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Potential Development of Hydrocarbon in Basement Reservoirs In Indonesia

Pengembangan Potensi Reservoir Hidrokarbon Batuan Dasar di Indonesia

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Abstract

Basement rocks, in particular igneous and metamorphic rocks are known to have porosity and permeability which should not be ignored. Primary porosity of basement rocks occurs as the result of rock formation. The porosity increases by the presence of cracks occurring as the result of tectonic processes (secondary porosity). Various efforts have been carried out to explore hydrocarbon in basement rocks. Some oil and gas fields proved that the basement rocks are as reservoirs which so far have provided oil and gas in significant amount. A review using previous research data, new data, and observation of igneous rocks in some fields has been done to see the development of exploration and basement reservoirs in Indonesia. A review on terminology of basement rock up till the identification of oil and gas exploration in basement rocks need to be based on the latest technology. An environmental approach is suggested to be applied as an alternative in analyzing the policy on oil and gas exploration development, especially in basement reservoirs.

Keywords: hydrocarbon, reservoir, basement rock, Indonesia

Abstrak

Batuan dasar khususnya batuan beku dan malihan diketahui memiliki porositas dan permeabilitas yang tidak boleh diabaikan. Porositas awal batuan dasar tersedia akibat pembentukan batuan (porositas primer). Porositas bertambah dengan adanya porositas sekunder, yang berasal dari rekahan yang terbentuk akibat proses tektonik. Berbagai upaya sudah dilakukan untuk eksplorasi hidrokarbon pada batuan dasar. Beberapa lapangan migas Indonesia terbukti bahwa batuan dasarnya sebagai reservoir, selama ini sudah menyumbangkan produksi minyak dan gas bumi yang jumlahnya signifikan. Dilakukan kaji ulang dengan kompilasi data penelitian terdahulu, data baru, serta pengamatan batuan beku di lapangan. Hal ini dimaksudkan untuk melihat perkembangan eksplorasi dan potensi reservoir batuan dasar Indonesia. Peninjauan kembali peristilahan batuan dasar sampai identifikasi eksplorasi migas pada batuan dasar, perlu dilakukan sesuai teknologi terkini. Pendekatan geologi lingkungan disarankan sebagai salah satu alternatif dalam analisis kebijakan pengembangan eksplorasi migas, khususnya pada reservoir batuan dasar.

Kata kunci: *karakteristik maseral, reflektan vitrinit, batubara South Walker Creek, Cekungan Bowen*

Introduction

The success of oil and gas reservoirs up till now is more informed as the application of new technology which among others is steemflood injection or thermal in Enhance Oil Recovery (Haans and Usman, 2010). While the success of oil and gas production as the result of the discovery which comes from basement reservoirs is relatively only a few which have been revealed. In Indonesia, hydrocarbon reservoir discovery coming from basement rocks have occurred since 1970's (Yuwono, 2012). The field production is as the additional potential for production fields in the existing clastic sedimentary basins.

Oil and gas reservoirs which have an economical value have been found in igneous rocks. A survey at the beginning of 1948 found hydrocarbon potential in the cracks of basement reservoir in California, and its production was up to 15,000 barrel per day. Then, many small reservoirs and some giant fields were found. Jatibarang field in andesitic igneous rocks in the northern part of West Java, has produced 1.2 billion barrel of oil and 2.7 TCF of gas (Kartanegara *et al*., 1996 in Petford *et al.*, 2003). Kudu gas field in Namibia has produced 3 TCF of gas from sandstone interfingering with the edge of south volcanic Atlantic (Bray *et al*., 1998 in Petford *et al.*, 2003).

Nowadays, all parties know that Indonesia is no longer as a rich oil and gas country. It is now as an oil and gas producer and consumer as well. It is necessary to motivate stakeholders to innovate hydrocarbon exploration in rock complex besides in clastic sedimentary deposits. Limitedness in new oil and gas discovery can be used as the chance to increase the production including basement reservoirs.

Therefore, the correction on the definition of basement rock and reservoir potential which is still limited will be the topic of the review in this paper. The correction aims to avoid misleading in exploration of basement rocks in the future by striving to look for alternative solutions for oil and gas explorations, and simultaneously to innovate oil and gas upstream activities in basement rock reservoirs.

The Meaning of Reservoir and Basement Rock

Up to now, the definition of basement rock in several literatures refers to two keywords. Firstly, it means igneous or metamorphic rock (by ignoring the age). Secondly, it is unconformably overlain by clastic sedimentary deposits. Basement complex in The Penguin Dictionary of Geology (Whitten and Brooks 1978) is synonymous with Precambrian rock, and it can also be explained as the assemblage of widely spread igneous or metamorphic rocks overlain by sedimentary rocks.

Another definition in Kamus Minyak dan Gas Bumi (LEMIGAS, 2009) says that it is igneous or metamorphic rock underlying sedimentary rocks and it generally does not contain oil. The drillings are usually not continued if they have reached such rocks. While a reservoir is an underground place for oil and/or gas to be trapped, it is porous and permeable covered by nonpermeable rocks.

The concept of basement rock in an oil and gas basin (Koesoemadinata, 2008) is usually as igneous (plutonic) and metamorphic rocks. Economical basement rock is as a sedimentary layer undergone a very strong tectonic process, so it has a small chance to produce and keep the hydrocarbon accumulation.

Basement rock as an intrusive igneous rock contains or forms significant porosity. The existing porosity is initiated by cracks formed at magma cooling. The primary process of intrusion forms effective porosity. Interpores or rock joints are connected by cracks formed at the last tectonic phase. Some other crack systems are formed by hydrothermal occurrences, interrelated with magma differentiation at the last phase of andesitic and basaltic intrusion (Guttormsen *at al*., 2008).

Cracks or foliations usually exist in all rocks as planes formed due to stress or overload upon rocks like repetition of thin layers on sedimentary rocks, layers due to mineral composition or cleavage on igneous rocks, and the occurrence of thinness or other structural planes in metamorphic rocks (Passchier and Trouw, 1996).

Method

The method used is potential review completed with data discussion on Indonesian oil and gas fields having basement reservoirs. To discuss the problem, literatures and related reports with some field data are chosen. The nature condition is used as an analog and proof that basement rocks can keep and pass water, oil, and gas. The field data chosen are

the descriptive ones about granite and granodiorite rocks of Barito Basin, South Kalimantan. The other things studied are rock distribution and quality and quantity of the local people well water on igneous rock in Bayat, Klaten, Central Java.

Petrological aspects of crystalline rock were applied in discussion on the definition of basement rock which was significant with the characteristic of reservoir. Based on cracks, both hydrothermal cracks and cracks caused by tectonic process (joint and fault structures) as in Figure 1, show copper porphyry in igneous rock environment used as metal mineral exploration theory. It is also used as a guidance in analyzing the exploration of igneous rock cracks. This includes the target of the development of reservoir exploration with significant rock porosity at hydrothermal alteration zones (Yuwono, 2012).

Data of Oil and Gas Fields

Data of production, exploration, and field development can be optimized by applying rock analysis technology to see the potency of basement rocks as oil and gas reservoirs. Petrological and petrographical analyses are applied on old and new data as the effective modes representing many ways of oil and gas exploration. Five Indonesian oil and gas fields known having produced hydrocarbon from basement reservoirs (both igneous rock and limestone) are Beruk, Suban, Sei Teras, Tanjung, and Oseil Seram Fields (Figure 2).

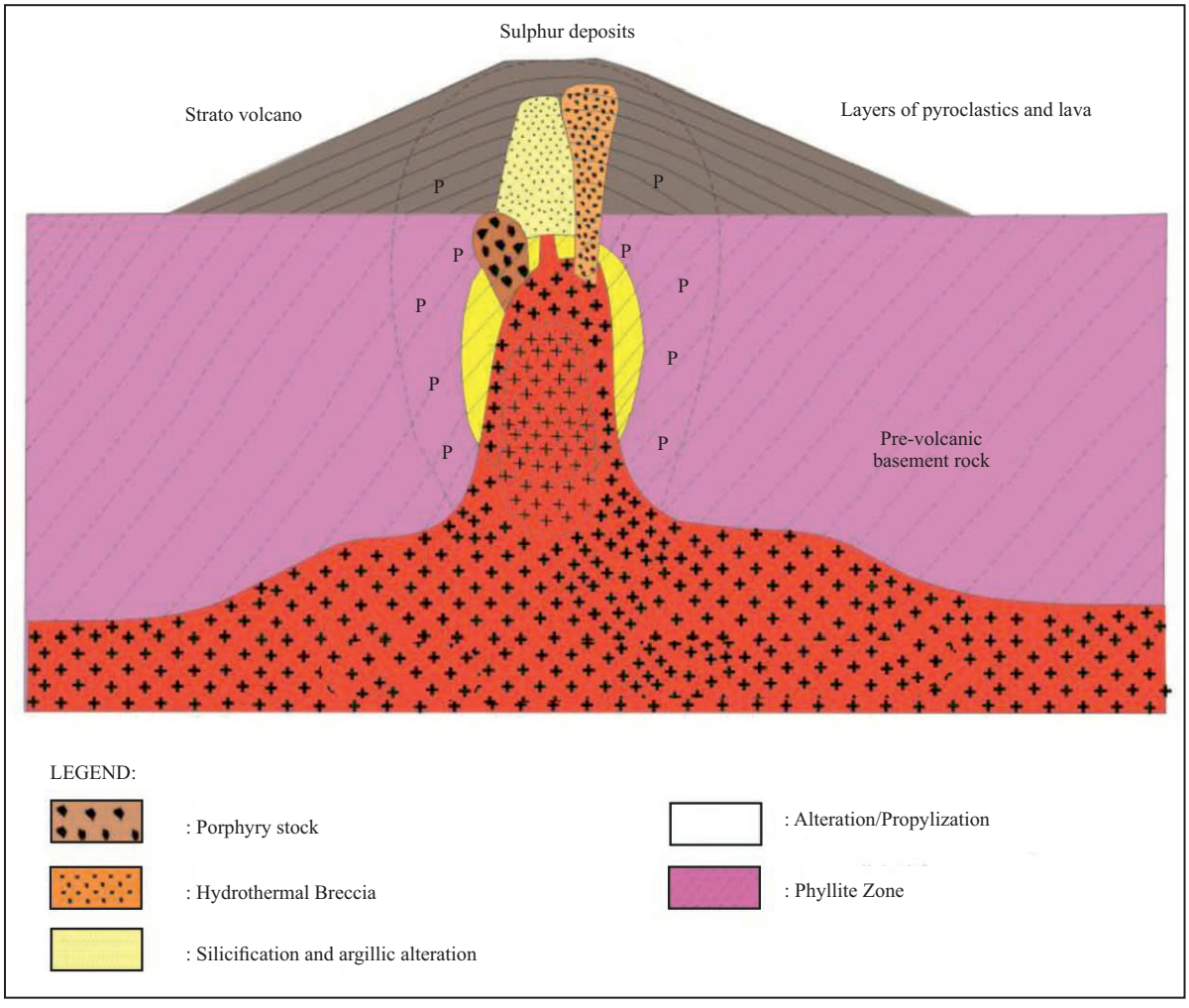

Figure 1. Simple copper porphyry system on plutonic and volcanic igneous rocks forming potential basement reservoirs (Sillitoe, 1973 *in* Yuwono, 2012).

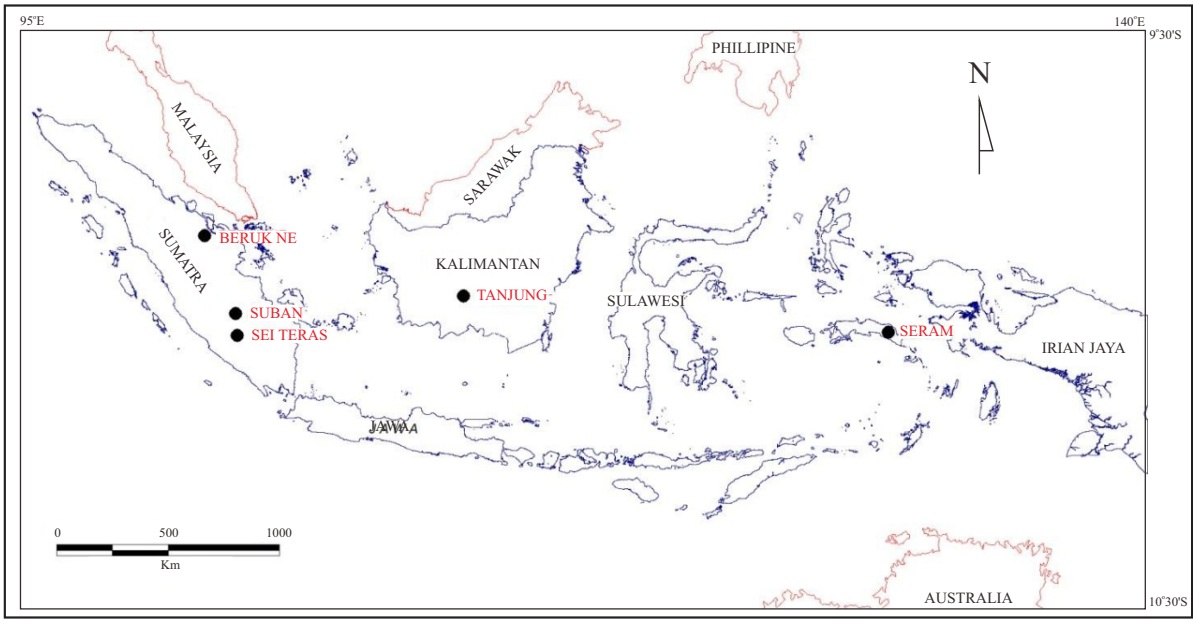

Figure 2. Oil and gas field from basement rocks of Pre-Tertiary (Map source: Koning, 2003, in Yuwono, 2012).

Beruk Field, Central Sumatra

Beruk field is located in Minas area, Siak Subregency, Bengkalis, Riau, in Central Sumatra Basin. Oil producing zones of Beruk Field from Sihapas Group are Duri, Bekasap, Bangko, Menggala, and Pematang Formations (Caltex Pacific Indonesia, 1995).

Koning and Darmono (1984) describe the subsurface geological section cutting Beruk Field at Beruk Well NE-2, Beruk NE-3, and Berk NE-4 (Figure 3). The section orienting west–east shows that the drilling penetrates Sihapas Group (Beruk NE-2). Downward, it penetrates respectively granitic rock and hornfels and granite in weathered condition. Another data at Beruk NE-1 shows that it penetrated cracked metaquarzite rock.

Suban Field, South Sumatra

The Suban Field is located in South Sumatra Basin. The stratigraphy of the field from bottom to the top respectively is: basement rock of Pre-Tertiary granite, Talangakar Formation (sandstone-shale, transgression sediments, Late Oligocene), Baturaja Formation (limestone reef, marine sediment, Early Miocene), Gumai Formation (Lower Miocene shale), Air Benakat Formation (alternation of sandstone and claystone and coal, Middle Miocene), Muara Enim Formation (sandstone and thin coal intercalation, Late Miocene – Early Pliocene). The sedimentation and tectonics of Suban area are as shown in Figure 4. Hydrocarbon reservoir of Suban Field lies on jointed granite, Talangakar sandstone, Baturaja limestone reef, Gumai, and Air Benakat sandstone (Budiman and Hendarsyah, 2007).

Sei Teras Field, South Sumatra

Sei Teras Field lies in Palembang Subbasin Area, South Sumatra Sedimentary Basin. Sei Teras Field has produced oil since 1977 from two wells in limestone and marble basement rocks (Gutmanis *et al.*, 2010). Crack reservoir in this field is more limestone crack oriented (carbonate fracture). At the limestone crack field there is tectonic causing tensile strength creating cracks followed by the appearance of dissolution, dolomitization, and karsting on the surface.

Tanjung Field, South Kalimantan

Tanjung Field is situated in Barito Basin, South Kalimantan. At the northern side of Meratus Mountain, group of rocks named Ayuh Massive occurs as a basement rock (Figure 5). Ayuh rock (Ayuh Massive) consists of granodiorite, diorite,

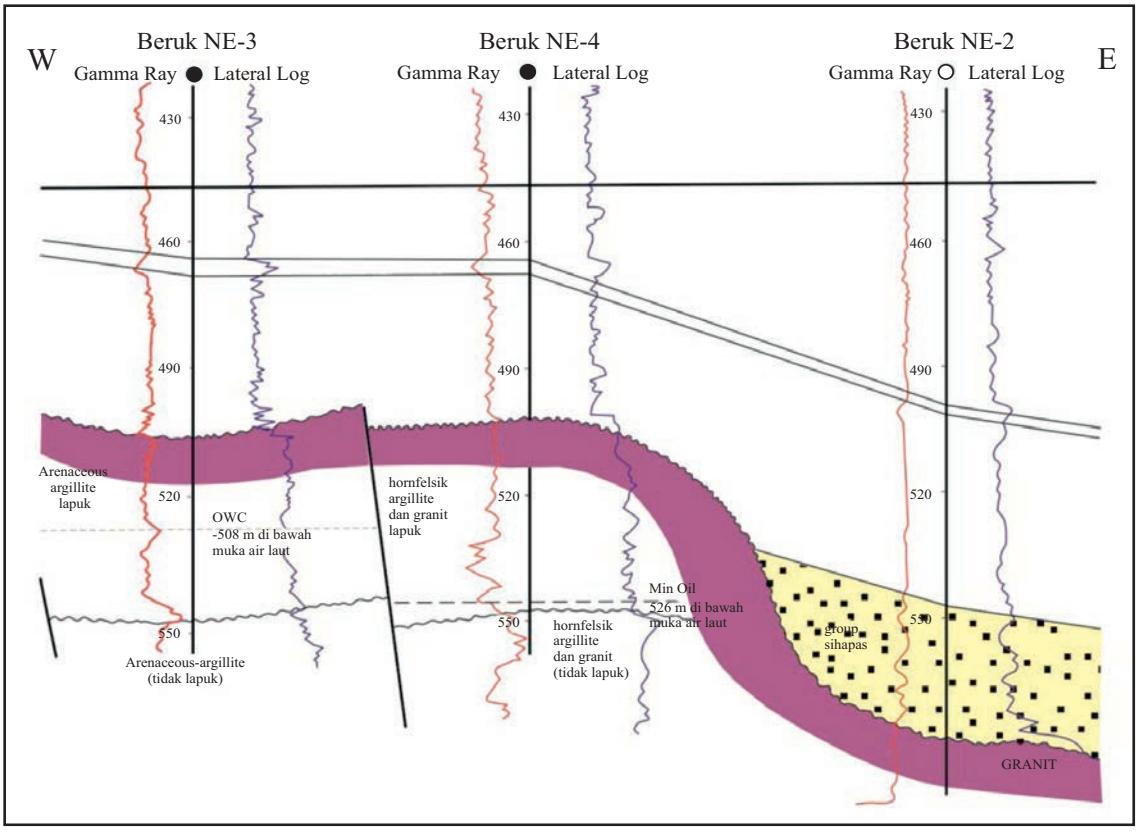

Figure 3. Subsurface geological section of Beruk Field (modified from Koning and Darmono, 1984).

gabbro, dolerite, schist, gneiss, and volcaniclastic sediments. The volcaniclastic sediments are correlated with Manunggal Group forming plutonic igneous rock of Rimuh Complex (Satyana, 1994).

According to Ruswandi *et al.* (2011) basement rock as granite of Early Cretaceous crops out in Hantakan River area, Barabai, Barito Basin, South Kalimantan. The rock, megascopicaly, in the field is brown and grey in colour, conchoidal cleavage, polymic fragment, most of them altered to become claystone or other minerals. Cracks or joints are intercrossed forming a regular distribution pattern. The sediment settlement above and the tectonic process as well as stress release played a positive role in increasing the quality of Tanjung Field reservoir. Densely paired of folds and faults proved the strong tectonics in this area (Figure 5).

Oseil-Seram Field, Maluku

Oseil Field, Seram, is included into Buru-Seram Basin. The Seram area is geologically included into Banda Arc area. The island is similar to most of the eastern part of Indonesia. Tectonically, it is part of the edge of the Australian Continental crust (Pigram and Panggabean, 1981 in Hadipandoyo *et al*., 2007). One of potential reservoirs in Seram Field is limestone of Manusela Formation having Jurassic age. Figure 6 shows geological section of East Seram where ophiolite and metamorphic rocks (Pretriassic) were undergone tectonic causing some locations to have higher positions. The Australian plate looks overlies younger sedimentary rocks.

Based on data of Oseil-1 well drilling, hydrocarbon of Manusela Formation lies among pores of grains, vugs, as well as cracks. The porosity based on log measurement is between 6% and 12.2%, while based on core measurement it is between 0% and 11.9% (Hadipandoyo *et al.*, 2007).

Another case on Sula Sedimentary Basin showing that it contains oil and gas potential coming from Pre-Tertiary rocks. The reservoir rocks are sandstone and limestone of Bobong Formation

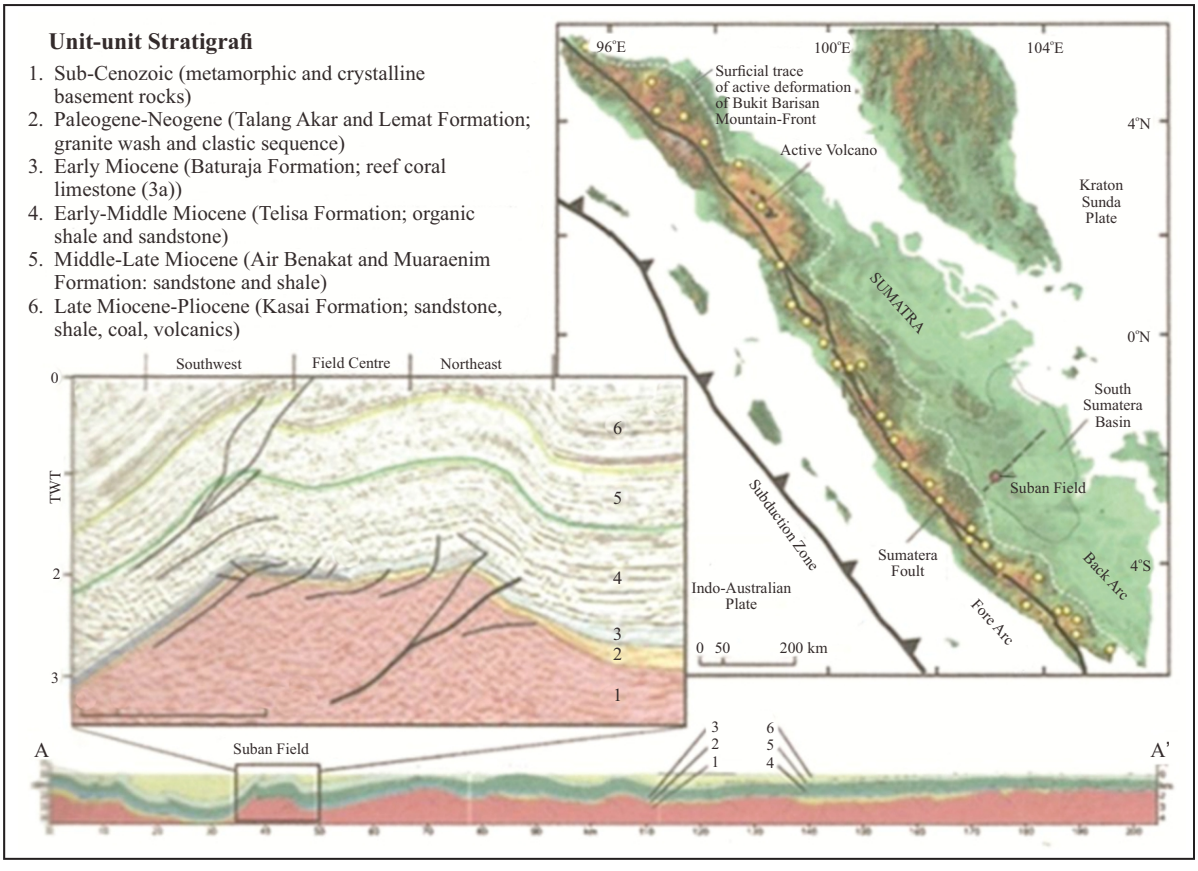

Figure 4. The configuration of tectonic and stratigraphy of Suban Gas Field, South Sumatra (Hennings *et al.*, 2012).

having Jurrasic age. Its basement rock is Permian-Triassic granite with an intensive joint as another potential reservoir. Data of Loku-1 and Alpha-1A wells show that the granitic basement rock shows cracks or vertical and horizontal joints (Lelono, 2010). A joint analysis has not been carried out yet, but the analysis can be chosen as one of ways in searching basement rock reservoirs of Sula and the surrounding areas. The effort of exploration on Pre-Tertiary rocks can be as a target in discovering new oil and gas reservoirs which is supported by the occurrence of oil and gas blocks in eastern Indonesia classified as frontier areas.

Result of the Study

The development of oil and gas field from basement reservoirs has much been applied in many countries. In Vietnam, so far oil and gas production in the country has 50% proved to come from basement reservoirs. In some other locations, proved reserves of oil and gas are ready to be produced. In Indonesia, some basement reservoirs are proved to produce significant amount of oil and gas. At least eight oil and gas fields in Indonesia, besides from clastic sedimentary rocks, are from basement reservoirs or crystalline rocks.

Oil and gas exploration and production out of basement rocks needs to be well planned conforms to the latest technology, besides exploration of Pre-Tertiary rock also needs to be more intensified. In eastern Indonesia, Pre-Tertiary rocks are widely spread consisting of igneous, metamorphic, and sedimentary rocks. The available knowledge and further researches to map the distribution of cracks and their relation to reservoirs can be used to increase the exploration and production of oil and gas.

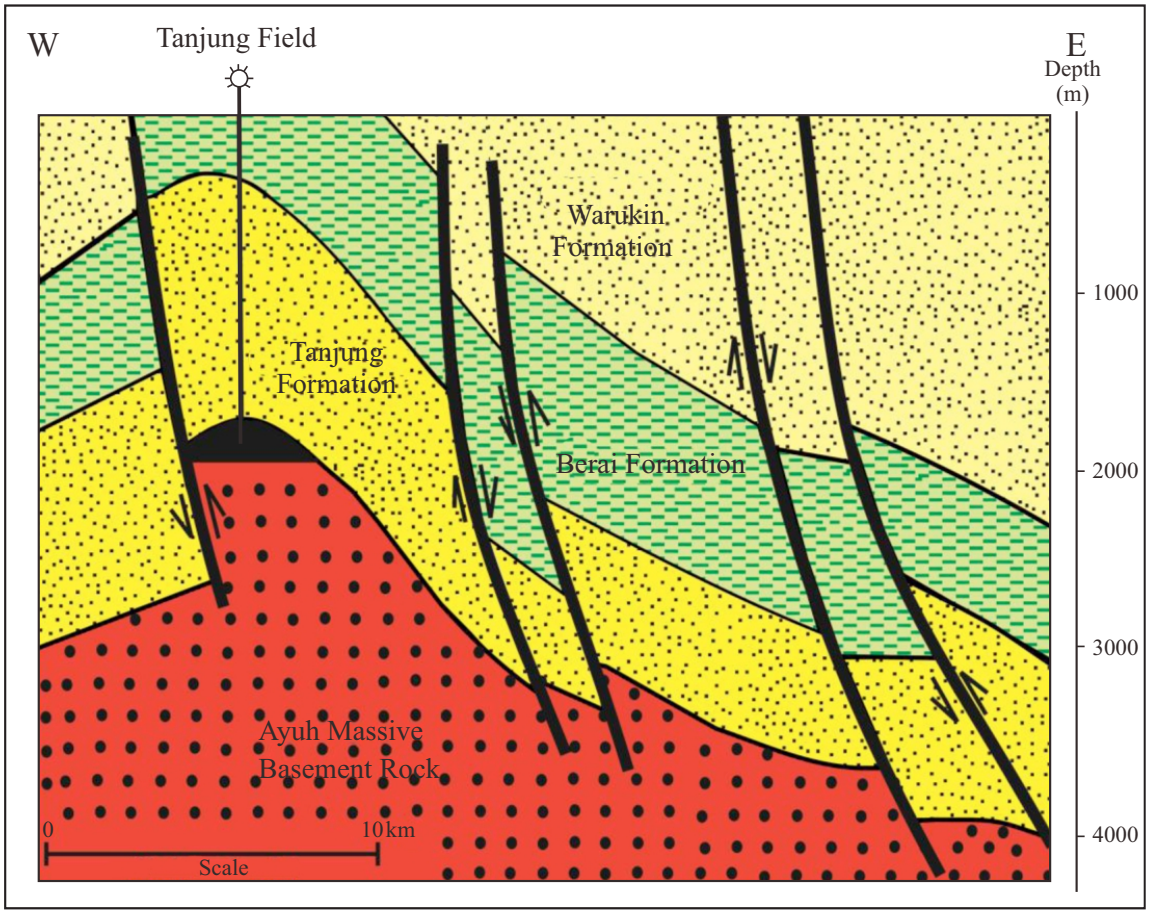

Figure 5. Geological section cutting Barito Basin (Tanjung Field), South Kalimantan (Koning, 2000).

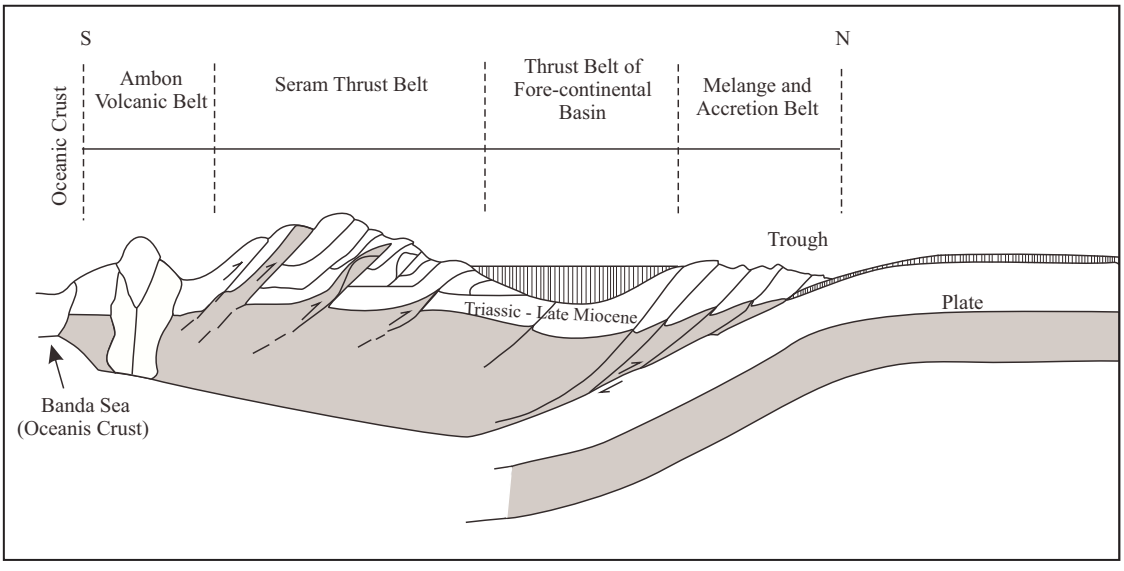

Figure 6. Schematic section cutting Banda Sea – Seram Trough (Kemp and Mogg, 1992 in Hadipandoyo *et al.*, 2007).

The compilation result shows that oil and gas exploration and development in Indonesia are so far intensive in Tertiary sedimentary basins. Based on several discussions, the discoveries of oil and gas reserves that penetrated basement rocks are without being planned. An example of an exploration drilling that penetrated a volcanic rock is when an operator still found not hard rock or as granite wash. He undeliberately reached weathered granite forming basal conglomerate with granite fragments. Although the discovery was initially an undeliberate drilling, the basement rocks below are hydrocarbon reservoirs and they become the target in the next productions.

Crack analysis was carried out as an important way in searching basement rocks. Up till now, the occurrence of rock porosity causes problems in research application or reservoir discovery because of the limitation in knowledge on igneous rocks. Experiments and the use of empirical data on crystalline basement rock in oil and gas field show that the amount of porosity is between 6 % - 30 %. Besides cracks occurring as the result of volcanic activities, high porosity of basement rock cracks is described by another evaluation factor. Paleohydrothermal alteration is the only guidance that can explain unconformity or why big porosity can be formed on the crystalline basement rock (Yuwono, 2012).

Hydrocarbon of Oseil Field in Seram Island, Maluku, is produced from crack reservoirs in Manusela Formation. Study of engineering geology on reservoir mechanics is needed to solve the problem of oil and gas exploration, especially when carrying out drilling and reservoir test. The knowledge on reservoir characteristic where rock properties will be used is to determine fracturing zones in a well (Trilangga and Dradjat, 2012).

Another important process is rock weathering that can also be as a factor which can increase the quality of reservoirs. Close sediment compactions and stress release process act as the local influence, but they possibly play an important role in some areas. While hydrothermal process is functioning both positively and negatively. In some cases they increase the quality of reservoirs, but in general if they play a negative role, they decrease the basement rock porosity and permeability (Cuong *et al.*, 2007).

In natural crack reservoirs, there are a difference and discontinuity due to the presence of two contrast porosity systems in the similar rocks or formation. The first system comes from rock matrix consisting of fine pores having big storage capacity but small in flowing capacity. This matrix is related to the second system that is rock that has small storage capacity but has big flowing capacity (Haans and Usman, 2010). Basement rocks potentially have higher porosity with two-crack system combination. The first pore system is formed at hydrothermal fracturing process. While cracks which are formed by joints or faults can function as pipes relating pores.

Discussion

The definition of old literature stated in the Dictionary of Oil and Gas is regarded as old paradigm. The definition states that basement rocks are igneous and metamorphic rocks underlying sedimentary rocks that usually do not contain oil. Drilling is usually not continued when reaching such rocks. Improvement in the definition and terminology is needed so that it is not misleading. The number of basement reservoirs in Indonesia is only five to eight out of hundreds of active oil and gas fields. The comparison is the indicator that reveals field potential is still very small. Hydrocarbon reservoir exploration and the discovery in basement rocks have not yet become the attention of many parties. Various researches and expert discussions have been carried out in R & D institutions, universities, and cooperation contract contractors as well as professional organizations. The role of decision makers is needed in accelerating the application of the research results in the fields.

The number of Tertiary clastic sedimentary reservoirs which are potential and ready for production causes investors or cooperation contract contractors have not been attracted yet to carry out explorations in basement reservoirs. To increase investment, enforcement and mandatory of exploration in basement reservoirs are needed as well as the government policy. An approach of environmental geology can be used as the reference.

Physical appearance in the fields shows that basement rocks have porosity and permeability

that must not be ignored. Recent technological development is able to detect the occurrence of oil, gas, and water in basement rocks. A simple example is that there is a dig well in igneous rock in Bayat, Klaten, Central Java. The depth of water level in dry season is about 12 m, and the fluctuation of the water level is relatively small. The quality of the water is good, and it is constantly watery and consumed by the people through out the year.

Environmental geology is an interaction between the nature and human beings. Geological processes influence human beings, both as resources which can be used or as a limitation like natural disasters and geologhical hazards or other natural phenomena (Brahmantyo, 2009). In this context, the geological process includes the occurrence of hydrocarbon in basement rocks or igneous rocks. While useful resource includes water, oil, and gas.

Environmental geology as an alternative solution, especially in analyzing policy on the development of basement reservoirs has the following reasons:

1. Limitation in oil and gas resources in Tertiary sedimentary rocks, exploration of igneous and metamorphic rocks should continuously be increased.
2. Geologically, sedimentary basin and basement rocks are interrelated in geological environmental units. Each oil and gas potential sedimentary basin always has basement rock, either as igneous, metamorphic, or sedimentary rocks. Kingston *et al.* (1985) in Koesoemadinata (2008) observes that there is a relation among types of basement rocks underlying sedimentary basins with characteristics of sediments filling the above basins.
3. In geology, there are three important aspects, *i.e.* material, time, and process. The first which is related to material aspect are mineral and rock. The second, time aspect is related to age or geological time as described in the history of geology, stratigraphy, and paleontology. Process is related to geological dynamics, that is geological structure and tectonics (Yuwono, 2012). With environmental geology, the synergy of the three aspects can be increased for being applied in earth researches and technology. Geological application is included into this in oil and gas exploration in basement rocks.
4. Work supervision needs to be optimized for companies or cooperation contract contractors in exploration activities and oil and gas production. This should be carried out from the beginning of development plan of cooperation contract contractors on environmental geology aspect. The exploration is related to location and targeted rocks as well as surrounding geological environment. For example, the drilling has almost reached basement rocks or always stops before it reaches basement rocks. Do not consider only the time and budget, research factor and development are suggested to be considered as well. Regarding the important of environment and oil and gas potential aspects, the target needs to be added to reach the basement rocks.
5. System of work area contract that is based on the depth is suggested not to limit to clastic sedimentary potential rock. Cooperation contract contractors are suggested to explore and develop the rocks below it as well. Analogy as in the distribution of mature and frontier areas with their aspects and classification given to the frontier areas, should also be given to basement rock exploration.
6. The development of oil and gas reservoir rocks will involve experts, data, and studies of other geological subdisciplines, like porphyry that has been developed in metal mineral exploration, igneous rock exploration in hydrothermal alteration and igneous rock weathering. Likewise, the geological study on reservoir rock mechanics is needed in oil and gas exploration and exploitation, especially in determining fracturing zones of an oil and gas well.

Most of the result of the review in this paper is still in compilation form of research and laboratory reports. But suggestion for correction on definition and the lack of number of reservoir field of basement rocks can more remind all parties to explore the new potential available in Indonesia. As in previous definition that basement rocks are igneous, metamorphic, or sedimentary rocks, it needs definition correction stating drillings are usually not continued. There should be an addition in the definition that basement rocks are very probable to function as reservoirs for water, oil, and gas.

Besides five fields which are known to produce hydrocarbon from basement reservoirs, there are

other crystalline rock reservoirs: Jatibarang in the northern part of West Java, and Mount Kemala and Mount Kembang in South Sumatra. Therefore, the approach of environmental geology is suggested as one of alternatives in analysis policy on oil and gas exploration. This is now the time to optimize the policy on oil and gas exploration and development in basement reservoirs.

Conclusions

According to the old paradigm, basement rocks usually do not contain oil; drillings are usually not continued when they have reached such rocks. Field data and researches prove that crystalline rocks have porosity and permeability and has the potential as reservoirs. The latest technology is able to detect the occurrence of oil, gas, and water in basement rocks. It is suggested to make correction on definition/terminology of basement rock in the existing oil and gas dictionary, that basement rocks are very probable to function as hydrocarbon reservoirs.

Based on the compilation result, there are eight oil and gas fields in Indonesia that prove to have crack reservoirs of basement rocks (igneous and limestone). Eight out of hundreds of active oil and gas fields are the indicator that the field potential is still very small. The development needs to be carried out again through mapping especially basement rocks completed with identification and distribution/density analysis on cracks. New exploration and development programmes should more be focused on drillings with basement reservoir target, besides target of rock reservoir lying above it.

Hydrocarbon exploration and development often do not pay attention to the storage of data record and sample of igneous and metamorphic rocks. Review on previous exploration data needs to be optimized, especially drilling data related to crystalline rock in oil and gas fields.

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