インドネシア・グンディガス田における CCS 研究プロジェクト（その２）
ー圧入層周辺の地質モデルとシミュレーションー

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CCS Project in Gundih gas field, Indonesia (Part 2)
- Reservoir characterization and simulation -

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Abstract: A pilot CCS project in Indonesia will be implemented in Gundih area, Central Java Province in Indonesia. Before implementing CO_2 injection, the reservoir for CO_2 injection must be characterized carefully by conducting geophysical exploration, in order to make sure that the reservoir is suitable for CCS. Here we report preliminary results of site surveys for the determination of CO2 injection site in the Gundih area. Subsurface structures imaged on seismic reflection profiles indicate that the Ngrayong formation is one of the candidates for CO_2 injection. To reveal hydrological properties (e.g., permeability) of the Ngrayong formation, we obtained rock samples of the Ngrayong formation from outcrop and boreholes. Using (1) hydrological properties, (2) subsurface structures extracted from seismic data (e.g., geometry of the Ngrayong formation) and (3) physical properties predicted by integrating seismic and logging data, we apply reservoir simulation and evaluate potential of the CO2 injection site.

1. Introduction

Carbon Capture and Storage (CCS) is recognized as a reliable mitigation option for substantially reducing CO_2 emissions from fossil fuel combustion and from hydrogen-production. CCS can have near-term impact on emissions, and can contribute significantly to a carbon-neutral future. The roadblocks for implementation of CO_2 storage are (a) risk of CO_2 leakage, (b) risk of induced seismicity, and (c) high-cost. Because these roadblocks are strongly related to the highly uncertain local geological characteristics of potential storage sites, (1) reservoir characterization and (2) monitoring/modeling of injected CO_2 are crucial steps in the development of CCS. Especially, the CCS projects in plate convergent margins (e.g., Japanese Island or Indonesia) have some difficulties, compared to the oil fields with stable formations. Since we need to overcome these roadblocks to promote CCS, we have developed the method of reservoir characterization and monitoring /modeling of injected CO_2 in geological structures in plate convergent margins (i.e., plate subduction zone). For these geological formations, the following issues should be considered for the promotion of CCS project;

(a) Heterogeneous geological formation

Because geological formations in plate convergent margins are complicated compared to the large-scale CO_2 injection sites in the countries on continental plates (e.g., Australia), we need to consider heterogeneity in constructing geologic models for reservoir simulation and in designing monitoring surveys. When it is difficult to find structural closure (i.e., anticline structure) for CO_2 injection around their continental margins, we need to consider CO_2 storage using the mechanisms of residual trapping, dissolution trapping, and mineralogical trapping. If we can use reservoirs without structural closure for CO_2 injection, reservoirs in Japanese islands have a capacity of over 100 billion tons CO_2 (e.g., Ogawa et al., 2011).

(b) Limited information for CO_2 storage

There is limited geophysical data available that can be brought to bear for CO_2 injection into aquifer formations, although much well data can be used for CCS-EOR projects in oil fields. Therefore, we need to characterize a reservoir from limited geophysical /geological data.

(c) Long-term monitoring

Since monitoring in CCS projects should extend about several hundred years, the requirements are much different from the conventional approaches in EOR. We need to develop the capability to monitor injected CO_2 using simple, convenient methods. Furthermore, the dissolution rate, as well as chemical reaction rates, of injected CO_2 should be considered for long-term reservoir simulation.

(d) Earthquakes

Earthquakes are a critical issue in the countries along the plate convergent margin. Since CO_2 injection changes the pore pressure of the reservoir, we must accurately monitor and control pore pressure variations due to CO_2 injection.

To establish the methods of reservoir characterization as well as monitoring/modeling of injected CO_2 in plate convergent margins, therefore, we try to conduct pilot CCS project including Japanese island and Indonesia. Here, we focus on "Gundih CCS project" (Matsuoka et al., 2013; Tsuji et al., 2013). This CCS project will be a first pilot CCS project for research and development of technologies for assessing deep strata at CO_2 injection and for monitoring of underground distribution of CO_2. By intensively applying reservoir characterization, monitoring and reservoir simulation, we try to develop effective tools for the CCS in plate convergent margins.

Indonesia has a plan to reduce CO2 emission by 26% by 2020. Since CO_2 emission from gas production fields is a major problem in Indonesia, we try to start CCS project in the Gundih gas field (Fig. 1). Especially the CO_2 content within the produced gas is more than 20% in the Gundih field, so that CO_2 injection near the gas production well could be effective way to avoid abundant CO_2 emission from this area.

2. Gundih gas field & Lithology for CO_2 injection

The Gundih gas field is located at the vicinity of the east Java basin (Fig. 1), where contains of thousands meters of Tertiary sedimentary sequences. This sedimentary sequence has a good potential of hydrocarbon source rock and reservoir rock. The east Java basin is a back-arc basin at the southeast end of Sundaland bounded by Karimunjawa Arc and Sundaland shelf in the west, to the north by Meratus high, to the east by Masalembo-Doang high and volcanic sot the south by a line of Java (Sribudiyani, 2003). Basement configuration of east Java basin is controlled by two main structural trends, that NE-SW trend are generally only found in northern shelf and E-W trend contained in Mandala Central high and South basin. The geologic structures observed in the Gundih gas field are extended mainly for E-W direction.

The lithology we try to inject CO_2 is the Ngrayong formation (Fig. 2), because the lithology is sandstone and because the depth of this formation is ~1 km in the Gundih area. In the deeper than ~800m, we can inject CO_2 as a supercritical state. The physical and hydrological properties of the Ngrayong formation are much different between northern and southern regions; the northern Ngrayong formation is sandy and well sorted (Figs. 1 and 3). The permeability of the outcrop samples obtained in the northern formation is high (>1000md). Whereas, in the southern formation, the lithology is mud dominant and has low permeability (Kitamura et al., 2013).

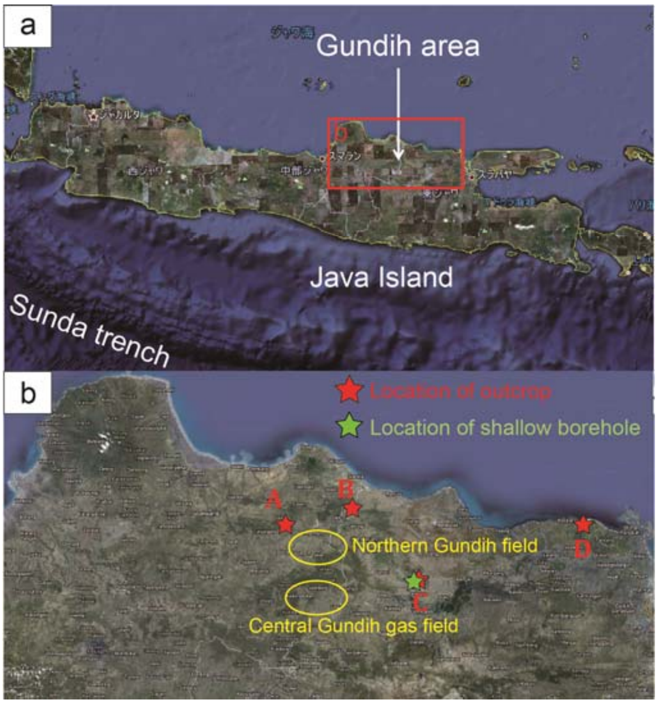

Fig. 1 (a) Map of the Java Island, Indonesia, provided by Google. **(b)** Locations of two candidates for CO2 injection (yellow circles): (1) Gundih gas field and (2) Northern Gundih field. The red and green stars indicate the locations of outcrops and boreholes, respectively. From these locations (stars), we extracted discrete samples for laboratory measurements (e.g., permeability measurements).

The Ngrayong formation is overlaid by the Wonocolo formation, composed by massive grey fossiliferous sandy marl (Fig. 2). This formation is deposited during late Miocene in the outer neritic environment. Since this formation has low permeability, it may work as a seal layer. Actually we measured the permeability of the rock samples extracted from this lithology and obtained low permeability.

3. Reservoir characterization and simulation at CO2 injection sites: Comparison of two candidates

There are two main candidate sites for CO_2 injection around the Gundih gas field; (1) Central Gundih Gas field, and (2) Northern Gundih field (yellow circles in Fig 1b). Both candidates have advantages and disadvantages, so we summarize them by conducting reservoir characterization as well as reservoir simulation. We then provide information for the decision of CO_2 injection site.

Here we mainly use seismic reflection data and limited logging data for reservoir characterization. We apply common reflection surface (CRS) stacking (Minato et al., 2012) to the multi-channel seismic data in order to improve the seismic profiles. To construct geologic model from these geophysical data, we apply (i) acoustic impedance (AI) inversion as well as (ii) seismic attributes analysis (e.g., Tsuji et al., 2004). To characterize the hydrological properties, furthermore, we obtain rock samples from outcrops as well as shallow boreholes (stars in Fig.1; Fig.3). We conduct the reservoir simulation using the constructed geologic model in order to evaluate potential of CO_2 injection.

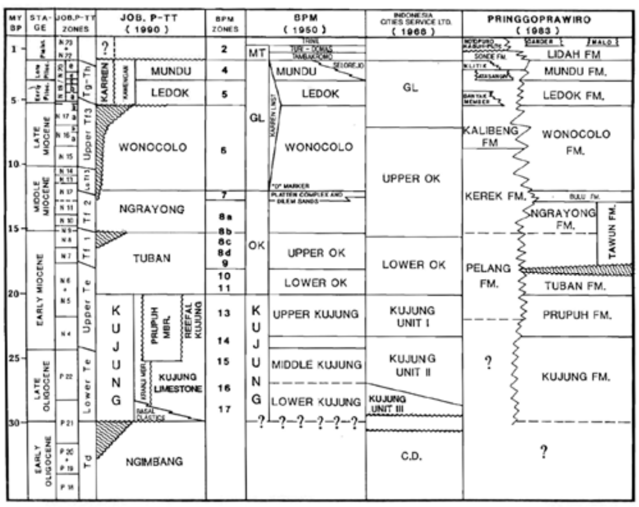

Fig. 2 Lithology around the East Java Basin (Ardhana, 1993).

(1) Central Gundih Gas field

In this region, high-resolution 3D seismic reflection data was acquired and can be used for reservoir characterization (Fig. 4). This site is located within the gas field, therefore CO_2 can be supplied using pipelines. However, since there is no borehole which we can use for CO_2 injection, we need to drill new borehole.

Since we could not find large-scale structural closure (i.e., anticline) for the Ngrayong formation in this region, we need to consider residual trapping or dissolved trapping. The horizon of top of the Ngrayong formation extracted from 3D seismic data (Fig. 4) demonstrates that dislocation plane (i.e., fracture or fault) is not observed in the northern half of 3D seismic volume. Reservoir simulation using realistic hydrological properties constructed AI inversion and considering residual trapping demonstrates that the injected CO_2 is safely trapped over 1000 years (Ariadji and Ekowati, 2013).

Fig. 3 Pictures of outcrops of Ngrayong formation. The location of each outcrop is noted in Fig. 1. Hydrological properties of this formation are much different between northern and southern regions.

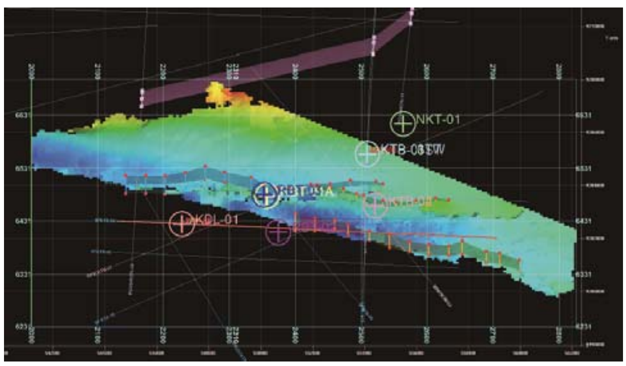

Fig. 4 Map view of surface of the Ngrayong formation extracted from 3D seismic volume (Tsuji et al., 2013). We cannot observe dislocation planes in the northern half of this survey area. At the southern side, we observe several faults.

(2) Northern Gundih field

We may be able to use the depleted well for CO_2 injection in this region. The geological formations imaged on seismic profiles indicate that the depleted well is located at the top of anticline structure whose axis is continued for E-W direction. Therefore, the structural trapping could be expected in this site. The shallower part of the Ngrayong formation in this region is shale dominant, but the logging data (gamma ray log) indicates the interbedded sand layers. The sand layer interbedded by shale layers may be used for the CO_2 injection. In the Gundih pilot CCS project, the injection amount of CO_2 is not large (Matsuoka et al., 2013). Therefore, the thin sand layer could be enough for injection reservoir. We are measuring the permeability of this lithology in the laboratory. We further conduct the reservoir characterization using AI inversion, and apply reservoir simulation for the Ngrayong formation of this region.

At the northern side of the anticline (depleted well), the strike-slip fault may be existed. The fault is dipping to south and may extend beneath the depleted well. To clearly interpret this fault, we are applying CRS stacking analysis to the seismic reflection data. Furthermore, we need to evaluate pore pressure, because overpressure induces the earthquake as well as mud eruption. The overpressure zone is existed at the southern region of Central Java basin and at deeper lithology (e.g., Tuban formation). The pore pressure is believed to be nearly hydrostatic conditions in this site because the Pertamina drilled through the Ngrayong formation in many locations around this region and did not observe overpressure in the Ngrayong formation.

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要旨: インドネシアのグンディ地域で､試験的なCCSプロジェクトが計画されている｡CO_2圧入の前には、物理探査などを用いて、貯留層の特徴を正確に知る必要がある。それによって、地層のCO_2の貯留能力（長期間CO_2を貯留する能力）を評価する必要がある。つまりCCSプロジェクトにおいて、物理探査が果たす役割は大きい。我々はグンディ地域周辺で、最適なCO_2圧入地点を決定するために、実地調査または物理探査データの解析を行った。反射法地震探査から推測される地下構造や検層データなどから、Ngrayong層がCO_2圧入の候補となった。Ngrayong層の水理特性（例えば浸透率）を調べるために、露頭や掘削で岩石試料を取得し、実験室で測定を実施した。これらの水理特性と反射断法地震探査データから得られる貯留層構造（物性分布）を用いて、貯留層シミュレーションを実施し、CO2圧入層（候補地点）のポテンシャル評価を行った。