Crustal fluids beneath Kyushu forearc region

*Koichi Asamori[1], Yuki Hama[1], Koji Umeda[1]

1.Japan Atomic Energy Agency

In this study we have determined two dimensional (2-D) resistivity and three dimensional (3-D) seismic velocity structure beneath Kyushu subduction zone. 40 magnetotelluric (MT) stations were deployed in the study area. The MT data were collected using five component wide-band MT instruments (Phoenix MTU-5 system). A simultaneous remote reference measurement was carried out at the Sawauchi site (900 km northeast of the study area). The observed apparent resistivity and phase data were inverted simultaneously using the 2-D inversion code of Ogawa and Uchida [1996]. We have applied a tomographic method [Zhao et al., 1994] to P and S arrival times from regional earthquakes and teleseismic events to determine a detailed 3-D P and S wave velocity structure beneath Kyushu. The obtained resistivity and seismic velocity model through the inversions show as follows: (1) In central Kyushu, a prominent conductive anomaly exists in the crust beneath the forearc region. (2) A low-velocity zone corresponding to the conductive anomaly was revealed in the crust. (3) These results indicate that the conductive and low-velocity zone may reflect crustal fluids in the forearc region.

Possible fluid-related earthquakes from seismic spectra analysis: detection and mechanism

*Kuo-Fong Ma[1], Hidemi Tanaka[2]

1.Institute of Geophysics, National Central University, Taiwan, ROC, 2.School of Science, University of Tokyo, Japan

Fluid had been considered as a possible factor in triggering earthquakes, but, the evidence in elucidating the behavior and mechanism is still unresolved. Fracture zone associated with fault zone after an earthquake could be considered as a fluid reservoir, which possibly yields to some observations/detections of phenomena associated with pre-, co- or post-seismic of a larger earthquake. The fluid might behave from high pore-fluid saturation within fractured fault zone from fully to partial saturation as a transient feature after a large earthquake. We suspect this process might yield the migration of fluid flow, and thus, related to the occurrence of some aftershocks. Considering that the fluid flow triggering events might have a mechanism from tensile cracks rather than tensile shear, the S/P spectra ratio would be around 2-0.7 rather than higher values of 6-2 for tensile shear. We investigate the spectra ratio of the selected events from the analysis of the recorded broadband waveforms, we found significant association of the S/P spectra ratio of 2-0.7 in about 10-60 days after the Chi-Chi earthquake. It might give the evidence of the tensile crack events in association to the fluid flow and give the migration of the seismicity. These events are mostly in the negative Coulomb stress regime of the mainshock and are in the depth f about 5-8km. Our assumption on this is that the migration of fluid flow increases the pore-pressure, which reduces the normal stress, and, thus, yield the co-seismic negative Coulomb's stress regime to become positive to trigger these fluid flow associated aftershocks. The migration of this aftershock to the distance of the fault is with a speed of about 220m/day for our Chi-Chi case study in about 10-60 days after the Chi-Chi earthquake. More profiles along the fault will be further examined to assure our understanding on fluid migration within the crust. Moreover, if the zone of the fluid triggered events could be constrained spatially and temporally, we might be able to estimate the possible amount of fluid involved during this process.

Keywords: aftershocks, fluid flow, S/P spectra ratio

Remarkable crustal strain and Groundwater level changes associated with reflood of the underground gallery

*Yasuhiro Asai[1], Hiroshi Ishii[1]

1.Tono Research Institute of Earthquake Science, Association for the Depvelopment of Earthquake Prediction

Tono Research Institute of Earthquake Science has been investigating the relationship between the variation of groundwater level and variations of crustal tilt, stress, and strain. We have installed a multi-component borehole instrument (three Ishii-type borehole strainmeters, two borehole tiltmeters and thermometer) at the bottom of boreholes site (BH-1; 50m depth) in the Tono mine (JAEA) in the Tono region, central Japan, as a part of the research. The BH-1 site is located in the Toki granite.
At Tono mine, backfilling of underground galleries were started from March 2012 and completed in March 2015. The drainage pump stopped on December 9, 2014. In this study, we report the crustal strain changes associated with reflood of the underground gallery. As research advances, the following results were obtained: (1) Observed strain change of maximum principal strain, minimum principal strain, and areal strain at the BH-1 site are -1.075×10^{-6} strain, -5.448×10^{-5} strain, -5.556-05$\times10^{-5}$ strain, respectively. (2) Compression of ENE-WSW direction is remarkable at the BH-1 site.
We consider that observed ‘compression to excellence in ENE-WSW direction’ may be caused by the hydrogeological structure, such as the orientation of the crack in Toki granite neighborhood of borehole strainmeter.

Keywords: reflood of the underground gallery, Strain observation, Groundwater level observation

Estimate of hydraulic properties of the crust - An example from water discharge by Naganoken-Hokubu earthquake

*Hidemi Tanaka[1], Kuo-Fong Ma[2], Tsutomu Sato[3], Fumiaki Tsunomori[1], Norio Matsumoto[3], Koji Umeda[5], Kohei Kazahaya[3], Kazunori Fujisawa[4], Fumitake Kusuhara[1]

1.School of Science, The University of Tokyo, 2.nstitute of Geophysics, National Central University, Taiwan, ROC Institute of Geophysics, National Central University, Taiwan, ROC, 3.Geological Survey, AIST, 4.Graduate school of Agriculture, Kyoto University, 5.Tono Geoscience center JAEA

On November 28, An M 6.7 earthquake occurred at northern part of Nagano Prefecture, Central Japan. The Kamishiro Fault,which has been well known as to be a part of Itoigawa-Shizuoka Tectonic Line, was activated by the earthquake and surface rupture about 9 km in length was appeared along it’s trace.
Post-seismic fluid discharge was observed from the fracture zone of the Kamishiro Fault. Our team has been observed and monitored the flow amount and chemical characteristics of the fluid for about 5 months from one week after the earthquake.
In this presentation, we describe the occurence of earthquakes and its relation to the hydraulic propertes and discuss about the governing equations of fluid flow in fracture zone ofthe Kamishiro Fault.

Keywords: Naganoken-Hokubu earthquake, Kamishiro Fault, Fluid discharge, Fracture zone, Hydroraulic property

Distribution of slab-derived fluid mixed into groundwater system in NE Japan arc

*Kohei Kazahaya[1], Yoko Togo[1], Hiroshi Takahashi[1], Masaaki Takahashi[1], Masaya Yasuhara[1], Tsutomu Sato[1], Keika Horiguchi[1], Noritoshi Morikawa[1], Hikaru Iwamori[2], Hidemi Tanaka[3]

1.Geological Survey of Japan, AIST, 2.Geochemical Evolution Research Program, Japan Agency for Marine-Earth Science and Technology, 3.School of Science, The University of Tokyo

The Li/Cl ratio of groundwater is proposed as useful indicator for detecting minor amounts of slab-derived saline fluid mixed into groundwater aquifers (Kazahaya et al., 2014). An weak point of the Li/Cl indicator appears in case that slab-derived fluid is mixed into saline groundwater. An extended indicator for detecting slab-derived fluid using Li and halogens is shown to solve complicated mixing groundwater system. We report here the distribution of upwelling of the slab-derived (and magmatic) fluid into groundwater system in NE Japan arc using an extended chemical indicator for groundwater. The areal distribution feature is explained by upwelling model of slab fluid controlled by subduction system.

Keywords: slab-derived fluid, NE Japan arc, groundwater

The behavior of surface radicals on mechanochemically activated silicates

Yuta Owari[1], *Chisaki Inaoi[2], Hirokazu Masumoto[2], Jun Kameda[3]

1.Department of Earth Sciences, School of Science, Hokkaido University, 2.Department of natural history sciences, Graduate School of Science, Hokkaido University, 3.Department of Earth and Planetary Sciences, Faculty of Science, Hokkaido University

High concentration of hydrogen gas has been occasionally observed in soil gas along active faults (Wakita et al., 1980; Sugisaki et al., 1983). Such hydrogen gas is thought to be generated by a chemical reaction (radical reaction) between fluid and active surface of minerals newly created by fault activities (Wakita et al., 1980). Subsequent laboratory experiments have confirmed that hydrogen gas is truly generated during fracturing of silicate minerals in wet condition (e.g., Kita et al., 1982, Kameda et al., 2003). However, the reaction mechanism has not been fully understood.
Delogu (2011) carried out a crushing experiment of quartz in a solvent of ethanol with 2,2-diphenyl-1-picrylhydrazyl, as a radical scavenger, and evaluated directly the amount of hydrogen radicals using UV-vis spectrophotometry. In this study, we applied this method to albite, another common constituent mineral in crustal faults, in an attempt to elucidate the behavior of hydrogen radicals in natural fault zones.
Our experiments revealed that hydrogen radical is generated during grinding of both quartz and albite. The amount of the hydrogen radicals increases as the specific surface area of the ground sample increases. Comparing the amount of the hydrogen radicals generated, those from albite is much smaller than from quartz. These results are reasonable because the density of Si radicals on well-cleaved (010) and (001) planes of albite is estimated to be 1/6 of that on quartz. In addition, Hochstrasser and Antonini (1972) showed that alkali metals interfere the generation of hydrogen radicals. This property may also affect the amount of surface radicals on ground albite.
When we compare the amount of hydrogen radicals with those of hydrogen gas per unit area of newly created surface reported by Kameda et al. (2003), the hydrogen radical is more than one order of magnitude greater than hydrogen gas. This suggests that most of generated hydrogen radicals disappear before combining to be hydrogen molecules.

Keywords: radical reaction, mechanochemistry, hydrogen gas

Evidence suggesting crustal fluids beneath earthquake source regions

*Koji Umeda[1]

1.Tono Geoscience Center,Japan Atomic Energy Agency

Electrical resistivity is highly sensitive not only to the temperature and bulk composition of rocks, but also to the presence and connectivity of melt, volatiles, and aqueous fluids. A great deal of effort has been made using MT soundings to obtain information on subsurface electrical conductivity anomalies around seismically active regions in subduction zones. Strike-slip intraplate earthquakes such as the 1997 Kagoshima (M6.6), the 2000 western Tottori (M7.3) earthquakes, tend to occur near the boundaries between conductive and resistive crust, generally resistive side. Rheological heterogeneities driven by aqueous fluids in the crust would produce strain concentrations within resistive crust due to anelastic deformation under strike-slip fault type stress. In the case of the 2011 Hamadori swarm earthquakes, which are thought to be triggered the 2011 Tohoku-Oki earthquake, an anomalous conductor with a width of 20 km has been detected below the seismic source region, extending down to the base of the crust. The swarm activity is likely caused by increased pore pressure, within resistive crust, as a result of fracturing stimulation. Assuming that aqueous fluids produce the low-electrical resistivity, the plausible explanations for the generation of fluids are limited to the following: (1) sediment porosity reduction and from smectite-illite and opal-quartz reactions in the subducting deep-sea sediments, (2) metamorphism of fore-arc basin sediments, sedimentary and/or volcanic rocks detached from the plate or (3) dehydration reactions in the subducted oceanic crust and/or hydrated mantle below the fore-arc mantle wedge.

Keywords: helium isotope, electrical resistivity structure

Relation among crustal deformation, precipitation and groundwater in Kosei area of Shiga Prefecture

*Naoji Koizumi[1]

1.School of Environmental Science,the University of Shiga Prefecture

It is said that around 20% of the water flowing into Lake Biwa is groundwater. The main part of it is considered to be the groundwater in the Kosei area of Shiga Prefecture or the west coast area of Lake Biwa. In the Kosei area there are many mountains. The precipitation in the mountain area supplies a lot of water to the groundwater in the Kosei area. Using an autonomous underwater vehicle, Kumagai et al.(2015) found the vent, which is an outlet of groundwater and gas, around the deepest part of Lake Biwa or the northwestern part of Lake Biwa in December 2008. In addition Kumagai et al.(2015) found that the area of the vent has been magnified since December 2010 and suggested that the magnification should have some relation to crustal deformation in and around Lake Biwa. The area in and around Lake Biwa is actually included in the Niigata-Kobe Tetonic Zone and has been in large contraction (10^{-7}/year) for at least a recent few decades. However, it has not been reported that the contraction rate was changed around 2010. Daily positional information of the Geospatial Information Authority of Japan (GSI) shows that length of the east-west baseline across Lake Biwa (Hikone-Takashima baseline) has been uniformly contracted at 10^{-7}/year since 1996. On the other hand it was found that precipitation in and around Lake Biwa has been increased since 2010. Since 2010 groundwater pressure has been also increased at HNO groundwater observation station of Geological Survey of Japan, AIST, which is located in the Kosei area. Therefore it is possible that the increased precipitation in and around Lake Biwa raised the groundwater pressure at Kosei area, which in turn increased groundwater flow to Lake Biwa. If it is right, the increased groundwater flow can magnify the area of the vent. In the presentation, I will show the relation among precipitation, groundwater pressure and crustal deformation in and around Lake Biwa.

Keywords: Lake Biwa, crustal deformation, precipitation, groundwater, Niigata-Kobe Tectonic Zone

Hydraulic properties, water chemistry and gas composition at Hongu observatory, Wakayama Prefecture

*Norio Matsumoto[1], Tsutomu Sato[1], Akinobu Miyakoshi[1], Noritoshi Morikawa[1], Masaaki Takahashi[1], Hitoshi Tsukamoto[1], Kohei Kazahaya[1]

1.Institute of Earthquake and Volcano Geology, National Institute of Advanced Industrial Science and Technology (AIST)

In order to explore potential sites for in-situ continuous $^{3}He/^{4}He$ gas mass spectrometer which is under development, we performed temperature and electric conductivity logging and hydraulic tests at a 1000 m well at the Hongu observatory. We also collected groundwater and gas samples from the well after the hydraulic tests. There are several reasons why we selected the Hongu observatory as the potential site: (i) High $^{3}He/^{4}He$ ratio were observed in the hot springs near the Hongu observatory; (ii) Several ancient texts reported that discharge of hot spring at the Hongu area were stopped in response to past Tonankai or Nankai earthquakes, and (iii) we have been observing groundwater, crustal deformation and seismic data near the Hongu observatory to detect non-volucanic tremors and short-term slow slip events occurring at plate boundary directly underneath the Hongu area. As a result, we obtain medium transmissivity of the aquifer (2.0 - 2.8 x 10^{-5} m^{2}/s), high $^{3}He/^{4}He$ ratio (4.69 Ra) in the gas sample and similar chemical composition of the sampled water to the surrounding hot springs.

Keywords: hydraulic property, water chemistry, gas composition, deep well

Time series of gas composition in groundwater monitored at Atotsugawa Well

*Fumiaki Tsunomori[1], Hidemi Tanaka[2]

1.Geochemical Research Center, Graduate School of Science, University of Tokyo, 2.Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo

We discuss on time variation of gas composition dissolved in groundwater of Atotsugawa observatory from October 2010 to February 2013. An observation well of Atotsugawa observatory was drilled in southern-west part of Atotsugawa fault located in Gifu Prefecture. Groundwater is sampled directly from an aquifer with a TEFLON pipe by 1 L/min. Dissolved gas makes may bubbles in the TEFLON pipe because the pumping reduces the pressure of groundwater. All bubbles are collected in a gas-water separator on the ground, and are introduced into a quadrupole mass spectrometer in the observatory. A gas composition is analyzed by the mass spectrometer equipped with a gas dryer every 1 hour. Results are transported to our server computer, and all spectra are automatically analyzed. A gas ratio of He-N2-Ar tri-component is calculated from a mass spectrum. This ratio is corrected by oxygen component in order to subtract air contamination. Tri-component ratio scatters on a mixing line of the air and the crust. Some data point on a line between the air and the mantle. Time series of the tri-component plot might have a potential to monitor gas migrated from a deep part to the ground surface.

Keywords: Groundwater, Dissolved gas, Time variation

Depth profile of helium concentration in a hot-spring well in Beppu, Japan

*Tomo Shibata[1], Naoto Takahata[2], Yuji Sano[2]

1.Graduate School of Sciences, Kyoto University, 2.Atmosphere and Ocean Research Institute, University of Tokyo

Volatile components degassing from the crust provide important information on Earth interior. Helium fluxes from the crust because of its inert property are important precursors of crustal tectonic and thermal events. Helium isotopic ratios in crustal fluid serve as tracers in resolving groundwater age in the crust and contribution of mantle-derived fluid. Here, we will describe depth profile of helium concentration in a hot-spring well in Beppu, Japan using new sampling devices. The sampling devices allow gas exchange between the headspace in the sampler volume and the dissolved gases in the water though gas permeable silicon tubing, and we collected helium gases dissolving in well water by the devices.

Beppu is situated on east end of subsidence of the Beppu-Shimabara Graben in Kyushu Island, southwest Japan (Matsumoto, 1979), and is a famous area as a geothermal system. The geothermal system is located on the eastern flanks of the Tsurumi-Garandake volcanic center and spread until the coastline to the east. The geothermal activity is mostly concentrated in two areas, on the northern and southern sides of the fan deposit. These two areas are known as the Kamegawa and Beppu thermal zones, which are along with two faults, the Kamegawa and Asamigawa faults, respectively (Allis & Yusa, 1989).

The sampling devices were installed every 50 m from near bottom of the well to the surface in the periods of July 13-15 and August 21-24, 2015. The collected gases were measured by a noble gas mass spectrometer (Helix SFT; GV Instrument) installed at Atmosphere and Ocean Research Institute, University of Tokyo.

Helium concentrations and isotope ratios ($^{3}He/^{4}He$) is gradually lower, as setting depth becomes shallow. The highest in the isotope ratio shows 6.79 and 7.08 Ra (Ra=1.4E-6) around the bottom, and its high ratio can be of mantle origin. The screen of the borehole ranges 278-300 m, mantle helium could enter the well with hot spring water through the screen, and could go to the surface.

References

Allis R.G. and Yusa Y. (1989) Fluid flow processes in the Beppu geothermal system, Japan. Geothermics, 18, 743-759.

Matsumoto Y. (1979) Some problems on volcanic activities and depression structure in Kyushu, Japan. The MEMOIRS of the Geological Society of Japan, 16, 127-139.

Keywords: helium, isotope ratios, hot spring, depth profile of concentration

Water flux model around TRIES/MIU to explain the gravity change - II

*Ryo Honda[1], Koichi Yanagizawa[2], Makoto OKUBO[3], Toshiyuki Tanaka[1]

1.Tono Research Institute of Earthquake Science, Association for the Development of Earthquake Prediction, 2.Japan Atomic Energy Agency, 3.Natural Science Cluster, Kochi University

Gravity measurement has been operated in three observation stations in and around the Tono Research Institute of Earthquake Science (TRIES) since 2003, and detected the gravity change in the 2011 off the Pacific coast of Tohoku Earthquake. The change was about 10 micro Gal (1×10^{-4} m/s^2) decrease in all three stations which exceeds the effect of ground deformation, moreover it is opposite sense of change for the 14 m of ground water level increase in nearby station. We have constructed the ground water flux model to explain the gravity decrease and the water level increase simultaneously. Based on gravity change simulations on hydraulic geological structure in the study area, we confirmed that the water flux which flows down to the deeper area can explain both the gravity and the ground water level. Niwa et al. (2012) reported the coseismic ground water level changes of the Tohoku Earthquake in several wells in and around the Mizunami Underground Research Laboratory (MIU, JAEA), which is near by the TRIES.

In this report, we first reviewed the effect of ground deformation including the afterslip to the gravity data obtained in and around the TRIES/MIU. Ground water level is almost recovering in this 5 years, nevertheless the gravity values are still same as of just after the earthquake. Coseismic vertical displacement is less than 1 cm in the study area, which gravitational effect is about 1 micro Gal. Postseismic vertical displacement shows about 4 cm uplift in the last 5 years. This is an amount of 9 micro Gal decrease for the gravity, which cancels the coseismic step. We conclude that the gravitational effect of the ground water level recovery is masked by the effect of postseismic displacement. We also studied the individual coseismic ground water level response for all the wells in the study area, including reported in Niwa et al. (2012). For each well, we compiled the amount of change, time to the peak of the change, duration for the recovery and so on. The correlation was found between the recovery speed and the water catchment area on the basement topography. We also quested for the implication of downward water flow in the wells where the water pressure is monitored by multi packer system.

Keywords: Gravity, Ground Water, Coseismic Response

Groundwater and crack behaviors after underground gallery closure inferred from observation of S-wave travel time change by the seismic ACROSS

*Takahiro Kunitomo[1,2], Koshun Yamaoka[1], Hiroshi Ishii[2], Yasuhiro Asai[2], Toshiki Watanabe[3]

1.Graduate School of Environmental Studies, Nagoya University, 2.Tono Research Institute of Earthquake Science, ADEP, 3.Earthquake Research Institute,The University of Tokyo

Constant monitoring of temporal seismic velocity change by the seismic ACROSS has been practiced for more than 13 years since 2002 at Tono mine (Toki City, Gifu Prefecture). At Tono mine, back-filling of underground galleries were started from March 2012 and completed in March 2015. The drainage pump stopped on December 9, 2014. In this study, we report the significant changes of the S-wave travel time associated with reflood of the underground galleries. In addition, we conclude that S-wave velocity change has occurred in the Toki granite under sedimentary formation (Mizunami Group, about 90m thick), and discuss that groundwater flow in and around the packed gallery control the opening and closing of cracks and the S-wave velocity change.

Keywords: seismic ACROSS, Tono mine, reflood, seismic velocity change

