕獲時に液体シンチレータ中を長距離移動出来ない α 線を放出する ^{6}Li を導入した液体シンチレータを開発した。この新しい液体シンチレータにより上記の二つの問題点を解決し、同時に開発中である高い位置分解能で発光点を検出する装置と組み合わせることによって電子型反ニュートリノの飛来方向を検出することが出来ると期待される。

本講演では独自の方法で開発したリチウム含有液体シンチレータについて講演する。

キーワード: 地球ニュートリノ
Keywords: geo-neutrino

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大型ニュートリノ実験による地球トモグラフィー
Tomography of the earth with large-scale neutrino experiments

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Experimental techniques to study inside of the Earth have been developing remarkably in the past decades. For example, in-situ x-ray diffraction measurements under high-pressure and high-temperature opened new era for studying about possible chemical components and structures of deep Earth. In the next ten years, we will obtain yet another technique for direct measurements of the Earth's interior.

Probing inner structures of the Earth with neutrinos has been discussed for more than 30 years. Neutrinos are chargeless particles and have very small cross-sections. They normally penetrate the Earth without any interaction, and from the rare interactions that do occur we obtain information on the density profile of the Earth's interior. However, the elusive characteristic of neutrinos poses a challenge for detecting them at experimental sites. To compensate for the small interaction cross-section, one needs a large volume neutrino detector.

The IceCube[1] neutrino observatory, completed in 2011 and has 1 cubic kilo-meter volume of detector size, is a possible candidate for this study. Current status of a study for measuring the core density of the Earth with atmospheric neutrino will be presented.

Another characteristic of neutrino is that they change their flavor periodically (neutrino oscillation). These oscillation patterns are affected by the density profile of electrons along the path of the neutrino. Comparisons between the Earth's mass-density profile and the electron-density profile give us ratio profiles of atomic number vs mass number (A/Z), which contains information of chemical composition of the Earth.

It is crucial to use a specific energy range for source neutrinos in order to perform the neutrino oscillation tomography. For Earth's core, the energy range is ~1GeV to 30GeV. To detect the GeV-range neutrinos with sufficient statistics, next-generation experiments Hyper Kamiokande[2] and PINGU[3] have been proposed. Possible discrimination powers of some chemical models of the Earths core will be discussed.

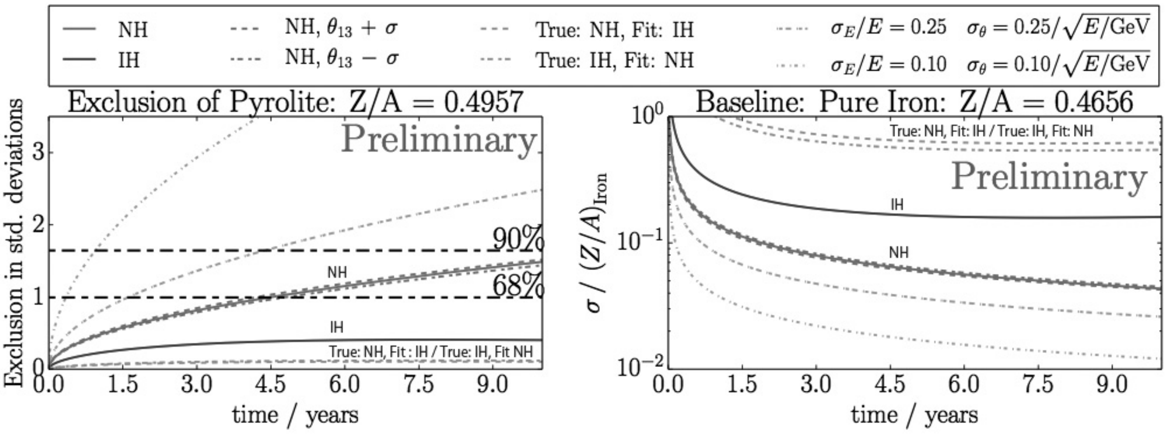
Fig.1

Left: Exclusion of a pyrolite core model with respect to a pure iron core a time range of ten years. Right: The accuracy, measured in units of sigma, of the Z/A measurement for the assumption of an iron core. Calculated for PINGU[3].

References

1.IceCube Collaboration, Astroparticle Physics 26, 155(2006)
2.LoI: The Hyper-Kamiokande experiment, arXiv:1109.3262(2011)
3.LoI: The Precision IceCube Next Generation Upgrade, arXiv:1401.2046 (2014)

キーワード: ニュートリノトモグラフィ, ニュートリノグラフィ, アイスキューブ
Keywords: neutrino tomography, neutrino radiography, IceCube


NH
IH
NH, $\theta_{13}+\sigma$
NH, $\theta_{13}-\sigma$
True: NH, Fit: IH
True: IH, Fit: NH
$\sigma_E/E = 0.25$ $\sigma_\theta = 0.25/\sqrt{E/\mathrm{GeV}}$
$\sigma_E/E = 0.10$ $\sigma_\theta = 0.10/\sqrt{E/\mathrm{GeV}}$
Exclusion of Pyrolite: Z/A = 0.4957
Preliminary
90%
68%
True: NH, Fit : IH / True: IH, Fit NH
Exclusion in std. deviations
time / years
Baseline: Pure Iron: Z/A = 0.4656
True: NH, Fit: IH / True: IH, Fit: NH
σ / $(Z/A)_{\mathrm{Iron}}$

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多層式ミュオグラフィ検出器による有珠山の内部構造探査
Muographic imaging of Usu volcano with a multilayer detector

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Usu volcano is one of the most active volcanoes in Japan and has erupted for four times in the recent 100 years (1910, 1943, 1977-1978 and 2000). In the 1977-1978 eruption, 18 craterlets and a U-shaped fault were formed in the summit crater. The eruption also caused the deformation in the summit crater area with a diameter of 1.8 km and formed an upheaval called Usu-Shinzan.

Preceding studies suggested that the cooling magma intrusion with a height of 600 m and a width of 300 m was located below the Usu-Shinzan by magnetotelluric soundings (e.g. Ogawa et al., 1998, Matsushima et al., 2001). And Yokoyama and Seino (2000) built a tilt model to interpret the formation of Usu-Shinzan. In this model, a block with a width of 800 m tilted approximately 11^{o} on a pivot at a depth of 800 m. So, in the present work, we conducted the muographic imaging (radiography with cosmic-ray muon) of Usu volcano to confirm the existence of magma intrusion beneath Usu-Shinzan.

But there is the issue of background (BG) noise of muographic imaging for a large volcano ($>$1 km thick). Since the integrated intensity of traversing cosmic-ray muons steeply decays as a function of the thickness of the target, the signal-to-noise (S/N) ratio also decreases seriously as the size of target becomes larger, and thus the density distribution cannot be accurately measured at a large volcano. The background (BG) noise that reduces the S/N ratio mainly consists of the fake tracks that are generated by the accidental coincidence of the electromagnetic (EM) shower particles. The values of BG noise were 10^{-6} cm^{-2} sr^{-1} s^{-1} (Lesparre et al., 2012) and 10^{-7} cm^{-2} sr^{-1} s^{-1} (Carloganu et al., 2013). BG noise of 10^{-7} cm^{-2} sr^{-1} s^{-1} corresponds to integrated cosmic-ray muon intensity after traversing 1 km of 2.65-g cm^{-3} rock.

In order to solve this problem, we developed a novel muon detection system that consists of multiple layers of position sensitive detectors (PSDs) in conjunction with a trajectory analysis method to effectively reduce the BG noise. In this method, the EM shower-originated fake tracks are rejected by requesting a linear trajectory for a muon event (linear cut method) since EM shower particles randomly hit each PSD layer and make a non-linear trajectory in the detection system. This detection system was applied to Usu volcano, Hokkaido, Japan to image its internal density structure (the spatial distribution of the density). In this measurement, we utilized a muon detection system that consisted of 7 layers of PSDs. One PSD consisted of x- and y- arrays of plastic scintillator strips with an active area of 1.21 m^2 and a segmented area of 10x10 cm^2. The angular resolution was +/- 3^{o}. The measurement duration was 1977 hours (82 days).

In this measurement, we compared the integrated cosmic-ray muon intensity traversing 2500 m of 1.5-g cm^{-3} rock with observed data at an elevation angle of 55.6 mrad. Assuming that the residual between the calculated intensity and data is BG noise, we obtained the BG noises of 5.4x10^{-5} cm^{-2} sr^{-1} s^{-1} with two PSDs and 1.9x10^{-6} cm^{-2} sr^{-1} s^{-1} with seven PSDs. The multilayered muon detector was effective to reduce the BG noise. However, BG noise remains and they may be attributed to another source of BG noise such as upward-going particles(Jourde et al., 2013). This measurement yielded the following results: (A) by analyzing the region that has a thickness of more than 1000 m, we confirmed that our detection system is sensitive to a density variation of 10% in 1300-m rock; and (B) there are high- and low-density anomalies beneath between Oo-Usu and Usu-Shinzan peaks, which is consistent with the magma intrusion and the resultant fault generation suggested by Yokoyama and Seino (2000), Ogawa et al. (1998) and Matsushima et al. (2001).

For the future prospect, we will try to use the shield in order to distinguish the upward-going particles from muons arriving from a volcano side.

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