Japan Geoscience Union Meeting 2013
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HRE29-P01 Room:Convention Hall Time:May 22 18:15-19:30

Coupled fluid flow and geomechanical modeling in geological CO2 storage: Application to Matsushiro phenomena

Takahiro Funatsu[1*], Yasuko Okuyama[1], Xinglin Lei[1], Shinsuke Nakao[1]

[1]Institute of Geo-Resources and Environment, AIST

The mechanical responses of CO2 reservoir and the caprock around the storage region become crucial for Japanese geological CO2 storage (GCS) after the M9.0 East Japan earthquake on March 11, 2011. The CCS Research Committee, METI (Ministry of Economy, Trade and Industry), recommended to screen out areas having a large-scale faults in the process of selection of storage site for 105t-scale demonstration (2009). Although the site for the planned demonstration adequately selected, we do not exclude fully at present the possibility of GCS reservoir failure and/or leakage of stored CO2 from GCS site(s) elsewhere in Japan caused by geomechanical motions.

The examples of such phenomena are the re-activation of pre-existing faults, induced seismicity, reservoir failure and unintended uplift and so on, some of which are observed in an actual demonstration site (Mathieson et al., 2009; Vasco et al., 2010; Onuma et al., 2011).

The unintended phenomena listed above are essentially connected with stress filed changes due to the increase in pore pressure, around the area of GCS, which is inevitable as GCS injects pressurized CO2 into an underground reservoir. The rise in pore pressure reduces an effective confining stress to modify the conditions toward the critical failure line of Mohr-Coulomb law. The change in pore pressure is most probably cause micro-scale (or, pore-scale) deformations within the rocks, which will give rise to the changes in rock permeability. The permeability change probably cause a change in fluid flow underground in the next step, which will promote further rock deformation and then change in fluid flow. The sequence of process can be analyzed by a coupled analysis using fluid flows simulator for rock media and that calculating the geomechanial process under the changing pore pressures. The TOUGH-FLAC code is a good and working example of this coupled simulator, being applied to follow the CO2 motion within faulted and tectonically active formations (Rudqvist et al., 2007, 2008) .

We consider that the coupled simulation of fluid flow and geomechanics, exemplified by TOUGH-FLAC simulation collaborating with LBNL, is the most important tool in developing the scheme to assess the fluid-mechanical conditions around the underground storage regions of CO2.

As not enough data such as rock deformation related to fluid flow is available from GCS site for evaluation of TOUGH-FLAC code applicability to Japanese geological condition, we investigate the Matsushiro field, Nagano, central Japan is selected for our natural analogue study. The Matsushiro field is famous for the earthquake swarm associated with the CO2-rich fluid upwelling during the period of 1965-1967. The Matsushiro phenomena was previously studied by using TOUGH-FLAC (Cappa et al., 2009), however, the geological model was simplified very much, so it is afraid that the possibly important geological features can be missed.

In this study, we modified their model based on the various filed and laboratory data and re-constructed the geological model with three layered strata according to P-wave velocity profile.

TOUGH-FLAC simulation has been conducted using updated geological model. The simulation results indicated the ground uplift due to fluid injection and the maginitude of the ground uplift is reasonably agree with actual observation in Matushiro field during the swarm.

Keywords: Coupled fuild flow geomechanical modelling, Geomechanics, Geological CO2 storage, Natural analogue, Matushiro phenomena

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The potential of Vp and Vs monitoring for MVA program of offshore CCS project

Keigo Kitamura[1*], Ziqiu XUE[2]

[1]WPI-I[2]CNER Kyushu University, [2]Research Institute of Innovative Technology for the Earth

For the safe operation of CCS, we are required to monitor the CO_2 behavior and to accurately account for the storage volume of CO_2 in deep reservoirs. It is well-known that the P-wave velocity measurements (Vp) can be used for monitoring the CO_2 behavior in deep reservoirs. However, it is difficult to accurately estimate the storage volume of CO_2 by only using Vp. Takahashi (2000) indicated the potential of S-wave velocity for monitoring of fluid behavior and accounting for the storage volume of natural gas in deep reservoirs. S-wave monitoring can be achieved by deploying a permenent ocean bottom cable(OBC) system at the off-shore CCS sites. In our own study, we conducted a simultaneous measurement of Vp and Vs of porous sandstone by injecting various types of fluids under set in-situ pressure and temperature conditions. For this study, we use the Tako sandstone, which is an early Miocene marine sandstone, mainly composed of quartz and plagioclase. Tako sandstone has near 10mDarcy of permeability and almost 24% porosity. The sample was cut into a column shape (5cm in diameter and 10cm in length), and polished on both ends (1PV=47 ml). In this study, we tried to estimate CO_2 saturation, and to monitor the CO_2 behavior in porous sandstone by measuring Vp and Vs. First, we injected near 1.3PV water into the vacuumed specimen (Water injection). After this process, over 2.2PV CO_2 is injected into the water saturated specimen (Drainage). Finally, CO_2-saturated water over 2.3 PV is re-injected into the CO_2-injected specimen (Imbibition). We illustrated the Vp-Vs relationships of all the processes. This Vp-Vs relationship diagram clearly illustrates the obvious differences between water injection and drainage. On the other hand, drainage and imbibition show the similar tendency of Vp-Vs change with injecting CO_2 and CO_2-saturated water. These changes indicate the changes of CO_2 saturation during drainage and imbibition stage. This result suggests the potential to estimate CO_2 saturation by using the Vp-Vs relationship. Additionally, Vp does not recover to pre-drainage levels after end of imbibition process. This Vp difference is considered to be the effect of residual trapped CO_2. This result also indicates the potential of monitoring the residual trapped CO_2 from seismic wave velocities.

Keywords: P-wave velocity, S-wave velocity, Porous sandstone, CO_2 saturation, MVA

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HRE29-P03 Room:Convention Hall Time:May 22 18:15-19:30

Acoustic characteristics of formation water when injecting scCO2 microbubbles

Yumi Katasho[1*], Tamotsu Kiyama[2], Shinya Tsuji[1], Ziqiu Xue[2], Toshifumi matsuoka[1]

[1]Kyoto University Graduated School of Engineering Department, [2]Research Institute of Innovative Technology for the Earth

The effectiveness of CO_2 microbubble method for geological sequestration was investigated. For the comparison of the conventional method and CO_2 microbubble method, the CO_2 behavior in Berea sandstone saturated by the KCl solution was monitored by measuring ultrasonic compressional velocity (Vp) in both method.

However, in the injection of CO_2, there were two factors of the change of Vp. One is CO_2 dissolution into pore water and another is replacement of CO_2 and pore water. To separate the factor of the change of Vp, Vp of saline water was measured when injecting CO_2 microbubbles into saline water. The change of Vp effected by CO_2 dissolution was less than 1 %. Therefore, in first experiment. the change of Vp in the injection of CO_2 was effected by the CO_2 replacement of pore water more than the CO_2 dissolution. And the change of Vp in Berea sandstone showed the slow CO_2 migration in CO_2 microbubble method. This is because dissolution of amount of CO_2 microbubbles increased.

This result shows microbubble method could increase the reservoir potential for CO_2, which also showed by X-ray CT scan results.

Keywords: microbubble, carbon capture and storage, P-wave velocity

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Monitoring the Strain of Tako sandstone injected with CO2 using Optical Fiber Sensing

Yuki Horiuchi[1*], Tetsuya Kogure[2], Ziqiu Xue[2], MATSUOKA, Toshifumi[1]

[1]Kyoto University Graduate School of Engineering, [2]Research Institute of Innovative Technology for the Earth

CO2 capture and geological storage (CCS) is a significant technology to reduce CO2 emissions. Surface deformations around CO2 injection wells at In Salah, Algeria were analyzed by InSAR data. For the safety of CCS, it is required to ascertain the relationship between pore pressure buildup by CO2 injection and rock deformation in the depth direction. Traditional strain gauges can measure rock deformations only at installation points. However, optical fiber sensing enables us to obtain the rock deformation distribution over 20 km. In this study, we conducted the laboratory experiment to confirm that the optical fiber sensing can measure the strain of rocks.

In the experiment, we measured strain changes during injection of CO2 into water-saturated Tako sandstone. The rock sample was cylindrical and had a fine part and a coarse part. The strain changes were measured using an optical fiber and strain gauges. Strains measured by the optical fiber sensing accorded with strains of strain gauges. Strains at the coarse part were greater than strains at the fine part. The optical fiber sensing could measure physical properties of different layers. Such results suggest the possibility of monitoring the rock deformation distribution in the depth direction using the optical fiber sensing at CO2 geological sequestration sites.

Keywords: CO2 geological sequestration, porous sandstone, optical fiber sensing, strain

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Strain analysis in Rock samples using Neutron diffraction at J-PARC/BL19 ”TAKUMI”

Jun Abe[1*], Kotaro Sekine[2], Stefanus Harjo[1], Gong Wu[1], Kazuya Aizawa[1]

[1]JAEA, [2]JOGMEC

A high-intensity proton accelerator facility named J-PARC (Japan Proton Accelerator Research Complex) has been constructed at Tokai in JAPAN. Various neutron experiments using high intensity pulsed neutron beam are being performed at J-PARC. The Engineering Materials Diffractometer ”TAKUMI” was constructed at BL19 in J-PARC, which is dedicated to investigate the stress-strain state using neutron diffraction technique. In order to develop neutron diffraction technique applicable to rock samples, strain measurements in rock sample have been performed at TAKUMI. As results, in spite of the long neutron path length (ca. 40 mm) and small sample gauge volume (2 x 2 x 2 mm), sufficient neutron diffraction patterns could be obtained. In addition, as results of in situ strain measurements under uniaxial compression loading, discrepancy was found in strain values obtained by strain gauge and neutron diffraction. It was suggested that macroscopic strain value of rock sample included intragranular strain and intergranular slip.

In order to utilize underground environment, e.g. CCS, accurate estimate of crustal stress is indispensable. Borehole core sample might have residual strain corresponding to crustal stress the core sample was taken. Neutron diffraction measurements of borehole core sample have been performed, and we have attempted to analyze residual strain in borehole core sample.

A borehole core sample is a tuff, which was taken by drilling in underground rock mass (depth: 589m) at Mie in 2009. Variations of the P-wave velocity exhibited orthotropic anisotropy. Lattice plane spacing of quartz grain and that of feldspar grain varied with measurement position. It was speculated that quartz grains contain tensile strain, on the other; feldspar grain contains compression strain. Residual strain in borehole core might become helpful to estimate states of the crustal stress where the core was taken. Therefore, it is expected that strain measurements using neutron diffraction serve to understanding of stress state in underground environment.

Keywords: Neutron diffraction, strain measurement

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Continuous gravity measurement with an iGrav superconducting gravimeter for CO2 sequestration

Mituhiko Sugihara[1*], Kazunari Nawa[1], Yuji Nishi[1], Tsuneo Ishido[1], Masao Komazawa[1], Nobukazu Soma[1]

[1]AIST

We have started gravity monitoring at the Farnsworth test site in Texas along with US's project of Southwest Regional Partnership. We have been making three kinds of gravimetric baseline measurements: continuous gravity measurements at the gravity hut with an iGrav superconducting gravimeter (SG), co-located absolute gravity measurements at the gravity hut, and relative gravity measurements around the gravity hut with portable gravimeters. The SG is distinguished from other gravimeters by superior precision, better than 1 nm/s2 and by the ability to record gravity continuously over periods of months and longer. The SG meter is a type of relative gravimeter, therefore, it is necessary to monitor temporal changes of its scale factor and the zero level of its output signals. We have made the first co-located measurements with the FG5/217 absolute gravimeter for a week (08/01/2013-15/01/2013) to determine the scale factor of the SG meter. We decomposed the continuous gravity data using the program BAYTAP-G into tidal effects and irregularities such as drift, occasional steps and disturbances caused by external mass displacements (CO2 sequestration, oil and/or gas production, atmospheric, hydrological, and tectonic processes). This research is funded and supported by Ministry of Economy, Trade and Industry (METI).

Keywords: CO2 sequestration, gravity monitoring, superconducting gravimeter, Farnsworth

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Gravity Survey in Farnsworth, Texas

Masao Komazawa[1*], Mituhiko Sugihara[1]

[1]AIST

A gravity survey was carried out January in 2013 in order to understand a shallow and whole underground structure. The measurement points were arranged at every 300m interval along the road and the number of measurement points became 141 points. The characteristic Bouguer anomalies are that the gravity high anomalies corresponding to anticline structure extend from NW to SE.This research is funded and supported by Ministry of Economy, Trade and Industry (METI).

Keywords: Texas, Fansworth, Gravity anomaly, CO2 sequestration

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Threshold pressure measurement by several methods on sedimentary rock in Japan

Masaki Ono[1*], Hiroshi, KAMEYA,[2], Kohichi, HOSODA[1], Yotsuo, KAMIDOHZONO[1], Junya, TAKESHIMA[2]

[1]OYO Corporation Core Lab, [2]OYO Corporation Energy Division

We conducted laboratory tests to investigate threshold pressure in CO_2/water system. First technique is mercury intrusion test (MIT). Second technique is threshold pressure measurement with N_2 using step by step method. Third technique is threshold pressure measurement with supercritical CO_2 using step by step method. These techniques are commonly used but have both advantages and disadvantages. MIT is less time consuming but we cannot control the direction of injecting fluid. Test apparatus for threshold pressure measurement with N_2 is much simpler than that using supercritical CO_2. However, we have to estimate actual threshold pressure in CO_2 storage condition by converting threshold pressure in N_2/water system using interfacial tensions and contact angles. Threshold pressure measurement with supercritical CO_2 is most reliable.

Rock cores used in this study were derived from outcrop of The Yourou-valley, located in Chiba prefecture in Japan. This outcrop belongs to Kiwada formation of the Kazusa formation group which is thought to be formed in Plio-Pleistocene. Porosity of sample is 45%, natural density is 1.89g/cm^3, water content is 31%.

In MIT, we used two methods to calculate threshold pressure. By first method, we drew the tangent line with minimum grade against the curve relating saturation and capillary pressure. The tangent line is spread to the vertical line which expresses mercury saturation is zero and this intercept means the threshold pressure. By second method, threshold pressure is determined by the pressure at 10% mercury saturation1). Threshold pressure evaluated from former method is 4.08MPa and 4.87MPa is obtained by second method. Using the contact angles and interfacial tensions, we can convert threshold pressure in Hg/Air system to that in CO_2/water system. Estimated threshold pressures in CO_2/water system are 0.32MPa in first method and 0.38MPa in second method.

Threshold pressure measurement with N_2 was also conducted. Room temperature was kept approximately 21 deg c. By N_2 injection, pore water in a rock core was pushed out from a specimen but water production ceased according to the passage of time. Injection pressure was increased step-wisely when water production stopped. This procedure was repeated until continuous water flow was observed. In this test, continuous water flow was observed after injection pressure reached to 1.71MPa. We evaluated threshold pressure in N_2/water system is 1.66MPa which is average pressure of final pressure step and former pressure step (1.60MPa). Estimated threshold pressure in CO_2/water system is 0.66MPa.

Threshold pressure measurement with supercritical CO_2 was conducted under the temperature of 40 deg C. Pore water pressure of 10MP was applied to ensure that CO_2 was in supercritical state during the test. After injection pressure reached to 1.10MPa, continuous water flow occurred. Threshold pressure in CO_2/water system is evaluated 1.04MPa.

Threshold pressure estimated by MIT was lowest. Threshold pressure obtained from direct measurement with supercritical CO2 was highest value which is 1.6 times higher than that of N_2. Possible reasons for these test results are listed below;

1. Change of the structure of rock by drying procedure might affect the result of mercury intrusion test.
2. Difference of flow direction between mercury intrusion test and other techniques may have an influence on the value of threshold pressure.
3. Uncertainty of contact angles and interfacial tensions of displacing fluids is also a possible factor which leads different test result.

We gratefully acknowledge special support received from New Energy and Industrial Technology Development Organization(NEDO). Part of this study was performed under Innovative zero-emission integrated coal gasification combined cycle project.

1) Tim T. Schowalter. Mechanics of Secondary Hydrocarbon Mitigation and Entrapment. AAPG Bulletin, 1979, 63, 723-60

Keywords: Threshold Pressure, Supercritical CO2, Sedimentary Rock

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Permeability of fault and grain size distribution -Evaluation for the permeability of methane-hydrate bearing layers-

Sho Kimura[1*], Hiroaki Kaneko[1], Hideki Minagawa[1]

[1]Methane Hydrate Research Center, National Institute of Advanced Industrial Science and Technology

Permeability of sediments is important factors for production of natural gas from natural gas hydrate bearing layers. Methane-hydrate is regarded as one of the potential resources of natural gas. As results of coring and logging, the existence of a large amount of methane-hydrate are estimated in the Nankai Trough, offshore central Japan, where has a lot of faults. For the purpose of a rational evaluation of permeability of methane-hydrate layers, it is important to understand properties of fault zone because of different condition from other layers due to large displacement shear. In this study, we investigated the permeability of a specimen formed artificial fault in ring-shear test. Moreover, under high and low normal stresses the difference in grain size distribution of shear zone and other zones were discussed. This study is financially supported by METI and Research Consortium for Methane Hydrate Resources in Japan (the MH21 Research Consortium).

Keywords: Fault, Permeability, Grain size distribution

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Examination of the possibility of gel trapping using artificial-mineral Sumecton

Tomohiro Katayama[1*], Naotatsu Shikazono[2]

[1]Faculty of Science and Technology, Keio University, [2]Keio Research Institute at SFC

Smecton SA which is is a synthetic inorganic polymer with a saponite structure became hard gel by ion conbination when it is mixed with water at the acid condition.
If the character of Smecton SA could be applied to CCS,the safety of CCS may improve by it.
Therefore, we verified in the experiment of reacting Smecton SA and water, carbon dioxide.

Keywords: Smecton, Smectite, CCS, gel

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Global underground gas winery absorbing air CO2 and reproducing methane gas reservoirs : underground carbon recycling

Hitoshi Koide[1*]

[1]AIST

A new counter-geoengineering scheme: leak-free air-CCS under hydrate sealing is proposed here to slash the artificially increased atmospheric CO2 level directly. The naturally most secure and extensive storages for CO2 are the deep aquifers in cold regions and beneath ocean floors. The high-pressure experiments suggest the precipitation of CO2-hydrate occurs in CO2-saturated aquifers at the pressures higher than about 3MPa. Huge volumes of secure CO2-storages under the CO2-hydrate autogenous sealing are expected in deep aquifers in the sub-permafrost regions throughout the world. Virtually limitless secure CO2-storages under the CO2-hydrate autogenous sealing are possible in worldwide marine sediments and oceanic basalts under sea floors deeper than about 300m. The conventional carbon capture and sequestration (CCS) scheme is not viable in the remote areas due to the large infrastructure investment and energy loss for long-distance transportation of huge amount of CO2. However, the air-CCS may be viable while CO2 is extracted directly from the atmosphere instead of the flue gas of fossil fuels. As the atmospheric CO2 concentration is very thin (about 390ppm), the excess energy is required to extract the CO2 from the atmosphere. CO2 is selectively injected into deep aquifers by the air microbubbles sequestration with the pre-concentration by micro-porous membranes. The unused natural energy (wind, solar, geothermal and natural gas) is used for the recovery of CO2 from the atmosphere and for the underground injection of CO2-rich gas. Energy penalty of air-CCS can be compensated by use of unused natural energy in the remote regions.

Carbon dioxide injection under gas-hydrate-filled layers or under permafrost layers may realize the greenhouse gas mitigation and recovery of unused natural gas. Autogenous sealing of carbon dioxide in deep and cool aquifers assures virtually complete and practically unlimited subsurface containment of carbon dioxide. Chemoautotrophs fix carbon dioxide in deep aquifers even in the absence of sunlight. Thermophile methanogens can convert the carbon dioxide into methane in anoxic aquifers. Biogenic restoration of subsurface hydrocarbon deposits is possible in CO2-injected aquifers probably after some ten of years. Microbiological recycling of carbon dioxide in aquifers brings the renewable hydrocarbon gas energy resources into reality.

Keywords: carbon recycling, CCS, hydrate, methanogen, renewable energy, natural energy

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New Formation Model of Carbon-Bearing Materials Produced Greenhouse Gases on Earth-Type Planets

Yasunori Miura[1*]

[1]Visiting (Universities)

Fundamental problem on the atmosphere of greenhouse gases with carbon has not solved completely mainly due to simple and local discussion on activity in the atmosphere (and ocean) of the planet Earth (Miura, 2008). This is mainly because basic problems of carbon-bearing carbon dioxides are not solved on the origins, reservoirs and existences in air of planet Earth. Thus estimation and calculation of interior carbon contents on underground carbon changes have not taken into account sufficiently on the dynamic carbon circulation (especially coal etc.) due to unknown lost and old process. On the present wide-area JpGU Society, the Earth (planetary) sciences have main characteristics of visual developments with accurate and detailed descriptions relatively in short-time period. On the other hand, it is considered exceedingly to be academic black-box with unknown knowledge of long active Earth planet with repeated formation and extinction processes strongly (Miura, 2012). However, it should unravel the academic black box with long unknown history to develop fundamentally appropriate ideas to human society for the air pollution and green house problem (Miura, 2013).

Supply of carbon and hydrogen to the Earth is considered to be transported from the Asteroids, Comet and planetary debris finally to the well-formed Earth (Miura, 2000), so that origin of main hydrogen-bearing air and water are explained by quenching by asteroid collisions, with subsidiary flows by carbon-bearing phases. Previous outline of primordial carbon-dioxides airs in the Earth-type planets (Mars and Venus) have been existed on primordial Earth surface, where main carbon-bearing air on primordial Earth has been changed and formed wide carbonate minerals deposits in the ocean-sea finally (Miura, 2010). The problem of the previous model is difficult to explain formation of wide ocean-water system on Earth-type planets without carbonates deposits remained as main gas processes of normal smaller impacts on the planetary surfaces. New breakthrough reverse model of underground carbon coals produced greenhouse-gas in planet Earth is proposed based on carbon dioxides airs on the Venus and Mars originally by other surface material data.

The surface on the moon and Mars reveal voids-rich grains to penetrate gaseous fluids to the interior by many impact processes to form carbon-rich resources (Miura, 2012). Carbon dioxides in the interior of primordial Venus and Mars are lifted by volcano-like process by the pulled tidal forces during the rotations from the Sun etc., and form stable carbon dioxides air (even in high temperature) than hydrogen-bearing water (Miura, 2011). The primordial ocean waters of Earth-type planets are based on the present water-planet Earth which is considered to be generated by huge planetary impact with much water contents with less carbon dioxides in the interior of large planets collided.

From the present model of multi-steps (i.e. impact-penetration to store light elements and the lift-up to the surface), the interior carbon and coal etc. are considered to be concentrated to large resources eventually for natural energy to generate artificially industrial greenhouse gas finally.

Three types of carbon origins and cyclic processes with time periods on our Earth reported at the JpGU-2012 meeting are long-range natural resources, short-range life, and industrial wastes (Miura, 2012), The former two main carbon processes cannot change on Earth by artificial short-time period as main untouchable carbon cycles. However it is expected strongly by applied global carbon process model (Miura, 2008-2013) that the main point of the third carbon gas process generated by industrial carbon gas as artificial wastes should be applied to dynamic stable changes of states by global planet Earth (Miura 2013)

Keywords: Carbon dioxides gas, Greenhouse warming, Carbon-bearing materials, Earth-type planets, Multy-steps formation model, Primordial air-planets