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Review of Geological Framework and Hydrocarbon Potential of the Banyumas Basin

Telahaan pada Kerangka Geologi dan Potensi Hidrokarbon di Cekungan Banyumas

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Abstract- The presence of numerous oil and gas seeps along the Pamanukan-Cilacap Fault Zone of the Banyumas Basin. This indicate that the Banyumas Basin is an active petroleum system. However, oil and gas exploration in this area is complicated by extensive volcanic rocks from Paleogene to Recent Times. Thick volcanic covers are responsible for the poor seismic data quality and making subsurface imaging is difficult. Therefore, there is prospective sedimentary sequence beneath the volcanic rock as potential hydrocarbon resources in this basin.

This review will focus on geochemical and geophysical approach. Geochemical analysis was used to reveal petroleum generation underneath the volcanic cover. The combined geophysical methods, i.e. gravity, magnetotelluric and passive seismic tomography were applied to image subsurface sedimentary thickness and geology structure in this area. Biomarker analysis of oil seeps from study area indicates that the oil generation in the Banyumas Basin was derived from Late Cretaceous to Eocene sedimentary rocks which deposited in fluvial to deltaic environment. The gravity data delineation analysis shows two sedimentary sub basins, Majenang Sub Basin and Citanduy Sub Basin, a relatively northwest to southeast trends, correlates with the regional structural trend. These sub basins were also well determined from magnetotelluric data. The passive seismic tomography method enhancing the sub surface image. The Vp, Vs and Vp/Vs ratios can identify the sedimentary layer under the volcanic rocks, as well as geological structure feature within the basin. The flower structure and anticline structure are well imaged and could be the potential structural trap in the Banyumas Basin. Thus, this new insight provides opportunities for further petroleum exploration in this area.

Keyword: Geochemistry, Banyumas Basin, passive seismic tomography, hydrocarbon potential

Abstract- *Hasil pengamatan lapangan sebelumnya, terdapat banyak rembesan minyak dan gas bumi pada sepanjang Zona Patahan Pamanukan-Cilacap di Cekungan Banyumas. Hal ini menunjukan Cekungan Banyumas dikategorikan aktif secara sistem perminyakan. Namun demikian, eksplorasi minyak dan gas bumi di daerah ini cukup komplek karena keterdapatan batuan volkanik dari umur Paleogen sampai Kuarter. Batuan volkanik yang menutupi area ini diperkirakan menjadi penyebab buruknya kualitas seismik dan kendala identifikasi gambaran bawah permukaan. Untuk itu, perlu diungkap batuan sedimen di bawah batuan volkanik yang menjadi prospek sebagai potensi hidrokarbon di cekungan ini. Pada telaahan ini akan difokuskan pada kajian geokimia dan geofisika. Analisis geokimia dilakukan untuk mengungkap generasi hidrokarbon di bawah batuan volkanik. Kombinasi metode geofisika, gayaberat, magnetotellurik dan passive seismic tomography (PST) diaplikasikan untuk mengidentifikasi batuan sedimen dan struktur geologi dibawah permukaan di wilayah ini. Analisis biomarker rembesan minyak dari daerah penyelidikan menunjukkan generasi minyak di Cekungan Banyumas dihasilkan dari batuan sedimen yang berumur Kapur sampai Eosen yang diendapkan pada lingkungan fluvial sampai delta. Deliniasi dari data anomali gayaberat menunjukkan Cekungan Banyumas dapat dibagi dalam dua sub cekungan, yaitu Sub Cekungan Majenang dan Sub Cekungan Citanduy, dengan pola berarah Baratlaut – Tenggara berasosiasi dengan tren struktur regional. Kedua cekungan tersebut juga teridentifikasi oleh analisis magnetotellurik. Metode PST mampu meningkatkan gambaran bawah permukaan. Data Vp, Vs dan rasio Vp/Vs dapat mengidentifikasi lapisan sedimen dibawah batuan volkanik dan juga fitur struktur geologi. Flower sructures dan antiklin tergambar dengan jelas dari hasil PST yang menjadi potensi perangkap hidrokarbon di Cekungan Banyumas. Dengan demikian, pandangan baru dari telaah ini dapat menjadi peluang untuk eksplorasi hidrokarbon lebih lanjut di wilayah ini.*

Keyword: *geokimia, Cekungan Banyumas, passive seismic tomography, potensi hidrokarbon*

INTRODUCTION

Banyumas Basin is located in the southern part of the Central Java Province (Figure 1). Based on the sedimentary basin map of Indonesia (Indonesia Geology Agency, 2009), this is categorized as intermontane basins covered by Paleogene to Recent volcaniclastic sediment. Oil and gas seepage were found in several locations in the Banyumas Basin. The presence of oil and gas seeps in volcanic areas within this basin indicate that the presence of active petroleum systems underneath the volcanic covers (Satyana 2007). Several previous researchers have been widely discussed about the petroleum geology of this basin (Noeradi *et al*. 2006; Subroto *et al*. 2007, 2008; and Setiawan *et al*. 2018), however due to a thick volcanic cover, the petroleum system in this basin is still poorly understood. The presence of volcaniclastics causes poor quality data in the 2-D seismic reflection method. The most recent studies by the Center of Geological Survey (CGS) which Integrating geology and geophysics methods give better understanding of petroleum system of the Banyumas Basin (Hidayat *et al*., 2021; Junursyah et al., 2019; Hendyarso and Hidayat, 2019; Setiawan, 2019). This paper provides review of geological frameworks and hydrocarbon potential within the Banyumas Basin.

Geological Setting

Geology of the Banyumas Basin is predominantly covered with alluvial and volcaniclastic deposits (Figure 2). The oldest outcrop in this basin is the Gabon Volcanic Formation (Tomg), which is an Oligocene–Middle Miocene volcanic sequence found in the southwestern part of our studyarea. This is followed by the deposition of the Pemali Formation (Tmp), which consists of Lower–Middle Miocene turbidite deposits. Next is the Rambatan Formation (Tmr), which was deposited in the Middle Miocene and consists of limestone, sandstone, and conglomerates. Then follows the Kalipucang Formation (Tmk), which consists of Middle Miocene limestone; this is followed by the Halang Formation (Tmhs), which consists of napal and sandstone and are Middle Miocene–Early Pliocene turbidite deposits. The Kumbang Formation (Tmpk), which consists of sandstone breccias, is volcanic facies deposited in the Middle Pliocene era. Furthermore, the Tapak Formation (Tpt) is a sandstone intercalation of calcarenite with marl deposited in the Middle Pliocene–Late Pliocene; and finally, the volcanic and basalt of the Quaternary volcanic facies (Qa) (Setiawan *et al*., 2018). The geological structures in this basin comprises of three main structurs, the northwest-southeast of Gabon strike-slip fault, Karangbolong strike-slip fault in a northwest-southeast direction and represented by fault and fold structures, and the direction of the South Serayu Anticline, which consists of disturbed zones and the west–east trending anticline zone (Pulunggono and Martodjojo, 1994).

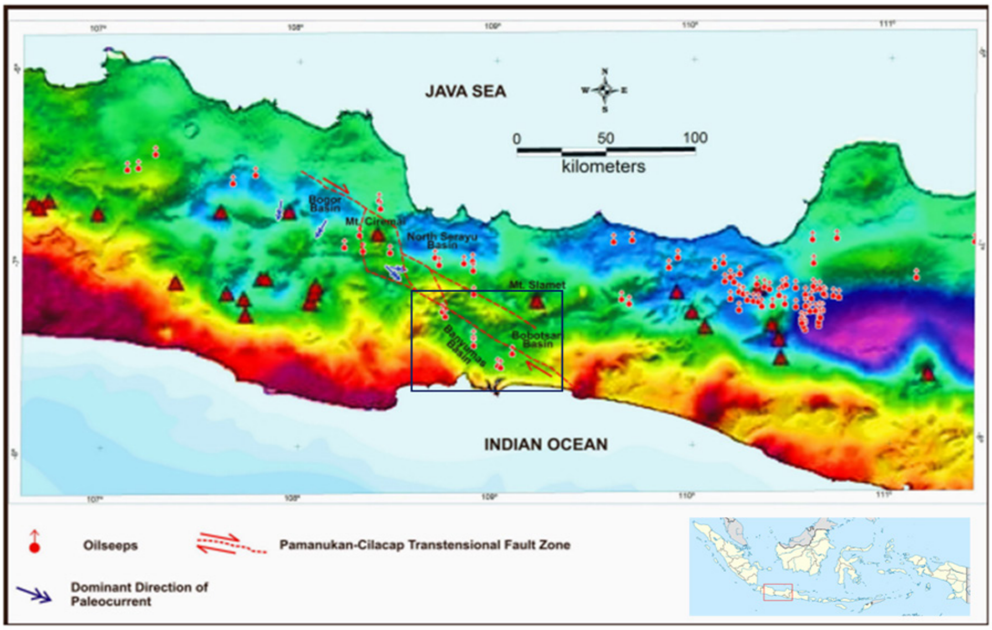
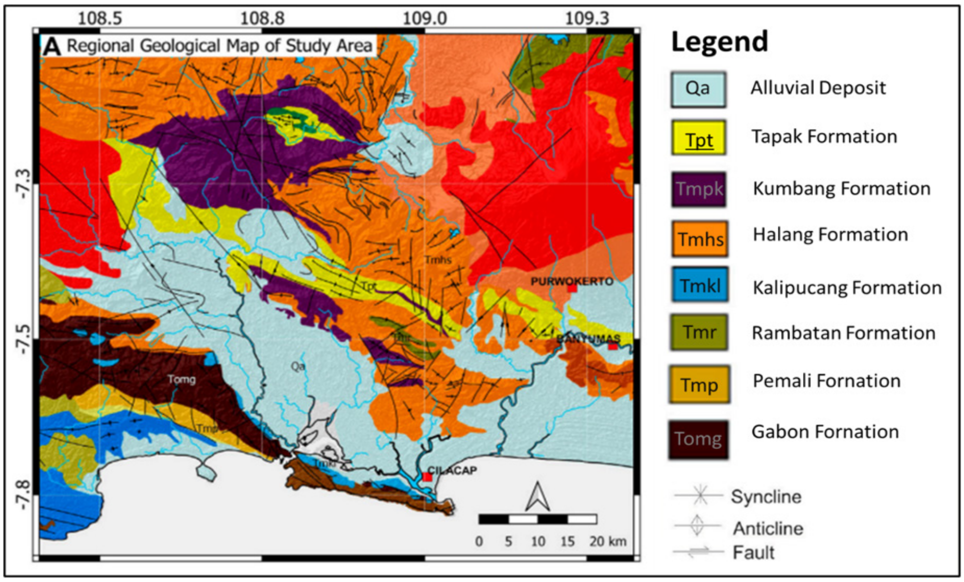


Figure 1 Banyumas Basin (dark blue rectangular), shows numerous oil seepages (red full circle with arrows)



sumber: modified from Hidayat et al., (2021

Figure 2 Geology of the Banyumas Basin

Methods

This study was performed by integrating the geological, geophysical and geochemical (3G) approach (Figure 3), which includes geological sampling and measurement, geophysical acquisition including field gravity, magnetotelluric and passive seismic tomography, geochemical analysis, and reinterpreted the available sub surface data. Field geological was performed by measuring detailed stratigraphic section in the available outcrop in the Banyumas Basin. Systematic sampling was also applied, aiming to reconstruct stratigraphic unit and source rocks studies. Geochemical methods, includes processing and analysis of data from rock samples and oil seepages for more detail on stratigraphy, source rocks, geological structure and petroleum systems identification.

Geophysical methods, includes processing and analysis of field geophysical data from gravity, magnetotelluric and passive seismic surveys for structural and basement interpretation, as well as re-analyzing of well logging data for rock properties and play hydrocarbon potential.

RESULT AND DISCUSSION

Stratigraphy

The regional geological map of Majenang (Kastowo and Suwarna, 1996), indicate that the older formation underneath the Rambatan Formation consists of the Pemali Formation, however the lithostratigraphic unit of this formation in the study area is different compared to the type locality of the Pemali Formation in North Serayu Basin (Setiawan, 2018). The flysch deposits which mainly consist of intercalation carbonaceous claystone, sandstone, and calcilutite, with convolute and slumping sedimentary structure, and composed of various materials, andesite, dacite, basalt, calcilutite, sandstones and carbonate mudstone proposed as new stratigraphic nomenclature "Penanjung Formation" (Figure 4). Based on the microfossil content, namely *Globorotalia fohsi fohsi, Globorotalia Peripheroronda*, and *Globorotalia peripheroacuta,* shows Middle Miocene in age (N10), which is much older than the Pemali Formation (Late Pliocene).

Geochemistry

Volcanic products and sedimentary deposits presented in the Banyumas Basin were close to the tectonic and volcanism periods that occurred in this area. Geochemical analyses of the volcanic rock of Gabon Formation shows basalt to dacitic rocks. The geochemical composition basaltic lava consists of SiO_2 (46%) and MgO (15%), which indicate primitive basalt (Figure 5). The samples from lithic dacite of this formation shows high concentration of Sr around 1700 ppm, which indicate adakitic type. Previous researcher believes that adakites area associated with subduction zone derived from magma of basaltic source. The source could be a subducted oceanic slab or thick, under plated lower crusts (Drummond and Defant, 1990; Peacock *et al.*, 1994). Thus, the volcanic Gabon Formation as the basement of Banyumas Basin was formed by subduction process during the Oligocene -Early Miocene, associated with volcanic arc or oceanic island.

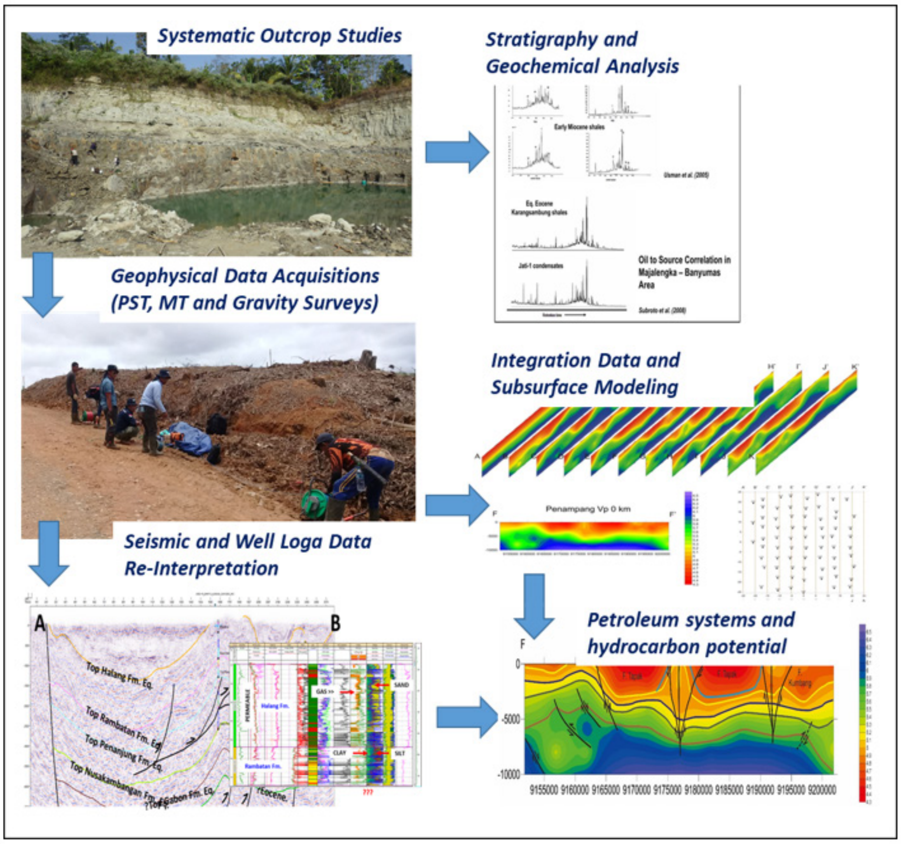


Figure 3 Integrated geological, geophysical and geochemical methods

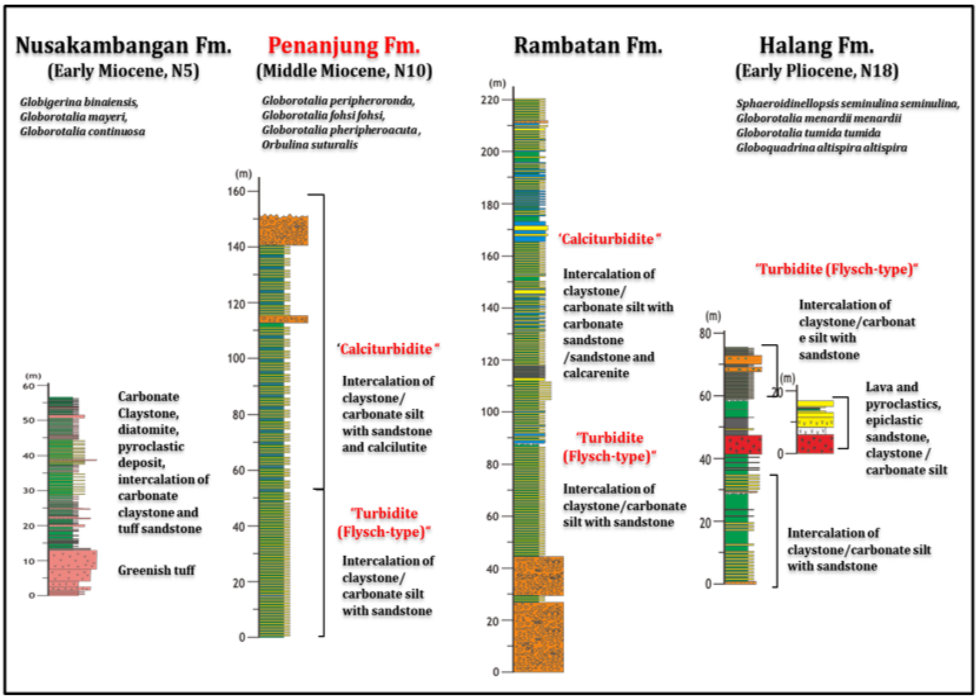


Figure 4 Lithostratigraphic correlation within the study area, shows the Pananjung Fomation Middle Miocene in age (N10).

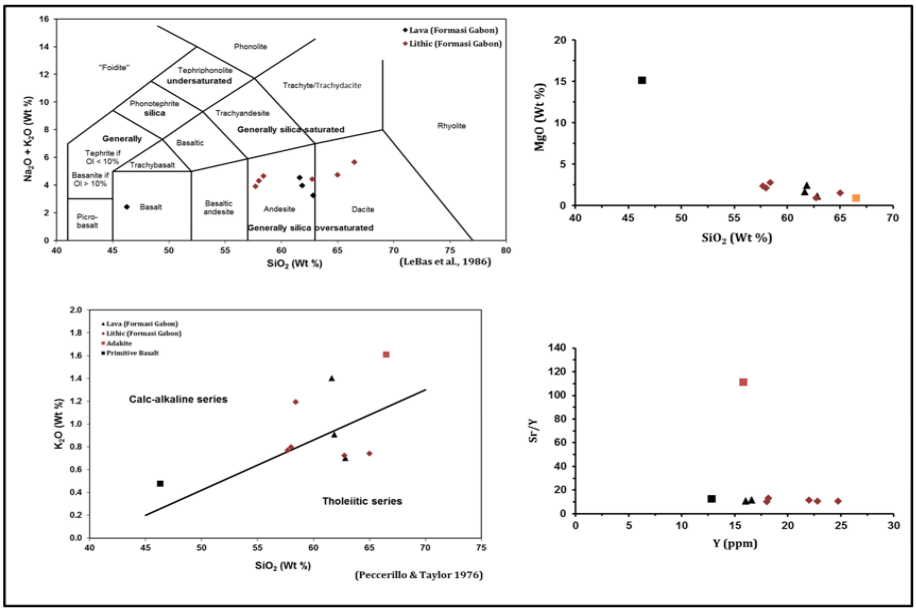


Figure 5 Plotting the geochemical composition of the Gabon Formation in the Banyumas Basin, showing basaltic to dacitic composition, tholeiitic to calk-alkaline affinity, and presence adakitic type

In order to define the source rocks hydrocarbon in the Banyumas Basin, some sedimentary rocks and seepage discoveries were sampled for geochemical analyses. 10 (ten) samples for organic geochemical analysis of TOC and Rock-Eval Pyrolysis were carried out from the fine clastic sediments of the Nusakambangan Formation, Penanjung Formation, Rambatan Formation and Halang Formation (Table 1). The GC-MS was also performed by analyzing the oil seepage samples from 4 (four) location in the study area. The organic contents (TOC) ranging from 0.23-0.99% (fair), with Tmax values ranging from 312 °C-559 °C. The diagrams of generative source potential (TOC vs S2), quality of organic matter type (TOC vs HI), kerogen type (TOC vs S2) , and maturity of organic matter (HI vs Tmax), show that fair hydrocarbon generation, type III and IV kerogen type, with mature to immature source rocks potential (Figure 6).

The biomarker characteristics show suggest that oil seepage in the Banyumas Basin is derived from a deltaic fluvial depositional environment deposited in the Late Cretaceous to Eocene (Figure 7). This indicates that the possible existence of source rock potential beneath the Gabon Formation (Subroto et al. 2007; and Setiawan et al. 2018).

Gravity and Magnetotelluric Interpretation

The bouguer anomaly map shows two sedimentary sub basins, Cintanduy and Majenang Sub Basins, with depocenter at average 8 km depth (Figure 8A). The structural pattern derived from residual gravity anomaly indicate a relative northwest -southeast and an east-west trend basement high pattern. Forward modelling of line A-A and B-B are quite well illustrated of thrusted anticline in the Banyumas Basin (Figure 8B, 8D, 8E). The inversion data of magnetootelluric shows a high resistivity zone which indicate older plutonic body. From 2D model of the magnetotelluric shows two low resistivity zone which interpreted as Citanduy and Majenang Sub Basins (Figure 8C, 8F).

As summary, based on the regional structural patterns and residual gravity anomaly and 2D Model of the magnetotelluric patterns in the study area, it is estimated that the Majenang Sub Basin and Citanduy Sub Basin are graben structures that are parallel and elongated in a northwest-southeast direction. The heights that separate these two subbasins are hills dominated by Kumbang Formation rocks which are characterized by high gravity anomalies. This northwest-southeast trending structural pattern is cut by a relatively northeast-southwest trending strike-slip fault. This strike-slip fault structure offsets the heights in the middle and both sub-basins.

Tabel 1 TOC and Rock Eval Pyrolysis Contents

No (oC)	Samples	Formation	TOC	S1 (mg/g)	S2	S3	PY	HI	OI	PI	PC	Tmax
1	18/RL/42A2	Nusakambangan	0.28	0.05	0.08	0.28	0.13	28	99	0.38	0.01	312
2	18/RL/44B	Nusakambangan	0.23	0.05	0.10	0.34	0.15	43	145	0.33	0.01	355
3	18/EY/05H	Pananjung	0.92	0.06	0.85	0.55	0.15	92	60	0.07	0.08	436
4	18/EY/06M	Pananjung	0.99	0.04	0.64	0.83	0.68	65	84	0.06	0.06	432
5	18/EY/07P	Pananjung	0.64	0.05	0.40	0.45	0.45	63	71	0.11	0.04	423
6	18/EY/08AB	Pananjung	0.85	0.04	0.58	0.62	0.62	68	73	0.06	0.05	434
7	18/EY/09C	Rambatann	0.68	0.04	0.39	0.43	0.43	57	63	0.09	0.04	438
8	18/RL/05E	Halang	0.75	0.06	0.14	0.32	0.20	19	43	0.30	0.02	559
9	18/RL/05G	Halang	0.66	0.05	0.13	0.22	0.18	20	33	0.28	0.0	559
10	18/RL/26D	Halang	0.91	0.05	0.07	0.24	0.12	8	26	0.42	0.01	351

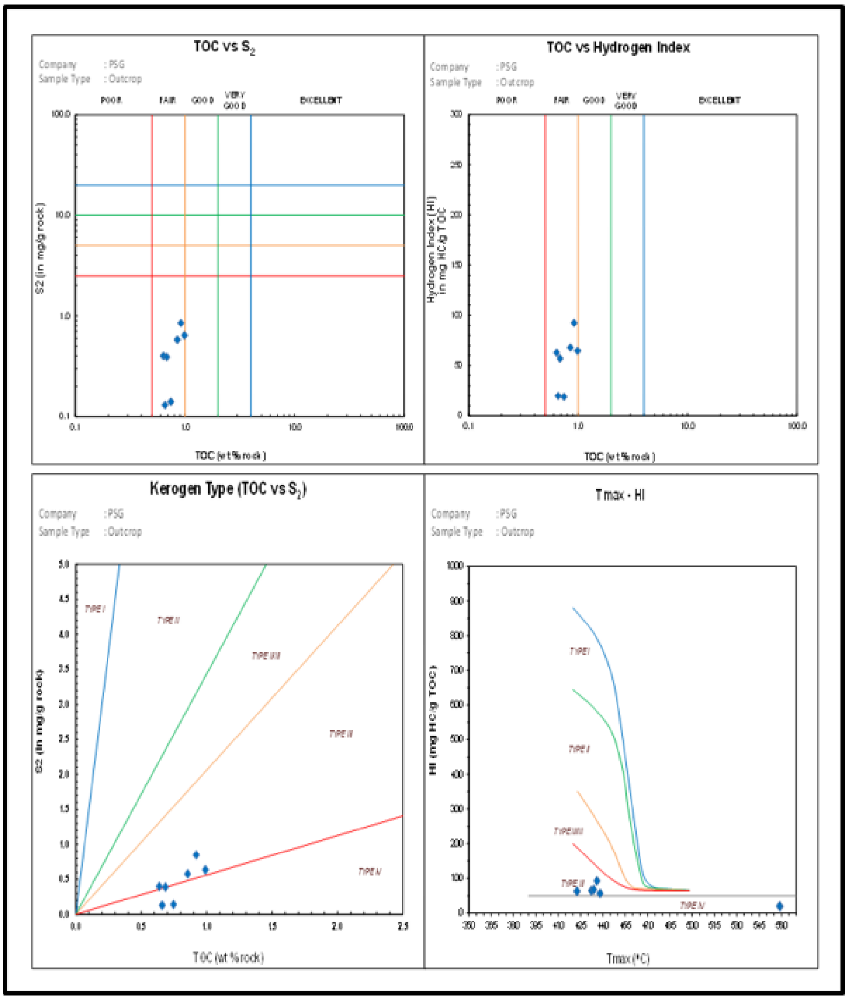


Figure 6 Plots of organic geochemical analysis of TOC and Rock-Eval Pyrolysis values that shows organic content of shales from Halang, Rambatan, Pananjung and Nusakambangan fair to good of organic richness, dominance of kerogen type III and IV, imature to mature source maturation, and potentially oil or gas generation.

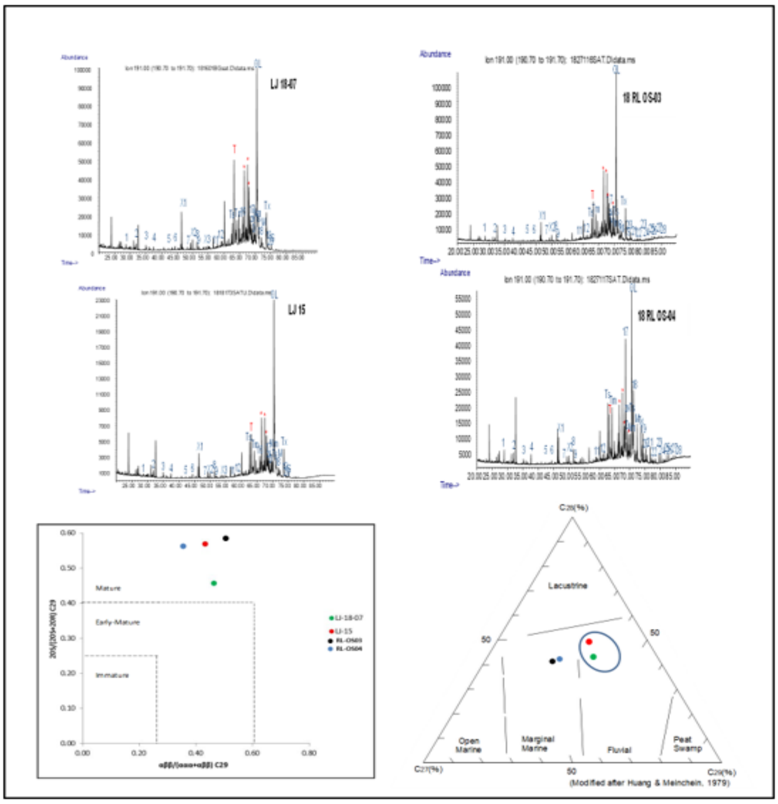


Figure 7 The Biomarker Analyses of Oil Seepage from the Banyumas Basin

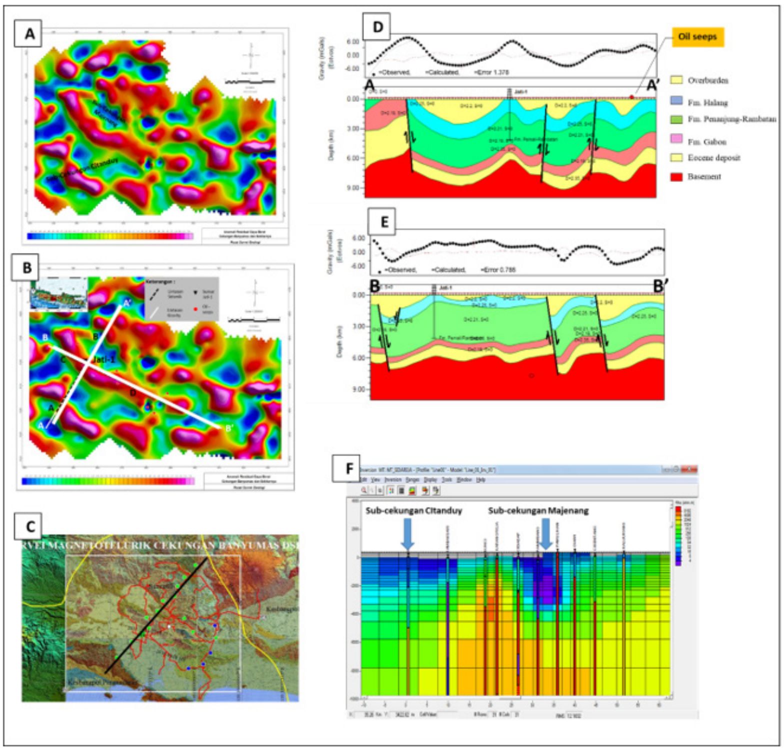


Figure 8 Bouger anomaly map and inversion of MT. A) Residual anomaly map show the Citanduy and Majenang Sub Basins; B) Cross Section of forward modelling gravity; C) Line of MT Section; D) and E) Modeling of gravity show the thrusted ancticline structure; F) Inversion MT, show the low resistivity of the Citanduy and Majenang Sub Basins

Passive Seimic Tomography

Exploration using the 2-D seismic is obtained a poor resolution due to the fact that the Banyumas Basin is covered by thick volcanic sediments. To image the presence of geological structures and determine the thickness of sediment covered by volcanic sediments, the passive seismic tomography (PST) method was applied in this basin. Based on the results of our tomographic inversion, we obtained geometries similar to geological structures in the form of fold structures with the top of the anticline found at the Jati-1 exploration well (Figure 9). The top of the anticline is interpreted as a subsurface image of the Cipari anticline trend confirmed by the regional geology map, 2-D seismic reflection methods, and a residual gravity anomaly. The velocity contrast of the tomographic inversion results is interpreted as the geological contact between the Halang and Rambatan formations; this interpretation correlates with the results of the Jati-1 well interpretation. Mudstone from the Halang Formation can be a caprock for the Banyumas Basin petroleum system, with the anticline structure as a trap mechanism (Hidayat *et al*., 2021).

Petroleum systems and hydrocarbon prospective

The integrated survey using surface geology to identify elements of the petroleum system and geophysics to image the subsurface geological structure of the Banyumas Basin. Based on physical parameters of the rock density using gravity studies, Hidayat *et al*. (2020) also showed the delineation of the Citanduy subbasin and the Majenang sub-basin. Te relatively thick volcanic deposits present our main challenge in obtaining good subsurface images of this basin. Based on the results of a previous geological study (Purwasatriya *et al*., 2019), reservoir rocks in the Banyumas Basin have their own unique characteristics because they are deposited in the volcanic environment. However, the presence of tectonic episodes during the Pliocene–Pleistocene period has made secondary porosity in the reservoir rocks, so that volcanic rocks in the Banyumas Basin area remain potential as reservoir rocks. Caprocks, which consists of volcanic rock and has low porosity and permeability, can be found as clay, silt, tuff, and marl in the Gabon and Halang formations. Potential trapping mechanisms in the Banyumas Basin can be structural traps, such as fault structures or anticline, and can also be statigraphic traps, such as reef and onlap (Figure 9). Based on a biomarker analysis, source rock for the Banyumas Basin is considered to have been generated from sediment deposited in the deltaic fluvial environment in the Late Crestaceous–Eocene period (Junursyah *et al*., 2019; Setiawan, 2018); this criterion is suitable for the black shale found in the Eocene sediment in the Karangsambung Formation.

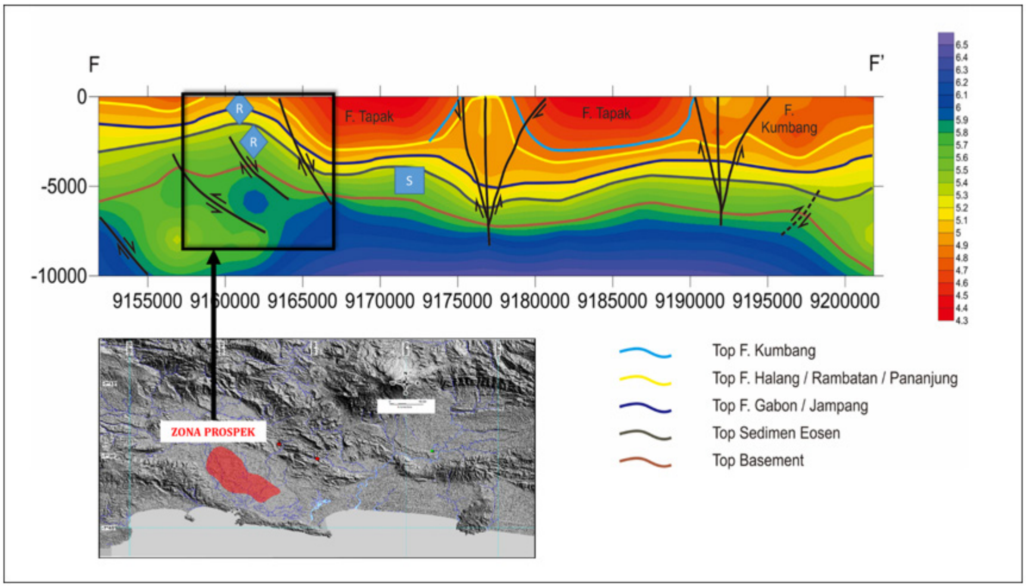


Figure 9 Tomography inversion results depict the petroleum systems and prospect hydrocarbon area in the Banyumas Basin

CONCLUSIONS

The integrated studies of geologic, geophysics, and geochemistry in the Banyumas Basin has open the *pandora box* of the petroleum exploration in this area. The source rock for the Banyumas Basin is considered to have been generated from sediment that was deposited in the deltaic fluvial environment during the Late Crestaceous–Eocene period. Potential trapping mechanisms in this basin can be structural traps, such as fault structures or anticline, and can also be statigraphic traps, such as reef and onlap.

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