Biogenic Gas Exploration in Karangringin Area, South Sumatra Basin, Indonesia

Eksplorasi Gas Biogenik di Daerah Karangringin, Cekungan Sumatra Selatan, Indonesia

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ABSTRACT

Biogenic gas has become an economic target of exploration and exploitation, due to the high demand for gas. Its geological occurrence is easily interpreted; it is significantly widespread and shallow; the gas quality is good with >97% content of CH\textsubscript{4}, low S and CO\textsubscript{2} content. Production tests from Karangringin block resulted in a production rate peak of 5 MMscf at Sagu-1 well. This article presents a summary of geophysical, geological, and geochemical aspects in order to assess biogenic gas accumulation in Karangringin Block. Seismically, the existing data clearly exhibit strong amplitude anomalies or a bright spot as a Direct Hydrocarbon Indicator. Furthermore, advanced geophysical analysis, AVO, seismic attribute, and AI methods, were carried out to confirm the gas presence. The result of this analysis has been helpful to distinguish between coal and gas-bearing reservoirs, where coal revealed a similar appearance in the seismic data. Seismic data were also important in delineating lateral gas distribution and exploring prospects and leads in Karangringin Area. The stable carbon isotopic composition analysis of the gas samples has shown δ\textsuperscript{13}C values between -60.36 and -60.39‰ for methane, while C\textsubscript{2} that is between -32.28 and -35.13‰ suggesting that gases were predominantly originated from bacterial degradation of the organic matter and have only a little association with thermogenic origin. The main gas-bearing reservoir has 730 ft thick of sand layer over the upper Late Miocene Muara Enim Formation, at a depth of 935 - 1310 ft below sea level. The Muara Enim Formation was deposited in a littoral environment that reflected the onset of a marine regression. The gas is trapped along a NW-SE anticlinal system, related to a thrust fault. Biogenic gas characteristically occurs at a shallow depth and in a high quality, which makes this gas economically attractive for production. Karangringin area, as one of the proven and potential biogenic gas targets, provides a typical setting for integration of geological, geochemical, and also geophysical features to assess gas accumulation.

Keywords: biogenic gas, direct hydrocarbon indicator, stable carbon, marine regression, gas accumulation

SARI

Gas biogenik secara ekonomis telah menjadi sasaran eksplorasi dan eksploitasi, karena tingginya permintaan akan gas. Secara geologis, kehadirannya cukup mudah diinterpretasikan, karena tersebar secara signifikan dan dangkal; kualitas gas baik dengan kandungan CH\textsubscript{4} >97%, dan kadar S dan CO\textsubscript{2} rendah. Uji produksi pada blok Karangringin ini, di sumur Sagu, menghasilkan tingkat puncak produksi 5 MMscf/d. Makalah ini menyajikan ringkasan aspek geofisika, geologi, dan geokimia untuk mengevaluasi akumulasi gas biogenik di Blok Karangringin. Data seismik yang ada jelas menunjukkan kehadiran anomali amplitudo yang kuat atau sebuah bright spot sebagai indikator hidrokarbon secara langsung. Selanjutnya, analisis geofisika yang lebih maju, AVO, atribut seismik,
INTRODUCTION

Karangringin Area is located in the South Sumatra Basin. This block is operated by PT Pertamina EP (Figure 1). Previously, operators of this block were looking for oil in a shallow target whilst shallow gas was considered as a drilling hazard. Nowadays, gas has become the economic target, due to its high demand and attractive price. Therefore, PT Pertamina EP is studying shallow gas intensively to achieve a better understanding of gas accumulation in Karangringin Area.

Shallow gas in that area is trapped within the upper Miocene Muara Enim Formation as the main target of exploration. The primary gas reservoirs are thin sand layers in the Muara Enim Formation at 935 - 1310 feet below sea level. The uppermost sands are from 7 to 30 feet thick, and commercial flow rates of biogenic gas have been proven.

In the Karangringin Area, the proven biogenic gas structures have a NE-SW anticlinal structural trend. These anticlinal structures are related to NE-SW trending thrust
faults, which are parallel to the regional structure in the South Sumatra Basin.

**Methodology**

Integrated geology, geochemistry, geophysical, and reservoir data of producible biogenic gas have led to the identification and general assessment of biogenic gas characteristics and occurrences in Karangringin Area.

**Regional Geology**

Karangringin Area is geologically situated in the South Sumatra back-arc Basin. Two main tectonics dominated the Tertiary tectonic evolution of the South Sumatra Basin. An extensional movement occurring during the Early Tertiary resulted in the N-S to NW-SE trending graben systems (Figure 1). The graben is filled with volcanics and non-marine Lahat and Lemat Formation.

In the Early Miocene, the basin was tectonically quiescent and a major marine transgression resulted from thermal sag and eustatic sea level rise. With continued transgression during the Early Miocene, carbonate build-up of the Baturaja Formation was overlain by marine shale of Gumai Formation. In the late Middle Miocene, deposition of the shallow marine Air Benakat Formation began followed by deposition of non-marine sediments of Muara Enim and Kasai Formations (Figure 2).

In the Late Miocene, subduction of the Indo-Australia Plate beneath the Eurasian Plate caused a compressional regime in Sumatra. This resulted in a basin inversion and uplift continuing until today. This compressional phase produced the NE-SW fault and folds that later become major hydrocarbon traps of South Sumatra including all fields in Karangringin Area.

**RESULTS AND DISCUSSION**

**Geophysical Aspects**

The Karangringin Area is covered by 2D seismic data acquired in 1988, 1996, and...
2003. Because the exploration wells targeted the deeper Talang Akar Formation, seismic acquisition parameters were not optimized for shallow gas. At that time, shallow gas was considered a drilling hazard, not a resource, due to a lack of gas markets. Fortunately, this 2D seismic data still revealed bright-spots in the shallow Muara Enim Formation (Figure 3). In a relatively soft sand, the presence of gas and/or light oil will increase the compressibility of the rock dramatically: the velocity will drop accordingly and the amplitude will decrease to a negative-bright spot anomaly.

Gas-filled sand may be transparent, causing a so-called dim spot, i.e. a very weak reflector. It is very important before interpreting seismic data to find out what change in amplitude is expected for different pore fluids, and whether hydrocarbons will cause a relative dimming or brightening compared to brine saturation (Avseth, 2005). It is hoped bright-spot amplitude anomalies would be reliable direct hydrocarbon indicators for gas reservoirs in this area. However, the Sagu-1 bright spot proved to be associated with any oil or gas shows, can be associated with thin stacked reservoirs, due to tuning effects (Figure 3). To determine whether each bright spot anomaly is associated with gas, the bright spots were overlaid on the depth structure map. If the bright spot anomaly conformed to the depth map, then it is likely associated with gas.

Fortunately, in this area, the control is available in the form of a proven oil field (Babat Kukui). Amplitude variations with offset (AVO) form the comparison of seismic amplitude changes to the offset of traces from the source. AVO has been used for over a quarter of a century in the hunt for gas and oil. Given the high sensitivity of AVO analysis, any gas, if present, will explain the class of the sandstone reservoir. The result can also support the study of the DHI - Bright Spot. Amplitude versus offset (AVO) interpretation is facilitated by cross-plotting the AVO intercept (A) and gradient (B).

Rutherford and Williams (1989) derived the classification scheme for AVO anomalies, with further modifications by Ross and Kinman (1995) and Castagna and Swan (1997). AVO modeling in synthetic of Seng-1 shows...
a negative intercept and gradient for top gas. This is the type of AVO class III anomaly. AVO modeling in synthetic of Siarak-1 shows a negative intercept and positive gradient for coal. The AVO analysis methods are applied to confirm the high-amplitude response in the tested structure located at the Siarak field.

An attempt has been made to assess the amplitude response of these sandstones on the seismic line at the Sagu-1 well. The result indicates that the amplitude is class III low-impedance sandstone with a negative intercept (Rp) and negative gradient (G). AVO analysis of CDP gathers in Sagu and AI inversion shows a response of AVO class III. (Figure 4). This result is confirmed by well logs and DST’s.

**Reservoir Geology**

The Muara Enim Formation is the main target, as a proven biogenic gas reservoir in the Karangringin Area. The sediments of Muara Enim Formation were deposited in a shallow marine characterized by the presence of flaser, lenticular ripples, wavy, and herringbone sedimentary structures. The Muara Enim Formation is conformably overlain by Kasai Formation, a monotonous regressive sequence of Late Pliocene-aged composed of claystones, siltstones, sandstones and minor coal. These sediments were deposited in a continental (dominantly fluvial) environment (Figure 2). The formation is predominantly composed of laminated sandstone, interbedded with several relatively thin claystones. Sandstone is the dominant lithology on this formation. The sandstone is described as very fine-to fine-grained, medium grey to light grey, soft to firm, loose rarely medium hard in the middle part, sub-blocky to blocky, generally non-calcareous, with traces of pyrite and glauconite in places. Sand is dominant in the upper part of the Muara Enim Formation, and the bottom part is dominantly composed of claystone. Sandstones in the Muara Enim Formation are described as white, loose to unconsolidated, subangular to subrounded, poorly to moderately sorted, with traces of pyrite and slightly calcareous. Reservoir sand in Muara Enim Formation is present in Sagu-1, Siarak-1 well as a lithotype for reservoirs on the Muara Enim Formation. All of this sand is biogenic gas reservoir sand, and no GWC (gas-water contact) has been identified from any wells in Karangringin area: all hydrocarbon contacts are described as gas down to (GDT).

![Figure 4. Sagu AVO analysis showing P*G Anomaly (+) and AVO Class III by AVO Crossplot, indicating a high porosity and low AI.](image-url)
Geochemistry

Molecular composition of the gas sample is not required in this study, but only a stable carbon isotope analysis on the C₁-C₄ and CO₂ gases. The stable carbon isotope compositions of the gas sample are reported in the conventional delta notation in permil (‰) relative to VPDB. Result of the analysis shows that the gas samples have δ¹³C values between -60.36 and -60.39‰ for methane, while C₂ is between -32.28 and -35.13‰. Such isotopic ratios suggest typical gases of predominantly bacterial origin and only little association with thermogenic origin, (Table 1). Plots of δ¹³C₃ against gas wetness and δ¹³C₁ vs. δ¹³C₂ clearly indicate a biogenic character of the gas source (Figure 5). The thermogenic origin is noted as ethane gases and is likely to derive from expulsion of source rock that is oil-mature, rather than gas-mature with respect to oil generation based on an equivalent vitrinite reflectance (0.70 - 0.80% Ro).

The carbon isotopic ratio for the CO₂ shows two groups of gas showing values in the -13.34 - -19.71‰ (DST#1 & DST#3), and -31.92 - -32.11‰ (DST#2 & DST#4). Carbon isotopic values in the range of -8 to -12‰ haves been suggested to be derived from the thermal degradation of organic matter, whereas that from bacterial oxidation of methane has -20 to -59‰ (James, 1990). Plots of δ¹³C₃ vs. δ¹³CO₂ (Figure 6) have shown the origin of both methane and CO₂ gases that is likely to be derived from microbial degradation of the organic matter, hence providing supportive evidence for the above suggestion.

Thermal maturity of the source rock for hydrocarbon gas can be inferred by using a typical stable carbon isotopic based natural gas plot (Figure 6) (Schoell, 1984). It is shown that the carbon isotopic data of the gas sample fall below 0.5%Ro for methane and in the range of 0.7 - 0.8% Ro, indicating low (biogenic) and moderate maturity (low thermogenic) gas respectively.

Reservoir Properties

The log and conventional core laboratory analysis of Muara Enim sandstone in Sagu structure indicates that the average porosity for reservoirs in B2A sand intervals ranges from 19-36% while mobility ranges from 84 - 126 md/cp (Figure 7). The high results of porosity and permeability measurements are due to the under compacted nature of the sedimentation. This evidence is seen in an image logging and the cutting, where the grains are loose sand. This type of loose sand allows greater porosity - also permeability, due to its open pore-throat system. A gas-bearing reservoir can be easily recognized from wireline log responses. High values

<table>
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<th>DST#3</th>
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<tr>
<td>(C₂-C₃)/(C₁-C₄)*</td>
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<td>0.002834</td>
<td>0.00386</td>
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Figure 5. Plot of carbon isotopic vs. wetness data showing characteristic of the gas samples and plot of carbon isotopic data inferring the likely origin of the gas.

Figure 6. The plot of carbon isotopic data methane vs. CO₂ inferring it’s likely source rock and plot of carbon isotopic data inferring thermal maturity of it’s likely source rock.

Remarks:
I: CH₄ and CO₂ from Marte
II: Biogenic CH₄ and CO₂
III: CH₄ and CO₂ from Organic Metamorphism

of deep resistivity, lower density and neutron response, and also slowness of transit time (Sonic) are the excellent signs which identify a gas-bearing reservoir (Figure 7). Crossover of density vs. neutron porosity is often used to determine the boundary of the gas. A gas-bearing reservoir yields a lower response of density and neutron and
also creates an excellent crossover, caused by the compressibility of the gas. This wireline response has been confirmed with DSTs in DST-1, DST-2, DST-3, and DST-4. The high quality of sand and gas mobility within the reservoir resulted in excellent gas test and production results. From Sagu-1 well DST test DST-1 to DST-4, the gas rate ranges from 3 to 5 MMscfd at 48/64 choke size and reservoir pressure is from 410 - 587 psig.

From gas component analysis, the gas produced has a very high content of CH4 (methane) at 97 - 98%, and low of H2S (hydrogen sulfide) content of 0 ppm, with CO2 (carbon dioxide) about 0.48-0.76%. No content of C3 - C7 is detected from gas analysis, reflecting the dryness of gas from biogenic origins. This characteristic, as explained above, makes this gas economical for production, due to the simplicity of the gas exploitation method and surface facilities design.

CONCLUSIONS

Gas in Karangringin is classified as biogenic gas based on gas isotope lightness, high content of CH4 (dry gas), and without C3 - C7 content in its composition. The gas was most probably generated from shale intervals in Air Benakat Formation and Muara Enim Formation, based on organic carbon content. All source rock samples are immature / just mature. Hydrocarbons were produced from microbial activity during anaerobic
sedimentation conditions. The Muara Enim Formation was deposited in rapid sedimentation conditions. It is reflected by restricted sand between shales, undercompacted sand and lack of bioturbation and root casts in the sediments. The presence of gas can easily be recognized from a bright-spot anomaly on the seismic, and it has been confirmed with AVO analysis to distinguish between gas presence and coal. This biogenic gas has been confirmed by flowing tests and Geochemistry Analysis. The characteristic of biogenic gas that occurs at shallow depths, easily recognized from geological and geophysical interpretation, is of high quality and relatively large volume, and the gas can economically be produced. Karangringin area, as one of the proven and potential biogenic gas source areas, provides a typical example of integrated geology, geochemistry, geophysical, and reservoir study to assess gas accumulation.

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