Japan Geoscience Union Meeting 2015
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SMP44-01 会場:102B 時間:5 月 25 日 09:15-09:30

深部掘削データからみえる地熱地帯のシリカ溶解度の特性
Characteristics of silica solubility in the geothermal fields presented by the deep drilling data

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Permeability is one of the important parameters for geological events and the development of geothermal systems. Water-Rock Interaction has a role for spatial and temporal change of permeability in the Earth's crust, although geophysical properties have been mainly focused on. Especially silica is one of the dominant components in the Earth's crust, thus dissolution-precipitation of silica minerals is an important geochemical reaction in the crust. The permeable-impermeable boundary is regarded to consist of the brittle-ductile transition (BPT) at around 300-450 degree C (Scholz, 2002). The depth of the boundary is typically at 10 to 20 km depth (Ingebritsen and Manning, 2010), which is too deep and too strict to be observed by drilling. Therefore, the structure of the Earth's crust has been studied by indirect geophysical measurements and experiments, not by geological observation and geochemical analysis.

In the geothermal field, however, some deep drilling wells are expected to reach the permeable-impermeable boundary at around 3 km depth because of high temperature gradient. The deep drilling wells in Italy, Iceland, and U.S.A. recorded higher pressure than hydrostatic pressure at the bottom of these wells (Fournier, 1991). The deep drilling well WD-1a at the Kakkonda geothermal field, Japan, is the only well in the world to penetrate the boundary between the hydrothermal-convection zone and the heat-conduction zone (permeable-impermeable boundary) at 3.1 km depth, in 24 MPa and 380 degree C (Doi et al., 1998), which is in the supercritical conditions of water. The Kakkonda granite at >2.9 km depth is the heat source of the hydrothermal system of the Kakkonda geothermal field. Saishu et al. (2014) calculated quartz solubility along the well WD-1a, and revealed that the local minimum of quartz solubility consists of the permeable-impermeable boundary at 3.1 km, indicating the possibility that a large amount of quartz precipitate induce fracture sealing, blocking the downflow to the impermeable zone, and control the depth of the permeable-impermeable boundary.

In this study, quartz solubility is calculated to reveal the relationship between the permeability and dissolution-precipitation of silica minerals in the 4 deep drilling wells recorded overpressure at the bottom: (1)San Pompeo 2, Italy, (2)the well NJ-11, Iceland, (3) Wilson No. 1, U.S.A., and (4) San Vito 1, Italy. In the geothermal fields, including the Kakkonda geothermal field, the condition at the permeable-impermeable boundary is in or near the supercritical conditions of water, and quartz solubility decreases and increases drastically in hydrostatic and lithostatic pressure, respectively. If fracturing occurs at the boundary, downward fluid from the shallower part would dissolve large amount of silica and enhance quartz precipitation due to decrease of quartz solubility in deeper part. In addition, upward fluid of high quartz solubility from the over pressure zone would also trigger precipitation of quartz because of pressure decrease. Thus, in the geothermal field, the permeable-impermeable boundary would be controlled by precipitation of silica minerals.

References) Doi, N., Kato, O., Ikeuchi, K., Komatsu, R., Miyazaki, S., Akaku, K., and Uchida, T., 1998, Geothermics, 27, 663-690.; Fournier, R.O., 1991. Geophys. Res. Lett., 18, 955-958.; Ingebritsen, S.E. and Manning, C.E., 2010, Geofluids, 10, 193-205.; Saishu, H., Okamoto, A., Tsuchiya, N., 2014, Terra Nova, 26, 253-259.; Scholz, C.H., 2002, 2nd edn. Cambridge University Press, Cambridge.

キーワード: シリカ溶解度, 析出反応, 深部掘削, 地熱地帯, 透水ー不透水境界
Keywords: silica solubility, precipitation, deep drilling, geothermal field, permeable-impermeable boundary

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電磁探査で見る脆性地殻の下の流体分布
Electromagnetic imaging of fluids under the brittle crust

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This paper presents a 3D inversion result of the magnetotelluric soundings over the caldera regions in the central part of NE Japan arc. The 181 MT stations in total were located around the Naruko volcano with ˜3km grid covering the area of 40km (EW) x 80km (NS). We have used the full tensor components of impedance tensors at representative eight periods (0.4˜1300s). The inversion code of WSINV3DMT was used. The initial model had a uniform earth of 100 ohmm with surrounding oceans (0.25 ohmm). The final model gave rms of 2.5 with error floor of 10%. Significant features of the model are the thick resistive upper crust in the caldera regions and sub-vertical conductors arising from the lower crust to the geothermal manifestations. The top of such sub-vertical conductor coincides with the cutoff depth of the shallow seismicity. In particular, the sub-vertical conductor at Naruko volcano has a deep root in the mid-to-lower crust underneath the Mukaimachi Caldera, which is located 20km west of the Naruko volcano. The supply of the high salinity fluid may be originated sideways and may imply the path of the fluids, which is presumably blocked by the impermeable consolidated volcanic rocks directly above the lower crustal conductor. The resistivity of the mid-to-lower crustal conductors is significantly low at the Naruko volcano, compared with those at Sanzugawa caldera to the north. The difference may be due to the salinity as well as the porosity of the fluid, because seismic tomography result does not show such differences. A helium isotope anomaly at Naruko volcano may support that the flux from the upper mantle is large.
Keywords: fluids, brittle crust, resistivity, electromagnetic induction, magnetotelluric method

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花崗岩の透水-難透水遷移および弾性-塑性遷移
Permeable-Impermeable or Elastic-Plastic Transition of Granite

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近年，再生可能エネルギー開発の分野で地熱エネルギーが注目されている．既往の地熱貯留層は比較的低温・低圧領域に形成されるため脆性的な力学挙動を示し，逸水や誘発地震を引き起こしてしまう．一方，超臨界流体となる高温・高圧環境下における地熱貯留層の形成はこれらの課題を解決し，さらに高いエネルギーを生み出す可能性がある．しかし，この領域では岩盤が延性的な力学挙動を示すと考えられており，透水率といった水理特性の評価が困難である．

本発表では稲田花崗岩に対し，力学的に半脆性～延性領域を示す温度・圧力条件の解明と各領域における水理特性の解明に関する研究について報告する．まず所望の環境下における水理学試験を行える実験システムを開発した．実験条件は温度 350，380，400，450 ℃，有効封圧 5，10，20，30，40，50，60，70，80，90MPa に設定し，間隙流体は 1～2MPa に定圧制御しながら試料内を透過させた．その結果，花崗岩の透水率が急激に低下する脆性-延性（弾性-塑性）遷移の圧力依存性が各温度条件で異なることを明らかにした．また，脆性領域と延性領域での透水率の減少率から透水率および力学挙動を予測する方法を見出した．

キーワード: 地熱貯留層, 花崗岩, 弾性-塑性遷移, 浸透率予測
Keywords: geothermal reservoir, granite, elastic-plastic transition, predicting permeability

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メルト包有物解析による地熱資源深度の評価：宮城県白沢カルデラの例
Depth estimation and evaluation of geothermal resource by melt inclusion analysis

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地熱発電は日本において資源量が豊富なことが長所であるが調査から稼働までに期間を要することが課題である。資源量の分布調査には容積法、より狭い地域での貯留層評価等が用いられる。それら方法の一つとして熱資源・地下水に関する評価のため、噴出前のマグマ組成を残す結晶中のメルト包有物解析による評価法を提案したい。本研究では地熱探査の未探査地域を対象に噴出物中の石英結晶に含まれるメルト包有物を解析することでマグマの温度・圧力を決定し、そのデータを用いた地熱資源評価方法の開発を行うことを目的とする。

仙台市西方に位置する白沢カルデラは鮮新世後期に噴出、カルデラ中心は古仙台湖に堆積した白沢層に覆われる。地震波探査によりカルデラ地下 2~5 km に高温領域 (低速度域) が地震波探査によって確かめられている。[1]

試料は白沢カルデラ北端から 4 試料、中心から南側にかけて 8 試料を採取した。岩相は凝灰質砂岩、凝灰角礫岩、軽石凝灰岩に分類される。

噴出物から石英結晶をピックアップし、樹脂で固化したものを研磨し薄片とした。EPMA を用いて Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K,P の 10 元素を定量分析した。北側 3 試料は石英が微量・微小のため分析を行うことができなかった。

EPMA によって石英に含まれるメルト組成を分析し、ノルム計算により石英 (Qtz)・曹長石 (Ab)・カリ長石 (Or) の割合を推定した (Fig.1)。マグマが冷却される際の圧力によって共融線の位置が変化するため、Qtz-Ab-Or ダイアグラム上のプロットと共融線 [2] から晶出した圧力を決定した。

カルデラ中央－南側から 8 試料を採取し解析した結果、試料の殆どは低アルカリソレアイト質流紋岩、カルデラ北端の 1 試料 (09) は高アルカリソレアイト質流紋岩に分類された。メルト包有物 44 点を計測して求めた鉱物割合は Qtz:30~43 %, Ab:35~52 %, Or:9~26 %であり、一部を除きほぼ直線上にプロットされる。晶出圧力は 0.1~320 MPa であり、その多くは 30~50 MPa に集中する。一部試料 (2305) の圧力は 5~320 MPa にプロットされ石英中のメルト包有物は Ab-Qtz 相図の共融点の組成を保ったまま上昇したと考えられる。流紋岩質マグマ密度を 2.0 g/cm^3 とすると深度は地下 16~1.5 km と見積もられる。マグマは地下約 16 km から上昇、1.5~2.5 km で平衡状態になり、その後噴出したと推測される。その他の試料においても晶出は同程度の深度を示す。結晶成長に伴い揮発成分濃集により圧力上昇、噴出したと考えられる。地震波探査による高温領域深度と圧力から求められたマグマ深度は矛盾しない。また Or に富む試料は採取地点から他マグマ溜まり由来のものであると考えられる。

本研究ではこれらのデータから地下のマグマ溜まりの温度について議論する。

[1] Sato et al. (2002) Earth Planets Space, 54,1039-1043.
[2] Blundy .and Chashman (2001) Contrib.Mineral.Petrol,54,631-350.

キーワード: メルト包有物, 白沢カルデラ
Keywords: melt inclusion, Shirasawa caldera

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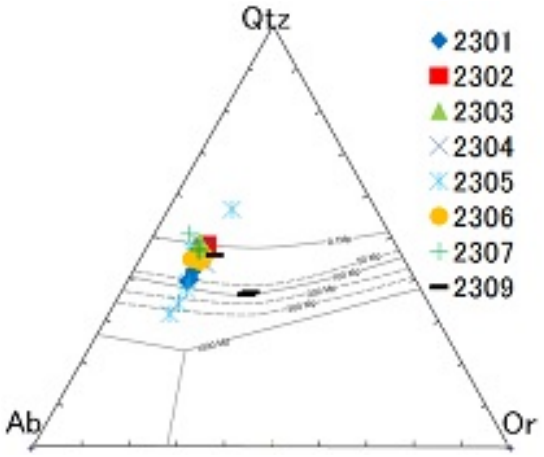

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き裂の鉱物溶解にともなう空隙構造変化と透水率減少
Porosity structure and permeability reduction by mineral dissolution in a fracture

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

In this study, we conducted the hydrothermal flow-through experiments at 350 ℃, 20˜34MPa under confining pressure 10˜15MPa to understand the evolution of porosity structure of a fracture and permeability change in granite by mineral dissolution. For this purpose, we developed a novel reactor, which has a inner tube in the vessel. Two types of granite core (Aji granite, ϕ10mm) were used, first one (85mm length) contained a slit with thickness of 0.5mm as parallel prates flow path. The other one contained the tensile fracture with no shear displacement. During the experiments under constant flow rate, we monitored the fluid pressures, and periodically sampled the solutions. After the experiments, we analyzed the porosity structure by X-ray CT (resolution was 10μm/pixel).

In slit-core experiment, the concentrations of Si was 100˜120 mg/kg, whereas the concentration of Al, Na, K were 7, 5 and 8 mg/kg respectively, indicating that the ration of dissolved volume of quartz, plagioclase and K-feldspar are 10:2:1. The X-ray CT also revealed that preferential dissolution of quartz, and that the average aperture increases especially near the inlet.

In tensile fracture experiment, fracture permeability decreased continuously from 10^{-13} to 10^{-15} (m^2) during the experiment of 90h. An increase in flow rate did not enhance the reduction whereas that in confining pressure accelerated the permeability reduction. The X-ray CT images revealed the complex structure of porosity: quartz dissolution made the local increase in the aperture, but the overall aperture decreased by dissolution of quartz and feldspar at contact areas, which is responsible the permeability reduction.

キーワード: 透水率, き裂, 水熱実験, 溶解
Keywords: permeability, fracture, hydrothermal experiment, dissolution

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超臨界地熱貯留層のナチュラル・アナログ
Natural Analogue of Supercritical Geothermal Reservoir

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To understand the geological properties of a supercritical geothermal reservoir, we investigated a granite?porphyry system as a natural analog. Quartz veins, hydrothermal breccia veins, and glassy veins are present in Neogene granitoids, Tohoku Japan. The glassy veins formed at 500-550 C under lithostatic pressures, and then pressures dropped drastically. The solubility of silica also dropped, and the quartz veins formed under hydrostatic pressures. Connections between the lithostatic and hydrostatic
pressure regimes were key to the formation of the hydrothermal breccia veins, and the granite?porphyry system provides useful information for understanding supercritical geothermal reservoirs.

キーワード: 超臨界流体, 地熱貯留層, 花崗岩－斑岩システム
Keywords: Supercritical fluid, Geothermal reservoir, Granite-Porphyry system