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

U02-01 Room:419 Time:April 28 10:00-10:15

Muographic observations in Satsuma Iwojima, Japan

TANAKA, Hiroyuki[1]*

[1]Earthquake Research Institute, The University of Tokyo

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.

Keywords: Muography, Muon, Volcanic Conduit, Imaging

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U02-02 Room:419 Time:April 28 10:15-10:30

Conduit magma convection: Constraints from Muography

SHINOHARA, Hiroshi[1*] ; TANAKA, Hiroyuki[2]

[1]GSJ, AIST, [2]ERI, Univ. Tokyo

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.

Keywords: Conduit magma convection, muon-radiography, shallow volcanic edifice, density structure

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U02-03 Room:419 Time:April 28 10:30-10:45

Development of coupled Stokes–DEM simulation scheme for geodynamical magmatic studies

FURUICHI, Mikito[1*] ; NISHIURA, Daisuke[1]

[1]Japan Agency for Marine-Earth Science and Technology

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.

Keywords: Magma, Particle-Laden flow, Stokes flow, Discrete element method, Melt roof, Numerical simulation

U02-04 Room:419 Time:April 28 11:00-11:15

Recent updates on the DIAPHANE project of muon tomography

MARTEAU, Jacques[1*] ; GIBERT, Dominique[2] ; DE BREMOND D'ARS, Jean[2] ; JOURDE, Kevin[3]

[1]Institut de Physique Nucleaire de Lyon, Univ Claude Bernard, UMR 5822 CNRS, Lyon, France, [2]Geosciences Rennes, Univ Rennes 1, UMR 6118 CNRS, Rennes, France., [3]Institut de Physique du Globe de Paris, Sorbonne Paris Cite, Univ Paris Diderot, UMR 7154 CNRS, F.

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.

Keywords: Volcanology, Muon tomography, Particles detector, Inverse problem

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U02-05 Room:419 Time:April 28 11:15-11:30

Muon radiography by nuclear emulsions - Report on activity in Italy

BOZZA, Cristiano[1*]

[1]University of Salerno and INFN

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.

Keywords: nuclear, emulsion, muography, Italy, volcano, fault

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U02-06 Room:419 Time:April 28 11:30-11:45

Development of Nuclear Emulsion Detector for Cosmic-ray Muon Radiography and Its Applications

MORISHIMA, Kunihiro[1*] ; NISHIO, Akira[1] ; KATO, Yoshito[1] ; NAKANO, Toshiyuki[1] ; NAKAMURA, Mitsuhiro[1]

[1]Nagoya University

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.

Keywords: cosmic-ray muon radiography, nuclear emulsion, non-destructive observation, Fukushima Dai-ichi nuclear power plant

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U02-07 Room:419 Time:April 28 11:54-12:09

Muon radiography Monitoring for Structural Survey of the Prambanan World Heritage Temple

HANAZATO, Toshikazu[1*] ; TANAKA, Hiroyuki[2] ; KUSAGAYA, Taro[1] ; OKAMOTO, Yumiko[1]

[1]Mie University, [2]University of Tokyo

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.

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

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U02-08 Room:419 Time:April 28 12:09-12:24

An Application of Muography to Exploring Gigantic Masonry Architectures: Evolution in Pyramid ConstructionTechnique

OHSHIRO, Michinori[1*]

[1]Komazawa University

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.

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Keywords: muongraphy, pyramid, civilization, earthquake-proof structures

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U02-09 Room:419 Time:April 28 12:27-12:42

Overview of Neutrino Geoscience

DYE, Steve[1*]

[1]Hawaii Pacific University

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.

Keywords: neutrino geoscience, radiogenic heat

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U02-10 Room:419 Time:April 28 14:15-14:30

KamLAND: geo-neutrino result

SHIMIZU, Itaru[1*]

[1]RCNS, Tohoku University

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.

Keywords: geo-neutrino

U02-11 Room:419 Time:April 28 14:30-14:45

Borexino: geo-neutrino results

SUVOROV, Yury[1*]

[1]Yury Suvorov

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.

Keywords: neutrinos, geo neutrinos, Earth, crust, mantle

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U02-12 Room:419 Time:April 28 14:45-15:00

A reference Earth model for geoneutrinos

HUANG, Yu[2] ; MANTOVANI, Fabio[1*] ; RUDNICK, Roberta L.[2] ; MCDONOUGH, William F.[2]

[1]University of Ferrara - INFN of Ferrara - Italy, [2]University of Maryland, College Park, MD, USA

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.

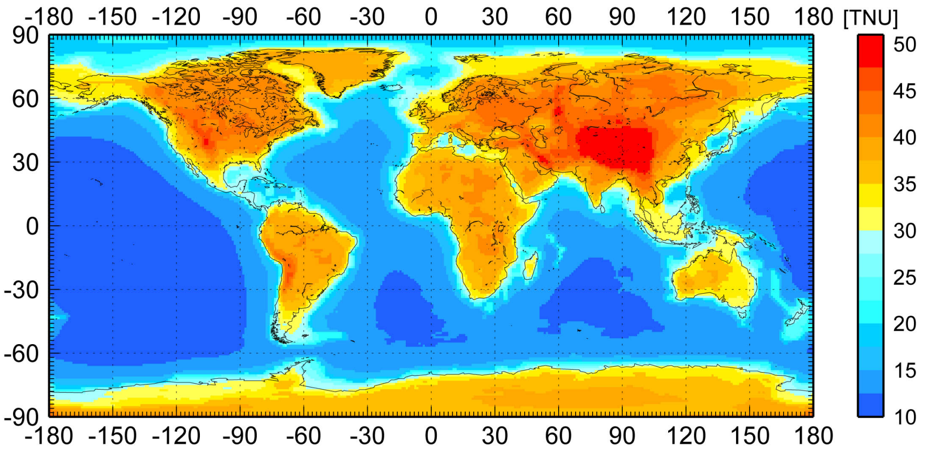
We developed a geophysically based, three-dimensional global reference model for the abundances and distributions of U and Th in a Bulk Silicate Earth (BSE) model. The structure and composition of the outermost portion of the Earth, the crust and underlying lithospheric mantle, are detailed in the reference model; this portion of the Earth has the greatest influence on the geoneutrino fluxes. The structure of the crust is based on $1^{o} \times 1^{o}$ 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.

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



U02-13 Room:419 Time:April 28 15:00-15:15

Can noble gas reservoirs in Earth's mantle be identified from the geoneutrino distribution?

SUMINO, Hirochika[1*] ; BALLENTINE, Chris[2]

[1]Geochemical Research Center, Graduate School of Science, University of Tokyo, [2]Department of Earth Sciences, University of Oxford

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.

Keywords: Noble gas, Mantle, Uranium and Thorium, Geoneutrino, LLSVP, D" layer

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U02-14 Room:419 Time:April 28 15:15-15:30

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

NAKAGAWA, Takashi[1*]

[1]IFREE, JAMSTEC

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.

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

U02-15 Room:419 Time:April 28 15:30-15:45

Anti-Neutrino Directionality with KamLAND

XU, Benda[1*]

[1]RCNS, Tohoku University

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.

Keywords: neutrino

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U02-16 Room:419 Time:April 28 15:45-16:00

Tracking geo-neutrinos towards the future geo-neutrinography

WATANABE, Hiroko[1*]

[1]RCNS, Tohoku University

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.

Keywords: geo-neutrino

U02-17 Room:419 Time:April 28 16:15-16:30

Geophysical Inversion of Geo-Neutrino Flux Data: Formulation for Reveling Chemical Structure in the Earth

TAKEUCHI, Nozomu[1*]

[1]Earthquake Research Institute, University of Tokyo

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.

Keywords: geo-neutrino, KamLAND, geophysical inversion

U02-18 Room:419 Time:April 28 16:30-16:45

Hanohano: Future deep ocean geo-neutrino measurement

LEARNED, John[1*]

[1]University of Hawaii

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.

Keywords: neutrino, uranium, thorium, geoneutrino, tomography

U02-19 Room:419 Time:April 28 17:03-17:18

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

ROTT, Carsten[1*]

[1]Sungkyunkwan University

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.

Keywords: Neutrino, Tomography, IceCube, PINGU, Hyper-K, Earth Composition

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U02-20 Room:419 Time:April 28 17:18-17:33

The Hyper-Kamiokande Project

YOKOYAMA, Masashi[1*]

[1]The University of Tokyo

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
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[2] Hyper-Kamiokande Working Group, Hyper-Kamiokande Physics Opportunities, arXiv:1309.0184 [hep-ex].

Keywords: neutrino, radiography

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Testing Geological Hypotheses Using Particle Physics

HERNLUND, John[1*] ; TANAKA, Hiroyuki[2]

[1]Earth-Life Science Institute, Tokyo Institute of Technology, [2]Earthquake Research Institute, Tokyo University

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.

Keywords: Thermal Evolution, Chemical Evolution, Composition of Earth, Earth Formation, Hadean Geology, Deep Earth