GEOLOGICAL INTERPRETATION OF THE OFFSHORE SEDIMENTARY BASIN OF NORTH CENTRAL JAVA BASED ON SPECTRAL ANALYSIS AND 2D GRAVITY MODELING

INTERPRETASI GEOLOGI CEKUNGAN SEDIMEN LAUT UTARA JAWA TENGAH BERDASARKAN ANALISIS SPEKTRAL SERTA PEMODELAN 2D DATA GAYABERAT

Restu Ningsih[1*], Imam Setiadi[2], Riza Rahardiawan[2], Ordas Dewanto[1], and Rahmi Mulyasari[1]

[1] Department of Geophysical Engineering, Faculty of Engineering, University of Lampung, Jl. Prof. Dr. Ir Sumantri Brojonegoro, Bandar Lampung, Lampung 35141

[2] Marine Geological Institute , Jl. Dr. Djunjunan No. 236, Husen Sastranegara, Bandung 40174

*Corresponding author: restuningsih913@gmail.com

(Received 31 October 2022; in revised from 2 November 2022; accepted 2 January 2023)

DOI : 10.32693/bomg.37.2.2022.788

ABSTRACT: The offshore sedimentary basin of North Central Java is a marine basin located in the northern part of North Serayu Basin. This basin was formed through the uplift of the southern part of Central Java (Bumiayu) caused by the movement of a pair of horizontal faults. Studies of sub-basin delineation and basement configuration are rarely carried out in this basin. Therefore, the gravity method referring to subsurface-density variations was carried out to obtain this information. This research aims to delineate sedimentary basins and interpret the geological subsurface based on gravity data using spectral analysis, highpass and lowpass filters, also 2D gravity modeling. An average estimation depth to the basement in the study area of about 2.22 km was determined using spectral analysis. Qualitative analysis shows the basement-high pattern, sub-basin, and structure lineament patterns. The 2D model shows three layers consisting of the upper sedimentary layer of Tertiary-Neogene and the middle layer of Tertiary-Paleogene sediment with a density value of 2.3 gr/cc and 2.5 gr/cc, respectively. The lower layer has the highest density of 2.67 gr/cc, assumed as a granitic basement. The results of the Second Vertical Derivative (SVD) analysis on the residual anomaly cross-sectional paths indicate the presence of thrust and normal faults which can be used to assist the interpretation of fault structures in subsurface geological models. Gravity analysis of the offshore North Central Java sedimentary basin indicates the occurrence of sub-basins and geological structure patterns that considered as a potential zone for the development of the petroleum system in this area.

Keywords: Bouguer Anomaly, Spectral Analysis, Highpass and Lowpass Filter, 2D Modeling, Offshore Sedimentary Basin of North Central Java

ABSTRAK*: Cekungan sedimen laut utara Jawa Tengah merupakan wilayah cekungan laut yang berada di sebelah utara cekungan Serayu Utara. Pembentukan cekungan disebabkan oleh pengangkatan bagian selatan Jawa Tengah (Bumiayu) akibat pergerakan pasangan sesar mendatar. Studi mengenai delineasi sub cekungan dan konfigurasi batuan dasar masih jarang dilakukan di cekungan ini. Gayaberat sebagai metode geofisika berdasarkan parameter fisis rapat massa (densitas) dilakukan guna mengetahui informasi tersebut. Tujuan dari penelitian adalah untuk mendelineasi cekungan sedimen dan menafsirkan geologi bawah permukaan berdasarkan data gayaberat menggunakan analisis spektral, highpass dan lowpass filter serta pemodelan gayaberat 2D. Estimasi kedalaman rata-rata batuan dasar daerah studi adalah sekitar 2.22 km berdasarkan analisis spektral. Analisis kualitatif pada daerah ini menunjukkan pola tinggian, sub cekungan dan pola kelurusan struktur. Model 2D memperlihatkan tiga perlapisan batuan terdiri dari lapisan sedimen paling atas Tersier-Neogen dan lapisan tengah Tersier-Paleogen dengan nilai densitas masing-masing 2.3 gr/cc dan 2.5 gr/cc. Lapisan bawah dengan densitas tertinggi 2.67 gr/cc, diperkirakan sebagai batuan dasar granitik. Hasil analisis Second Vertical Derivative (SVD) pada lintasan penampang anomali residual menunjukkan adanya patahan naik dan turun yang dapat digunakan untuk membantu* *interpretasi struktur patahan pada model geologi bawah permukaan. Analisis gayaberat pada cekungan sedimen laut utara Jawa Tengah menunjukan keberadaan sub-cekungan sedimen serta pola struktur geologi yang diperkirakan sebagai zona potensial untuk berkembangnya sistem petroleum.*

Kata Kunci: *Anomali Bouguer, Analisis Spektral, Highpass dan Lowpass Filter, Pemodelan 2D, Cekungan Sedimen Laut Utara Jawa Tengah*

INTRODUCTION

Java Island is located at the active tectonic edge of the interaction between the Eurasian Continental Plate and the Indian Ocean Plate. As a result, there are several main tectonic elements of Java, such as the accretionary prism, the subduction zone, the magmatic-volcanic arc, the back and fore arc basins (Satyana & Purwaningsih, 2002). Central Java is located in a transitional area of the continental and oceanic crust (the southern part is the oceanic crust and the northern part is the continental crust). Pulunggono and Martodjojo (1994) divided the patterns of the structure of–Java Island into 3 groups, namely the Meratus direction (southwest-northeast), the Sunda direction (north-south), and the Java direction (west-east). The offshore north Central Java sedimentary basin, known as the *North Serayu Range,* is a marine area adjacent to the North Serayu basin area. This area is one of the deep sea sedimentary basins on the Java Island, extends from the Bogor Zone in the west to the Kendeng Zone in the east. These two zones in the west and east of the basin also demonstrate different characteristics of deep sea sedimentation processes (Martodjojo, 1984).

The gravity method is one of the geophysical methods used to determine subsurface geological conditions based on physical parameters of rock mass density (Setiadi et al., 2010). This method is based on gravitational field variations due to density contrasts of rock mass below the surface. Therefore, the investigation is based on the difference in the gravitational field from one observation point to another (Sarkowi, 2008). The gravity method 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) and a zone in depth (regional). Several filter methods can be used to analyze gravity data, including a Gaussian filter to separate regional and

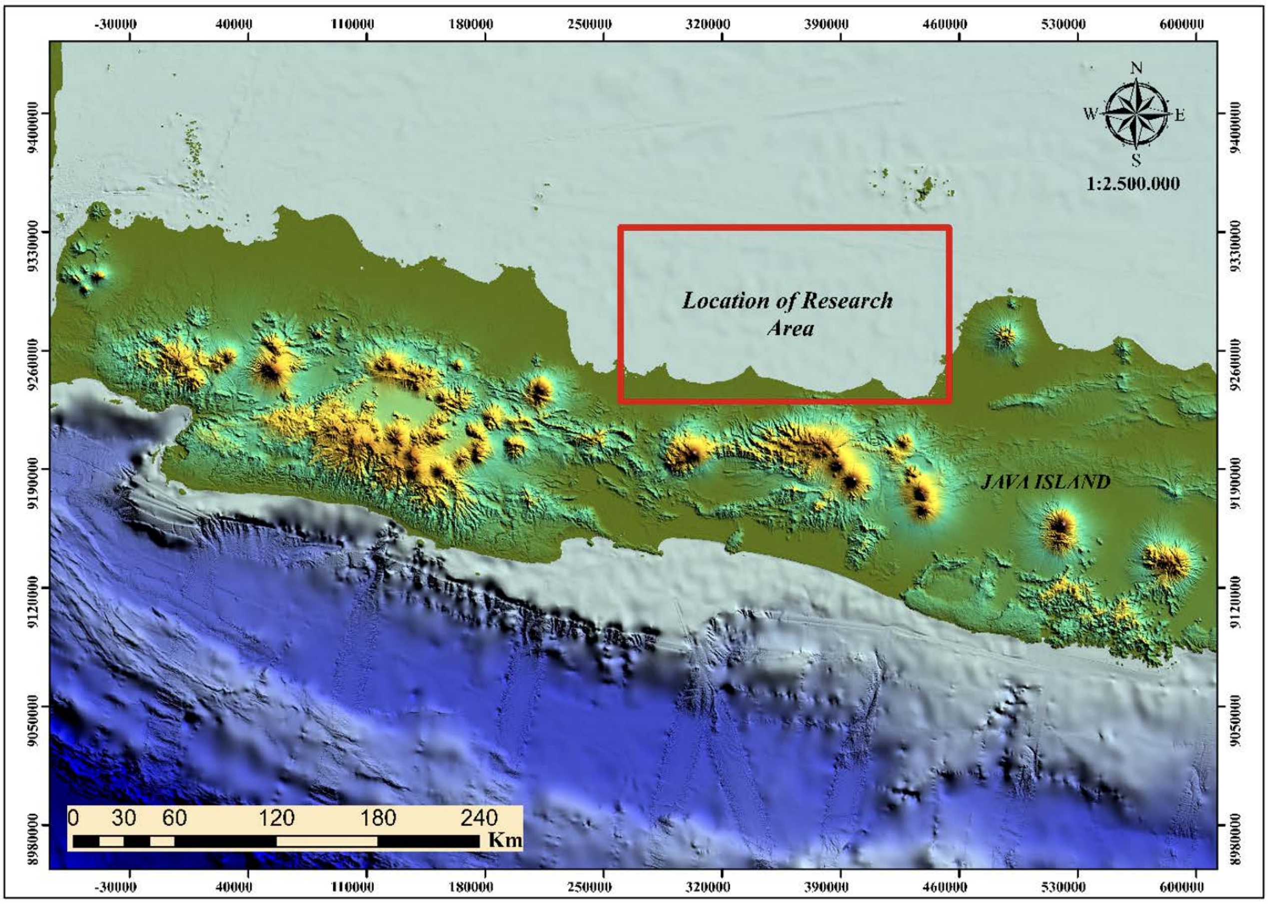


Figure 1. Location of research area offshore north Central Java sedimentary basin

residual anomalies from gravity data (Karunianto et al., 2017). Obasi et al. (2016) applied the trend surface analysis method to separate residual and regional anomalies from gravity data. Zahra and Oweis (2016) used a high pass filter on gravity and geomagnetic data to obtain short wavelength anomalies associated with shallow anomaly sources.

According to Setiadi et al. (2010), the gravity method has high ambiguity due to the effect of the density and depth of the rock as anomalous sources. High gravity anomalies are probably caused by a response of high-density rocks or relatively shallow sources. In contrast, a low anomaly is assumed to be affected by low-density rocks or relatively deep bodies. This ambiguity problem can be eliminated using the spectral analysis method by calculating the depth of anomalous features. Estimating basement depth based on spectral analysis is expected to reduce errors when initially building subsurface geological models. This study performed a spectrum analysis to estimate the basement depth and calculate the optimal window width. Furthermore, regional and residual anomalies were separated using lowpass and highpass filters. This study aims to determine the pattern of subsurface geological structures, distribution of sedimentary sub-basins, and basement configurations based on spectral analysis, highpass and lowpass filters, and 2D modeling. Geographically, the research area is located at 6^0 10' – 7^0 20'S and 108 ^{o} 30' - 110^o 30'E (Figure 1). This basin has an area of 16,660 km^2, with a land area of about 5,176 km^2 and an offshore area of about 11,484 km^2.

Geology of Research Area

According to Djuri et al. (1996), the history of sediment deposition in the basin begins with the deposition of the Eocene Siliclastic Worowari Layer and unconformably overlies the Pre-Ngimbang Sequence. These deposits are covered transgressively by Early Miocene deposits consisting of coarse conglomerate and quartz sandstone from the Lutut Layer and reef limestone known as the Sigugur Layer. Then there was significant subsidence, indicated by the deposition of thick turbidite sequences of the Early-Middle Miocene age. This deposit consists of marl claystone, quartz sandstone, and tuffaceous sandstone. This flysch-like series consists of the Merawu and Penyetan Layers in the central and eastern areas of the basin and the Pemali Layers in the west.

The uplift that occurred in the southern part of Central Java enhanced the subsidence rate of the basin floor. The sudden increase in orogenesis not only resulted from the gravitational sliding movement from the south northward but also from the northern flank sliding down to the deepest part of the basin transgressive and unconformity over the older series. Then the basin subsidence began, presumably compensated the strong Mio-Pliocene uplift in the southern part of Central Java. At the age of Mio-Pliocene basin filling, starting with the deposition of volcanic deposits interspersed with conglomerates, this succession ends with marl-clay and tuffaceous sandstones from the Kalibiuk Layer.

During the Pliocene age, the deposition of deep sea sediments continued in the basin. Facies analysis in Brebes-Tegal-Pemalang, North Central Java revealed that the presence of turbidite in the area is equivalent to the Pliocene Cisubuh Formation in the coastal area to the north, and there are indications of a depositional system that responds to a different time between exposures (shelf) and deposition in the basin. After volcanic activity in the Early Miocene, reef limestone accumulated above the Tapak Layer to the west and Kapung limestone to the east. The deposition in the basin indicates an uplift that started in the Plio-Pleistocene, because it only formed along the boundary of the North Serayu Range.

Traps in the Cipluk field were formed by anticlines that were faulted with a reservoir of volcaniclastic sandstone from the Late Miocene. The oil is believed to have originated from the Merawu Layer shale or Eocene shale of the Worowari Layer (equivalent to the Ngimbang shale in the North East Java Basin). The marl of the Cipluk layer causes vertical or lateral cover. One of the westernmost exposed Pemali Layers in the Madja area, west of Mount Ciremai in Cirebon, is reported to have oil seeps (Satyana and Armandita, 2004).

The source rock of the offshore north Central Java sedimentary basin is derived from non-marine shale – a shallow sea of the Worowari Layer and marl claystone of the Merawu Layer. These two rocks proven to be the source rock of hydrocarbons for the Cipluk Field. The reservoir is in the form of quartz sandstone and tuffaceous sandstone of the Lutut and Merawu Layers, as well as reef limestones of the Sigugur Layer. Hydrocarbons formed can migrate to the toe thrust anticlines traps formed in the Knee and Merawu Layers or the reef limestones of the Sigugur Layer through the toe thrust system fault. The sealing rock consists of shale within the Merawu and Penyatan Layers (Satyana, 2007).

METHODS

The data in this research are free air anomaly and bathymetry data from the Topex satellite combined with ground gravity data collected by the Center for Geological Survey of the Geological Agency, with a total data of around 6480 points. The method used in this study is gravity data analysis and geological information data. We used spectral analysis to find the optimal window width and to estimate the basement depth. Highpass and lowpass filters will also be performed to separate regional and residual anomalies from gravity data. Subsurface geological modeling was carried out using 2D forward modeling, and second vertical derivative (SVD) analysis was done on residual anomaly cross sections to determine the normal or thrust fault in the subsurface geological model. Data processing was performed by using Geosoft Oasis Montaj and GMSys software.

The qualitative interpretation was done to determine the lateral anomaly distribution and is usually used for interpreting structural patterns, basement high lineament faults, and delineation of sedimentary sub-basins in the study area. A qualitative interpretation was performed based on the residual anomaly of gravity data because of its position, which is a relatively shallow target anomaly. Quantitative interpretation was carried out by developing a subsurface geological model based on gravity data, so that the vertical distribution pattern of rock can be identified, which includes the model dimensions or size, the composition of the rock types which are interpreted based on the physical parameters of rock mass density. A complete research flow chart can be seen in Figure 2.

RESULTS AND DISCUSSION

Bouguer Anomaly

According to the results of gravity data processing, the Bouguer anomaly value is obtained with the distribution value in the range between 2 mGal - 42 mGal, as demonstrated in Figure 3.

Based on the Bouguer anomaly map, the high gravity anomaly value is located in the north and distributed in the middle, marked with red to purple colors. Meanwhile, the low anomaly value is located in the southern part, marked in blue to dark blue. The high anomaly is interpreted as the basement likely to be uplifted due to the active Muria - Kebumen and Cilacap - Pamanukan horizontal fault pairs. In contrast, the low anomaly is interpreted as a thick sedimentary rock in the area.

Spectral Analysis

Spectral analysis aims to estimate the basement depth and determine the optimum window width used in the filtering process. The line path of the spectral analysis can be observed in Figure 4a, while a sample graph of the results of the spectral analysis is presented in Figure 4b, which shows two slopes indicating the depth of the shallow and

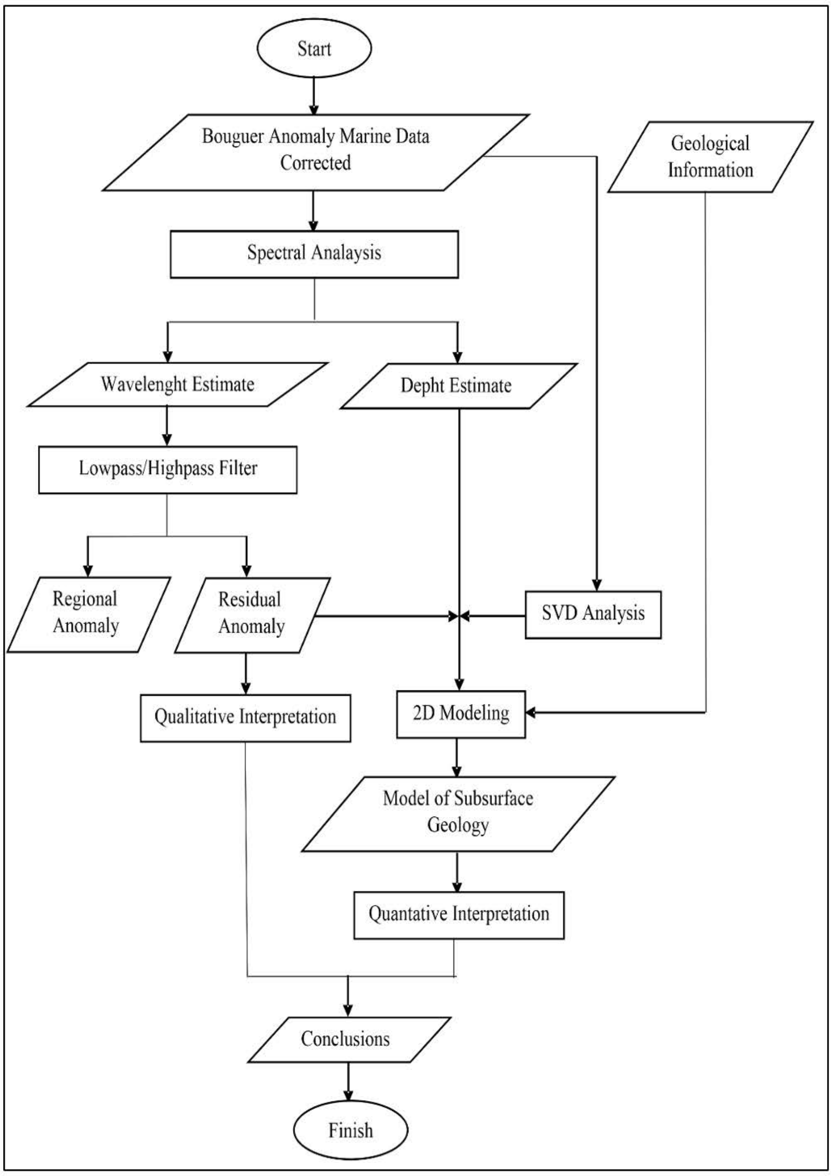


Figure 2. Research Flowchart

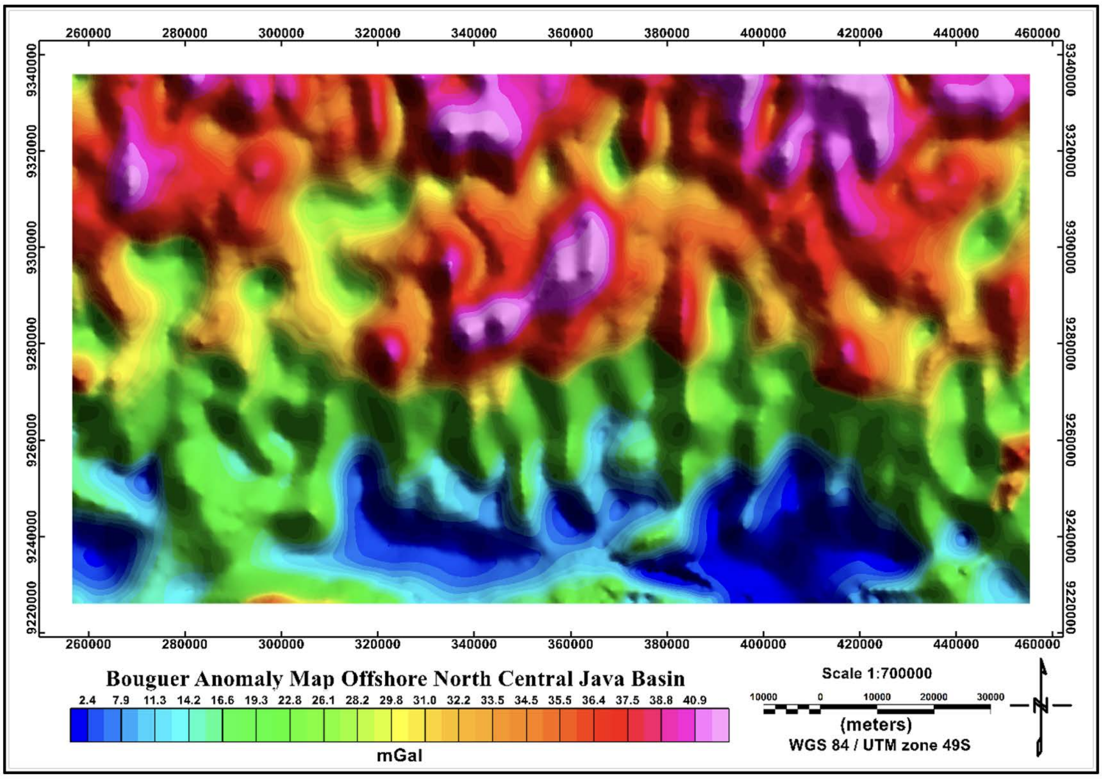
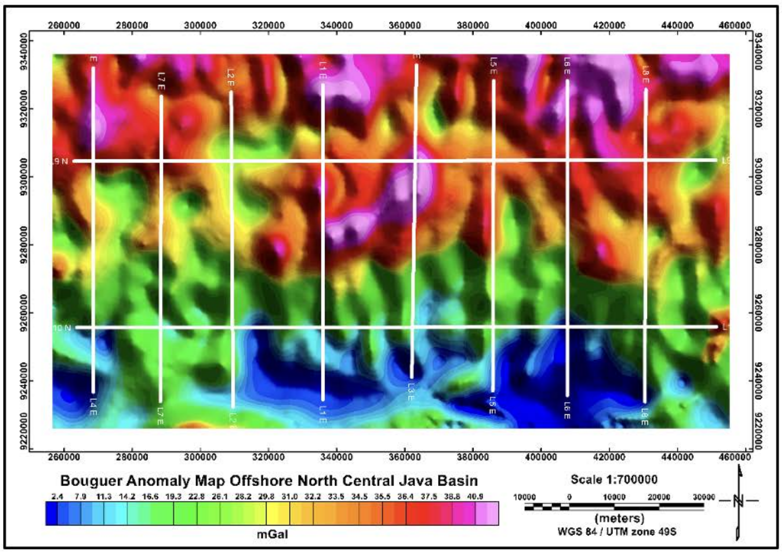
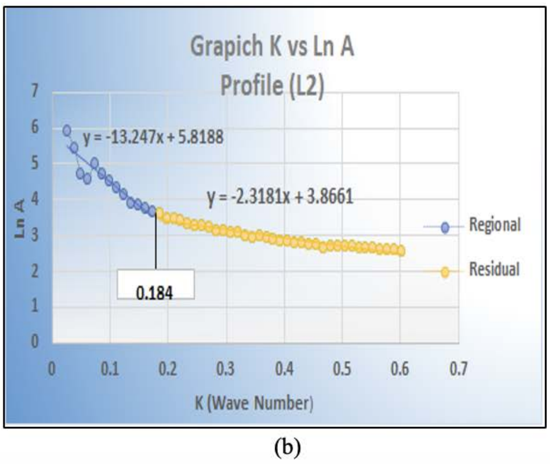


Figure 3. Bouguer anomaly map offshore north Central Java basin



(a)



(b)

Line	Depth Reg (Km)	Depth Res (Km)	Kc	N	Window Width
L 1	-15.198	-2.0765	0.184	9	32
L 2	-13.247	-2.3181	0.184	9	32
L 3	-15.314	-2.1831	0.184	9	32
L 4	-19.846	-2.1709	0.171	9	32
L 5	-16.986	-2,275	0.171	9	32
L 6	-16.5	-2.2483	0.171	9	32
L 7	-16.364	-2.3344	0.184	9	32
L 8	-12.734	-2.2617	0.184	9	32
L 9	-23.178	-2.1569	0.171	9	32
L 10	-19.018	-2.1306	0.165	9	32
Average	-16.8385	-2.21555		9	32

(c)

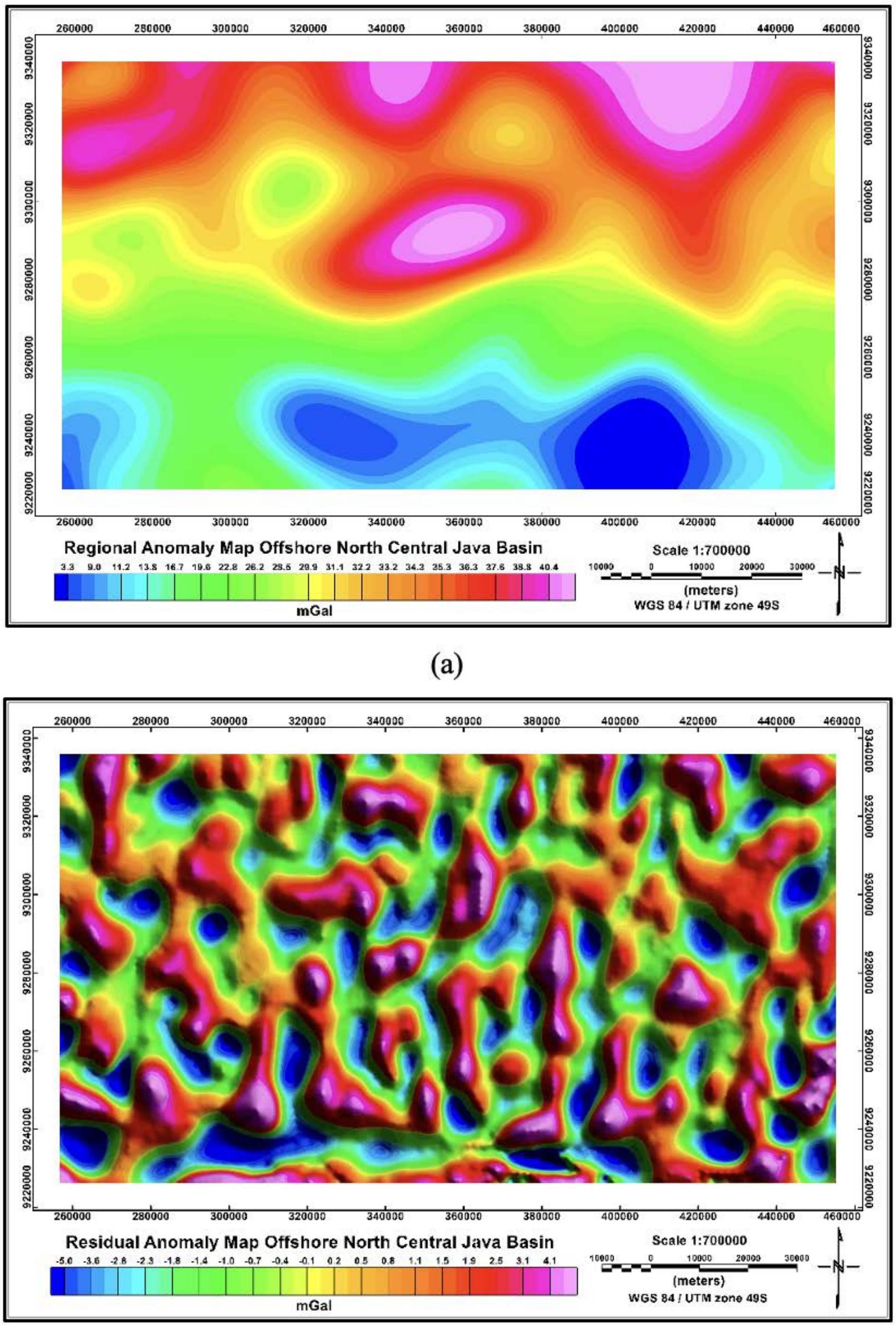
Figure 4. **(a)** Bouguer anomaly map and cross section direction of spectral analysis path, **(b)** example of spectral analysis chart of the L2 path, and **(c)** result of the calculation of regional and residual anomaly depth based on spectral analysis

deep discontinuity plane. The overall results of the spectral analysis process are illustrated in Figure 4c.

The average depth of the discontinuity plane in the study area is 16.83 km, as presented in Figure 4c, which is assumed as the depth of the lower crust discontinuity plane. Meanwhile, the average depth of the shallow discontinuity plane is 2.22 km which is interpreted as the average depth of the basement. The optimum window width of the spectral analysis results in this area is 32x32 km which will be used for lowpass and highpass filtering. We used a lowpass filter with 32 km wavelength to separate regional anomalies obtained from spectral analysis.

Separation of Regional and Residual Anomalies

The filtered gravity anomaly yield regional and residual anomaly used to determine patterns of deep and shallow geological structures. The complete separation



(a)

(b)

Figure 5. **(a)** Regional anomaly map, and **(b)** Residual anomaly map of the offshore north Central Java basin

results of regional and residual anomaly maps are displayed in Figure 5. A regional anomaly map of the offshore north Central Java basin area and its surroundings was obtained using a lowpass filter with a cut-off wavelength of 32 km (Figure 5a). From this figure, it can be seen that the anomaly ranges from 2 mGal - 55 mGal. The high anomaly indicated in red colour is located in the northern area. This regional anomaly represents undulation patterns of geological structures at deeper positions (inner discontinuity planes) characterized by longer wavelengths.

The residual anomaly pattern in the offshore north Central Java basin can be seen in Figure 5b, which shows anomaly values ranging between -5.3 mGal - 5 mGal. Residual anomalies have relatively short wavelengths, reflecting geological structures with shallower positions. The high anomaly shown in red is distributed almost evenly throughout the study area with a relatively north-south trend. The high anomaly is probably due to the influence of high density rocks, while the low anomaly indicated in blue may have been resulted from the influence of lower mass-density rocks value. The high anomaly characterized by the red colour is assumed to be the location of the basement high occurrence, while the low anomaly is probably due to the accumulation of sedimentary rock with a lower density value.

Qualitative Interpretation

A qualitative interpretation used to determine the anomalous changes laterally based on the results of residual anomalies. This qualitative interpretation is usually performed to identify the pattern of the geological structure, basement high and sub-basin delineation. Low anomaly indicates the presence of rocks with a low-density value (usually sedimentary rock). In contrast, high anomaly reflects the presence of high mass density rocks.

The basement high pattern of the offshore North Central Java basin as the boundary between sub-basins is presented in Figure 6a. It can be seen that the pattern of the basement high is a relatively east-west and north-south direction which might be influenced by the movement of the horizontal fault pair in the study area. Meanwhile, Figure 6b indicates the distribution pattern of the sedimentary sub-basins in the offshore North Central Java

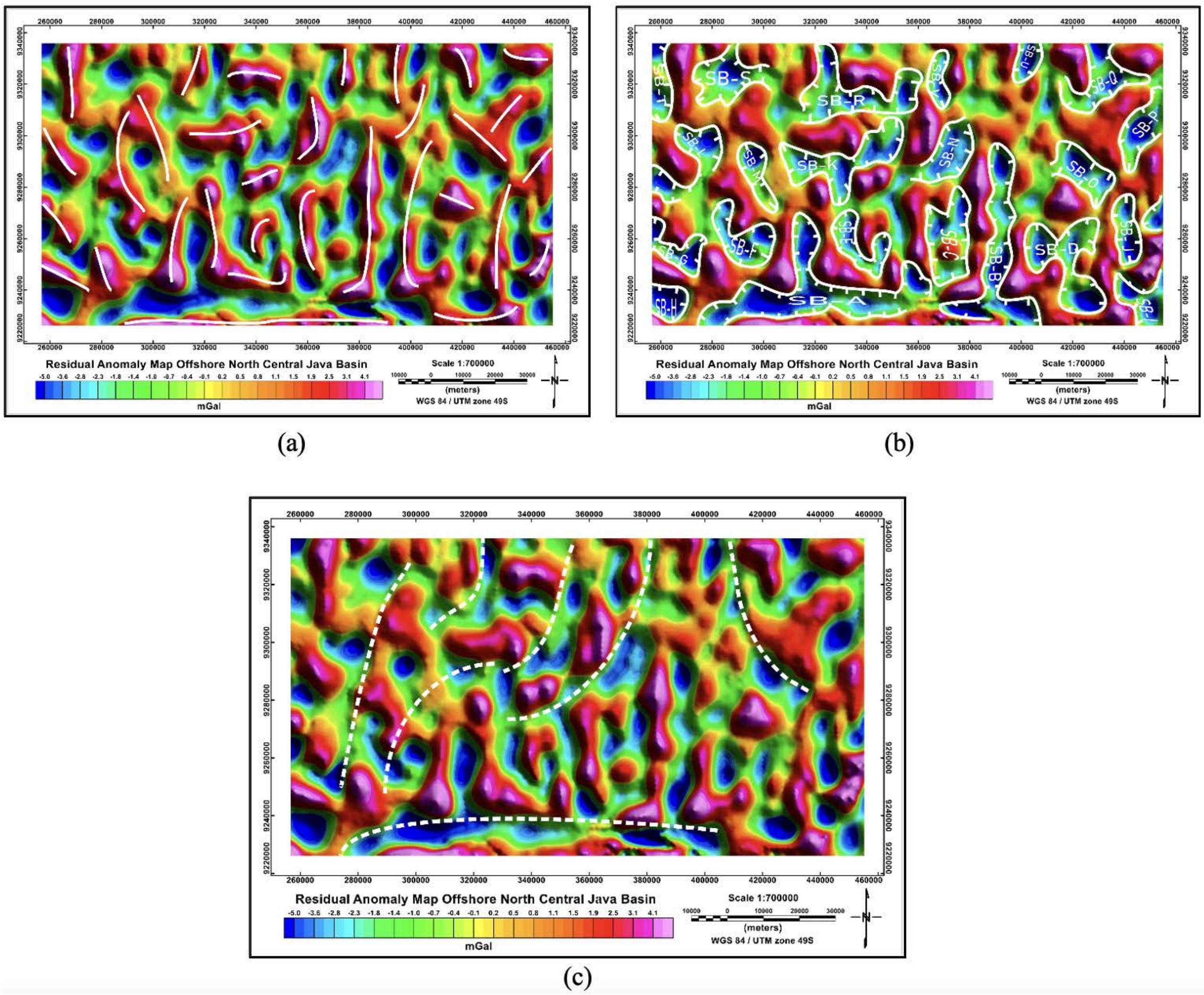


Figure 6. **(a)** Basement high pattern, **(b)** sub-basin delineation, **(c)** Lineament structure pattern of the offshore North Central Java basin

basin, which in total around 22 (twenty-two) sub-basins. Based on the residual anomaly pattern demonstrated in Figure 6c, the anomaly remark in the southern part is relatively west-east. Most likely, this is affected by the movement of the horizontal fault pair. The horizontal fault movements are sinistral with respect to the Muria-Kebumen Fault and dextral in respect to the Cilacap-Pamanukan Fault. Meanwhile, the anomaly from the middle to the north is relatively northeast-southwest, probably due to the effect of the old structure subduction known as the Meratus pattern.

Quantitative Interpretation

The purpose of quantitative interpretation is to determine the subsurface geological model, which includes the dimensions or size of the subsurface model, the rock types based on the geological information of the research area and rock density parameters. The depth of sedimentary rock determined by the average depth value of the residual anomaly from the spectral analysis process and sedimentary thickness data (Hamilton, 1974).

The fault structure determined based on SVD analysis, according to Reynolds (1997), where:

for thrust fault if $\left|\frac{\partial^2 g}{\partial z^2}\ max\right| < \left|\frac{\partial^2 g}{\partial z^2}\ min\right|$

and normal fault if $\left|\frac{\partial^2 g}{\partial z^2}\ max\right| > \left|\frac{\partial^2 g}{\partial z^2}\ min\right|$.

In this 2D model, two cross sections are used, namely A-A' and B-B'. The cross-section anomaly was analyzed by the SVD technique to obtain the location of the fault. Quantitative interpretation was performed by constructing a subsurface geological model based on gravity data, so the vertical distribution pattern of rock could be identified, including the dimensions or size of the model, and the rock types identification was based on the physical parameters of rock density. Figure 7 is a line direction of a 2-dimensional subsurface geological model. The result of the subsurface geological model is demonstrated in Figure 8. Figure 8a is a 2D model of line A-A' along 168 km with a relative northwest-southeast direction, and Figure 8b is a subsurface geological model of line B-B' along 166 km with a relative southwest-northeast direction.

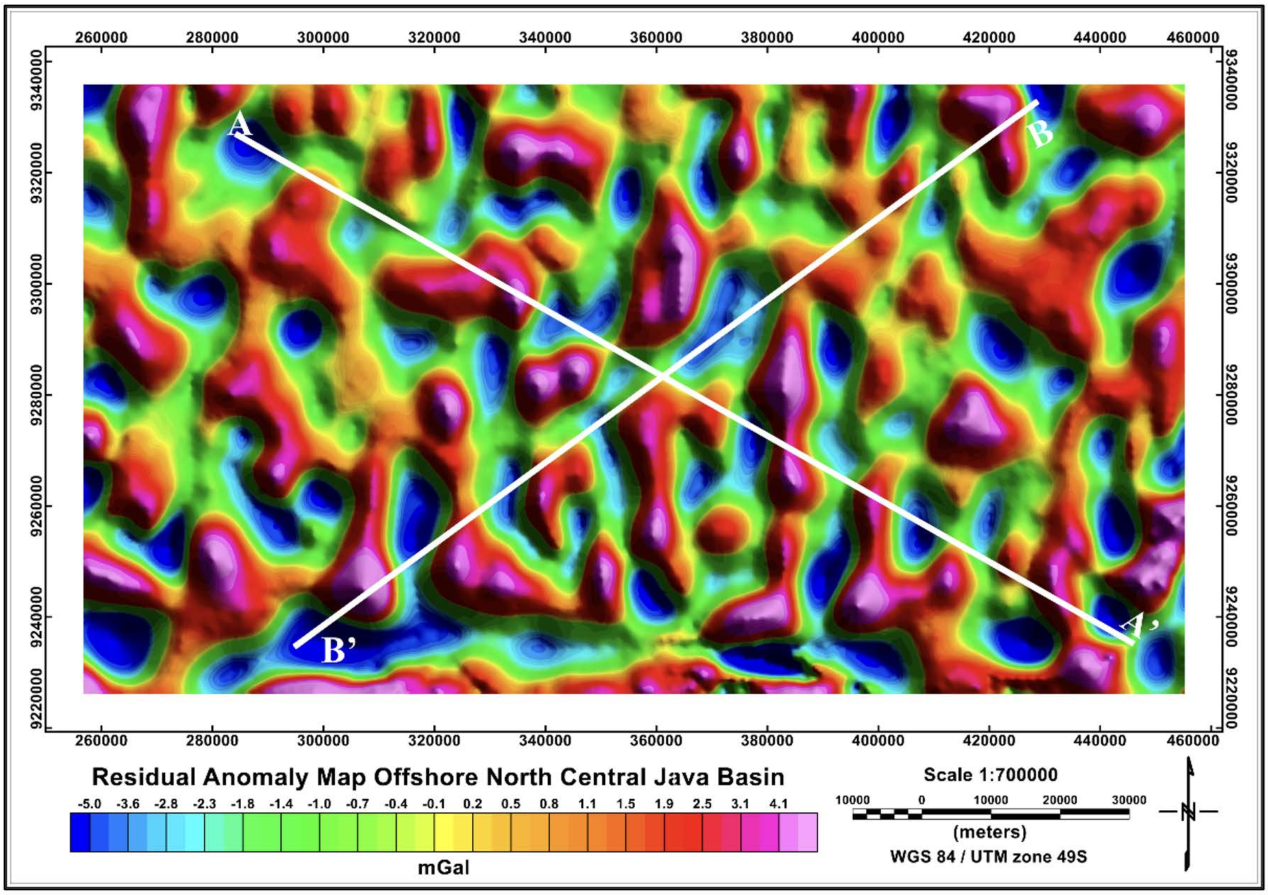
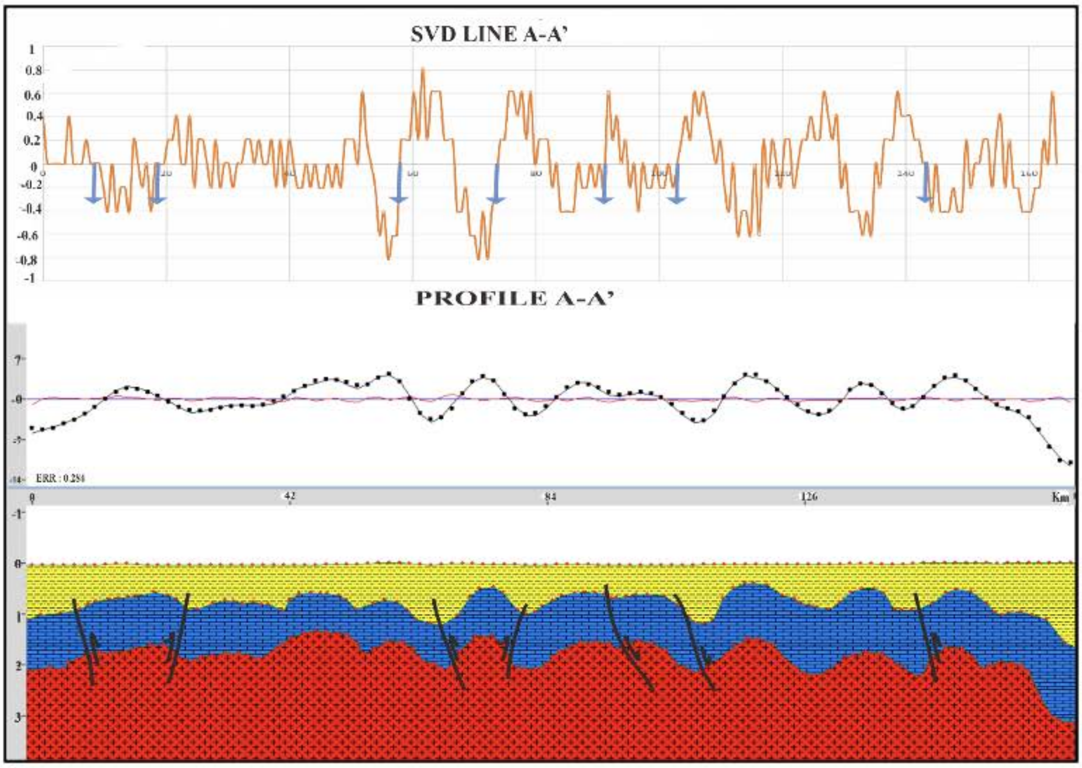
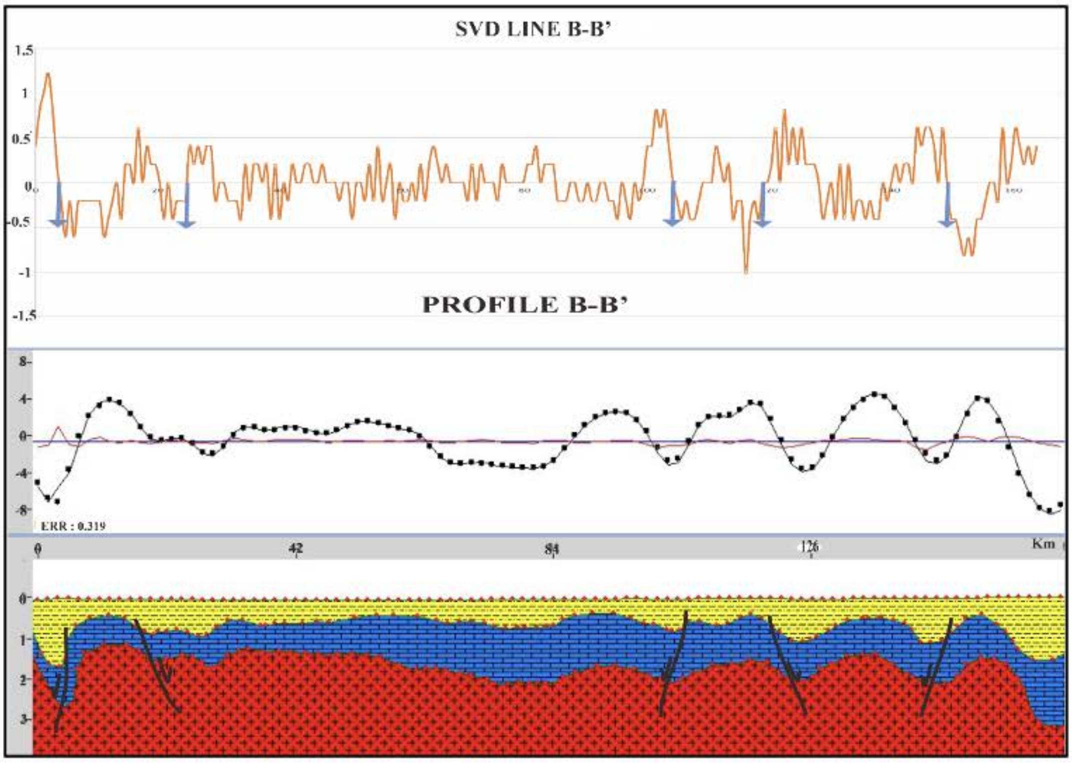


Figure 7. Line direction of 2D subsurface geological modeling of the offshore North Central Java basin

2D model of A-A' shows the cross section through the S, K, C, B and D sub-basins. The average depth of the basement based on gravity modeling is around 2.22 km, confirmed following the calculation of spectral analysis and thickness of sedimentary rocks (Hamilton, 1974). The basement that underlies the sedimentary basins is the continental crust and consists of granitic rocks with a density value of around 2.67 gr/cc. This continental crust



(a)



(b)

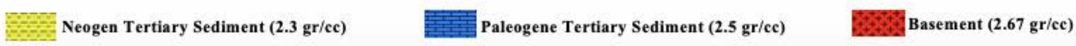


Figure 8. (a) 2D Model of subsurface geology A-A' line section, (b) B-B' line section of the offshore north Central Java basin

comprises Early Miocene volcaniclastic rocks (Van Bemmelen, 1949). Above the basement was deposited a Tertiary-Paleogene rock layer (density value of 2.5 g/cc), a combination of Worowari, Merawu, and Tapak Formations. This layer composed of marl, claystone, quartz sandstone, tuffaceous sandstone, and limestone. The uppermost layer in the A-A' cross-section model is Tertiary-Neogene sedimentary rock with a density value of 2.3 gr/cc, assumed to be a combination of the Pemali, Kalibiuk and Cipluk Formations consisting of conglomerate, tuffaceous sandstone, marl, calcareous claystone and a minor of sandstone. The Pemali Formation is supposed to be a deep-sea deposit, sedimented during the Early Pliocene. The subsurface geological model in Figure 8a shows several patterns of basement highs and graben, as well as thrust and normal fault structure. There are 2 normal faults and 4 thrust faults identified based on the SVD analysis. Setiadi and Arendra (2016) successfully conducted a second vertical derivative (SVD) analysis to determine the thrust and normal fault structure at the Tanimbar basin.

The result of the second modeling is the B-B' line section as shown in Figure 8b. This line section has a relatively southwest-northeast direction through the A, E and N sub-basins. Similar to the A-A' line section, the subsurface geological model of the B-B' line section contains three rock layers. The basement rock is interpreted as a granitic crust with a density value of 2.67 gr/cc. Above the basement at the age of the Tertiary-Paleogene deposited a combination of the Worowari, Merawu and Tapak Formations consisting of marl, clay stone, quartz sandstone, tuffaceous sandstone, and limestone with a density value of 2.5 gr/cc. The uppermost layer in the B-B' cross-section model is Tertiary-Neogene sedimentary rock with a density value of 2.3 gr/cc. This layer is interpreted as the Pemali, Kalibiuk and Cipluk formations consisting of conglomerate, tuffaceous, sandstone, marl, calcareous, claystone and a small amount of sandstone. The SVD analysis on the B-B line path cross-section indicates that there are 5 normal fault structures.

The source rock of the offshore North Central Java basin originates from shallow marine shales of the Worowari layer and marl claystone of the Merawu layer. These two rocks are proven to be hydrocarbon source rocks in the Cipluk Field. The reservoir consists of quartz sandstone, tuffaceous sandstone of the Merawu layer, and limestone reefs of the Sigugur layer. Hydrocarbons formed can migrate to the toe thrust anticlines traps formed in the Lutut and Merawu layers or the limestone reefs of the Sigugur layer through the toe thrust system. The traps in this field are formed by an anticline faulted with a reservoir of the Late Miocene volcaniclastic sandstones. Hydrocarbons derived from the non-marine shale of the Merawu layer or Eocene shale from the Worowari layer (equivalent to the Ngimbang shale of offshore North Central Java basin), and the oil fills the trap through the fault as its migration path. The northward gravitational sliding occurred due to the uplift of the North Serayu Range during the Middle-Late Miocene and formed geological structures in this basin. The existence of fault structures, sub-basins and basement highs which resulted from the gravity analysis in the offshore North Central Java basin, is interesting for further study to determine the potential of the existing petroleum system in this area.

CONCLUSIONS

Gravity anomalies in the North Central Java offshore basin show that the high anomalies generally occupy the northern part area and are interpreted as relatively shallow depths of the basement. In contrast, low anomalies in the southern part areas are assumed to be an effect of deeper basements. The spectral analysis estimates the average depth of the residual anomaly at 2.2 km, considered as depth to basement, and the regional anomaly depth of about 16.84 km, which is interpreted as the depth of the lower crustal discontinuity plane. Qualitative interpretation depicts structural patterns that indicate the basement high lineament with a relatively north-south direction that follows the Meratus trend, and the east-west lineament pattern aligns with the Java trend. The sub-basins that can be delineated from the residual anomaly based on spectral analysis are 22 sedimentary sub-basins. 2D modeling in the offshore North Central Java sedimentary basin shows that there are 3 layers of rock, the lowest layer is a granitic basement with a density value of 2.67 gr/cc. Above the basement is Tertiary-Paleogene sedimentary rock with a density value of 2.5 gr/cc as a combination of the Tapak formation which is composed of marl and limestone. The uppermost layer is Tertiary-Neogene sedimentary rock with a density value of 2.3 gr/cc, suggested as the Pemali formation, which consists of calcareous clay-stone and sandstone as the oldest sediment visible on the surface. Gravity 2D modeling and SVD analysis results reveal that there are normal and thrust fault structures at several basements high and sub-basins that can be proposed to be further researched to know the possibility of a potential petroleum system in this area.

ACKNOWLEDGEMENTS

The authors would like to thank the Center for Geological Survey of the Geological Agency for permission to use the data. We would also like to thank the Head of the Marine Geological Institute, the reviewers, and all parties who helped in data processing and contributed in writing this paper.

REFERENCES

Djuri, M., Samodra, H., Amin, T.C., and Gafoer, S., 1996. *Geological Map Sheets of Purwokerto and Tegal, 2nd edition*. Geological Research and Development Center.

Hamilton, W., 1974. *Map of Sedimentary Basins of The Indonesian Region*. Miscellanous Investigations Series. U.S. Geological Survey.

Karunianto, A.J., Haryanto, D., Hikmatullah, F., & Laesanpura, A., 2017. Penentuan Anomali Gayaberat Regional dan Residual Menggunakan Filter Gaussian Daerah Mamuju, Sulawesi Barat. *Eksplorium,* 38(2): 89-98. http://dx.doi.org/10.17146/eksplorium.2017.38.2.3921.

Martodjojo, S., 1984. *The Evolution of the Bogor Basin, West Java.* Doctoral Dissertation. ITB. Bandung.

Obasi, A.I., Onwuemesi, A.G., and Romanus, O.M., 2016. An Enhanced Trend Surface Analysis Equation for Regional-Residual Separation of Gravity Data. *Journal of Applied Geophysics,* 135: 90-99. https://doi.org/10.1016/j.jappgeo.2016.09.023.

Pulunggono, A. & Martodjojo, S., 1994. Perubahan tektonik Paleogen – Neogen merupakan peristiwa terpenting di Jawa. *Proceedings Geologi dan Geotektonik Pulau Jawa Sejak Akhir Mesozoik hingga Kuarter, Yogyakarta*: 37-50.

Reynolds, J. M., 1997. *An Introduction to Applied and Environmental Geophysics*. Chichester John Wiley and Sons Ltd, 796p.

Sarkowi M., 2008. Karakteristik Gradien Vertikal Gayaberat Untuk Interpretasi Anomali Gayaberat Mikro Antar Waktu. *Proceeding Seminar Hasil Penelitian & Pengabdian kepada Masyarakat*. Unila.

Satyana, A.H., 2007. Central Java, Indonesia – A "Terra Incognita" in Petroleum Exploration : New Considerations on the Tectonic Evolution and Petroleum Implications. *Proceedings Indonesian Petroleum Association (IPA), 31st Annual Convention.* Jakarta, 14-16 May 2007.

Satyana, A.H., and Armandita, C., 2004. Deepwater Plays of Java, Indonesia: Regional Evaluation on Opportunities and Risks. *IPA - AAPG Deepwater and Frontier Symposium*.

Satyana, A.H., and Purwaningsih, M.E.M., 2002. Lekukan Struktur Jawa Tengah: Suatu Segmentasi Sesar Mendatar. *Indonesian Association Of Geologists (IAGI), Jogjakarta – Centra Java Section*, 1-14.

Setiadi, I., Setyanta, B., & Widijono, B.S., 2010. Delineasi Cekungan Sedimen Sumatera Selatan Berdasarkan Analisis Data Gayaberat. *Jurnal Sumber Daya Geologi,* 20(2): 93-106. http://dx.doi.org/10.33332/jgsm.geologi.v20i2.164.

Setiadi, I., & Arenda, R.R., 2016. Delineasi Cekungan Sedimen dan Interpretasi Geologi Bawah Permukaan Cekungan Tanimbar Berdasarkan Analisis Data Gayaberat. *Jurnal Geologi dan Sumber Daya Mineral,* 17(3): 153 – 169. http://dx.doi.org/10.33332/jgsm.geologi.v17i3.14.

Van Bemmelen, R.W., 1949. *The Geology of Indonesia*. The Hague, Martinus Nijhoff, 732p.

Zahra, H.S., and Oweis, H.T., 2016. Application of High-Pass Filtering Techniques on Gravity and Magnetic Data of the Eastern Qattara Depression Area, Western Desert, Egypt. *NRIAG Journal of Astronomy and Geophysics*, 5(1): 106-123. DOI:10.1016/j.nrjag.2016.01.005.