Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SMP47-01 Room:203 Time:May 22 11:00-11:15

Volcanology and scientific drilling

Setsuya Nakada[1]*

[1]Earthquake Research Institute, The University of Tokyo

Drilling in volcanic fields is important to obtain an understanding of subsurface three-dimensional geological and thermal structures for not only volcanological interests but also geothermal development and disposal of radioactive waste. In addition, monitoring using drilled hole is an advantage for understanding of movement and circulation of fluids including magma to forecast volcanic eruptions and to evaluate geothermal potential.

Volcano and magma development histories were revealed by deep drilling at Mauna Kea volcano (Hawaii), Unzen volcano, Fuji volcano, etc. Challenging drilling was carried out into a hot basalt lava lake and a volcanic conduit of a recently erupted Kilauea volcano (Hawaii) and Unzen volcano, respectively. During geothermal drilling at Kakkonda and in Iceland, a solidifying magma chamber and rhyolite magma, respectively, were accidentally drilled. Three-D subsurface structures under caldera volcanoes have been understood by carrying out geothermal drillings at Long Valley, Aso, and Nigorikawa calderas. Many of new volcanological knowledge came from drilling projects in volcanic fields including those for geothermal development.

Keywords: International Continental Scientific Drilling Program, subsurface structure of volcano, development history of volcano, volcanic observation, volcanic disaster prevention

SMP47-02 Room:203 Time:May 22 11:30-11:45

Summary of the geothermal survey well WD-1a penetrating to the brittle-plastic boundary in the Kakkonda geothermal field

Tomoyuki Ohtani[1]*, Hirofumi Muraoka[2]

[1]Dept. Civil Engineering, Gifu University, [2]North Japan Research Institute for Sustainable Energy, Hirosaki University

The summary of the geothermal survey well ”WD-1a” penetrating the brittle-plastic transition in the Kakkonda geothermal field of NE Japan is necessary to discuss the thermal energy extraction from the region deeper than the brittle-plastic transition. The WD-1a was drilled by the New Energy and Industrial Technology Development Organization (NEDO) as part of the ”Deep-seated Geothermal Resources Survey” project. It was 3729 m deep and the temperature at the bottom of the hole was estimated to be more than 500 ?C (Ikeuchi et al., 1996; Kato et al., 1996). This borehole penetrated the Quaternary and Tertiary volcanic rocks and the pre-Tertiary sedimentary rocks, and encountered the Kakkonda granite at 2860 m depth (Kato et al., 1996). The Kakkonda granite continues to the bottom of the hole. K-Ar ages of biotite and hornblende from the Kakkonda granite range from 0.068 to 0.21 Ma and 0.08 to 0.34 Ma, respectively (Kanisawa et al., 1994).

From the viewpoint of the brittle-plastic transition, the boundaries of hydrothermal convection and conduction zones (Ikeuchi et al., 1996), seismic and aseismic zones (Tosha et al., 1995), and low and high resistivity zones related to fracture distribution (Kato et al., 1996) are present at a depth of about 3 km. These lines of evidence suggest that the WD-1a penetrates the brittle-plastic transition (Muraoka, 1997). The geothermal reservoir with fractures is developed in the region above 3 km depth and lower than 350 oC (Kato et al., 1996), while few deformation features are recognized below 3 km depth and higher than 350 oC. The drill core of WD-1a collected from 2936 to 2937 m includes the miarolitic cavities in the granite. The three-dimensional shape measurement of these cavities using the X-ray CT (Ohtani et al., 2000) and the ellipsoid fitting indicate that the minor axes of ellipsoids are preferred to E-W direction. This suggests that the cavities show the N-S shortening due to the effect of regional stress (Ohtani et al., 2001).

From the viewpoint of the thermal energy extraction, the Kakkonda geothermal field consists of shallow hydrothermal convection zone, contact metamorphic aureole, deep hydrothermal convection zone, and plastic zone toward the deeper part, and the hydrothermal convection for the conventional flash power generation is not occurred in the plastic zone (Muraoka et al., 1998). Therefore, the thermal energy extraction from the plastic zone needs new technology development such as EGS (Enhanced Geothermal Systems).

Ikeuchi et al., 1996, Geotherm. Res. Coun. Trans., 19, 598-505.
Kanisawa et al., 1994, Jour. Min. Petr. Econ. Geol., 89, 390-407.
Kato et al., 1996, Proc. 8th Int. Symp. on the Observation of the Continental Crust Through Drilling, 241-246.
Muraoka, 1997, Geotherm. Res. Coun. Trans., 21, 309-316.
Muraoka et al., 1998, Geothermics, 27, 507-534.
Ohtani et al., 2000, Eng. Geol., 56, 1-9.
Ohtani et al., 2001, Jour. Struct. Geol., 23, 1741-1751.
Tosha et al., 1995, Bull. Geol. Surv. Japan, 46, 483-495.

Keywords: brittle-plastic boundary, geothermal survey well, WD-1a, Kakkonda geothermal field

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SMP47-03 Room:203 Time:May 22 11:45-12:00

High fluid pressure and triggered earthquakes in the enhanced geothermal system in Basel, Switzerland

Toshiko Terakawa[1]*, Stephen A. Miller[2], Nicholas Deichmann[3]

[1]graduate School of Environmental Studies, Nagoya University, [2]Geodynamics/Geophysics, Steinmann-Institute, University of Bonn, [3]Swiss Seismological Service, ETH-Zurich

We analysed 118 well-constrained focal mechanisms to estimate the pore fluid pressure field of the stimulated region during the fluid injection experiment in Basel, Switzerland. This technique, termed focal mechanism tomography (FMT), uses the orientations of slip planes within the prevailing regional stress field as indicator of the fluid pressure along the plane at the time of slip. The maximum value and temporal change of excess pore fluid pressures are consistent with the known history of the wellhead pressure applied at the borehole. Elevated pore fluid pressures were concentrated within 500 m of the open hole section, which are consistent with the spatio-temporal evolution of the induced microseismicity. Our results demonstrate that FMT is a robust approach, being validated at the meso-scale of the Basel stimulation experiment. We found average earthquake triggering excess pore fluid pressures of about 10MPa above hydrostatic. Over-pressurized fluids induced many small events ($M < 3$) along faults unfavourably-oriented relative to the tectonic stress pattern, while the larger events tended to occur along optimally-oriented faults. This suggests that small-scale hydraulic networks, developed from the high pressure stimulation, interact to load (hydraulically isolated) high strength bridges that produce the larger events. The triggering pore fluid pressures are substantially higher than that predicted from a linear pressure diffusion process from the source boundary, and shows that the system is highly permeable along flow paths that allow fast pressure diffusion to the boundaries of the stimulated region.

Keywords: pore fluid pressure, stress, focal mechanisms of seismic events, inversion analysis, fluid injection

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SMP47-04 Room:203 Time:May 22 12:00-12:15

Characteristics of felt earthquakes occurred from geothermal field

Yusuke Mukuhira[1*], ASANUMA, Hiroshi[1], WYBORN, Doone[2], HARING, Markus[3], ADACHI, Masaho[4]

[1]Graduate School of Environmental Studies, Tohoku Univ., [2]Geodynamics Ltd., Australia, [3]Geo Explorer Ltd., Switzerland, [4]Okuaizu Geothermal Co., Ltd., Japan

The authors have reviewed three significant cases of the felt earthquakes occurred from geothermal field, Cooper Basin, Australia, Basel, Switzerland, and Yanaizu-Nishiyama, Japan. Recently, the occurrence of felt earthquake from the geothermal reservoir has become critical issue in geothermal development. Microseismic activity is observed in many of hydrothermal reservoirs. It is also common that the microseismic events occurred at hydraulic stimulation of EGS/HDR reservoirs. However, some of the micro earthquakes have unexpectedly so large magnitude and they were felt on the surface. The physics behind such felt earthquakes were not well understood so far.

1. Cooper Basin, Australia

Geodynamics ltd. developed HFR system at Cooper Basin. During the hydraulic stimulation and initial hydraulic test in 2003, several felt earthquakes occurred. The magnitude of the largest seismic events was estimated as Mw =3.0 by Geoscience Australia. The felt earthquakes occurred over initial hydraulic test and after shut-in. Hypocenters of the felt earthquake were located widely in the seismic cloud, although, geological structures where the felt earthquakes occurred were not observed. The source mechanism of the felt earthquakes may be common to other smaller events because of identical first motion of the P-wave at monitoring station. Spatio-temporal analysis revealed that the felt earthquakes occurred at the edge of the seismic cloud and then, the seismic cloud extended to the aseismic zone. Many small events were observed within the fault area of the felt earthquake as after shocks. So, it is concluded that the felt earthquake occurred from the asperity which play a role of the hydraulic barrier.

2. Basel, Switzerland

GEL (Geothermal Explorer Ltd.), an operating company of the Basel Project, conducted hydraulic stimulation in 2006 at Basel urban area. First felt earthquake with Mw =2.0 occurred at 5th day of the hydraulic stimulation. Then, following felt earthquakes including largest one with Mw =2.68 took place just after the shut in from the deep and middle part of the seismic cloud. After one month of the stimulation or later, three large events still occurred and their hypocenters were located in the middle or shallow part of the seismic cloud. Three felt earthquakes from deep part of the seismic cloud were likely occur from common fault plane and showed high similarity in waveforms to the smaller events. However, no apparent extension of the seismic area was observed. In contrast, the similarity in waveform between the felt earthquakes from shallow part of the reservoir was low, suggesting that mechanism was not identical to that of smaller events. In fact, hypocenters of felt earthquakes from shallow part of the reservoir were located outside of the seismic cloud.

3. Yanaizu-Nishiyama, Japan

Geothermal power plant at Yanaizu-Nishiyama, Fukushima, Japan has a 65,000 kW of the capacity and has been operated by Okuaizu Geothermal Co. Ltd. (OAG) since 1995. The hydrothermal reservoir is consisted by caldera-related fracture system and the reservoir is steam-dominant at around 2 km depth. There has been seismic activity for long years in this area and micro earthquakes were surely observed before the operation of the power plant. The hot water is re-injected by gravity feed. Large earthquake were sometimes observed in this area. Largest earthquake with JMA magnitude 4.9 occurred on October, 2009. There was no clear correlation between the operations of production/injection and the occurrence of the felt earthquakes. These felt earthquakes had hypocenters within the cloud of micro earthquakes. FPSs estimated by JMA for four felt earthquakes showed same normal fault plane of NW-SW strike and around 45 deg. of inclination. However, seismic structure where the many of the smaller events occurred had more different orientations. It is interpreted that the felt earthquakes were likely to occur from fracture plane in particular nature.

Keywords: Microseismicity, Felt earthquake, Magnitude, Cooper Basin, Basel, Yanaizu-Nishiyama

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SMP47-05 Room:203 Time:May 22 12:15-12:30

model of induced seismicity from JBBP-type EGS reservoirs

Hiroshi Asanuma[1]*, Yusuke Mukuhira[1]

[1]Graduate School of Environmental Studies, Tohoku University

Induced seismicity is typically observed at EGS (Engineered Geothermal Systems) reservoirs while its creation and circulation/production phases. Many of the hydrothermal reservoirs also have natural or induced seismic activity. The microseismicity has been effectively used as one of the few means which have ability to resolve reservoir extension and structure with practically acceptable resolution. However, some of the seismic events have large magnitude and they brought some degree of damages to houses and infrastructures on the ground surface. In the JBBP, the authors expect that the activity and released energy of the induced seismicity will be reduced, because the reservoir would be isolated in less fractured rock mass in the BDT, and the creation process of the reservoir woulud be different from that in the ductile zones. The authors will disucuss risk of induced seismicity with large magnitude from the JBBP reservoirs showing some possible models of the reservoirs.

Keywords: EGS, Induced seismicity, Stimulation

Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

SMP47-06 Room:203 Time:May 22 12:30-12:45

The role of geophysical exploration in detecting and monitoring enhanced geothermal system (EGS)

Toru Mogi[1]*, Toshihiro Uchida[2]

[1]Fac.Sci.,Hokkaido Univ., [2]AIST

The discovery of enhanced geothermal systems (EGS) prescribes the need for novel technology to detect high-temperature areas and monitor fluid contents at depth. To minimize cost and risk, engineers attempt to predict reservoir performance, for both planning and evaluation of geothermal resource development projects. Correct predictions of reservoir performance hinge on how well the reservoir is understood and has been described in the models used for fluid-flow simulation. An important role of the geophysical survey is to provide basic data for a reservoir simulation.

Imaging hot rock and fracture zones and monitoring fracture growth deep in the earth at 3 to 5 km is not a simple task. Regional survey methods such as gravity and airborne magnetic surveys are usually used to delineate regional geologic settings. Some researchers have examined the feasibility of using Curie isotherm depths, estimated from magnetic anomalies, as a proxy for lithospheric thermal structure.

The three-dimensional (3D) magnetotelluric (MT) survey method provides a relatively inexpensive way to obtain accurate images based on electrical conductivity, but the resolution in deeper areas is inherently low. MT is sensitive to conductors, making it a prime method for detecting electrically conductive fluids at depth. The areal extent of a reservoir at depth can be estimated by measuring the MT response before, during, and after fluids are injected. Forward modeling and repeatability estimates will be covered.

The 3D seismic survey method allows for imaging deep fractures with higher resolution. A P-wave reflector is detected at the top of a deep fractured layer, which must lie at the brittle?ductile transition and may be common in areas with magmatic activity. However, performing 3D land seismic surveys in areas with topographic variation is challenging. Even if such a survey could be performed, it would be difficult to image fractures in a crystalline formation because the aperture of the fracture is likely to be thinner than a quarter of the wavelength of the surface seismic wave. Most significantly, it may not be practical to monitor the growth of a fracture using 3D seismic surveys because of high cost.

Reflection imaging with micro-earthquakes generated during stimulation is a possible method for defining major flow paths in deep crystalline formations. The advantage of micro-seismic imaging is its higher frequency spectrum (up to several hundred hertz), meaning that thin fractures can be imaged.

Reservoir characterization, particularly in terms of reservoir architecture, flow paths, and fluid-flow parameters is the key to good reservoir engineering. Geophysical methods will play a central role in future reservoir characterization and in improving EGS monitoring.

Keywords: Geophysical Exploration, Geoteramal Resource, Enhanced Geothermal System