

長岡サイトにおいて繰り返し検層によって得られたフィールドスケールの トラッピング・メカニズム

Trapping mechanisms in field scale observed by time-lapse well logging at the Nagaoka site

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This paper discusses CO₂ trapping in field scale observed at the Nagaoka pilot-scale injection site. IPCC (2005) illustrated the contributions of various trapping mechanisms over time, and pointed out the importance of capillary and solubility trapping at the early stage of geological CO₂ storage. Capillary trapping is caused by interfacial forces at the pore of rock and prevents migration of CO₂ bubble. Solubility trapping means that gaseous CO₂ dissolves into formation water. After the report of IPCC, many laboratory experiments related to these trapping mechanisms have been conducted. Meanwhile, field observations were limited. In this paper, we study trapping mechanisms observed at the Nagaoka site.

Nagaoka project was undertaken in order to verify an ability of CO₂ injection into Japanese formation. The target reservoir is consists of a limb of anticline structure and have 15 degree dipping. About 10 k-tons of CO₂ were injected into a thin permeable zone from July 2003 to January 2005. Time-lapse well loggings have been carried out for more than 12 years, and the number of monitoring logging is 44 times so far. CO₂ breakthrough was detected at a down-dip well (OB-2) located 40m away from the injection well, and at a up-dip well (OB-4) located 60m from the injection point. From the neutron logging data, CO₂ saturation in super-critical phase was evaluated, and from the induction logging the existence of super-critical and dissolved CO₂ is deduced. At OB-2, CO₂ saturation peaked at 63% around 22 months after the start of injection, decreased gradually, and stabilized at around 20%. At OB-4, CO₂ saturation peaked at 69% around 15 months and remained relatively high value (40%).

We considered that the maximum saturation at each depth was corresponding to the initial saturation of drainage process and the latest observation could be assumed as the residual state. The relationship between the initial and residual saturation is called IR curve and represents the fundamental flow properties in drainage process. The results at OB-2 showed that most of the data can be explained by single Land' s model. Exception came from relatively silty layer, which means pore distribution is different from other layers. At OB-4, IR relationship was scattered and indicated that the latest state is far from the residual condition. The difference between down- and up-dip direction is thought to exhibit migration effects in the reservoir.

Concerning the dissolved CO₂, the thickness of the low resistivity anomaly became larger. This showed that the solubility trapping was progressing. The rate of thickening was the same order as the dissipation of bicarbonate ion. This was consistent with the expectation from the linear instability theory for density convection of CO₂ dissolved water.

These results showed capillary and solubility trapping mechanisms in the field scale observation. The drainage process in field scale could be explained by Land' s model as laboratory experiments, and the

fitted model was depend on rock type. Solubility trapping in several mD formations was confirmed that dissipation process was dominant during the first decade of CO₂ storage. These results could be used for simulation tasks to build a better flow model.

キーワード : CO₂地中貯留、多相流、残留ガストラッピング、溶解トラッピング、Landモデル、長岡サイト
Keywords: CO₂ geological storage, multiphase flow, residual trapping, solubility trapping, Land model, Nagaoka site

不均質堆積岩におけるマイクロバブルCO₂流動の可視化と定量評価 Visualization and measurement of CO₂ microbubble flooding in heterogeneous sedimentary rock

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We carried out laboratory experiments of CO₂ microbubble and normal bubble flooding in porous sandstone to confirm the difference in dissolution and sweeping effect. During the experiments, we obtained the specimen porosity and monitored fluid saturation process by using CT image analysis. Sarukawa sandstone (diameter: 34.80mm, length: 79.85mm, north central Japan) was used in this study. Porosity of specimen determined by X-ray CT imaging is 30.94%. The specimen has heterogeneous structure. The experiments were conducted under the pressure and temperature conditions that simulate underground environments; pore pressure: 10MPa, temperature: 40 degrees Celsius. The confining pressure selected in this study is 12MPa. The specimen was first saturated with KI aqueous solution (12.5%), and then oil was injected to make oil-water mixed state. Totally, ten steps of flooding were performed for each experiment. For each step, KI aqueous solution and oil were carefully recovered from the syringe pump (back pressure pump). We increased the differential pressure to examine the influence of differential pressure on oil recovery in heterogeneous media. The microbubble and normal bubble flooding tests were carried out until the total fluid injections reach about 3PV (pore volume). Figures a) and b) show the differential CT images when the CO₂ microbubble and normal bubble injections reach 2.95PV and 2.98PV, respectively. It is clear that the CO₂ microbubbles were able to sweep out more than the normal microbubbles. For example, the oil recoveries were identified as 56.04% and 45.12% after 1.0PV injection of CO₂ in the specimen. The case of microbubbles is about 10.92 % point higher than the case of normal bubble.

キーワード : X線CT、マイクロバブルCO₂、ノーマルバブルCO₂、不均質岩

Keywords: X-ray CT, CO₂ microbubble, CO₂ normal bubble, heterogeneous rock

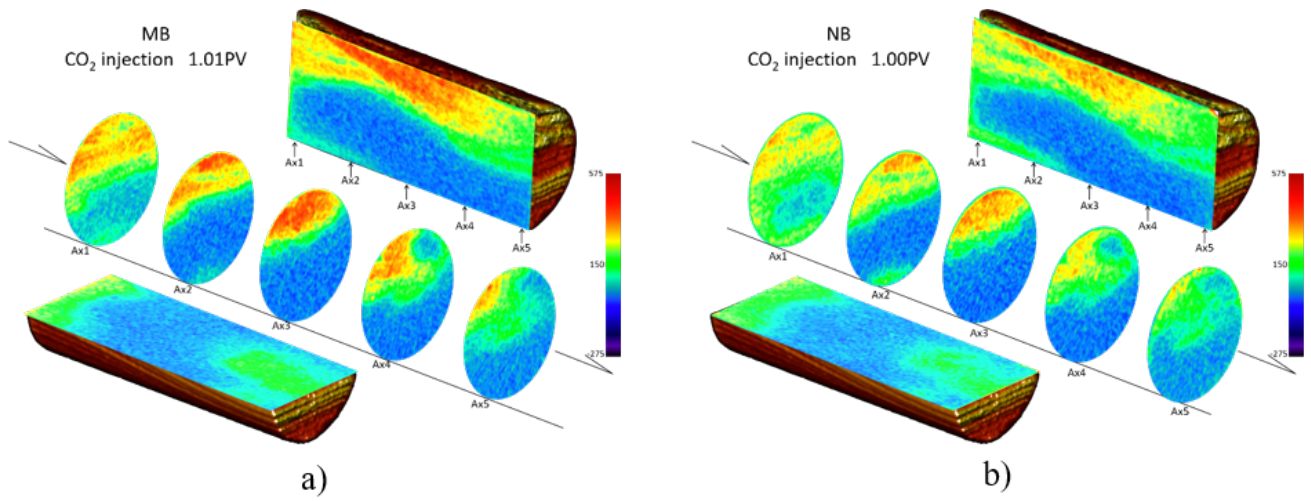


Figure. X-ray CT differential images of CO₂ microbubble and normal bubble flooding in the Sarukawa sandstone a) after 1.01PV(pore volume) injection of CO₂ microbubbles, b) after 1.00PV injection of CO₂ normal bubbles

地化学反応が遮蔽性能に及ぼす影響に関する予備的検討

Preliminary evaluation on geochemical impacts to rock's sealing performance

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CO₂地中貯留では、CO₂が地表に漏洩することなく安定に隔離され続けることが前提となる。このような地下のシール性能を決める因子が、キャップロックの浸透率と毛管圧（スレッシュヨルド圧）である。これまで貯留サイトの岩石に対する浸透実験からこれらのパラメータの計測が行われてきたが、CO₂が溶解した間隙水中で長期にわたる地化学プロセスを経た後も、同様のシール性能が保証されるかどうかは確認されていなかった。本研究では、キャップロックのシール性能および貯留層の圧入性の両方の観点から、岩石が反応する際の水理特性の変化を定量的に評価した。

日本各地の露頭から採取された堆積岩のうち、3種類の泥岩（浪花層、大原層および一志層群泥岩）、五日町層群泥灰岩、および2種類の砂岩（灰爪層石灰質貝屑砂岩および大泊有孔虫砂岩）を選定した。偏光顕微鏡によるモード測定および粉末X線解析からは、一志層群泥岩以外の全ての岩石が炭酸塩鉱物を含んでいることが示された。特に泥灰岩石と2つの砂岩で、炭酸塩鉱物の含量が多くなっていた。

初めに、超臨界CO₂-水反応システムにより、閉鎖系での反応実験を行った。反応に先立ち、岩石を直径14 mm、高さ10 mmの円筒状に成形した。個々の岩石に対して4個の試料を用意し、異なる時間別々に反応させた。反応時間は、1週間、2週間および4週間とした。実験中はオープン内を40℃に保持し、超臨界CO₂で10 MPaに加压維持した。次に、反応後の試料に対して、超臨界CO₂シール圧測定システムを用いて浸透実験を行った。室温、大気圧下での浸透率測定に引き続き、10 MPa、40℃の条件下で段階昇圧法によりスレッシュヨルド圧を測定した。

今回の実験により、水理特性に及ぼす地化学反応の影響が岩石種によって全く異なることが確認された。すなわち、浪花層泥岩、大原層泥岩および灰爪層石灰質貝屑砂岩は4週間の反応でほとんど変化がみられなかったが、その他の岩石では、反応時間の経過と共に、浸透率が増加し、スレッシュヨルド圧が減少した。実際には、一志層泥岩と五日町層群泥灰岩では反応後にクラックが形成していたため、これらの岩石の水理学的変化は地化学反応に起因したものではない。一方で、大泊有孔虫砂岩では、比較的少量に含まれる炭酸塩鉱物がCO₂溶解水中で溶解した結果、シール性能が低下したと考えられる。ここでは、同じ石灰質の灰爪層石灰質貝屑砂岩では水理特性が変化しなかった点が注目される。この理由として、灰爪層石灰質貝屑砂岩では炭酸塩が流路と接していなかったため、炭酸塩とCO₂溶解水の反応が進行しなかったことが予想される。発表では、溶出した化学成分と細孔径分布の変化データも併せた形で、地化学反応と水理特性の関係を議論する予定である。

キーワード：CO₂地中貯留、遮蔽性能、地化学反応、炭酸塩鉱物、キャップロック、スレッシュヨルド圧

Keywords: Geologic CO₂ storage, Sealing performance, Geochemical reaction, Carbonate minerals, Caprock, Threshold pressure

An option for marine monitoring at offshore CO₂ storage sites: observing pCO₂ in the sea

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Carbon dioxide (CO₂) capture and storage (CCS) is a promising option to reduce CO₂ emissions and consequently to mitigate global warming. Since reservoirs capable of storing CO₂ stably are selected, the risk of CO₂ leakage is extremely low. There is, however, concern that CO₂ might leak out. To verify that CO₂ is not leaking, as well as to detect CO₂ leakage if leakage occurs, monitoring is important. In offshore storage, since leaked CO₂ would go out into the sea out of the seabed, monitoring in the sea is necessary. However, there seems to be no monitoring method that is useful in all sea areas or for all situations. In the practical monitoring, it is necessary to combine a few methods according to the situation and the sea area. Partial pressure of CO₂ (pCO₂) in the sea is one of items to monitor since pCO₂ in the sea would increase by leaked CO₂. However, it is difficult to distinguish high pCO₂ values due to CO₂ leakage from those due to natural variability in some areas. In the present study, we discuss a method to assess anomalously high values of pCO₂ using not only pCO₂ but also dissolved oxygen. As an example, we analyzed data observed in Osaka Bay. We have shown that the method using both pCO₂ and DO is effective in the eastern (innermost) part, where stratification is relatively strong throughout the year. However, the method is less effective in the western part of Osaka Bay, where water is relatively well mixed vertically due to strong tidal currents. We have concluded that observing pCO₂ and assessing it based on both pCO₂ and DO is potentially a useful option for marine monitoring although this method is not effective in all sea areas.

キーワード：海底下貯留、CCS、二酸化炭素分圧、溶存酸素、海域モニタリング

Keywords: offshore storage, CCS, partial pressure of CO₂, dissolved oxygen, marine monitoring