PROCEEDINGS
GEOSEA XIV AND 45TH IAGI ANNUAL CONVENTION 2016 (GIC 2016)
The Trans Luxury Hotel, Bandung, October 10 – 13, 2016

Js-1 Ridge: Exploration in Ancient Melange Basement High

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Abstract

As one of several basement horsts in the northern part of East Java Basin, JS-1 Ridge is a unique geological component. Flanked by two deeps, East Bawean Trough on the west side and Central Deep on the east side make JS-1 Ridge important areas for hydrocarbon exploration and exploitation.

Tectonically, JS-1 Ridge is part of a horst-graben complex in the East Java Basin's segmented basement, trending NNE-SSW (Meratus pattern). This horst is also a "playground" for PHE WMO in finding and producing oil and gas from various reservoirs.

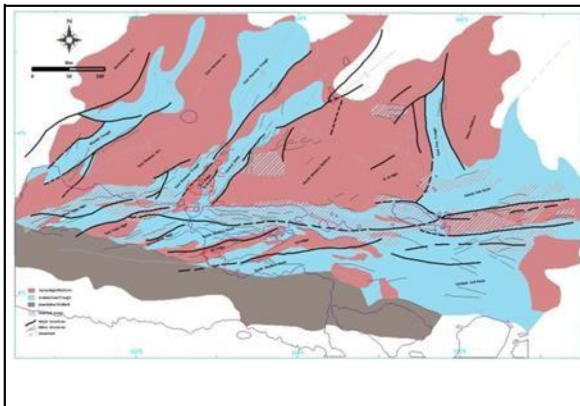
Basement geology of the JS-1 Ridge needs special attention for explorationist in this area due to its composition: several kinds of rocks with almost no pattern. Some wells penetrated the basement in the area of the JS-1 Ridge provides very interesting information. The northern part of the region is dominated by basic plutonic rocks such as Gabro and volcanic rock such as altered Basalt. Low temperature metamorphic rock such as Serpentinite also found at one of well in the northern part of JS-1 Ridge. The center of JS-1 Ridge is composed by metamorphic rocks, sedimentary and meta-volcanic rocks. Moving slightly to the south, JS-1 Ridge's lithology varies from diorite, volcano-clastics, to altered Andesite. Southernmost area is dominated by volcanic but some wells are found to penetrate the layer of older sediments to meta-sediments.

The Broadband 3D seismic in the area is success to reveal the geometry of this horst clearly and in the same way, enhance exploration confident. The latest tectonic reconstruction also provides other opportunity for a new play at the basement level.

Introduction

The East Java Basin (EJB) is located on the Southeast margin of Sundaland, South East Asia, and well known as hydrocarbon producer since early 1900's. This basin is dominated by several NE-trending basement highs and intervening half-grabens that formed during the Tertiary along the SE margin of the Sunda Plate (Manur and Barraclough, 1994). The northern WMO block is located close to the crest of one such basement high, known as the JS-1 Ridge.

West Madura Offshore Block is located relatively in the northern offshore area of Madura Island. The four blocks of PHE WMO separated by relinquishment of EPSA contract. Two blocks are located in the northern area of Madura, one block is in the Madura strait and the other is located in eastern offshore area of East Java (near Pasuruan). PHE WMO's main block lies on one of horst feature known as JS-1 Ridge which is a basement high trending northeast - southwest and bounded by East Bawean trough on the west side and Central Depression on the east side (Figure 1).



A Composite map of East Java Basin and its structural elements. The North part of this basin comprise NE-SW trending horst-graben set: Karimun Jawa Arc, Muriah Trough, Bawean Arc, East Bawean Trough, JS-1 Ridge, Central Deep and North Madura Platform

Figure 1: Regional East Java Basin Map and PHE WMO

East Java tectonic evolution was initiated at around Middle Cretaceous when several small plates from Northwest Gondwanaland (ancient Australia) subducting southern Sundaland. There is a significant difference delivered by Satyana (2014) regarding the reconstruction of the tectonic in the Cretaceous period, which stated that the Bayat area is not a connection of Luk Ulo, and Luk Ulo itself did not have the continuity of Meratus trend. This hypothesis then remodel classic tectonic theory, which is said Ciletuh - Luk Ulo - Bayat and Meratus represents the path of the Cretaceous subduction.

Bayat is not a continuity of Luk Ulo as there was no evidence showed petro-tectonic element of Bayat as a subduction zone. Luk Ulo have all of them: the upper mantle and oceanic crust ophiolite sequence of rocks as evidence of a typical subduction trenches, mélange, eclogite and blue schist marker that can be used for subduction dates (Satyana, 2014). Luk Ulo also cannot be strung together in line with Meratus. Based on petro-tectonic analysis, Meratus shows older subduction process by different mechanisms.

Ciletuh assumed to be constant in the direction of Luk Ulo; this subduction lines can no longer be drawn to Meratus, but it proposed toward Bantimala, South Sulawesi. Bantimala together Paternoster and Kangean supposed to be part of the small plates called Argoland (Metcalfe, 2013). This Argoland was subducting Meratus at approximately the Early Cretaceous to Middle Cretaceous. Subduction took place also in Ciletuh and Luk Ulo at approximately in the Middle Cretaceous. Bayat and Jiwo Hills are part of a separate small plate Gondwana origin which came over (docking) south Sundaland at about Late Cretaceous (Satyana, 2014).

At approximately the early Paleogene (Early to Late Paleocene) these small plates was sticking to Sundaland (amalgamated terrains) and rotated counter-clockwise as pushed by the Indian Plate. This arrangement is known as "Modern Sundaland". In the Late Paleocene to Eocene, The Sundaland was affected the southern part of the Indian Plate convergence movement. Indian subduction to Lhasa, part of Sundaland, implies giving style "rollback" resulting in highly intensive strain on the backarc (Bransden & Matthews, 1992 and Satyana, 2016). The previous pattern of tectonic grains (Cretaceous period) then torn by Eocene extension, opening the accommodation space for the deposition of sediment through a rifting process. Here is the deposition of rift sediments of the East Java Basin. This extensional regime is also responsible for the formation of horst-graben set in East Java Basin, so the found rows from west to east: Karimun Jawa Arc, Muriah Trough, Bawean Arc, East Bawean Trough, JS-1 Ridge, Central Deep, North Madura platform and JS-5 Trough.

Data and Method

Almost 20 years Kujung Fm served a good reservoir for most of oil and gas production of PHE WMO's fields. Exploration objective for the next campaign should be other formation, Ngimbang and basement. The Ngimbang Fm has been recognized to be well developed at the North East and the South West of PHE WMO north area. Stratigraphically, Ngimbang Formation is deeper and un-conformably overlain by Kujung-1, can be seen on seismic at section between 1800 to 2400 ms. Basement, in other hand, is less explored.

A fractured reservoir is defined as a reservoir in which naturally occurring fractures either have, or are predicted to have, a significant effect on reservoir fluid flow either in the form of increased reservoir permeability and/or reserves or increased permeability anisotropy. (R.A. Nelson, 2001). Basement, in term of petroleum geology has been defined as any metamorphic or igneous rock unconformable overlain by sedimentary sequence. However, we consider basement as all kind of rock unconformable overlain by the younger sedimentary packages in a specific basin.

There are 30 wells of PHE WMO drilled to the basement of JS-1 Ridge, most of them are exploration/wild cat wells. Basement lithology of JS-1 Ridge are varies from basic rocks, volcanics, metamorphic rock, and older sediments (Pre-Tertiary). Basement lithology distribution can be quantified 33% from all wells are volcanics, 23% are Altered rocks (altered diorite, altered andesite, and altered basalt), 22 % are metamorphic rocks (quarsite and said as just metamorphic), 4 % are granitic rocks, 7 % are gabbro and 11% described as pre-tertiary sediments. Some of those wells were penetrated basement with good indication of oil or gas. Lithology data from each well informed us that JS-1 Ridge is composed by multi-lithology of basement in the complex tectonic setting of East Java (Figure 2).

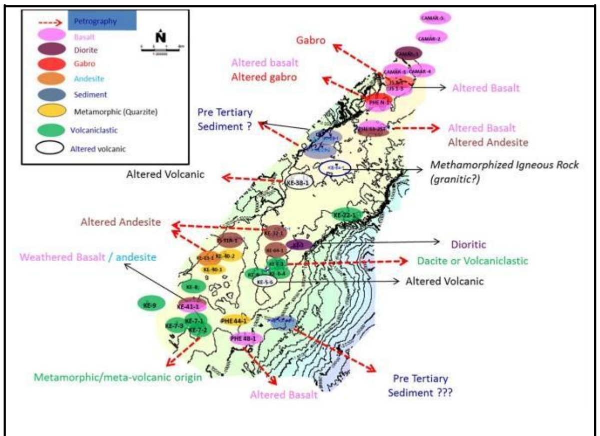
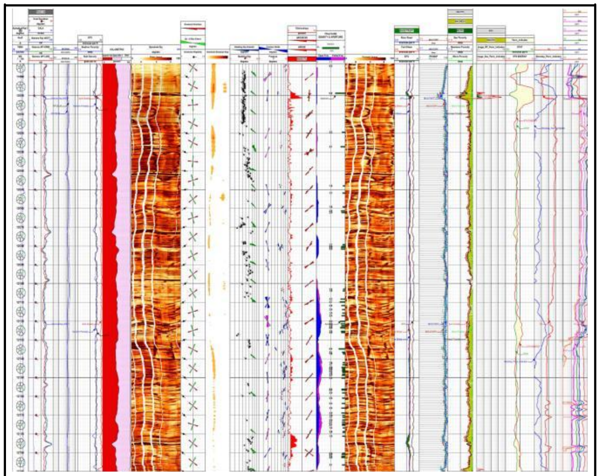


Figure 2: JS-1 Ridge Basement Lithology Map

With this composition of lithology on such tectonic setting, JS-1 Ridge is strongly assumed as a mélange area of ancient subduction (Early-Middle Cretaceous). A mélange in Geology is a large-scale breccia, a mappable body of rock characterized by very limited continuous bedding and the addition of rock fragments at any sizes, contained in a finer-grained deformed matrix. The mélange respectively consists of a jumble of large blocks of varied lithologies, mix together in the same area.

Sagita et al (2008) mention the brittle basement lithology the more fracture productivity on the area. We also consider other factors that influence fractures intensity such as multy-tectonic history (structural re-activation) on the mélange area like what we have on JS-1 Ridge.



A set of composite log consist of image log (XRMI), dip meter, anisotrophy, and stoneley to recognize fractures orientation and apertures.

Figure 3: Composite log of South-2 Well

Image logs are useful to identify which depth of basement is fractured, hence to be sure where the fractures are open, partially closed, and close. Fracture orientation can be recognized by using dip meter log. Data that had been acquired and use to identify fractures and its orientation is dipole sonic (Figure 3). Core (SWC), cutting and petrography analysis are also suitable tools to gain lithology information and so hydrocarbon identification directly from drilling result. Seismic is a must. For deeper target, 3D Broadband seismic with MAZ and Q-CBM processing are the ultimate tools. The seismic data was processed through High Fidelity Q Beam Migration PSDM algorithm that can be considered as the latest seismic processing technic. The attenuation effect was modeled using Q tomographic approach that honors actual wave-paths in both Q estimation and Q compensation to measure 'background' space and depth varying Q information from surface seismic data and has to apply an adaptive correction to the observed centroid frequency to fully account for the frequency dependent attenuation effects observed on our data. Anisotropic parameter derivation/modeling was incorporated to obtain the optimum output that will covered as much as possible velocity variation accurately. The processing result produce more better and reliable image compare to existing volume in term of steep dip imaging (easier for fracture indication interpretation), better image of deeper target (Ngimbang and Basement) and generally signal to noise ratio was generally improved. Those data are powerful to enhance dipping reflectors that can be used for fault identification.

Finally, the walk around VSP is the bridge for both well data (borehole scale) and seismic (field scale) since having 40 meters radius of investigation. VSP tells us the fracture strike (fast shear) estimation from hodograms, N200 E to N300 E which is relatively matched with the premise gained from both image logs and seismic attribute.

Result and Discussion

JS-1 Ridge was a mélange. It is a horst feature at least since Eocene time. Regionally, The East Java Basin tectonic evolution is clearly understood with at least 3 tectonic regimes: Paleogene extensional, Wrenching at Intra-Miocene, and Plistocene Compressional regime. Paleogene Extension regime trending NE-SW as the logical implications of the pulling force behind the arc (rollback extension) generating sets of horst-graben. Such configuration is quite suitable to provide accommodation space for sedimentation in the graben basin, which later can act as a very active kitchen.

3D broadband seismic acquisition has successfully taken on 2013-2014, continued with Q-CBM seismic processing within objectives to improve seismic imaging for deeper exploration target: Ngimbang Fm and Naturally Fractured Basement. Spectrum frequency analysis show enhancement for low frequency range and dominant frequency on deeper target compare to vintage 3D seismic data (1999). The existing legacy seismic data has 15 Hz dominant frequency and 140ft of separability limit, while the broadband data have broader frequency bandwidth and better temporal resolution; the shooting direction also had perpendicular direction to the legacy data with the aim to have better illumination through broadband processing (Figure 4).

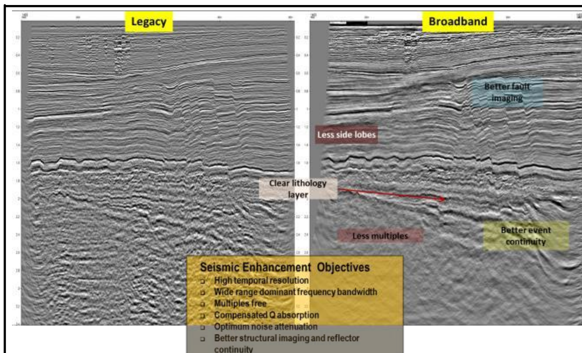


Figure 4: Seismic image comparison vintage 1999 - 2014

Some wells penetrated the so called economic basement in West Madura Offshore area and indicates the presence of meta-sediments of volcanic origin at depth around 8300ft. Structural analysis shows the possibility of basement fractures. Fractures can be recognized in whole area of JS-1 ridge and the intensity should be addressed to the NE-SW tectonic regimes (Figure 5).

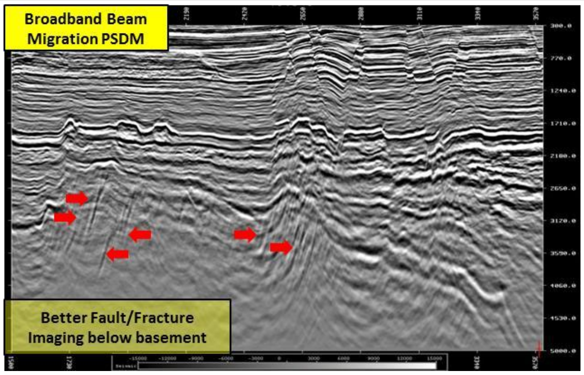


Figure 5: The presence of fractures on the JS-1 Ridge basement shown by Broadband 3D Seismic (CBM)

Seismic interpretation of JS-1 Ridge and Central Deep indicate that rifting processes been occur and develop into an accommodation space for Eocene - Oligocene sedimentary package. Flexure margin became the bases for the accommodation space while on the other side we found the bounding fault as a barrier on Madura Platform. The Bawean Trough, the basin at the west of JS-1 Ridge also showed a relatively similar pattern, with the bounding fault found to be more assertive on the west side of JS-1 Ridge.

With such pattern, a combination of flexure margin-bounding fault is a proper setting for the existence of fractured basement reservoir. With a very complex tectonic history of East Java Basin, whatever their basement lithology is, can be ensured torn by very intensive fractures. Positioning of this fractured basement will not be separated from the flexure margin position and bounding fault. The closer fractured basement to both of these areas, the greater potential for those fractures being filled by hydrocarbons. Regional tectonic analysis using all available data could help to determine which areas will be intensively fractured and furthermore, very attractive as naturally fracture reservoir.

Geological concept helps to understand how and where the fractures developed in JS-1 Ridge. Further, after knowing the area with intensive fracture, seismic interpretation with advance attributes together with image logs and VSP walk around will be very good combination tools to capture fracture distribution and orientation.

Result from age dating as well as provenance age give more insight understanding of possible age of the basement and their origin. Ar/Ar age determination method was selected as main method for determining basement age. After petrography analysis, four (4) samples were selected for conducting age dating. These are North-1, North-2, Centro-1 and South-1 respectively. Among all the wells, only three (3) samples were able to give plats ages as follow: 32.7 ± 4.5 Ma (altered Gabro), 81.4 ± 6.7 Ma (serpentinite), and 70.7 ± 1.3 Ma (altered andesite), which is ranging from Cretaceous to Oligocene. Most of the results of age determination show large number of uncertainty except for altered andesite. These occurred because of limited samples that can be used for dating. Therefore, these ages should be considered as a minimum age due to samples condition as well as lack materials to be dated since most of the samples are basaltic composition. However, this minimum age give very important information that these basement are pre-Tertiary age may be as old as Cretaceous or older which is expected from existing tectonic model of East Java Basement. Other possibility this results mostly reflected metamorphic or alteration ages rather than true age of the rock. Therefore, more works need to be done in collected un-altered samples as well other methods such Rb/Sr or U/Pb age dating respectively as comparison. On the other hand, result from Zircon geochronology using SHRIMP method for sandstone (Felspatic wacke) from South-2 Well show provenance age from several peaks including Cretaceous-Jurrassic-Cambrian-Archean. This result is quite remarkably similar to previous work by Smith et al. (2006), which concluded basement underlain East Java area as part of Australian plate or Gondwana terrain. Moreover, this result also support previous proposed tectonic model from Sribudyani et al. (2003) that collisional boundaries was located in the vicinity of the JS-1 Ridge.

South-1 is the first well having good indication of fractured basement drilled in 2012. It was drilled 509’ to what we called “quartzite” basement from cutting description, with 153-579 unit (C1-nC5), BG 43-94 unit gas reading during drilling but no trace oil/gas show from cut samples. Gas reading during operation gave a good indication of hydrocarbon with 158-2518 unit (C1-nC5) BG 15-500 unit along with gas and oil show in basement intervals. Finallly this well was able to get 1.1 MMSCFD and 80 BFPD.

After drilling, petrology analysis was conducted and resulted precise lithology as Altered Basalt. However, with this well we confirmed that geological concept applied is proven. The second well, South-2 well was drilled in the next year, reach 743’ to the “quartzite” basement. Petrography analysis after drill gave a very contrast result with the previous description during drilling: “highly compacted sandstone” basement and described as Feldspatic-wacke. However, this lithology can be considered as “economic basement” since this layer is stratigraphically older than syn-rift package at the basinal area (Central Deep). Seismic interpretation using the newest data shows a thick layer of sediment below what we assumed as basement in some areas of JS-1 Ridge. Previous seismic data could not provide a proper image quality to identify deeper layer than Kujung. This layer is considered as “Pre-Rift package” which probably derived from Gondwanaland (Figure 6).

JS-1 Ridge is NE-SW horst composed by multi-lithology basement, surrounded by grabens in both west and east sides. The regional fracture orientations have been successfully identified by using any available tools: relatively NE-SW. Image log from one of exploration well dedicated drilled for basement (South-2) indicates similar direction for partial and open fractures: NNE-SSW. However, the additional and advance analyses are needed to reveal the direction of fractures that allow any fluids for any lithological condition. Further investigation with geomechanics approach suggests that critically stress fractures are in the same direction with regional fracture orientation: NE-SW in the strike slip regime. This information is convenient with all data wells, VSP and seismic.

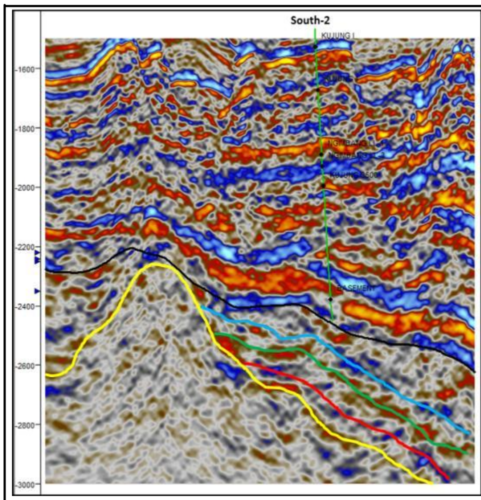


Figure 6: Pre-Rift sediment interpretation on JS-1 Ridge

Conclusions

As a horst features, JS-1 Ridge is one of basement high of East Java Basin that feasible to explore. The understanding of East Java tectonic evolution is able to encourage explorationists to go deeper using any proper tools. PHE WMO will dedicate all effort to establish fractured basement play and increase hydrocarbon production in the similar way.

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Acknowledgements (Optional)

We would like to thanks all of “Cacing Cau”, PHE WMO Explorationist for a great team work and for all job done. Special thanks to Pak Dwi Mandhiri, our former VP E&E

and Ibu Sri Budiyani and all the management for their support and encouragements.
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