Natural analog of the deep geothermal reservoir -Hitachinai Granitic Rocks-

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In present, temperature of geothermal fields operating in Japan ranges from 200 to 300 °C, and depth ranges from 1000 to 2000 m. In operating geothermal reservoir, mechanical behaviors of the rocks is presumed to be brittle. New target of geothermal resources is in 2000-5000m depth and temperature is more than 350℃.In this region, the mechanical behavior of the rocks is considered to be ductile and it is expected to prevent induced seismicity. Furthermore, it is expected to high enthalpy in supercritical state.
Lithostatic-hydrostatic pressure transition zone that is important to the deep geothermal development is estimated by previous study related to the deep geothermal resource. Therefore the purpose of this study is obtaining an evidence of the transition and proposing the natural analog of the deep geothermal reservoirs. Thus, we investigated granitoid that is thought to be a heat source. And we also investigated mineral filling veins and alteration zone. Further, we analyzed chemical composition of minerals and the fluid inclusion of the rock samples.
Many volcanoes and calderas are distributed in Tohoku district. In previous study of the Koaizawa-Ohmizuhata granitic rocks located in west of Tazawa-ko lake in Akita Prefecture, Tohoku District, NE Japan, a granite–porphyry system is proposed as a natural analog of the deep geothermal reservoir. Fournier(1999) suggested that the veins including magmatic fluid formed under lithostatic pressure condition and the granite body is accompanied by alteration of porphyry-copper type with self-sealing zone.
In this study, we investigated the Hitachinai granitic rocks, located in north of Tazawa-ko lake complex rocks in central Akita Prefecture. It is expected the material evidence of the lithostatic-hydrostatic pressure boundary in the granite body.
As a result of field survey, silicified zone and argillized zone in alteration zone. Further, several kinds of mineral filling veins were observed with it, too. Mainly, those were quartz vein, glassy vein and hydrothermal breccia vein. We evaluated depth and temperature of geothermal fluids. Which of magmatic fluid or hydrothermal fluid participates in the vein formation is thought that related to the stage to change from lithostatic to hydrostatic pressure, and we expect that it leads to new knowledge of the deep geothermal reservoir. In this presentation, we estimate geothermal potential based on petrologic, mineralogic and fluid inclusion study of host granitic rocks and mineral filling veins.

Keywords: the deep geothermal reservoir, brittle-ductile transition zone, geothermalfluids, mineral filling veins

Channeling flow generated by dissolution of granite fracture under hydrothermal conditions.

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Fractures act as dominant fluid pathways within the crust, and provide significant influences on transport of energy and heat. As silica solubility increases with increasing pressure and temperature, dissolution and precipitation of silica would provide significant effects on fracture permeability in the crust. Even for mineral dissolution within a single fracture, dissolution at free (non-contact) areas increases the aperture, whereas that at the contact areas decreases the aperture; therefore it is not clear how fracture permeability evolves by mineral dissolution under confining pressure.

The aim of this study is, based on the hydrothermal flow-through experiments, to reveal a porosity structure and permeability evolution during the dissolution of granite fracture. We developed a novel reactor, which enables us flow-through experiment under confining pressure at sub to supercritical condition (up to 350 ℃, and examined the porosity structure by X-ray CT repeatedly. In the experiments, fine-grained Aji granite core (Φ10 mm, 400 mm in length) was used. We conducted two series of hydrothermal experiments. First one is fluid flow through a slit (parallel plates) in the rock core. The analyses of solution chemistry passing through the slit and surface morphology revealed that quartz dissolved preferentially; Qtz was dissolved about five times greater than plagioclase.

Second experiments were performed with a tensile fracture introduced by Brazilian test, in which there was no shear displacement. In this fracture, very fine-grained gouge (granite powder) existed within some parts of the core sample. This experiment was conducted in three steps; at all steps, the fluid pressure was 20 MPa and confining pressure was 40 MPa (the effective pressure of 20 MPa). The first step was the flow through experiment (0.5 ml/min) at room temperature. At this stage (0-140h), fracture permeability decreased from 2.3×10^{-10} to 6.7×10^{-12} (m^2), which is consistent with decrease in mean aperture from 65 to 36 μm revealed by X-ray CT images. At the second step (140-290 h), the core sample was set without fluid flow (stagnant fluid) at 350 ℃. At this stage, permeability continuously decreased from 6.7×10^{-12} to 4.0×10^{-12} (m^2), corresponding to the decrease in aperture from 36 to 21μm. During the interval of stages 1 and 2, the aperture decreased uniformly for the entire fracture plane. These finings indicate that the aperture decrease attributes to the compaction of gouges within the fractures. At the final stag (290-300 h), flow though experiment (0.5 ml/min) was conducted at 350 ℃. At this stage, permeability recovered immediately toward 8.5×10^{-12} (m^2), and complex aperture structure was developed by mineral dissolution. Preferential dissolution occasionally occurred at the quartz grains as found in the experiment with a slit, but an interesting feature is that connected porosity network was developed regardless the minerals on the fracture plane. A flow simulation with using the X-ray CT-based 2D aperture distribution indicates that the preferential flow path (channeling flow) was developed along this porosity network. We interpret that this flow path was developed by preferential dissolution of gauge in the fracture. In contrast, the preferential dissolution of quartz does not contribute the flow due to the isolated distribution of quartz in granite. In natural settings, gauge was produced in fractures during fracturing or faulting of a rock. Our experiments suggest that, even when the initial aperture was very small for these gauge regions, the preferential dissolution occur due to significant surface areas of the gauges, which would significant effects on the formation of the preferential flow path under hydrothermal conditions.

Keywords: Channeling flow, dissolution, hydrothermal

Mechanical and Hydraulic Characteristics of Rock Fracture Under Brittle-Ductile Transition

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A new concept of Enhanced Geothermal System (EGS), in which geothermal fluids are produced from a fractured reservoir created artificially within an originally semi-brittle or ductile basement, has been proposed . To assess the potential of the new geothermal system, the “Japan Beyond-Brittle Project (JBBP)”has also been recently initiated, and the author have conducted fundamental investigations on mechanical and hydraulic characteristics of the new type of reservoir, in which the rock is first experiences hydraulically and/or thermally induced brittle failure, and then subjected to the temperature and pressure conditions where the rock exhibits semi-brittle or ductile stress-strain behavior at the natural condition. Kawarago tuff have been used in the present study, because brittle, semi-brittle and ductile stress-stain behaviors of the tuff specimen can be controlled only with confining stress level at the room temperature . At confining stresses up to 40 MPa, tri-axial compression and fluid flow experiments have been conducted on the specimens without and with thermal fracture.

Keywords: brittle-ductile transition zone, EGS, Mechanical Characteristics, Hydraulic Characteristics

The formation rate of quartz vein along seismogenic megasplay fault Nobeoka Thrust, southwestern Japan

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Precipitation of minerals has a role to fill the fractures, to form mineral veins, and to affect spatial and temporal change of the permeability of the Earth's crust. However, the change of permeability of crustal rocks has been discussed based on the geophysical properties, not on the geochemical reactions as dissolution-precipitation of minerals. Based on the ubiquitous observation of quartz veins and silica sinters, silica polymorphs are one of the most effective minerals on permeability change. Okamoto et al. (2012) and Saishu et al. (2012) revealed that precipitated silica minerals and precipitation rate depend on the concentrations of minor components in the fluid by the precipitation experiments at 430 ℃ and 30 MPa. Saishu et al. (2014) also revealed that the depth of the local minimum of quarts solubility where the quartz precipitation is dominant reaction correlates to that of the permeable-impermeable boundary at the Kakkonda geothermal field.

Fault zones including the damage zone and the fault core have a controlling influence on the crust's mechanical and fluid flow properties. In the Nankai subduction zone, southwestern Japan, the velocity structures indicate the contrast of the pore fluid pressure between hanging wall and footwall of the megasplay fault (Tsuji et al., 2014). At Nobeoka Thrust, a major fault bounding the northern and southern Shimanto belt of the Cretaceous-Tertiary accretionary complex in Kyushu, southwestern Japan, the microchemical features of syn-tectonic mineral veins along fault zones of the Nobeoka Thrust provide evidence of temporal fluctuations in redox state during repeated earthquake cycles within a seismogenic megasplay fault in an ancient subduction zone (Yamaguchi et al. 2011). The measurement of the strike, dip, width and length of the quartz veins that fill mode I cracks (extension quartz veins) around the fault zone of the Nobeoka Thrust indicated that the fluid driving pressure ratio P* at the time of fracture opening are 0.15-0.40 in the hanging wall and footwall, respectively (Otsubo et al., 2015). Otsubo et al. (2015) suggested two possible explanations for the observed spatial variations in P*: spatial variations in pore fluid pressure P_f are directly responsible for P* variations, or P* variations are controlled by differences in mechanical properties between the hanging wall and footwall.

In this study, the amount and rate of silica precipitation for the formation of the extension quartz veins of the Nobeoka Thrust were calculated to consider the relationship between the time frequency of fracture opening-closing and the precipitation of silica minerals. The initial pressure was lithostatic condition. Basically, the larger pressure drop enhances the larger amount of silica precipitation and the faster sealing of cracks. However, the precipitation rate depends not only PT conditions but also the host rock and fluid compositions etc. The time for the formation of quartz vein at Nobeoka Thurust was estimated in the various models, for example, that pressure drop from lithostatic to lithostatic, hydrostatic, and atmospheric pressure.

References: Okamoto et al. (2010) GCA., 74, 3692-3706; Otsubo et al., (2015) AGU abstract; Saishu et al. (2012), Am.Min., 97, 2060-2063; Saishu et al. (2014) Terra Nova, 26, 253-259; Tsuji et al. (2014) Earth Planet. Sci. Lett., 396, 165-178; Yamaguchi et al. (2011) Earth Planet. Sci. Lett., 302, 369-377.

Keywords: Nobeoka Thurust, Quartz vein, Precipitation rate

Availability of magnetoelluric resistivety survey to explore deep geothermal resources

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A supercritical geothermal resource, which exists at a deeper part than a brittle-ductile transition, can be one of the dominant renewable energy sources in a volcanic zone. In order to find an appropriate field for utilizing this resource, highly accurate geophysical explorations should be required. A resistiveity exploration including the magnetotelluric (MT) method is considered to be a powerful tool for this purpose because resistivity is very sensitive to existence and connectivity of fluids in rocks. We estimated an availability of the MT method to explore such a deep geothermal resource, applying the 3-D resistivity simulation.
We composed 3-D resistivity models to demonstrate geothermal fluids beneath old calderas in NE Japan, which included surrounding seawater and sediments. At first, the conventional MT method examined different bottom depths of the conductive body (=fluids zone). The MT responses from these different cases were compared. All models showed considerable response changes, which were more than 20% compared with the non-conductor model. The existence of the conductor itself can be identified by inversion analysis. However, the change was less than 5%, comparing the response between the models with the 6km and 10 km bottom depths. It might be difficult to identify this difference by any resistivity inversions because the estimated changes were smaller than observational errors.
Next, we calculated the MT responses in the situation that both the electric and magnetic fields were measured in the earth. The different measurement depths were examined. The calculated responses showed the highest change in the case that the measurement depth was deeper than an overlying conductive layer (e.g. sediments). This situation is similar to marine electromagnetic explorations. However, it is technically too difficult to measure the electric field in the earth.
Finally, we calculated the MT like response in the situation that the magnetic field was measured in the earth, while the electric field was on the surface. This trial also showed the highest response change in the case that the magnetic measurement depth exceeded a conductive layer. Thus, the downhole magnetic field measurement can drastically improve the accuracy of the MT method. A development of the magnetometer to be available under the condition in high- temperature and pressure should be required in order to realize this method.

Keywords: geothermal, resistivity structure, magnetotelluric method

Physicochemical properties of water confined between quartz surfaces at elevated temperatures by molecular dynamics simulation

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Interfacial water, of which physicochemical properties were different from bulk water, was recognized in the vicinity of solid surface. The physical properties of interfacial water show unique characteristics, for example the self-diffusion coefficient, thermal expansion coefficient and freezing point. The property of interfacial water is essential for understanding geophysical and geochemical phenomena.

Although the phenomena of interfacial water have been studied theoretically and experimentally, the dynamics of the interface at high temperature and pressure remains unclear. In this study, we performed the molecular dynamics (MD) simulations to understand the structure and dynamics of water confined between quartz surfaces at 298-573 K, 10 MPa.

We tested some systems of water confined between quartz surfaces characterized by the termination of silanol (Si-OH) group. At low temperature, the density profiles showed several layered structures near the surface, and the self-diffusion coefficient was reduced in 1.0 nm distance from the surface. At high temperatures, the layered structures were disappeared and the self-diffusion coefficient was reduced in 1.5 nm.

The activation energies of the diffusion process in confined geometries were calculated based on the Arrhenius theory, and these values were close to that of bulk water. This implied that the diffusion mechanism in confined geometries is similar that in bulk and the activation energy may be interpreted by the dissociation energy of hydrogen bond.

Based on these results, the relationship of between geophysical phenomena and interfacial water will be discussed.

Keywords: interfacial water, quartz, Molecular dynamics, self-diffusion coefficient

