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Basement Configuration and Delineation of Banyumas Subbasin Based On Gravity Data Analysis

Konfigurasi Batuan Dasar dan Delineasi Sub Cekungan Banyumas Berdasarkan Analisis Data Gayaberat

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Abstract - Many oil and gas seepages occurred on the surface of Banyumas Basin as one of the active petroleum systems manifestation. Geological complexity of this basin makes it difficult to discover the oil and gas reserves unlike the basin of the East and West Java area. The aims of this research are to determine the subsurface geological structure patterns, distribution of sedimentary sub-basin, and basement configuration. Gravity data of Banyumas and surrounded area is analysed by using spectral analysis, moving average filter, and 2D forward modelling. The gravity data delineation analysis resulting about six sedimentary sub basins with depocentre of 5.5 km positioned at Purbalingga and Karangkobar Sub-basin. The structural pattern derived from residual gravity anomaly shows a relative southeast-northwest strike-slip fault and an east-west trend basement high pattern. Concerning from the oil and gas seepage presence in the study area, sufficient sedimentary rock thickness, and supporting petroleum system, this region is considered as an attractive subbasin for further petroleum prospect investigation.

Keywords : gravity analysis, sedimentary basin, spectral analysis, moving average, 2D modelling

Abstrak *- Terdapat beberapa rembesan hidrokarbon yang muncul di permukaan Cekungan Banyumas yang menjadi salah satu tanda aktifnya sistem petroleum. Kompleksitas geologi yang ada pada cekungan ini menyebabkan sulitnya penemuan cadangan migas, tidak seperti cekungan yang ada di daerah Jawa Timur dan Jawa Barat. Tujuan dari penelitian ini adalah untuk menentukan pola struktur geologi bawah permukaan, penyebaran subcekungan sedimen, dan konfigurasi batun dasar. Analisis data gayaberat dilakukan di daerah Banyumas dan sekitarnya dengan menggunakan teknik analisis spektral dan filter perata-rataan bergerak, kemudian dilanjutkan dengan pemodelan menggunakan metode pemodelan ke depan 2 dimensi. Hasil analisis delineasi data gayaberat menunjukkan terdapat enam sub cekungan dengan kedalaman pusat cekungan mencapai 5.5 km terletak di Sub cekungan Purbalingga dan Karangkobar. Bentukan struktur yang terlihat dari anomali gayaberat residual yaitu berupa sesar geser dengan arah relatif baratlaut-tenggara dan pola tinggian yang mempunyai arah relatif timur-barat. Berdasarkan data adanya rembesan migas, batuan sedimen yang cukup tebal, dan petroleum sistem yang mendukung keberadaan minyak dan gas bumi menjadikan daerah ini sebagai sub cekungan menarik untuk diteliti lebih lanjut terutama mengenai prospek keterdapatan hidrokarbon.*

Kata Kunci : *analisis gayaberat, cekungan sedimen, analisis spektrum, perata-rataan bergerak, modeling 2D*

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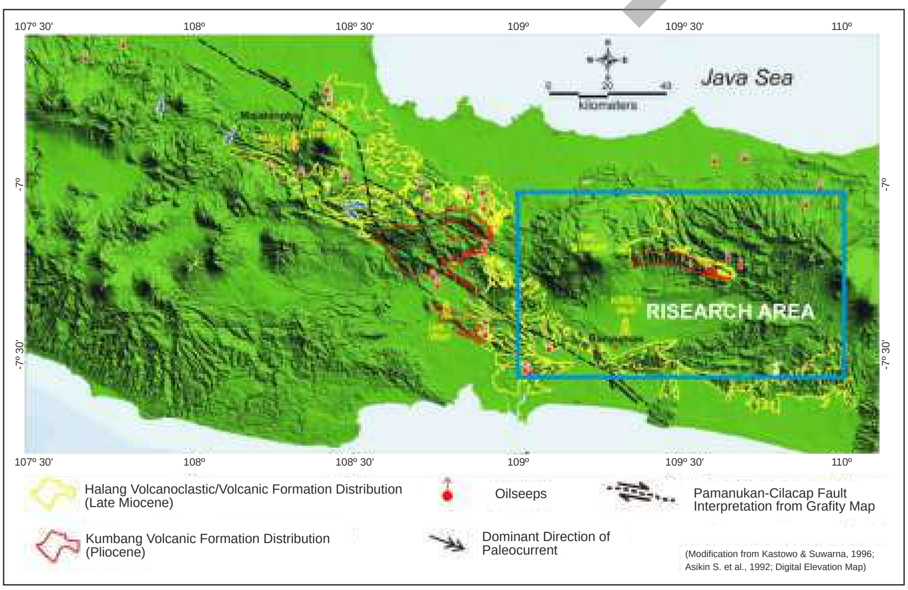
INTRODUCTION

Background

Banyumas Basin has a considerable potential for the presence of hydrocarbons, but until now there are no oil and gas producing wells in this area. It was probably because of the volcanic area so that conventional seismic method could not optimally penetrates the subsurface. Other than that, it is also because of the lack of integration between geological and geophysical data to determine the presence of hydrocarbons in this area. Several studies have been conducted in the southern part of Central Java, especially in Banyumas and surrounding areas. Santoso *et al* (2007) explained that the tectonic activity in Neogene and the marine and transition sediments accumulation of Pemali Formation as type-II kerogen is the potential source rock for oil and gas producer. The research area and oil seeps locations of Banyumas and surrounding area can be seen in Figure 1.

Oil seeps can be found in sandstone of the Halang and Rambatan Formation, which act as the potential hydrocarbon reservoirs of Banyumas Basin (Purwasatriya and Waluyo, 2010). High geothermal gradient and heat flow due to pull-apart and volcanism activities, fault structures, and thick Pemali burial sediment has support the maturation of source rock which lead to petroleum generation, hydrocarbon migration updip to the Majalengka-Banyumas structural high, and hydrocarbon structural trap (Armandita *et al*, 2009). Satyana (2007) stated that unlike basin in East and West Java area, the Central Java has seen a definite lack of oil and gas exploration, which making it a terra incognita (unknown land) in petroleum exploration. The presence of two opposite regional strike-slip faults (Muria-Kebumen and Pamanukan-Cilacap faults) crossing each other in southern Central Java has influenced the petroleum system of Central Java.

Gravity method is usually used for the preliminary surveys of hydrocarbons or minerals exploration. Gravity anomaly measured at the surface is a combination (superposition) of various sources below the surface, where one of them is a target depth to be separated, both located in the zone of shallow (residual) or a zone in the depth (regional). Sub basin delineation example of the subsurface tectonics and lithological inferences using gravity anomaly has been done at the eastern area of Qattara Depression (Zahra and Oweis, 2016). It is considered that ambiguity factors that affecting the subsurface geological modelling using gravity methods are depth and density (Setyanta and Setiadi, 2010). To solve this ambiguity, it is necessary to do the estimated depth calculation using the spectrum analysis method. By calculation the depth estimation, it was expected the errors reduction in the resulted depth model determination. Spectral analysis and two dimensional (2D) modelling are used to estimate the depth of the bodies and determine the source rocks along the profile at suspected area (Ndougsa-Mbarga et al, 2014). The aims of these studies are to know subsurface geological structure pattern, the spread of sedimentary subbasin and basement configuration based on spectral analysis, moving average filter and 2D Modeling.



Source : Armandita, et al.,(2009)

Figure 1. Location of the study area and oil seeps in the Banyumas and surrounding Areas

Geology of the Study Area

Central Java is divided into seven large physiographic provinces, respectively from North to South part as a North Java Coastal Plains Zone, Rembang Anticline Zone, North Serayu and Kendeng Anticline Zone, Randublatung Depression Zone, Quaternary Mountains Zone, South Serayu Mountains Zone, and Southern Mountains Zone (Bemmelen, 1949). Two major structures fault are flanking from the West to East parts of Central Java. The Eastern fault known as the Kebumen-Muria Fault while the Western part as Pamanukan-Cilacap Fault. Both of these faults are considered to be the factors that develop the different physiographic of Central Java area from the West and East Java area (Satyana, 2007).

METHODOLOGY

Bouguer anomaly maps that used in this study has been published by Geological Research and Development Centre covering Banyumas Quadrangle (Siagian *et al*, 1995); Purwokerto and Tegal Quadrangle (Suharyono *et al*, 1995); Kebumen Quadrangle (Dibyantoro dan Sutisna, 1977); and Banjarnegara and Pekalongan Quadrangle (Dibyantoro and Sutisna, 1977). The gravity data analysis is done by including spectral analysis to estimate window width and depth of anomaly source. Other than that, this method also applied in filtering process using moving average and finished by 2D forward modeling.

In gravity method, the spectrum derived from gravity potential field was observed on a horizontal plane (Blakely, 1996) using followed Fourier Transformation:

$$F(g_z) = 2\pi G m e^{|k|(z_0 - z_1)}, \quad z_1 > z_0 \quad \text{......................(1)}$$

$$A = C\, e^{|k|(z_0 - z_1)} \quad \text{......................(2)}$$

$$\ln A = \ln 2\pi G m e^{|k|(z_0 - z_1)} \quad \text{......................(3)}$$

$$\ln A = (z_0 - z_1)|k| + \ln C \quad \text{......................(4)}$$

The resulted equation can be analogized in a straight line equation:

$$y = mx + c \quad \text{......................(5)}$$

while lnA act as the y-axis $|k|$ as the x-axis, and (z_0 - z_1) as the slope (gradient). Therefore, slopes of the lines indicate the depth of shallow and deep planes. $|k|$ as the x-axis is defined as the magnitude of the wave number $\frac{2\pi}{\lambda}$ in 2 cycle/meter units, while λ is the wavelength. Window width can be formulated as follows:

$$y = mx + c \quad \text{......................(5)}$$

Basically the separation method concept is by applicating anomalies separation based on the frequency associated with depth of anomaly source. Residual anomaly associated with a high frequency, while the regional anomalies associated with low frequency (Sari, 2012). This separation process is to obtain the value of residual and regional anomalies that appropriate with subsurface actual condition.

The moving average concept is by averaging the anomaly value which results the regional anomaly. Residual anomalies obtained by subtracting the measured data to the regional gravity anomaly using following formula.

$$\Delta g_{reg}(i) = \frac{\Delta g(i-n) + \cdots + \Delta g(i) + \cdots + \Delta g(i+n)}{N} \quad \text{............(7)}$$

where *i* is the station number, N is the width of the window, and Δg_{reg} is regional anomalies.

2D modelling usually use to quantify the effect of the gravity model of subsurface objects with arbitrary shaped which can be represented by n polygon and expressed as a line integral along the sides of the polygon (Talwani *et al*,1969). Density values can be used for subsurface forward 2D modelling based on a reference (Telford *et al*, 1990). Forward 2D modelling is often called data fitting or data matching which sought model parameters to generate a response that fits with the observational data (Grandis, 2009).

RESULTS AND DISCUSSION

Figure 2 presents the results of data processing. Analysis of the sedimentary basins from gravity data needs a separation between a regional and residual anomaly. Spectral analysis process needs to be completed before separation process of regional and residual anomalies while the spectral analysis on gravity anomaly of several line sections is shown in Figure 2.The 15 lines in Figure 2 indicates the spectral analysis that will be calculated.

Graphic of wave numbers (k) vs amplitude (LNA) can be seen in Figure 3. Figure 3.a point out about residual discontinuity plane depth in the line P1 which resulted 2.72 km while the regional discontinuity plane depth is 18.88 km. Figure 3.b shows the shallow depth of discontinuity plane which equal to 3.27 km while depth of discontinuity plane is 21.05 km. The results of deep discontinuity plane (regional) and shallow (residual) depth from 15 lines are presented in Table 1. Table 1 indicates that the average depth of shallow discontinuities plane (residual) is approximately 2.9 km while the depth of deep discontinuity plane (regional) is 21.13 km.

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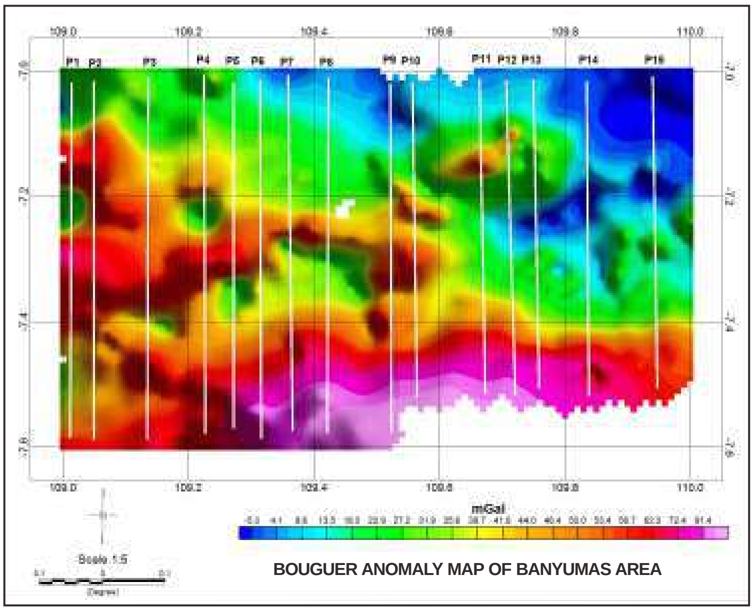

Figure 2. Bouguer anomaly map and lines of section designate of spectral analysis

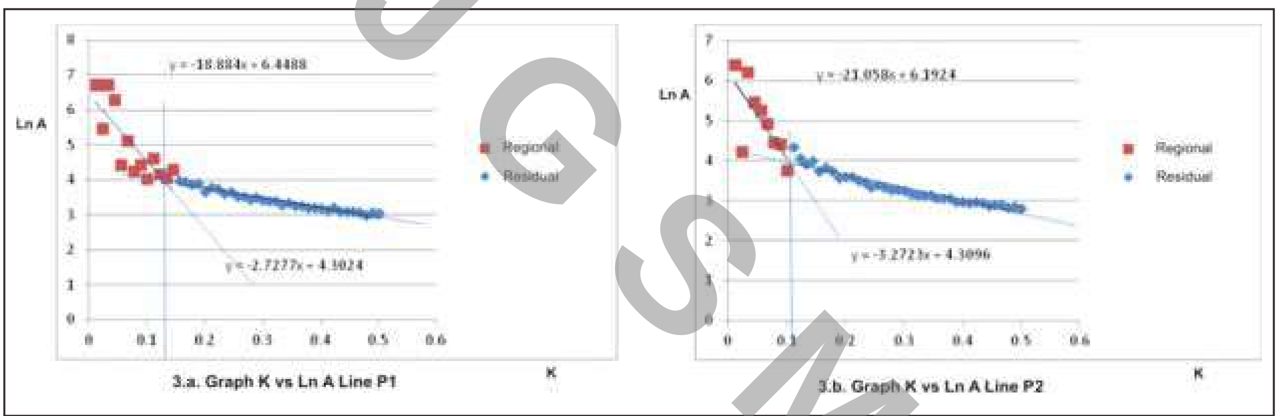

Figure 3. Graphic wave number (K) versus Ln Amplitudo (LnA)

Table 1. Results of the calculation depth boundary planes of deep and Shallow boundary plane based on spectral analysis

No	Line	Depth of the Deep Boundary Plane (km)	Depth of the Shallow Boundary Plane (km)
1	Line P1	18.88	2.72
2	Line P2	21.05	3.27
3	Line P3	19.63	3.08
4	Line P4	24.80	2.72
5	Line P5	19.17	3.10
6	Line P6	22.38	3.21
7	Line P7	21.57	3.08
8	Line P8	20.76	2.97
9	Line P9	22.47	3.09
10	Line P10	17.82	2.66
11	Line P11	18.91	2.74
12	Line P12	24.33	2.85
13	Line P13	22.12	2.71
14	Line P14	21.47	2.75
15	Line P15	21.25	2.66
	Average	**21.13**	**2.90**

The depth of shallow discontinuity plane is interpreted as the boundary between the sedimentary and basement rocks, while the deep discontinuity plane at is interpreted as the boundary between the upper crust and the lower crust which have a significant different density values. Other than calculate the depth of regional and residual anomaly, spectral analysis is used to calculate the wave number cut off and width of the window as shown in Table 2. This cut off and window number then will be used in selecting the optimal window width and separation process of regional and residual anomalies. Table 2 results the averages wave number cut off calculation which equal to 0.12 that indicate the regional and residual anomaly boundary. The resulted number then will be used to calculate the width of the window. The calculations of average window width from 15 lines results 13.6. Therefore the window width of moving average filtering process is N = 13.

Qualitative interpretation

Qualitative interpretation aims to determine the patterns or lateral structure trends of residual anomaly obtained from moving average filter. The result of this interpretation is expected to determine the pattern of basement high and of subbasins in the study area.

Figure 4 shows the structural pattern of strike slip fault determined from residual anomaly. This indicates there are three lineaments taken from lateral shifting. The offset at the eastern part relatively shift to the southward, while the western block shift to the northward, denotes that there is a dextral strike-slip movement along this block. Generally, the direction of movement of the fault was suitable with major NW-SE trending fault called the Pamanukan-Cilacap Fault Zone, and possibly occured since the early Neogene or could be slightly older (Armandita *et al*, 2009). Figure 5 shows the basement high structure from residual anomaly indicates relatively East-West pattern. This structural pattern is suitable with a south-north compression direction. The structural pattern is relatively simmilar with Hall *et al,* (2007) model as a thrust fault northwards, yet the overlying over thrust volcanic arc has almost been entirely removed by erosion. It is possible that in Central Java has no equivalent structure with the Southern Mountains Arc of West and East Java. Figure 6 shows delineation of Banyumas sedimentary basins based on residual anomaly patterns.The map implied that the Banyumas Basin can be divided into six sedimentary subbasins, the Purbalingga, Wonosobo, Karangkobar, Watukumpul, Bantarbolang, and Lobang Sedimentary subbasins.

2D Modelling

Three line sections modelling is shown in Figure 7. L1 nearly has north-south orientation. L2 is located at the eastern side of L1 with also nearly has north-south orientation. L3 has perpendicular orientation to L1 and L2. Subsurface geological model line of L1 can be seen in Figure 8 with a relatively north-south orientation. Modelling of L1 results the average thickness of the sedimentary rock is equal to 3 km. This is consistent with the calculated depth of discontinuity plane between sedimentary rock and basement which equal to 2.9 km.

Table 2. Results of the wave number calculation (Kc) and window width (N) of each line profile based on spectral analysis

No.	Line	Wave Number (Kc)	Window Width (N)
1	Line P1	0.13	12.07
2	Line P2	0.11	14.27
3	Line P3	0.12	13.08
4	Line P4	0.13	12.07
5	Line P5	0.13	12.07
6	Line P6	0.11	14.27
7	Line P7	0.12	13.08
8	Line P8	0.12	13.08
9	Line P9	0.12	13.08
10	Line P10	0.13	12.07
11	Line P11	0.13	12.07
12	Line P12	0.10	15.7
13	Line P13	0.12	13.08
14	Line P14	0.11	14.27
15	Line P15	0.12	13.08
	Average	**0.12**	**13.16**

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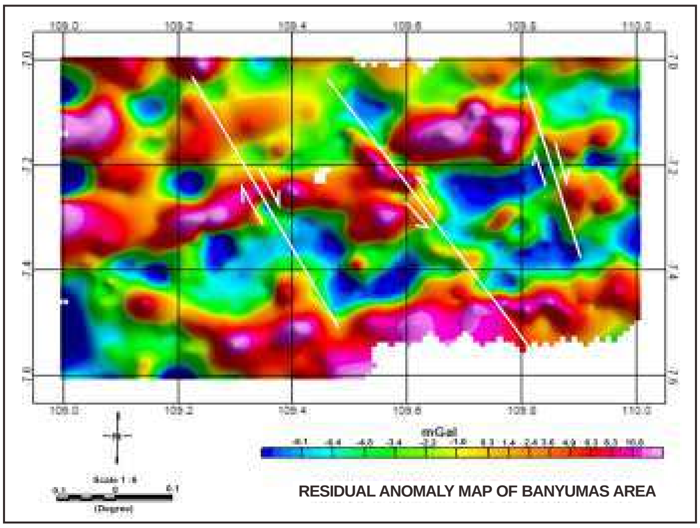

Figure 4. Structure pattern (strike slip fault offset) determined from residual anomaly of the Banyumas and surrounding area.

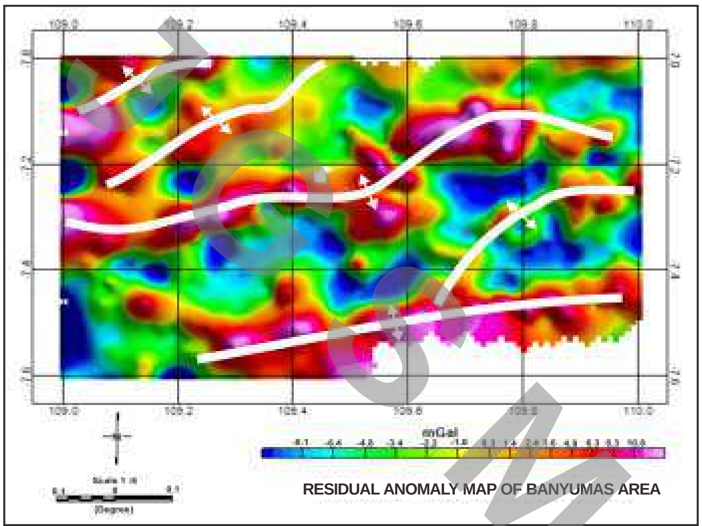

Figure 5. Basement high pattern determined from a residual anomaly of the Banyumas and surrounding area.

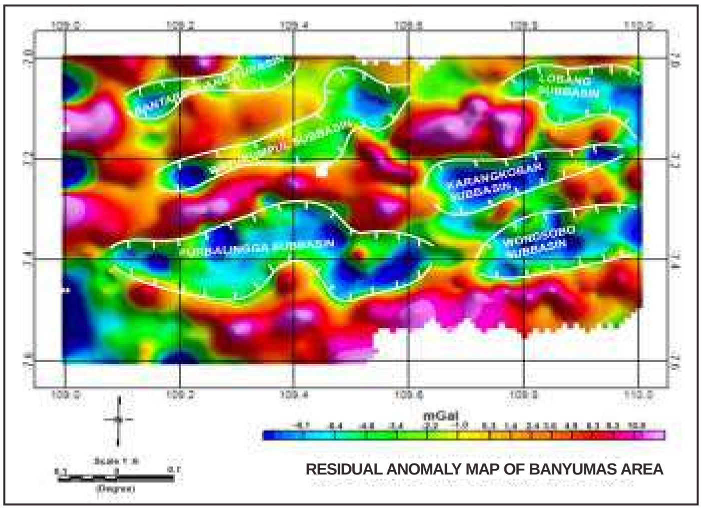

Figure 6. Distribution pattern of sedimentary subbasins of the Banyumas and surrounding area.

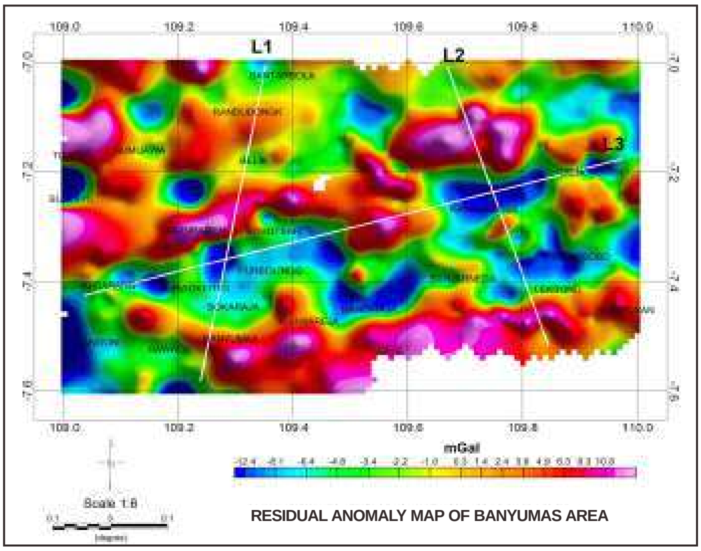

Figure 7. Direction of line sections of subsurface geological modeling.

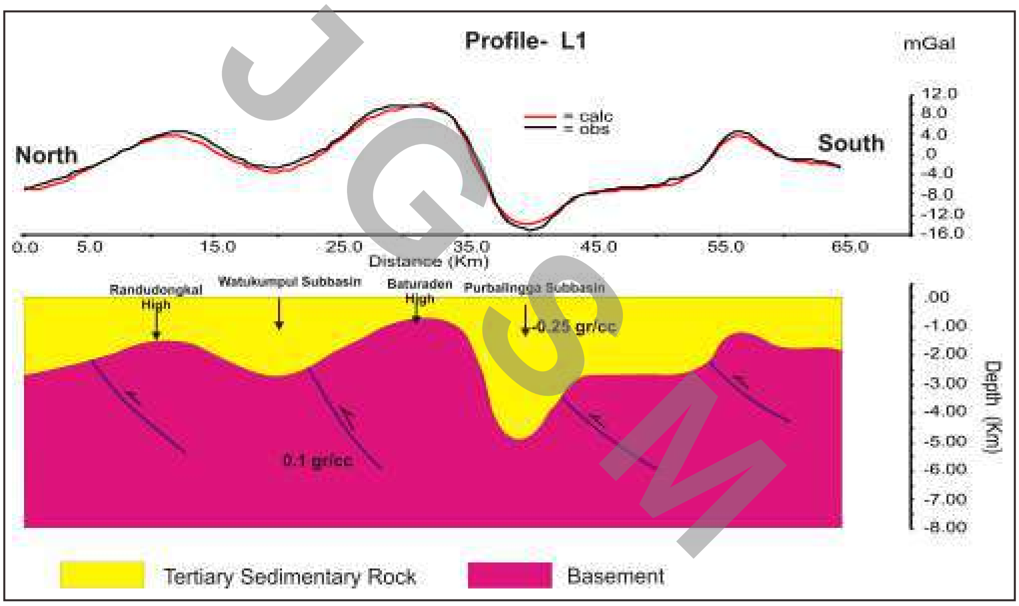

Figure 8. Subsurface geological model Line L1 of the Banyumas basin and surrounding area.

The value of the density contrast on the modelling results -0.25 g/cc and interpreted as the Tertiary sedimentary rocks, while the bedrock (basement) based on the modelling result has a contrast density value about 0.1 g/cc and is interpreted as an andesitic rocks. Basement rock of Central Java occupies a transition between continental dominant basement at West Java and intermediate/basalt dominant basement at East Java (Satyana, 2005). The L1 2D modelling also reflects the fault structures that develop in the study area as a reverse fault, which is corresponding with the geological feature in fore arc basin that shows many reverse fault. Subsurface geological model line L2 is presented in Figure 9. The pattern of the L2 2D modelling indicates the density contrast value of the upper block is about -0.25 gr/cc and interpreted as the Tertiary sedimentary rocks. Subsequently the lower block has a density contrast value of 0.1 gr/cc and interpreted as an andesitic rocks basement. Subsurface geological model line L3 is shown in Figure 10. The profile shows that the average depth of basement rocks is 3 km. The basin filling sedimentary rock consists of clays, sandstones, marls, and volcanic breccias with contrast density values of -0.25 gr/cc, while the basement composed of andesitic rocks with contrast density value of about 0.1 gr/cc.

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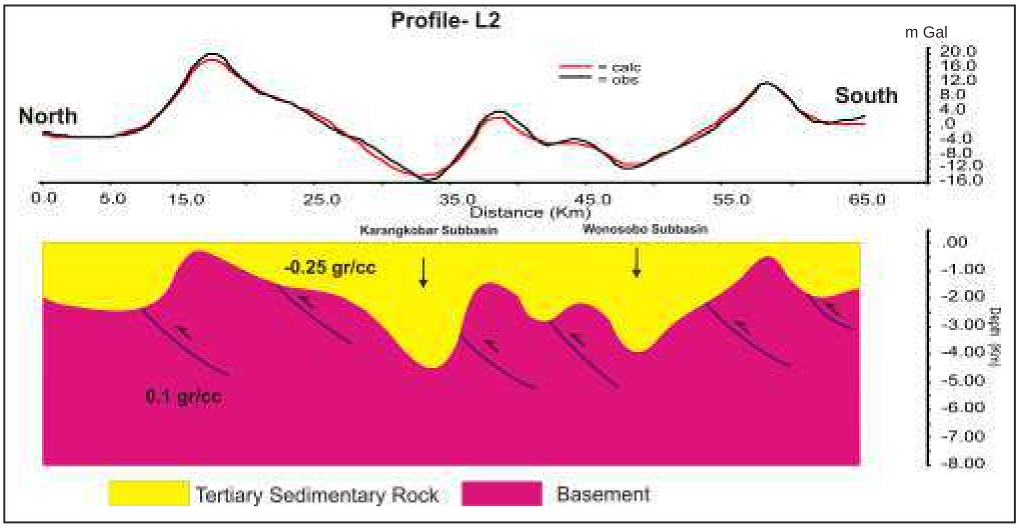

Figure 9. Subsurface geological model Line L2 of the Banyumas basin and surrounding area.

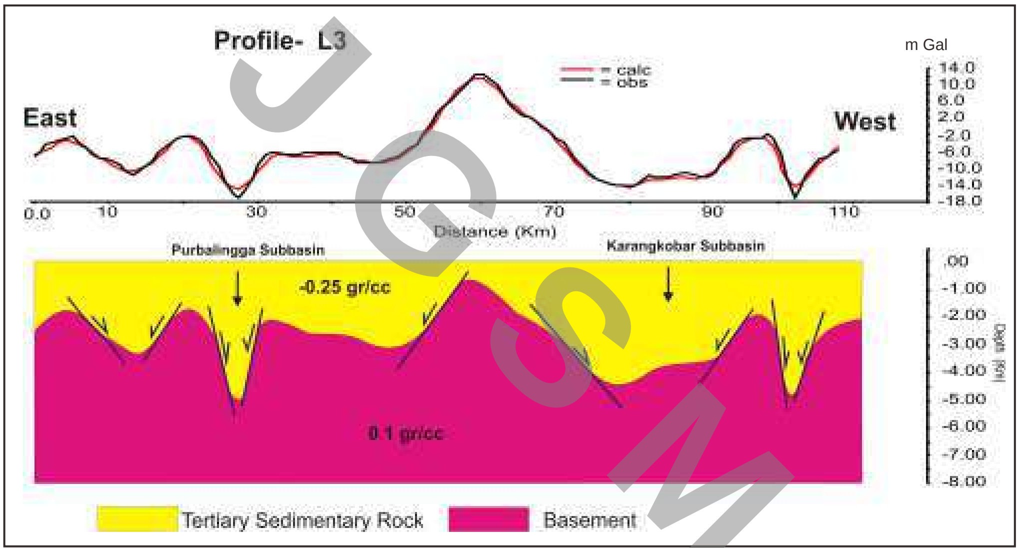

Figure 10. Subsurface geological model Line L3 of the Banyumas basin and surrounding area.

CONCLUSION

The spectral analysis results show that there are two depth boundary planes in the study area, the deep and shallow boundary plane. The deep boundary plane depth (regional) at 21 km indicates the boundary plane between upper and lower crust. Thereafter the shallow boundary plane depth (residual) at 2.9 km indicates the boundary plane between basement and sedimentary rocks. Shallow boundary plane is used to determine depth of basement high at the Banyumas sedimentary basin and surrounding area. The residual anomaly delineation results six sedimentary subbasins in Banyumas area, the Purbalingga, Karangkobar, Wonosobo, Watukumpul, Lobang and Bantarbolang subbasins. The 2D modelling analysis results three potensial subbasins for the possible hydrocarbon presence, the Purbalingga, Karangkobar, and Wonosobo subbasins, with depocenter depth approximately 4 to 5 km.

SUGGESTION

Detailed geophysical methods such as passive seismic tomography (PST) and magnetotelluric (MT) need to be carried out in the Purbalingga, Karangkobar, and Wonosobo subbasin to investigate more detail of geological feature in this area especially related to the hydrocarbon prospect.

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