Study of Gas Potency Based on Gravity Anomaly Modeling And Seismic Profile Analysis at Banggai-Sula Basin

Kajian Potensi Gas Berdasarkan Pemodelan Anomali Gaya Berat dan Analisis Penampang Seismik di Cekungan Banggai-Sula

Ediar Usman [1*] and Panuju [2]

[1] Marine Geological Institute, Jl. Dr. Junjunan No.236 Bandung

[2] Research and Development Centre for Oil and Gas Technology "Lemigas", Jl. Cileduk Raya Kav.109, Cipulir, Jakarta Selatan.

Email : *ediar.usman@gmail.com

(Received 31 July 2013; in revised form 16 November 2013; accepted 10 December 2013)

ABSTRACT: Banggai-Sula Basin is one of the basins with character of the micro-continent derived from northern part of Australia. Some traces the migration in the central part of Papua are slate, schist, and gneiss, current movement is facilitated by the Sorong Fault, which runs from the northern part of Papua to eastern part of Sulawesi. Results of gravity anomaly model (2D and 3D), seepage distribution, seismic and fields existing of oil and gas production in the western part of the Banggai-Sula Basin obtained a new prospect area in the northern part of Peleng Island, western part of Banggai Island, southern part of Banggai-Taliabu Islands, western and eastern part of Sulabesi Island.

The new prospect area is reflected in the centre with form of ??the low morphology on gravity model and prospect trap on seismic data in the western part of Tolo Bay. Results of chemical analysis on the source rock of Buya Formation on Tmax vs Hydrogen Index (Tmax vs HI) Diagram shows the type III kerogen quality and the Oxygen Index vs Hydrogen Index (OI vs HI) Diagram shows the gas prone Type II, so that giving the impression that this area has the potential to containing the gas. The quality of the gas is included in the category of immature to mature type.

Keywords: marine geology, gravity anomaly model, trap, source rock, hydrocarbon quality, Banggai-Sula Basin

ABSTRAK: *Cekungan Banggai-Sula merupakan salah satu cekungan dengan karakter mikro-kontinen yang berasal dari pecahan Australia bagian utara. Beberapa jejak migrasi terdapat di bagian tengah Papua berupa batuan slate, schist, dan gneiss, pergerakannya saat ini difasilitasi oleh Sesar Sorong yang membujur dari Papua bagian utara hingga bagian timur Sulawesi. Hasil pemodelan gaya berat (2D dan 3D), daerah rembesan, seismik dan keberadaan lapangan produksi migas di bagian barat Cekungan Banggai-Sula diperoleh hasil daerah prospek baru di bagian utara P. Peleng, bagian barat P. Banggai, selatan P. Banggai-Taliabu, barat dan timur P. Sulabesi.*

Daerah prospek tersebut tercermin dari daerah pusat cekungan dengan bentuk morfologi rendahan pada data gaya berat dan prospek perangkap (leads) pada data seismik di bagian barat sekitar Teluk Tolo. Hasil analisis kimia batuan sumber pada Diagram T_{max} vs Indeks Hidrogen menunjukkan kualitas kerogen tipe III dan pada Diagram Indeks Oksigen vs Indeks Hidrogen menunjukkan tipe II gas prone, sehingga memberikan gambaran bahwa daerah ini berpotensi mengandung gas. Kualitas gas tersebut termasuk dalam kategori belum matang sampai matang.

Kata kunci: *geology kelautan, model anomali graviti, perangkap, batuan induk, kualitas hidrokarbon, Cekungan Banggai-Sula*

INTRODUCTION

Study area is located between coordinates 121°30'00' to 127°30'00" E and 0°25'00" to -2°50'00" S, with total area reaches 6,000 km^2.

Study area location, covers of eastern part of Central Sulawesi, and also including the waters around Banggai and Sula Islands and the waters of Molucca and Banda Sea. Banggai Islands consist of Peleng and Banggai Islands, while the Sula Islands consist of Taliabu, Mangole and Sulabesi Islands. In the geological termination, Banggai-Sula Basin covers the area such as of Tolo Bay, along east coast of Central Sulawesi, Banggai and Sula Islands are entirely included in the Banggai-Sula Microcontinent (Figure 1).

Banggai Sula basin is located in the eastern part of Central Sulawesi, consists of two islands of Banggai Islands and Sula Islands, which is known as the Banggai-Sula Islands. Banggai-Sula Basin is a basin with status of basin production. The area of gas production are located in Senoro, Donggi and Maleo Fields, of which there are around the eastern coast of Central Sulawesi. In this study, Banggai-Sula Basin region not only the Banggai Sula Micro-continent, but including the waters of Molucca and Banda Seas, Tolo Bay and the eastern part of coastal area of Central Sulawesi.

Geologically, Banggai-Sula Basin including on type of microcontinent as a part fractions of Australian Continent, that all the existing sediment characteristics of thick continental type and lithology varied as limestone lenses, carbonates shelf and sandstones. Based on these conditions, Banggai-Sula Basin has the potential to be further developed, especially around the production area with the same pattern of geological history, such as Peleng, Taliabu, Mangole Islands, and waters in southern part of Tolo Bay.

In the context of the hydrocarbons, the challenge now is to increase reserves and production efforts, as the current trend is the decline in reserves and production, so it is necessary to search new sources of oil and gas prospects. The main alternative is in the production basin, which will accelerate the discovery of new oil and gas reserves and will eventually support the national oil and gas production. Banggai-Sula Basin is one of the oil and gas producing basins, as a prospects area, especially in the direction of the same geological condition with production field around the east coast of Central Sulawesi.

The propose of this study to get the new prospect area as a base of determination for work area of oil and gas at Banggai Sula Basin. In addition, the need evaluation of geological conditions, especially kitchen area, sources rock, sediment thickness, migration process and traps, so as to determine more detailed regional exploration prospects in the future.

The regional geology of study area can be discussed as follow :

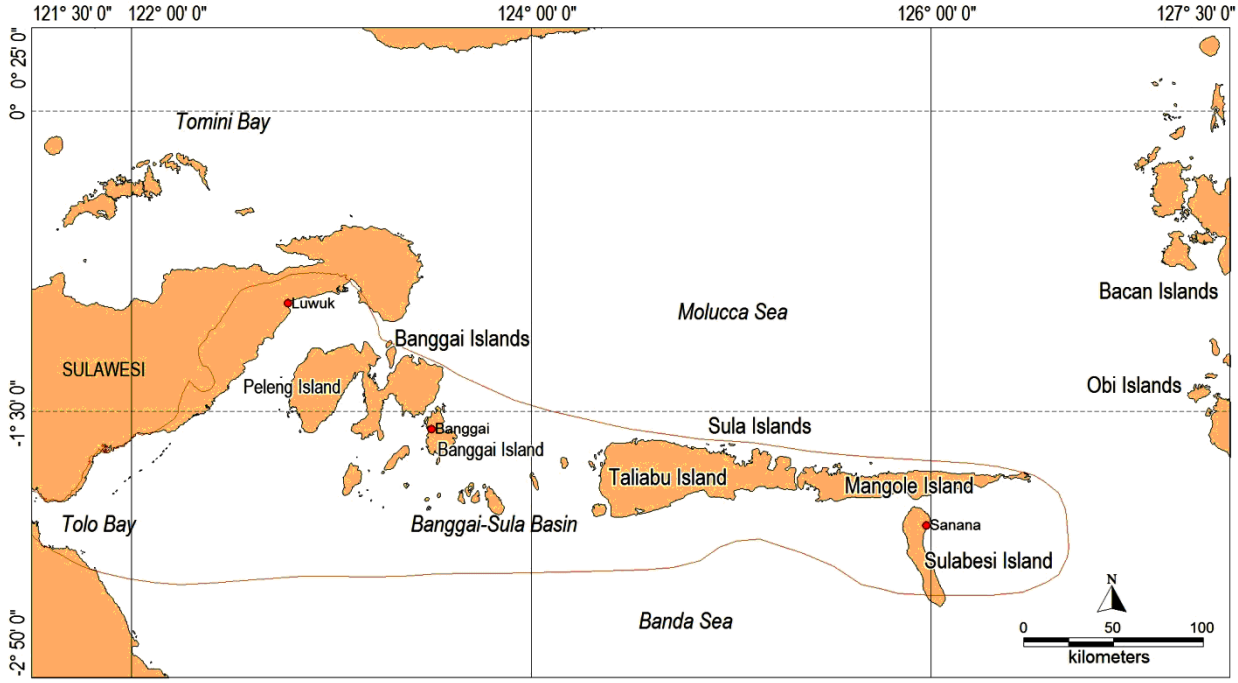

Figure 1. Location map of Banggai-Sula Basin and it's surrounding.

History of Formation the Micro-continents

Some early researchers agree, that based on geological similarities in tectonic processes and stratigraphic variations, the micro-continents in Eastern Part of Indonesia are Banggai-Sula, Mekongga, Tukangbesi-Buton, Buru-Seram, Obi-Bacan, Misool-Bird's Head, Lucipara and Sumba (Figure 2).

The micro-continents such as allochthonous micro-continent (allochthonous terrains) are based on rock sequences and the age is estimated to come from the northern part of the Australian continent, there are also around the central region of Papua (Hamilton, 1979; Simandjuntak, 1986; Simandjuntak and Barber, 1996; Hall, 2001). South Papua (including New Guinea) as a northern slope of the Australian Continent, and structurally has not separates at Neogen occurs when extensional faults time, which forms Terban Torres Strait which separates the mainland of Papua Craton interior mainland Australia. However, in understanding of continental crustal plate, the two regions is an unity with Australia Plate.

The presence of micro-continents around the study area since the Cretaceous to Early Miocene; is a series of tectonic activity associated with the movement of the Australian Plate and Pacific to the Indonesian Archipelago. Collision lines as the orogen lines its own characteristics and anatomy; depending masses of crusts and tectonic control. Anatomical pattern of the collision lines is the foreland and hinterland are composed of foreland basin, folding lines, foreland fault, suture melange, metamorphic lines and back arc (Satyana, 2007). The collision lines will be able to give the movement condition of micro-continent before and after collision with other masses of continet to form foreland basin type and suture of micro-continent. Type of suture forms fragments of oceanic sediments are uplifted and sandwiched between the ophiolite and oceanic sediments, which forms the basin suture narrow and complicated.

The earth scientists, generally believe that the micro-continents come and separate from Papua and move to the west by Sorong Fault since Cenozoic (Crostella, 1977). This opinion is based on the similarity of geological micro-continents with the Bird's Head in Papua, and the presence of ophiolite rocks as an oceanic product in central Sulawesi, Papua, Halmahera, Sulawesi and South Kalimantan; able to explain the condition of the Pacific Plate to the Indonesian Archipelago (Sopaheluwakan, 2007).

In Papua and micro-continents, tectonic extension is characterized by the formation of syn-breakup sequences, is called as red beds, which formed by the

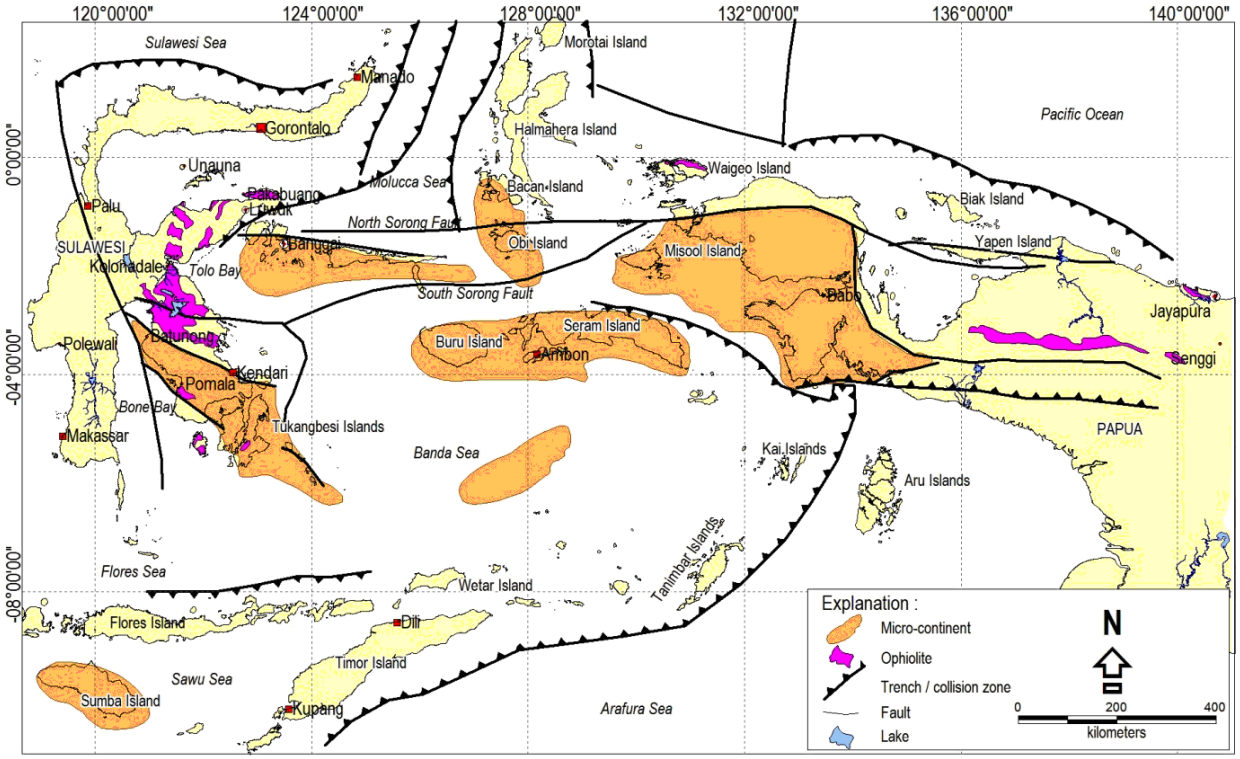

Figure 2. Distribution map of micro-continents in the eastern part of Indonesia are Banggai-Sula, Mekongga, Tukangbesi-Buton, Buru-Seram, Obi-Bacan, Misool-Kepala Burung and Lucipara as an area containing hydrocarbon prospects (compiled from: Hamilton, 1979; Simandjuntak , 1986; Hall, 1996 & 2001; Usman, 2009).

red sandstone arkosa brownish, terrestrial sediment and carbonate in slope on the edge of the continental along Late Triassic. Red sandstone exposed only in a narrow place in the Banggai-Sula Islands (Simandjuntak, 1986).

During Late Cretaceous, deposition of limestones (ooze) occurs in micro-continents (Simandjuntak, 1986; Hartono, 1990), so that the micro-continents separated from the northern part of Papua and the Australian Continent. Extension and changes of position the micro-continent and Papua during Early Cretaceous above sea level, so it does not allow the deposition of sedimentary rocks occur. At the end of the Middle Cretaceous, the position change of micro-continents below sea level (sub-marine), so that the deposition limestone (Tanamu Formation) in the Late Cretaceous (Simandjuntak and Barber, 1996).

Since the Eocene in the regions, the formation of carbonate exposures in almost all the micro continents, carbonate deposition exposure does not occur again until Early Miocene. This is due to tectonic activity and position changes of micro-continent, has given rise to several fragments smaller islands in the Paleocene, Oligo-Miocene and Middle Miocene. Therefore, the presence of limestone lenses later known as hydrocarbon traps in the Misool-Head Bird and Banggai-Sula Basins (PND, 2006).

In the Paleocene is formed the fragments in micro-continents of Banggai-Sula, Tukangbesi, Buton, Buru-Seram, Misool and Bird's Head and Salawati Bintuni Basin in extension line with Papua. On Eocene the formation of carbonate on shelf of micro-continents and more intensive and widespread in Papua and New Guinea, while in Salawati and Bintuni Basin occurs the sedimentation of clastic to form the sediment thickness reaches 3,000 meters from Eocene to Oligocene (Karig et al, 1987).

Important episode in the formation of Banggai Sula Micro-continent on Oligo-Miocene epoch which is caused by separation of the continents from Bird's Head to form the Banggai Sula Basin and then the movement of west-northwest direction by horizontal movement of Sorong Fault transform. At the same time followed by a formation process of limestone lens. At the Eocene-Miocene, the limestones at the shelfs of continents; later fill in the basins. Banggai-Sula and Salawati Basin are separate with Bintuni, currently the most prospect containing hydrocarbons basins on tracks of Misool - Bird's Head. The presence of hydrocarbons formed in the layer of sandstone and limestone lenses in Salawati and Bintuni Basins. Even on other micro-continent origin around the Banda Sea; based on tectonic processes and stratigraphy layers have a thicker layer of sediment are compared with some sediment in the ocean basins, both basins have the same level of prospective for hydrocarbon content.

Physiography of Banggai Sula Basin

Generally, physiographic conditions of Banggai-Sula Basin and its surrounding affected by regional tectonic patterns, especially the role of Sorong Fault. The existence of Sorong Fault as an indication the movement of Banggai Sula microcontinent from Australia to Asia directions. Banggai Sula micro-continent fragments entirely as a continent with a pattern altitude is relatively elongated shape with the west - east and lithology variations associated with the continent.

Banggai Sula Basin are covers of islands and waters of Banggai Sula, physiographically forms the high and low morphology. High area such as Peleng, Banggai, Taliabu, Mangole and Sulabesi Islands. This high formed by movement of Banggai-Sula micro-continent to west direction and pushed the central part of east and north-east arm of eastern part of Sulawesi Island, so that central part of Banggai Sula micro-continent is upraised above sea level (Figure 3).

At the northern and southern part of Banggai-Sula Basin are bordered by North and South of Sorong Faults formed the low mophology (see Figure 2). The western part of Baggai-Sula Basin is pushed the eastern part of Central Sulawesi to west direction, so structurally, geological conditions in the Banggai Sula Basin constantly to the eastern Sulawesi and has similarities with the geology around the east coast of Central Sulawesi. Around the east coast of Central Sulawesi there is a gas production field, such as Senoro, Donggi and Maleo Fields. This condition is also caused by the collision between the micro-continent of Banggai-Sula and eastern arm of Sulawesi, the majority of western Banggai Sula to interaction with the central Sulawesi.

The Banggai Sula basin is 52,490 km square wide are covers Banggai-Sula Islands (including most of eastern part of Central Sulawesi), south Molucca Sea and north Banda Sea.

METHODS

The methods that were used are the compilation of data processing (2D and 3D) of gravity modeling data from Aero Gravity USGS (2009) and the geochemistry analysis of source rock on Buya Formation (Panuju, 2006). Geochemical analysis to determine the type and level of maturity of the gas using the Diagrams of Tmax vs Hydrogen Index (Tmax vs HI) and Oxygen Index vs Hydrogen Index (OI vs HI).

Another analysis are secondary data and hydrocarbon seepage compilation from some publication data.

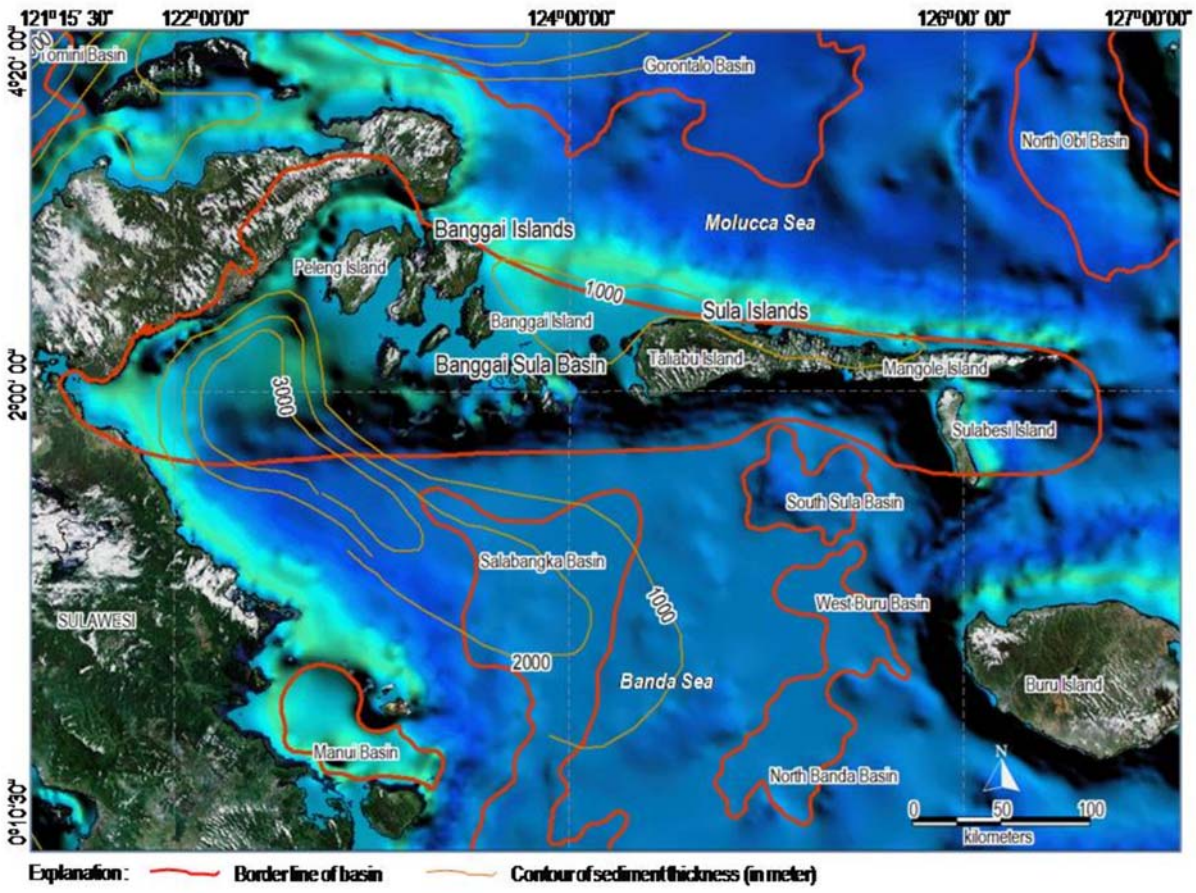

Figure 3. Border line of Tertiary sediment thickness in Banggai-Sula Basin and it's surrounding (Hamilton, 1979).

RESULTS

Morphology of Basement

Gravity data can describe the pattern of basement morphology such as high and valleys around the Banggai-Sula Basin, especially to the central, north and south direction. Result of gravity data processing and modeling shows that valley areas around the Molucca Sea in the north, and the southern part of the Banda Sea. This condition is representative of heights/ridges around Taliabu, Mangole and Banggai Islands (western Taliabu lsland). These results may describe the morphological pattern of basement around the Banggai-Sula Basin, particularly for predicting the central basin (depocentre) and the sources location of hydrocarbon formation.

Gravity anomaly data can also be correlated with the data of sediment thickness and seepage distribution in order to predict the source of hydrocarbon migration direction and trap system. Result of gravity anomaly analysis shows that four valley in the bedrock in Banggai-Sula Basin and i'ts surrounding. The fourth valley that can be categorized as a sub-basin, located in the north and south-west Peleng Island, the southern part of Taliabu Island and southern part of Mangole Island. The subsequent pattern of highs and valleys was made in the three-dimensional (3D) forrm, in order to describe the pattern of basement morphology in Banggai-Sula Basin and it's surrounding (Figure 4).

Trap Structure

In order to strengthen the data on oil and gas in the Banggai-ula Basin, used the seismic line BS07-11 with west - east direction is located in the southern Banggai Island or eastern part of Central Sulawesi. On the cross-section shows the folding pattern and faulting complex (Figure 5).

In the oil and gas exploration, these showing the sediment thickness pattern gives the prospect about tectonic interaction between westrn part of Banggai-Sula Micro-continent with central part of Eastern Sulawesi which forms the trap structure *(lead)* as a prospect area of gas.

In the seismic section above shows the foldings and fracturings patterns are more obvious. On the cross section also showed a pattern of anticlines and hydrocarbon traps (lead) a clear and larger size. The trap is connected by a pattern structure with older rocks

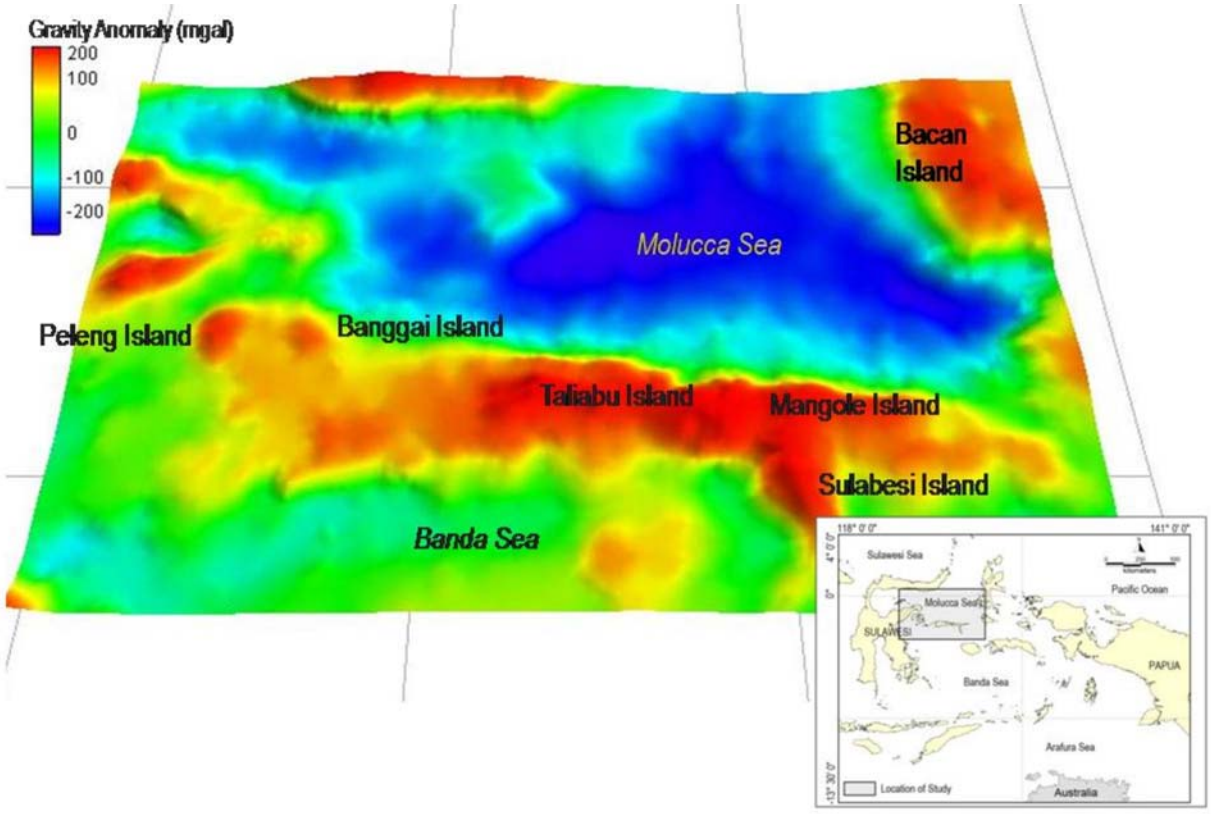

Figure 4. 3D Block of Banggai-Sula Basin based on gravity modeling.

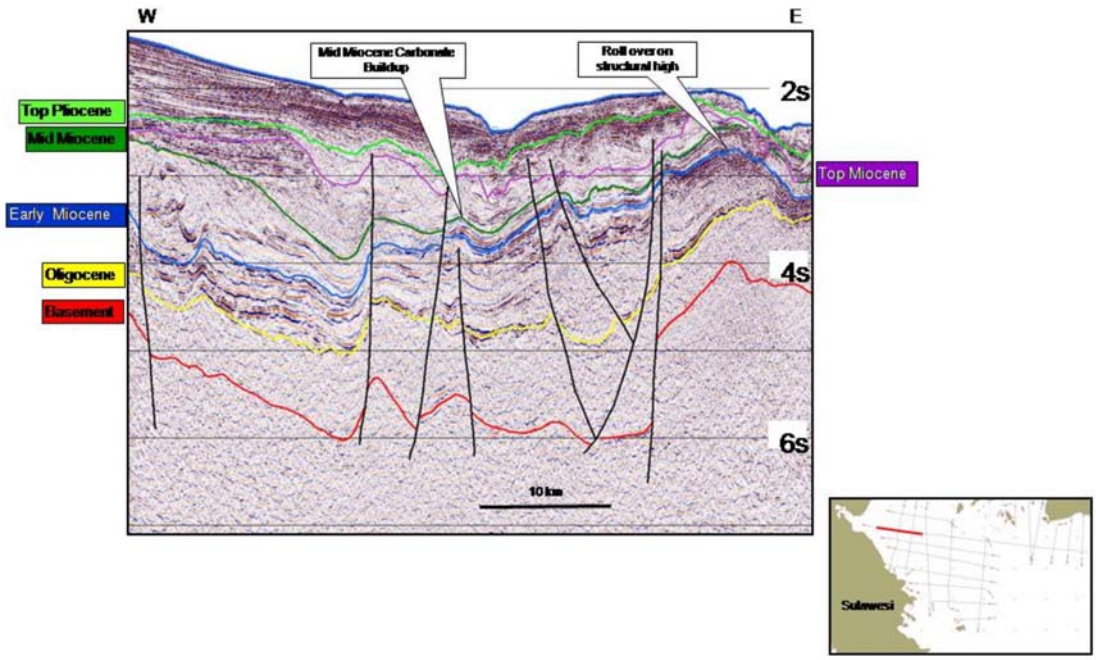

Figure 5. Seismic section of BS07-11 with west - east direction at east Sulawesi (data source: ISIS-TGS, 2011; in Satyana, 2011).

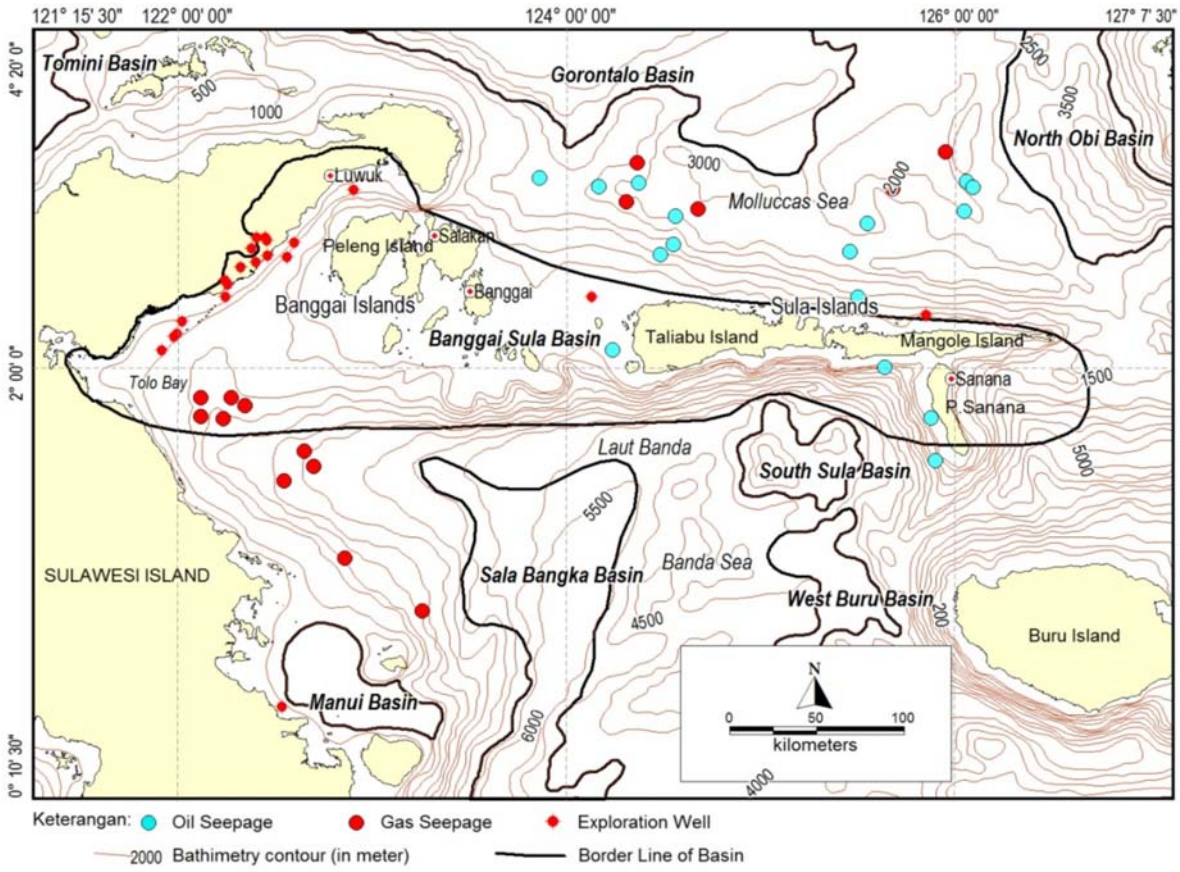

Figure 6. Distribution location map of seepage around Banggai-Sula Basin (compiled from: Panuju, 2006; Satyana, 2011).

in the bottom, so that based on system hydrocarbons, further enabling the development of hydrocarbon traps in the eastern part of BS07-11 seismic line. Generally, the seismic BS07-11 showed the formation of carbonate which is believed to be the limestone lens. In addition there is also anticline that is connected to the heights of basement.

Hydrocarbon Seepage.

The area of hydrocarbon seepage in the Banggai-Sula Basin to describe the migration process is still ongoing. This condition also indicates the existence of an active petroleum system. Hydrocarbon seepage is generally in the offshore of islands, and some of them at the bottom of the Molucca Sea at a depth of 3,000 meters. This area Including the depth of the marine environment. Seepage is not only found in the basin area, but also outside the basin boundary.

This condition also illustrates the pattern of spread of seepage which follow the regional tectonic pattern, so it is not limited to the basin area, but also in all the tectonic lines (faults and fractures) which allows oil and gas out. Around the Molucca Sea, there is seepage of oil and gas, but the gas seepage is more dominant than the seepage of oil (Figure 6).

Around Taliabu, Mangole and Sulabesi Islands showed the mostly petroleum seepage, and is commonly found in the ocean. In the western part, around the Tolo Bay shows the gas seepage. The existence of gas seepage is correlated with several gas fields that have been in production around the eastern part of Sulawesi, such as Senoro, Donggi and Maleo Fields.

Gas seepage in the Tolo Bay region occupies about exposure and slope the offshore of East Sulawesi. Most are in the marine environment (deep sea) around the Banda Sea at depths between 2000 to 6000 meters. Seepage is not far away from the gas field has been in production. This condition indicates that the seepage develops toward reservaoir traps around the eastern coast of Sulawesi. This condition, it can be predicted that the area around the gas seepage, or areas of the eastern part of the field which has been producing to the south around the east coast of Sulawesi is a region for oil and gas exploration prospects in the future.

Quality of Hydrocarbons

The target on the this study of hydrocarbons in the Banggai Sula Basin is Bobong and Buya Formation. Buya Formation lies above Bobong Formation, and Buya Formation is formation the rich of fossils was formed in the Middle Jurassic to Lower Cretaceous, containing shale limestone and quartz sandstone layers thick at the base (PND, 2006). Buya Formation thickness reaches 2,000 meters and deposited in anoxic environments. Buya Formation is one part of Pre-Tertiary transgressive cycle.

Quartz sandstone on the Bobong and Buya Formation is the main reservoir formed from the continental shelf with the value of porosity 17-22%. Furthermore, shale in the Buya Formation, is also the main source rock in Banggai Sula Basin and its surrounding areas. Based on the plot of T_{max} vs HI diagram shows the quality of source rocks in the Buya Formation as a Type III kerogen (P3TMGB "Lemigas", 2010) - (Figure 7).

Both formations produces the gas seepage in Peleng Island, and oil and gas in Tiaka, Tomori Block, the western part of the basin. The type of kerogen for both formation are type III kerogen. This condition is potential to produce the gas and less likely to produce the oil in mature thermal condition.

Claystone at Upper Bobong Formation as a source rock with thermal maturity is a good potential for hydrocarbon, and HI 65 - 133 and Tmax 428 - 440^{o}C. Jurassic mudstone at the top of the Buya Formation, formed of claystone / siltstone buildup of carbon in the

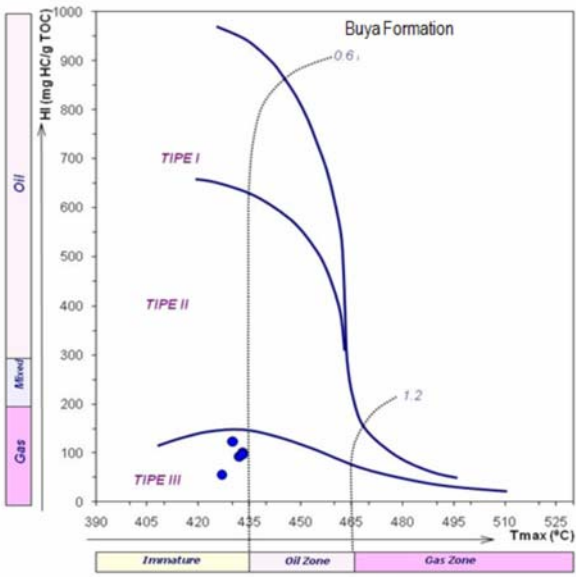

Figure 7. Plot of chemical analysis of Buya Formation (Pra-Tersier) on Tmax vs HI Diagram (P3TMGB "Lemigas", 2010).

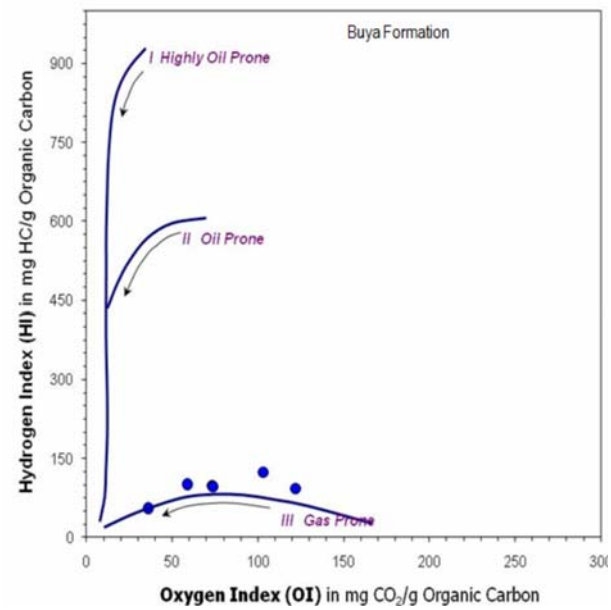

Figure 8. Plot of chemical analysis of Buya Formation outcrop (Pra-Tertiary) on OI vs HI Diagram (P3TMGB "Lemigas", 2010).

shallow sea. It is the source rock thermal maturity, the potential for moderate (0.67 to 1.05%), HI 51-78, and T_{max} 417 to 436^{o}C. Formation quartzite sandstone reservoir at Bobong in Peleng Island serves as a reservoir rock, while the Buya Formation indicates the porosity from 3.4 to 21.9% or an average of 10.5% (PND, 2006).

Furthermore, the results of chemical analysis plot of Buya Formation sample (Pre-Tertiary) in the OI vs HI Diagram shows the gas prone Type II (Figure 8). These results are supported by analysis of hydrocarbon source rocks in this area are included in the type III kerogen, and potential for gas. However, the quality of the gas is included in the category of immature, and also the relatively low TOC content.

Traps and migration are generally as a clos structure for hydrocarbon traps, Taliabu Shelf is represents the most exciting areas. Around continental crust in the eastern part of Banggai Island and northern Taliabu and Mangole Islands also potential for gas trap. Several large regional traps on Taliabu Shelf identified as a Tertiary carbonate.

DISCUSSION

Regional geological conditions of Banggai-Sula Basin and its surrounding are very supporting in the strengthening of conclusions about the rocks and tectonic setting as an area of microcontinent type. Banggai-Sula Basin has a geological character is dominated by red sandstone, arkosa brownish,

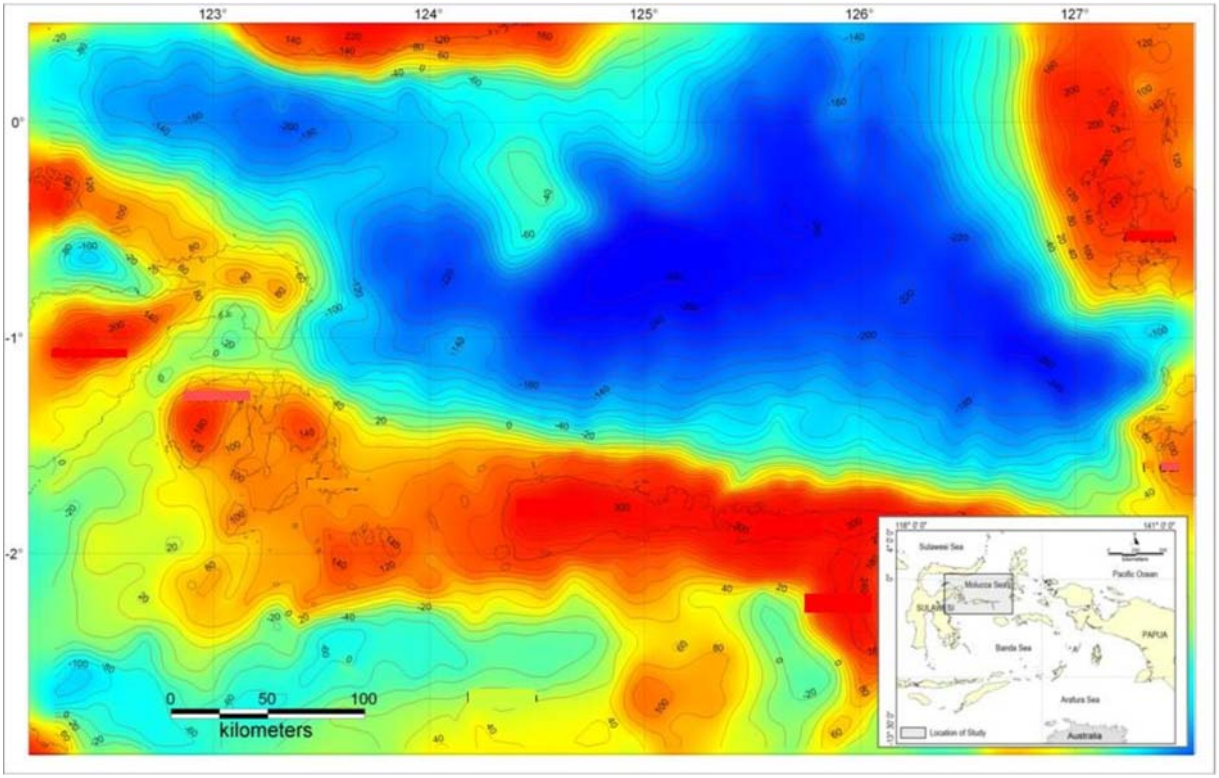

Figure 9. Map of gravity anomaly (in mgal) in Banggai-Sula Basin and it's surroundings shows four valleys area as a source of hydrokarbon.

terrestrial sediment and carbonate in slope on the edge of the continental with Late Triassic age. Red sandstone exposed only in a narrow place in the Banggai-Sula Islands.

Base on gravity anomaly model can be detemined the area of valleys as order to predict the source of hydrocarbon migration direction and trap system. Result of gravity anomaly analysis in western and southern part of Banggai-Sula Islands shows that four valley in the bedrock in Banggai-Sula Basin and i'ts surrounding. The fourth valley that can be categorized as a sub-basin, located in the north and south-west Peleng Island, the southern part of Taliabu Island and southern part of Mangole Island.

The largest valley in southwest part of Peleng Island with the north - south direction and southern part of Banggai Island with west - east direction (Figure 9). Both areas are potential areas as a source of gas and the prospect area for gas exploration detail in the Banggai-Sula Basin.

The heights area are at the center of Peleng Island, the southern part of Banggai Island, central and southern parts of Taliabu Island, central of Mangole and Sulabesi Islands. The heights area are estimated as a migration destination and area of hydrocarbon trap (see also Figure 5).

Results of sample analysis at Buya Formation, still need to be developed to take some additional samples. This is due to tree samples shows that the type of gas prone and the maturity conditions are immature to mature. The maturity analysis will assist in determining the level of maturity in more detail.

These results are differ with the type of gas in the production field, the gas is at a mature level, so it needs further analysis on rock samples at Buya Formation, especially in the fresh better samples.

CONCLUSION

Based on study result, such as the gravity data (2D and 3D), seepage areas, seismic profile, Tmax vs HI and OI vs HI Diagrams and existing conditions of oil and gas production in the western part of the Banggai-Sula Basin obtain the information on opportunities to get new prospect area. Based on gravity modeling five valley that can be categorized as a sub-basin and source of hydrocarbon. These area are located in the northern part of Peleng Island, western part of Banggai Island, south Banggai - Taliabu Islands, western and eastern Sulabesi Island

Results of chemical analysis on the source rock by Tmax vs HI Diagram shows that type III kerogen quality and from the OI vs HI diagram shows that gas

prone Type II, so that giving the impression that this area has the potential to contain gas. However, the quality of the gas is included in the category of immature. and also the relatively low TOC content.

The above result is an early indication that still require further verification by geochemical and petrographic. Samples are analyzed on outcrop at the surface of the Buya Formation. At a more detailed analysis needs to be done more samples and also part of the sample on the deeper exploration drilling results.

AKNOWLEDGEMENT

The authors thank to Head of Marine Geological Institute Mr. Susilohadi for his permission and support this paper in the Bulletin of Marine Geological. Also thank to scientist in office of Marine Geological Institute, and Research and Development Centre for Oil and Gas Technology "Lemigas" for some data collections in this paper, and also for cooperation and discussion.

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