Geological Characteristic and Fault Stability of the Gundih CCS Pilot Project at Central Java, Indonesia

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Geological characteristic and fault stability of the Gundih CCS pilot project at central Java, Indonesia

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ABSTRACT

Gundih CCS pilot project is located within the Gundih gas field operated by PERTAMINA at Central Java, Indonesia. Geologically, this field is part of East Java Basin, which is well known as prolific hydrocarbon basin in South East Asia region. Gundih field and surrounding area is a gas field, which has been in production since the end of 2013. CO_2 content, which is generated directly from this field, is 21% of the produced gas. Government of Indonesia is highly committed in reducing CO_2 emissions. Therefore, flaring CO_2 to the atmosphere is not an option anymore. CCS by injection to depleted oil and gas reservoir known as geological storage will be the best choice. The main objectives of CCS pilot study is to understand subsurface reservoir behavior and best monitoring technology. To achieve the best storage location as well as injection scenario detail evaluation including geology, geophysics and geomechanics need to done to avoid reservoir or top seal failures, which can cause environmental disaster. There are two possible reservoir candidates, which can be used for injecting CO_2 in the Gundih field and surrounding area. Shallow (~1000 m) reservoir sequence consists of medium to thick quartz sandstone of Miocene Ngrayong Formation. The deeper (~2000 m) reservoir sequence consists mainly of carbonate units of Kujung Formation. Traps are mostly structures consist of fault-bounded anticline forming 4-way or 3-way dip closures. Fault-seal analysis suggesting most faults are sealing using SGR (20%). Geomechanics indicate strike-slip stress condition where Shmax>Shmin>Sv and most reservoir are in hydrostatic pressure condition. Overall, site evaluation results suggest that shallow reservoir target which is Ngrayong Formation is more suitable, stable and economic for conducting CCS pilot study.

KEY WORDS: CCS, Gundih Field, Ngrayong Formation, Geomechanics

INTRODUCTION

The most important aspect in site selection for CCS storage is long-term stability of reservoir condition. Therefore, detailed geological and geophysical evaluation particularly reservoir characteristic, structural geology and geocmechanics are critical to achieve best target (Tsuji et al., 2013).

Gundih field, which is operated by PT Pertamina EP, is situated in Cepu sub-district, District of Blora, Central Java Province, Republic Indonesia (**Figure 1**). This field is part of the back arc basin of Java Island, in which many hydrocarbon field are found here. However, this area also part of active tectonic region which are characterized by numerous earthquakes and active volcanoes. Such as unique condition need to be evaluate in very carefully particularly in relation to in-situ stress condition.

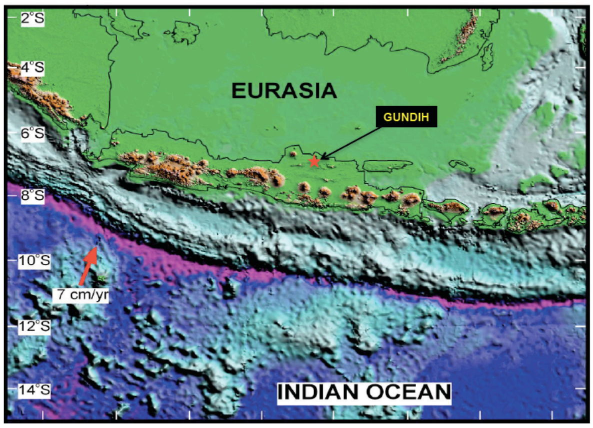

Figure 1. Location map of Gundih Field at Central Java showing active subduction marked Java trench and chains active volcanics.

Two of the most famous reservoirs are clastic and carbonate of Kujung Formation (deeper reservoirs) and sandstone of Ngrayong Formation (shallow reservoirs). Based on present study, CCS pilot project plan will conduct in the Ngrayong Formation specifically will concentrated in Jepon-1 well or known as Jepon structures.

This will present results of geological evaluation in particular concentrated in conducting fault-seal analysis and geomechanics of Jepon structures in relation to CCS pilot project plan in the Gundih field.

METHOD OF STUDY

The geology, geophysics and geomechanics evaluation in this study was conducted by integrating surface geological map, core, well logs and reprocessed 2D seismic sections. Surface geological mapping of site location was conducted in detail including samples collections particularly describing reservoir (Ngrayong sandstone) and structural geology. Two shallow drilling (ITB-1 and ITB-2) was conducted for getting fresh samples where most of the surface samples are highly decomposed and oxidized. Seismic interpretation was conducted using closed-spaced 2D seismic data, which has been reprocessed using CRS method during this study. Fault seal analysis and and 1D geomechanics evaluation was conducted using static modeling approach.

TECTONIC AND GEOLOGICAL SETTING

The East Java Basin is considered to be a back arc basin, situated on the southeastern margin of the stable Sunda Platform. The North Madura Platform represents the main structural element in this area, defined by the northeast-southwest trending Central Deep Basin to the northwest and the Madura Basin to the south. This basin later became inverted along the highly deformed Rembang -Madura- Kangean (RMK) wrench zone. The underlying basement comprises igneous intrusive, altered volcanic and meta-sedimentary rocks, which range in age from Jurassic through to late Cretaceous (Sapiie et al., 2006).

Gundih field lies in central high of the East Java Basin, The Central High consist of NE – Java (Kujung) – Madura – Kangean – Lombok High forms the Central High province. The famous E – W Sakala Fault Zone (known also as RMK) is part of this structural province. Dominated by structural patterns that trend E – W like those that develop in Northern Madura Platform, Madura High, and Madura Strait Sub-basin. To the east, E – W structural pattern is more developed as shown by Sakala Fault Zone, Kangean and Lombok Sub-basin. Presently the central high province initiated as a graben caused by extensional faulting commencing from Eocene to Late Oligocene, then followed by structural inversion during Early Miocene up to recent.

Kujung and Ngrayong Formation are the primary reservoir targets for hydrocarbon in East Java basin. Both formations were developed during a transgression phase. In the deeper area, the Kujung Shale developed while at the shallower area Kujung Carbonate and Prupuh Limestone developed. To the west, in the Rembang – Bulu Offshore Area, the area had already been a deeper from Early Miocene until Middle Miocene leading to interfingering between the Tawun Formation and Kujung Formation. While to the east, in the South Madura Area, the Tawun Formation had been developed later since the Middle Miocene to Late Miocene. Around the North East Madura Area, the Tawun Formation consists of the Tawun Member consisting of bioclastic limestone, reefal limestone and marl intercalation. To the west, the Tawun Formation consists of the Ngrayong and Tawun Members. The Ngrayong Member consists of interbedded of sandstone and limestone and well known the Ngrayong sandstone (**Figure 2**).

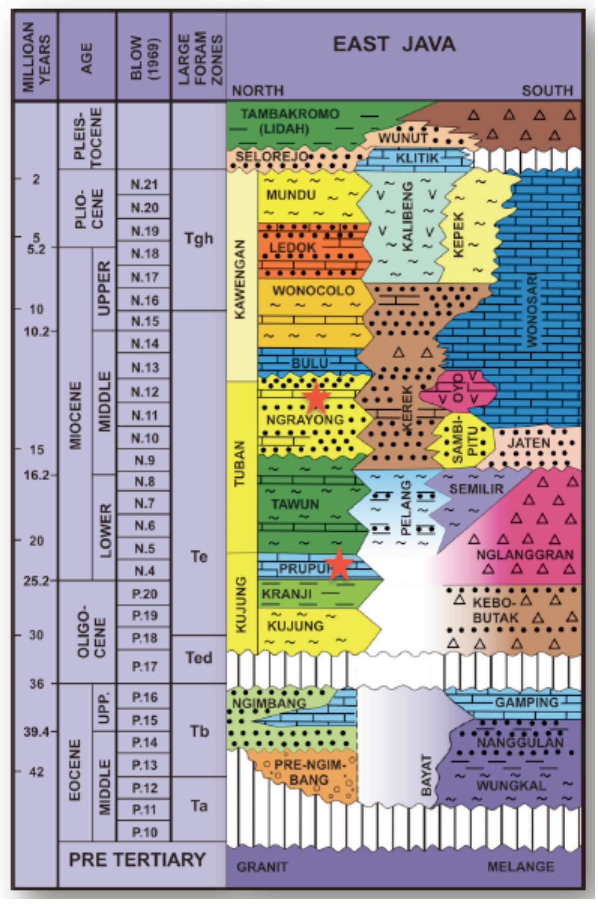

Figure 2. Stratigraphy compilation of East Java basin showing Ngrayong and Kujung Formations as main target for CCS storage (red star)

RESERVOIR CHARACTERIZATION

Based on fieldworks and core data from ITB-1 and ITB-2, Ngrayong Formation can be divided into two lithology characteristics: Lower Part and Upper Part.

Lower part of Ngrayong Formation consists of sandstone, shale, intercalation of coal and intercalation of limestone. Sandstone has white yellowish in color, very fine to fine in grain size, calcareous, close fabric, good sorted, good porosity and permeability, medium hard, mineralogy by quartz, feldspar, and lithic. Shale has black grey in color, very fine to fine in grain size close fabric, good sorted, good porosity and permeability, soft – medium hard. Coal has black in color, non-calcareous, has parallel lamination of sediment structure. Limestone has white in color, wackstone matrix, medium hard and compact. Upper Part of Ngrayong Formation consists of sandstone (Figure 1.23). Sandstone has white yellowish in color, fine to medium in grain size, non-calcareous, close fabric, good sorted, very good porosity and permeability, compact, mineralogy by quartz, feldspar, and lithic with bed thickness 30 - 60 cm.

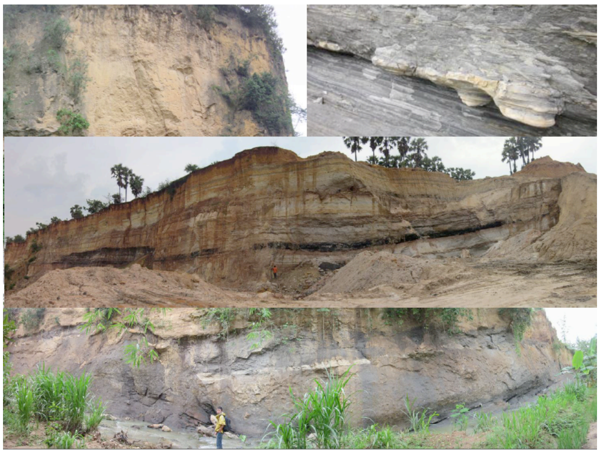

Figure 3. Outcrops of Ngrayong sandstone showing various lithology characteristic suggesting different facies setting.

Shallow core samples (< 100 meter) from ITB-1 and ITB-2 implies various lithology that represent geology formation in the area, started with interbedded sandstone and claystone from bottom layer and end with limestone domination at the top (**Figure 3**). These core was collected to represent more closely to reservoir Ngrayong found in Jepon-1 well.

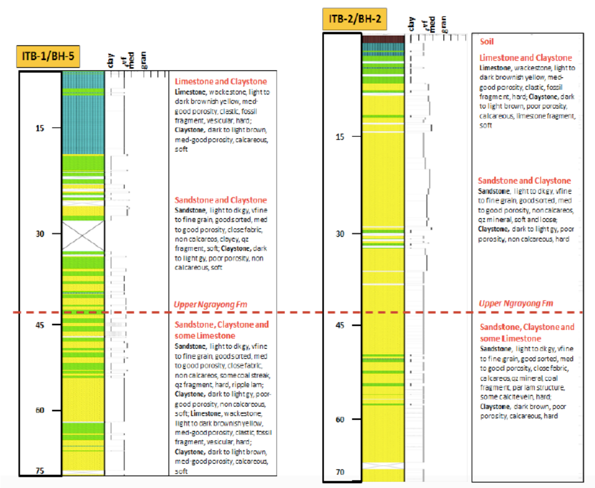

Figure 4. Descriptions of Ngrayong sandstone form shallow drilling core (ITB-1 and ITB-2)

FAULT-SEAL ANALYSIS

Fault Seal Analysis (FSA) techniques developed by Yielding et al. (1997) was adapted for FSA of the Gundih Area. Basically, this method used lithologic variation (stratigraphic) and fault attributes, such as throw and type displacement, to calculate sealing potential. Sealing potential is quantitatively determined by Shale Gouge Ratio (SGR) approach which is an estimated proportion of fine-grained material entrained into the fault gouge from the wall rocks. The result of the SGR calculation can be calibrated using well data. The most important input parameter in the building of FSA is stratigraphy and fault interpretation (kinematics and geometry). The results will be greatly influenced by those parameters of input. In this study, provided stratigraphy and fault interpretation of the area were used. Stratigraphy model is based on sequence stratigraphy and lithostratigraphy classification. Lithostratigraphy nomenclatures were used for well-based markers and reservoir identification. Stratigraphy nomenclatures (Lithofacies) used in this study was redefined using the Vshale value. Vshale value below 0.2 was defined as Sandstone (good reservoir), and above 0.4 as Shale and value of RHOB that above 2.6 as carbonate and the rest become shaly sand.

The results of correlation indicate consistent and well - developed continuous horizons and markers throughout the field. This evidence suggested that in most cases, the Gundih Area fault seal characteristic was not controlled by regional stratigraphy distribution such as facies changes. It was most likely controlled by local lithology variation and petrophysical characteristics.

Most of the faults would seal in cutoff SGR 10%. Therefore, it was very important to calibrate SGR values in order to have the correct cutoff for the Gundih Block. However, in this study as many others this cutoff could not be determined due to lack of data. SGR cutoff 30% was determined to characterize sealing and leaking fault. Based on this evidence, this value will be applied to characterize sealing capacity faults in the study area. One of the ultimate goals in this study is to characterize trap risking issues in conjunction with injection target. The main reservoir target is Middle - Late Miocene of Ngrayong Formation. The closure is 3-way dip closures of fault-bounded anticlines. Based on analysis using SGR cutoff 30%, Jepon-1 lead was characterized by leaky fault in the southern part (**Figure 5**).

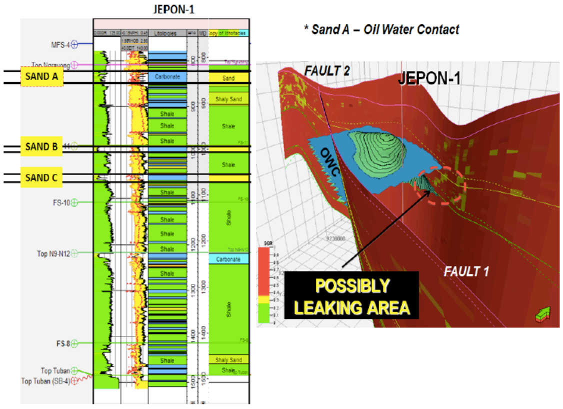

Figure 5. Trap risking analysis for Jepon-1. The drilled Leads (CCS target) in this area is characterized by a risking of leaky fault.

The results of Fault Seal Analysis study of the Jepon-1 Area reveal several major concerns in particular related to the faulting history due to the deformation history. Deformation history of the study area is dominated by strike-slip fault system styles which means appearance slip (throw) on most faults are not total movement history. Consequently, the results of the present FSA study should consider as minimum number of fault sealing capacity. In general, it can be concluded that qualitatively most of the fault in the study area will likely be to be sealing type. But the main issue for CO2 injection is how the fault can withstand the additional pressure because added more gas through the reservoir and seal. Geomechanical analysis approach can be answer of the differential pressure.

GEOMECHANICS ANALYSIS

Successful prediction of migration CO2 injected to the subsurface requires information about rock units within and surrounding the injection target. Potential storage sites commonly comprise a reservoir and overlying low permeability mudstone-dominated seal or caprock, which provide a barrier to the upward flow of fluids. Therefore, more knowledge in term subsurface of in situ stress condition is needed in order to understand reservoir and seal behavior at depth.

Geomechanics analysis in the reservoir layer inside Jepon-1 well as target. Building geomechanical model required knowledge of in situ stress orientations, in situ stress magnitudes, pore pressure and effective rock strength. Geomechanical model is dynamic trough production and injection operations. Therefore, in situ stress information can be concluded directly from well data or calculated using well logs specically using image logs evaluating any evidence of mechanical failure. Two unkown parameters is magnitude of Shmax and value of rock strength (Co). The main goals of building geomechanical model is to have each not only orientation but also magnitudes of stress in order to get present-day stress system.

Log available for geomechanic analysis in Jepon-1 includes wireline logs of Gamma Ray, Density, Neutron, Resistivity, and Sonic provided seperate in different inch and also drilling and PVT report. Some of the data can only find some of the geomechanic parameters (eg Pore Pressure, Overburden Stress, and Minimal Horizontal Stress). Calculated and 1D geomechanics modeling of Jepon-1 well is presented in **Figure 6**.

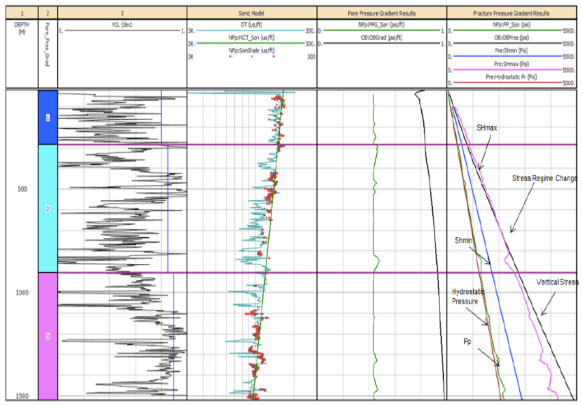

Figure 6. 1D geomechanics modeling of Jepon-1 well suggesting strike-slip stress condition.

SUMMARY AND CONCLUSION

1. Ngrayong Formation as reservoir storage for CO2 has adequate capacity in term of thickness, depth, porous and permeability.
2. FSA analysis likely to be sealing type.
3. Ngrayong Sandstone in the Jepon structure has capability as CCS reservoir target, with pore pressure is considered as hydrostatic condition.

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