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SUBSURFACE GEOLOGICAL INTERPRETATION OF THE NORTH SUNDA ASRI BASIN BASED ON SVD ANALYSIS AND GRAVITY ANOMALY MODELING

INTERPRETASI GEOLOGI BAWAH PERMUKAAN CEKUNGAN SUNDA ASRI BAGIAN UTARA BERDASARKAN ANALISIS SVD DAN PEMODELAN ANOMALI GAYABERAT

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ABSTRACT: The Sunda Asri Basin is dominated by normal faults and has little compressional structure. This basin consists of several depocenters with a thickness of up to 6000 m. Among the geophysical methods, gravity analysis has proven to be effective in determining the bedrock configuration and identifying sedimentary basins. This study aims to analyze sedimentary sub-basin patterns, basement height structures, faults, and bedrock configuration using trend surface analysis of polynomial filters. The analysis of polynomial filter show that a 10th-order anomaly yields optimal results. The high correlation value of 0.990925 provides the suitability of a 10th-order anomaly for qualitative interpretation. Spectral analysis results indicate an average bedrock depth of about 2.75 km within the Sunda Asri Basin. Furthermore, this analysis reveals the presence of 14 sedimentary sub-basin patterns in this area. The gravity modeling results indicate that the top layer has a density value of 2.37 g/cc, which interpreted as Pleistocene Tertiary sediment. The second layer consists of Tertiary-Miocene sediment with a density value of 2.28 g/cc, while the third layer comprises of Pre-Tertiary sedimentary rock at a density of 2.02 g /cc. The bottom layer of the model corresponds to metamorphic bedrock with a density 2.7 g/cc. SVD (Second Vertical Derivative) analysis successfully identified the presence of normal and thrust fault structures

Keywords: Gravity, Polynomial Trend Surface Analysis, Second Vertical Derivative (SVD), Sunda Asri Basin

***ABSTRAK**: Cekungan Sunda Asri didominasi oleh sesar normal dan memiliki sedikit struktur kompresional. Cekungan ini terdiri dari beberapa deposenter dengan ketebalan hingga 6000 m. Di antara metode geofisika, analisis gayaberat terbukti efektif digunakan untuk menentukan konfigurasi batuan dasar dan mengidentifikasi cekungan sedimen. Penelitian ini bertujuan untuk menentukan pola sub-cekungan sedimen, struktur tinggian, patahan, dan konfigurasi batuan dasar menggunakan analisis filter permukaan dengan tren polinomial. Analisis filter polinomial menunjukkan bahwa anomali orde 10 menghasilkan keluaran yang optimal. Nilai korelasi tinggi sebesar 0,990925 memberikan bukti bahwa anomali orde 10 cocok untuk interpretasi kualitatif. Analisis spektral menunjukkan kedalaman batuan dasar rata-rata Cekungan Sunda Asri sekitar 2,75 Km. Hasil analisis juga mengungkapkan adanya 14 pola sub-cekungan sedimen di daerah ini. Pemodelan gayaberat menunjukkan bahwa lapisan teratas memiliki nilai densitas 2,37 g/cc, yang diinterpretasikan sebagai sedimen Pleistosen Tersier. Lapisan kedua terdiri dari sedimen Tersier-Miosen dengan nilai densitas 2,28 g/cc, sedangkan lapisan ketiga merupakan batuan sedimen Pra-Tersier dengan densitas 2,02 g/cc. Lapisan terbawah pada model tersusun dari batuan dasar metamorf dengan densitas 2,7 g/cc. Analisis SVD (Second Vertical Derivative) berhasil mengidentifikasi adanya struktur patahan naik dan patahan turun.*

***Kata Kunci:** Gaya Berat, Polynomial Trend Surface Analysis, Second Vertical Derivative (SVD), Cekungan Sunda Asri.*

INTRODUCTION

The Sunda Basin, located about 30 miles southwest of the Asri Basin, or 30 miles northwest of Jakarta, is an offshore area in the Java Sea. The Sunda Basin extends northeastward, transforming into the Asri Basin, and is structurally separated by the Seribu Heights. In terms of regional context, the Asri Basin is positioned at the southeastern tip of the Eurasian Plate and specifically belongs to the Sunda Microplate (Todd and Pulunggono, 1971).

The Sunda Basin is an extension of the Northern Java Basin, known as the Asri Sub-basin. The Sunda Basin originates from the back-arc depocenter which is called the back-arc depocenter of Java Island. The faults trending northwest-southeast and north-south are active and act as basin boundaries (Daly, 1991).

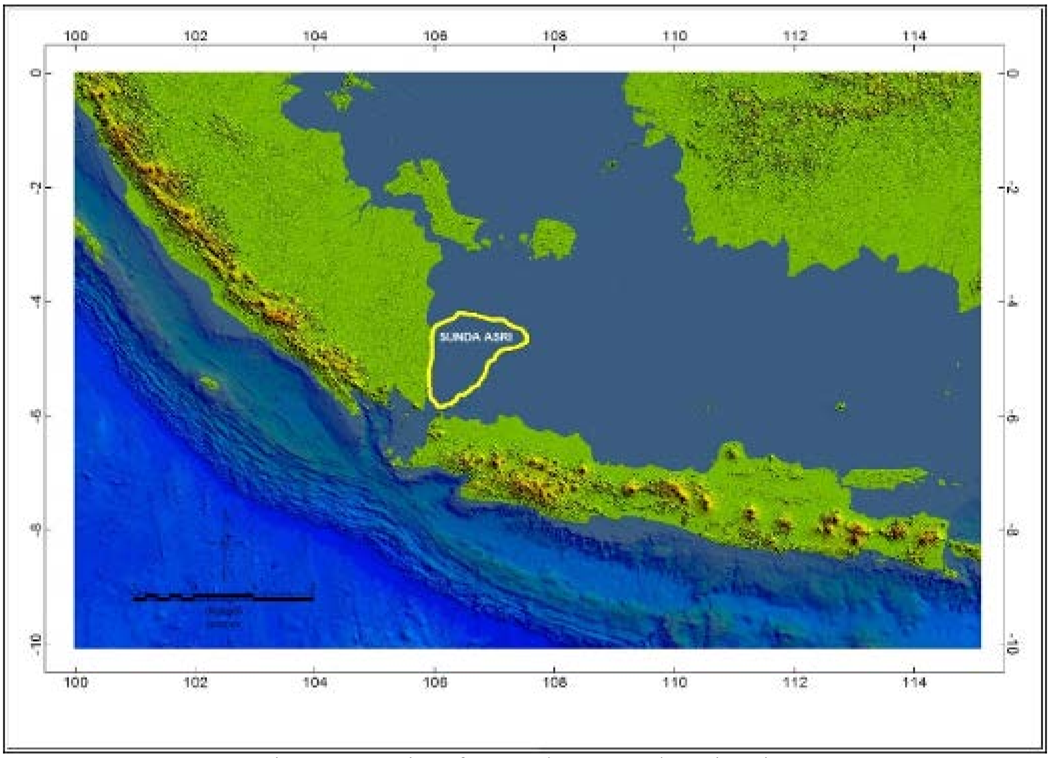


Figure 1. Location of Research Area Sunda Asri Basin

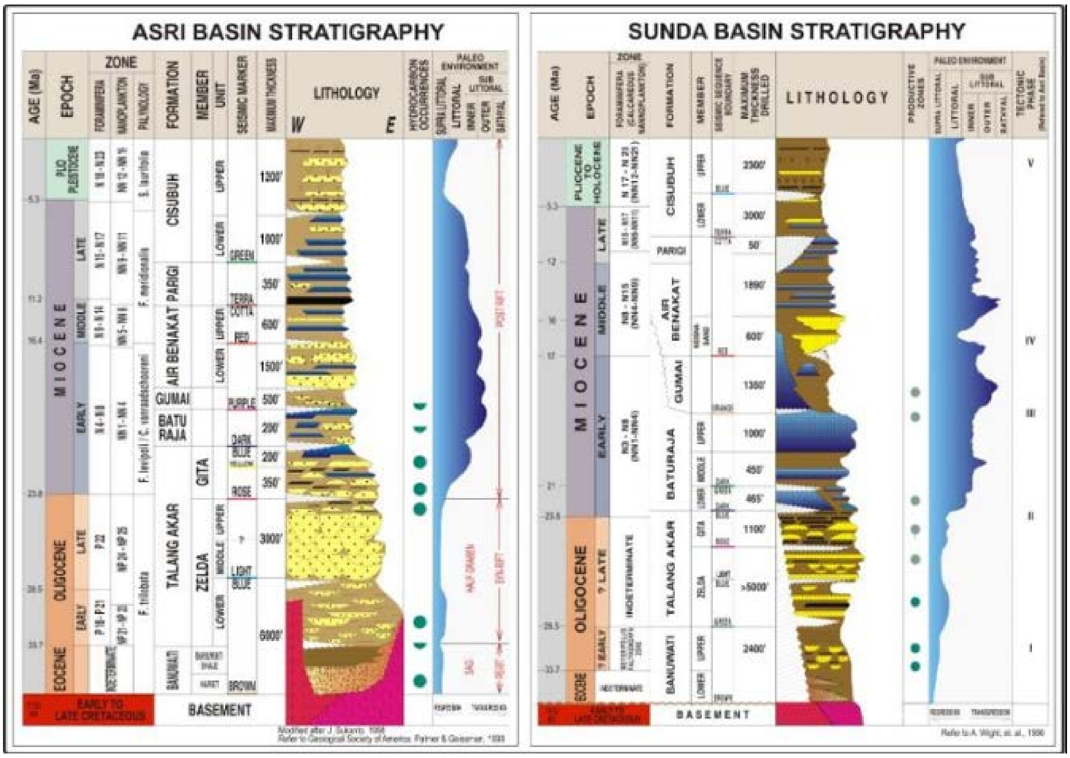


Figure 2. Figure 2. Stratigraphy of the Asri Sunda Basin (Wight et al., 1986)

According to Koesoemadinata (2004), the oldest rocks in the Sunda Asri Basin are bedrock consisting of metamorphic and igneous rocks. Meanwhile, according to Sukanto (1998), the stratigraphy of the Sunda Asri Basin shows a mega cycle of base level rise (Banuwati - Gumai Formation) and base level fall (Air Benakat Formation - Cisubuh).

The gravity method is a geophysical method that utilizes the Earth's gravitational field due to variations in rock mass density. The basic principle of this method is to measure the variation in the value of the gravitational acceleration caused by differences in the density of rock masses beneath the Earth's surface (Yan et al., 2020).

METHODS

The data used in this study comprises corrected Bouguer anomaly data for the Sunda Asri Basin area, collected by the Geological Agency in 2009. Data processing involved spectral analysis of corrected Bouguer anomaly data to obtain bedrock depth and window width used as a reference in modeling. Filtering uses Polynomial Trend Surface Analysis by filtering polynomials from orders 1 to 12. The selection of the optimal polynomial order was based on correlating regional anomalies derived from the polynomial results with regional anomaly references obtained from low pass filtering through spectral analysis. The correlation results show that the 10th order polynomial has the highest correlation value, so the 10th-order regional anomaly is used as the optimal filter result, which is then used to conduct a qualitative interpretation.

The gravity method is a geophysical method that utilizes the Earth's gravitational field due to variations in rock mass density. The basic principle of this method is to measure the variation in the value of the gravitational acceleration caused by differences in the density of rock masses beneath the Earth's surface (Yan et al., 2020). The 10th-order residual anomaly results are used to delineate the sedimentary sub-basin and the basement height of the study area. The residual anomaly results are also used to create cross sections for 2D modeling, which help in determining the fault structure of the study area using SVD (Second Vertical Derivative) analysis.

Spectral Analysis

The spectral analysis results obtain a graph of the wave number (k) as the x-axis with the amplitude (*ln A*) as the y-axis. In the gravity method, the spectrum is derived from the observed gravity potential in a horizontal plane (Blakely, 1996) as described by:

$$A = Ce^{|k|(z_0 - z_1)} \quad (1)$$

$$lnA = ln2\pi Gme^{|k|(z_0 - z_1)} \quad (2)$$

$$lnA = (z_0 - z_1)|k| + ln\,C \quad (3)$$

The equation is analogous to the equation of a straight line:

$$y = mx + c \quad (4)$$

Where *ln A* is the y-axis, |k| is the x-axis, and the slope of the line represents gradient. The window width is formulated as follows:

$$N = \frac{2\pi}{k_c \Delta x} \quad (5)$$

Polynomial Trend Surface Analysis

The process of separating regional and residual anomalies in research using a polynomial trend analysis filter involves utilizing the optimal order correlation results to obtain regional anomalies. The Trend Surface Analysis (TSA) equation is as follows:

$$Z_{obs_i} = f(x_i, y_i) + u_i \quad (6)$$

The polynomial method can be approximated by Bouguer anomaly with the following equation:

$$G_{ij} = (ax_i + by_j + c) + e_{ij} \quad (7)$$

$$e_{ij} = G_{ij} - (ax_i + by_j + c) \quad (8)$$

Where *Gij* is the Bouguer anomaly, *xi* is the measurement coordinate in the x-direction, *yj* is the measurement coordinate in the y-direction, *eij* is the residual anomaly, and *a*, *b*, *c* are polynomial constants.

2D and 3D modeling are conducted to examine the horizontal and vertical continuity of the structure in the study area. The results of 3D inversion modeling provide an overview of subsurface conditions based on density distribution and enhance subsurface model information obtained from 2D modeling. Inversion modeling is performed using the Grablox software (Pirttijarvi, 2008).

Second Vertical Derivative (SVD) analysis was carried out to determine the boundaries of the basin or to determine the types of faults present in the study area. In the SVD graph, the line drawn at point 0 indicates the presence of a fault structure. The direction of the slope of the SVD curve can indicate the type of fault, with maximum and minimum SVD values given by the following equation:

$$\text{For Thrust Fault } \left(\frac{\partial^2 \Delta g}{\partial x^2}\right)_{max} < \left|\left(\frac{\partial^2 \Delta g}{\partial x^2}\right)\right|_{min} \quad (9)$$

$$\text{For Normal Fault } \left(\frac{\partial^2 \Delta g}{\partial x^2}\right)_{max} > \left|\left(\frac{\partial^2 \Delta g}{\partial x^2}\right)\right|_{min} \quad (10)$$

RESULTS

The Bouguer anomaly in the Sunda Asri Basin is shown in Figure 3. The figure illustrates low anomalies indicated by blue shades, while high anomalies are represented by red to purple colors. Based on the Bouguer

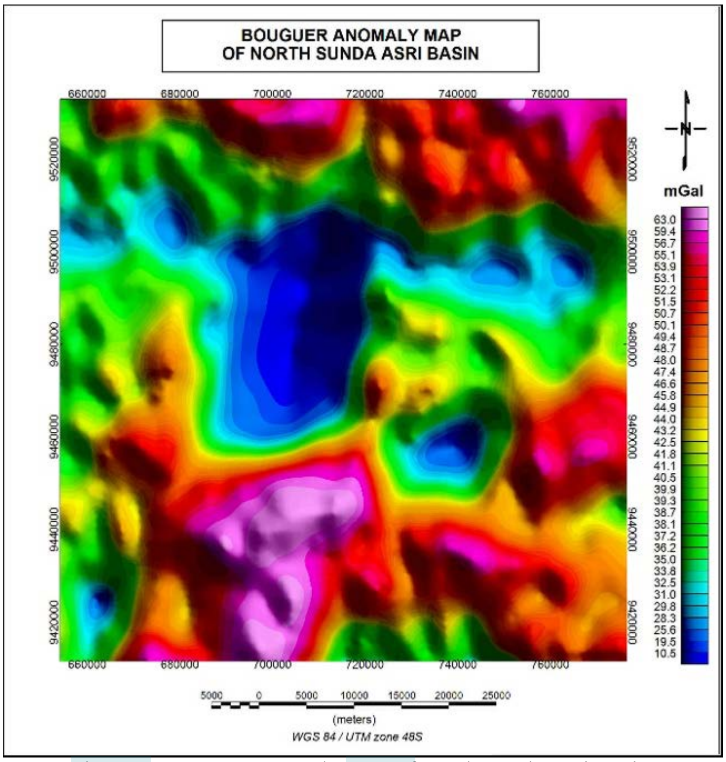


Figure 3. Bouguer Anomaly Map of North Sunda Asri Basin

anomaly map, the anomalous values range from 10.5 to 63.0 mGal. The low anomaly shown in blue ranges between 10.5 to 31.0 mGal, suggesting the presence of relatively thick sedimentary rock that occupies this area. The moderate anomaly, with values ranging from 32.5 to 48.7 mGal, is interpreted as the edge of the basin which delineating the sub-basins. The high anomaly, ranging from 49.4 to 63.0 mGal indicates the presence of uplifted high-density rocks. The Bouguer Anomaly map does not a detailed description of the local structure in the study area, as it combines both regional anomalies and residual anomalies. Therefore, it is necessary to separate these anomalies.

Spectral analysis was carried out to estimate the basement depth and window width of the study area. In this study, 8 cross-sectional tracks were created with a spacing (x) of 2 km, as shown in Figure 4. The slope or gradient of the line on the graph of *ln A* vs *k* represents the depth of the discontinuity plane. The width of the window used in the spectral analysis results is then applied in the filtering process, including lowpass and highpass filters. The separated anomalies obtained using the lowpass and highpass filters are used as a reference for the correlation process to determine anomalous pattern generated by the trend surface polynomial filter.

Anomaly separation using the trend surface polynomial filter is carried out by selecting the optimal order of the correlation results between regional anomalies from spectral analysis and polynomial trend surface analysis in the study area, as seen in Table 2. Complete data processing was carried out using Surfer software, DOS-BOX, and Matlab.

Regional and residuals anomalies of the 10th order polynomial results are shown in Figure 5. The regional anomalies of the 10th order range from 14.8 to 60.9 mGal. The low anomaly is represented by dark to light blue shades, ranging from 14.8 to 32.3 mGal. The medium anomaly, indicated by green to orange colors, has values ranging from 33.6 to 49.1 mGal. The high anomaly, shown by red to purple colors, ranges from 49.7 to 60.9 mGal.

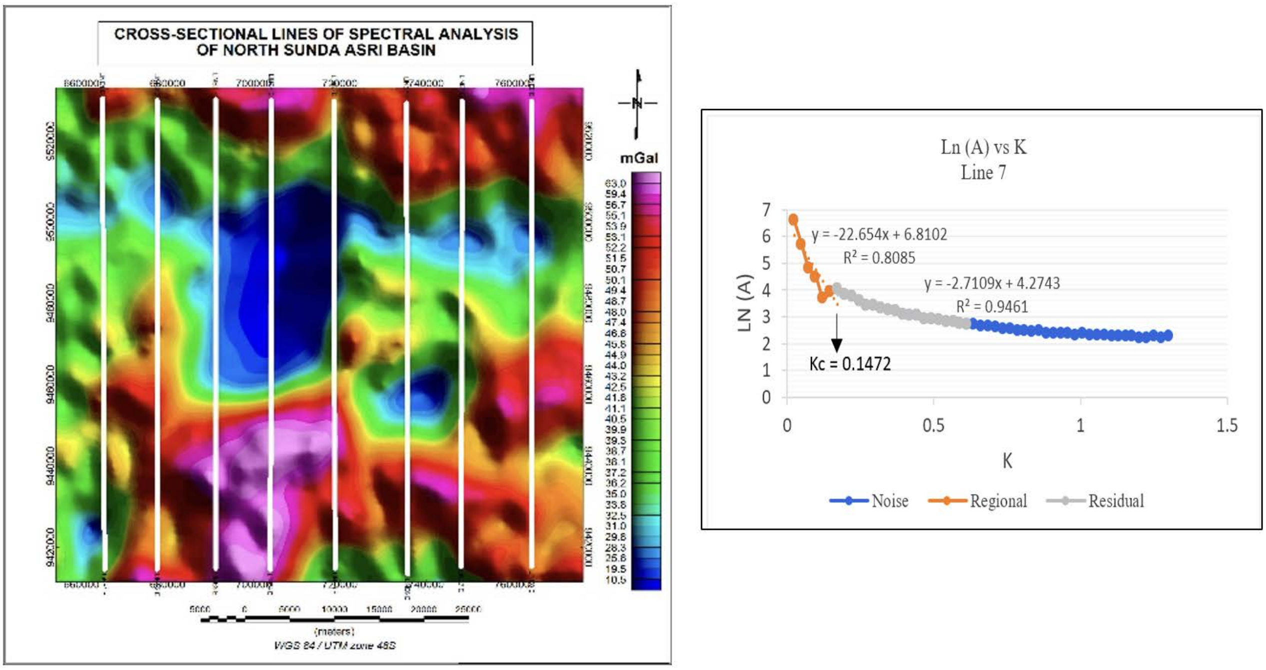


Figure 4. Cross-sectional lines of spectral analysis and the graph of ln A vs k of Line 7

Table 1. The depth of the regional and residual discontinuity planes

No	*Line*	*Regional (km)*	*Residual (km)*	*Kc*	*N*
1	Line 1	-21.467	-2.8254	0.1472	21.33
2	Line 2	-26.351	-2.8704	0.1227	25.59
3	Line 3	-13.66	-2.8876	0.1718	18.27
4	Line 4	-18.47	-2.9763	0.1472	21.33
5	Line 5	-22.259	-2.8523	0.1472	21.33
6	Line 6	-20.235	-2.6002	0.1472	21.33
7	Line 7	-22.654	-2.7109	0.1472	21.33
8	Line 8	-26.466	-2.239	0.1718	18.27
Average		**-21,45**	**-2,75**	**0,15**	**21,1**

Table 2. Regional anomaly correlation results from the spectral and polynomial analysis

No	*Order Polynomial*	*Correlation Results*
1	Polynomial Order 2	0,977892
2	Polynomial Order 3	0,986113
3	Polynomial Order 4	0,989687
4	Polynomial Order 5	0,991596
5	Polynomial Order 6	0,993682
6	Polynomial Order 7	0,996608
7	Polynomial Order 8	0,997768
8	Polynomial Order 9	0,998844
9	**Polynomial Order 10**	**0,998925**
10	Polynomial Order 11	0,998392
11	Polynomial Order 12	0,998190

The 10th order residual anomaly map shows values ranging from -8.4 to 8.0 mGal. The low anomaly ranges between -8.4 to -3.8 mGal, while the medium spans from -3.4 to 1.8 mGal. The high anomaly is observed from 2.1 to 8.0 mGal.

The regional anomaly pattern obtained using this polynomial still have a trend similar to the complete Bouguer anomaly. It reveals anomalyous sources effect at relatively shallow depths, as indicated by the presence of with both positive and negative anomalies. The North Sunda Asri Basin shows a north-south trend, likely formed by the subduction of the Indo-Australian plate to the east. This subduction process created a half-graben structure along the southern edge of the Sunda Plate during the Eocene-Oligocene period.

The lineament pattern and delineation of the Sunda Asri basin were determined based on the best filtering process of the residual anomaly, specifically utilizing the results of a 10th order polynomial filter, as shown in Figure 6. The lineament patterns of basement high have a relative north-south direction, possibly caused by the movement of the Indian Ocean crust from west to east, resulting in a high structure with a relative north-south direction. Setiadi et al. (2018) suggests that the high anomaly pattern likely caused by uplift due to tectonic events and compressional processes between plates. The analysis of residual anomalies indicates that these height patterns separate the sub-basins within the Sunda Asri basin, particularly at the blue low anomaly. The sub-basin in the Sunda Asri basin area probably formed due to openings in a relatively north-south direction, resulting in the formation of sub-basins with a similar orientation. A total of 14 sub-basins can be delineated based on the residual anomalies of the Sunda Asri basin.

Quantitative interpretation involves conducting 2D and 3D modeling to determine the shape and dimensions of the subsurface geological model. The 2D modeling is carried out along two paths, namely the AA' and BB' paths. The AA' path has a relatively northwest-southeast direction, while the cross section of the BB' path has a west-east relative direction, as shown in Figure 7.

The 2D modeling was performed using GM-SYS Oasis Montaj software, considering the stratigraphic references of the study area and depth information obtained from the spectral analysis results. Modeling process involved simplifying several formations into one-layer models based on the stratigraphic information. The first layer, consisting of the Air Benakat, Parigi, and Cisubuh formations, reveals lithologies such as claystone, sandstone, shale, and limestone, with an average density value of 2.37 g/cc. The second layer comprises the Baturaja Formation and Gumai, characterized by lithologies including limestone, claystone, shale, silt, and sandstone, with an average density value of 2.28 g/cc. The third layer consist of the Banuwati and Talang Akar formations, showing lithologies such as claystone, sandstone, and a small amount of coal content, with an average density value of 2.02 g/cc. Finally, the fourth layer represents the basement, composed of metamorphic igneous rock with an average density value of 2.71 g/cc.

The results of the SVD modeling and analysis in Figure 7 reveal the presence of normal and thrust fault

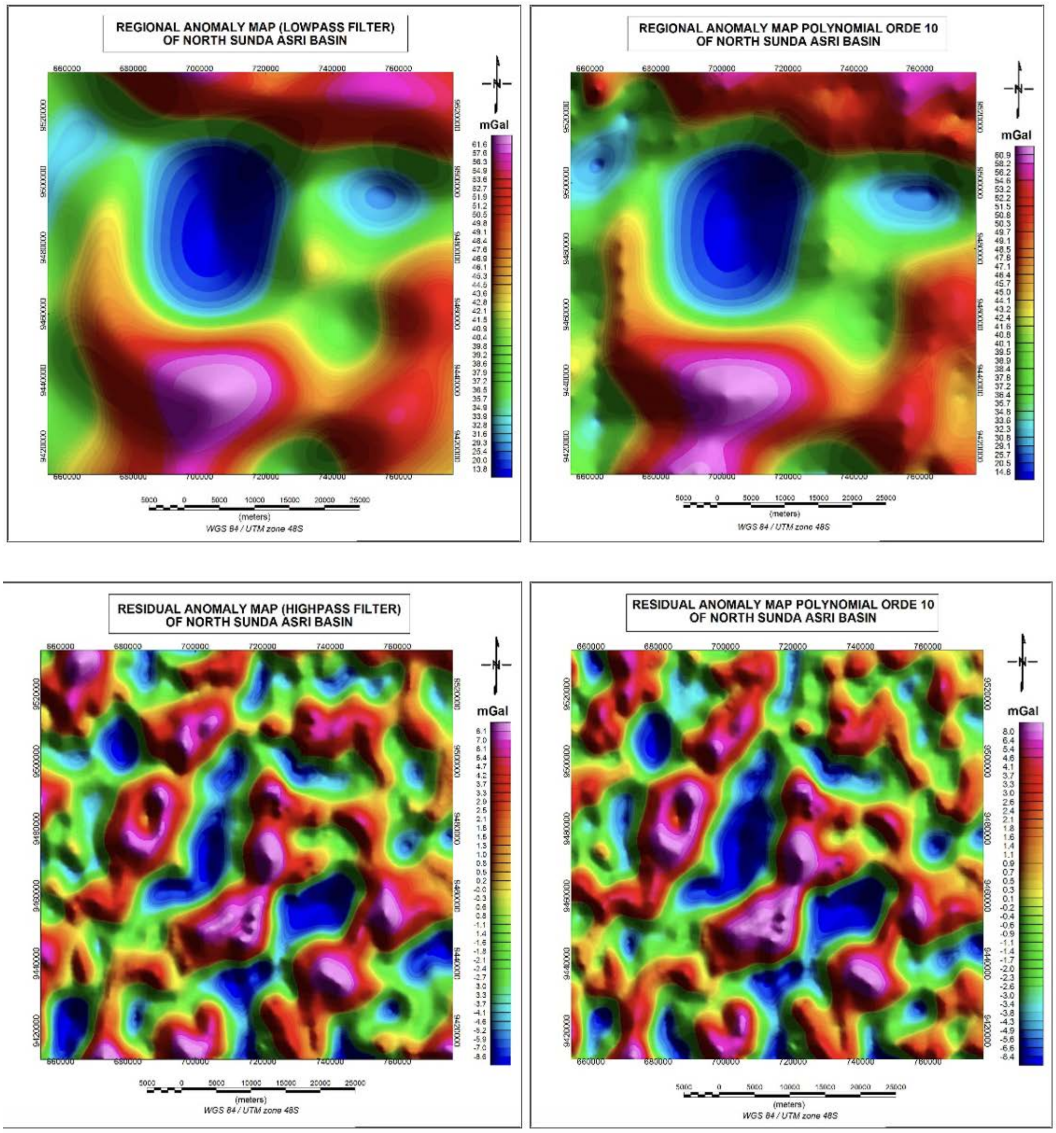


Figure 5. Regional and residual anomalies derived from polynomials of the 10th order

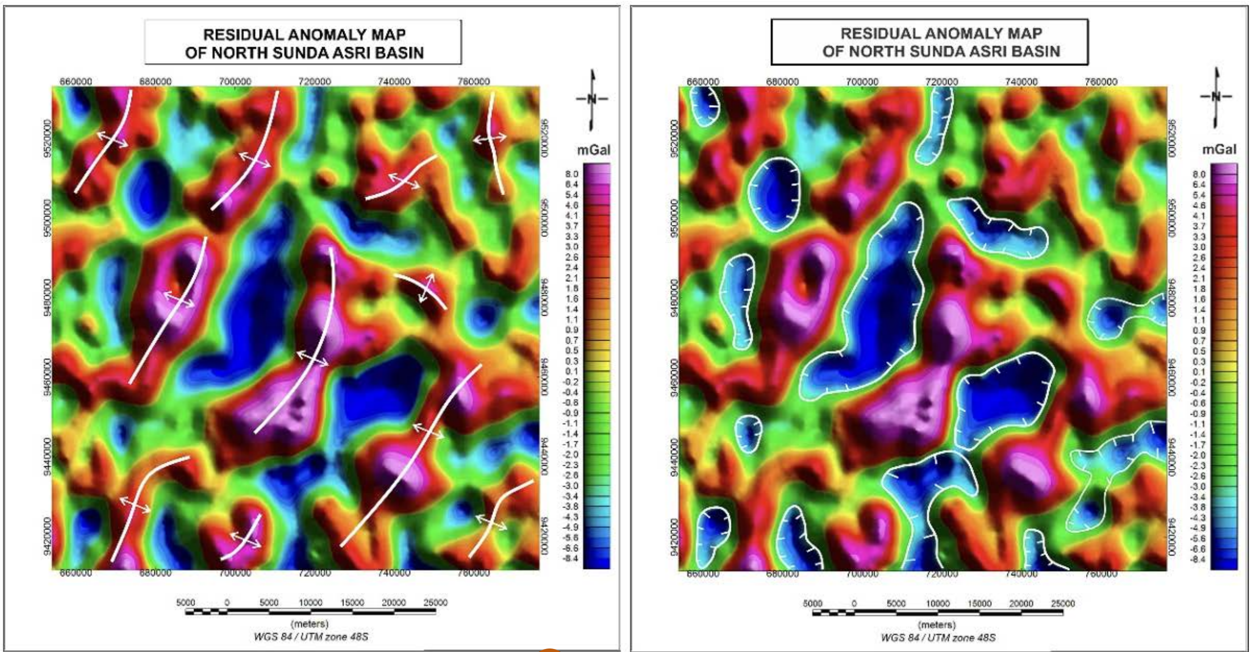


Figure 6. Lineament pattern and delineation of the Sunda Asri sub-basin

structures. The determination of the fault types in the SVD

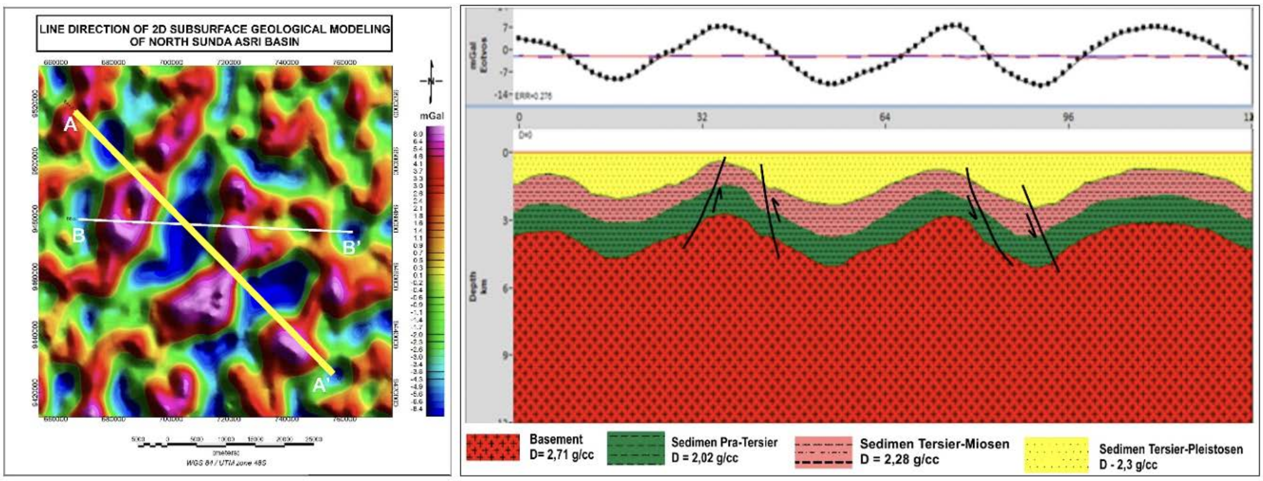


Figure 7. Line section and 2D Modeling of Line AA'

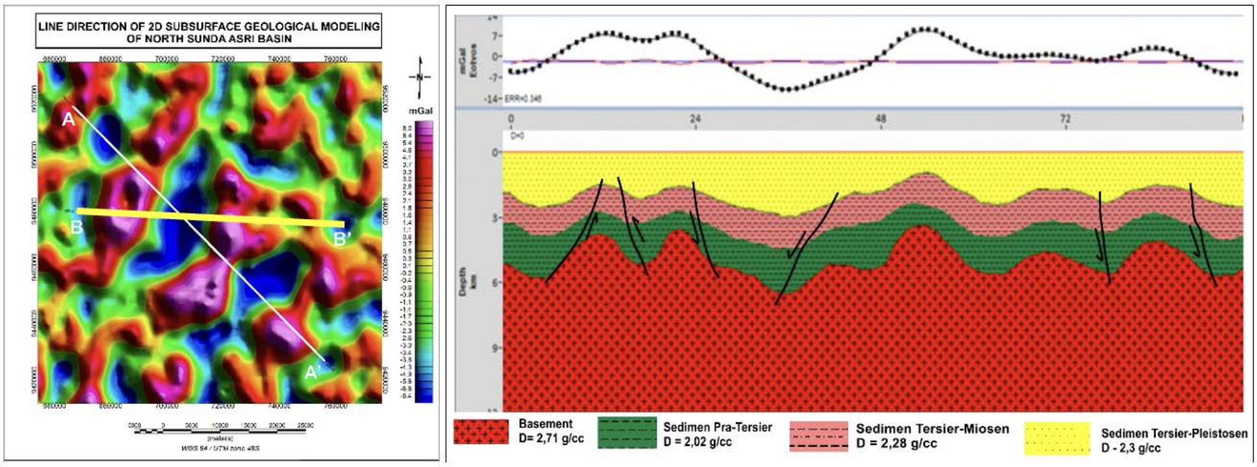
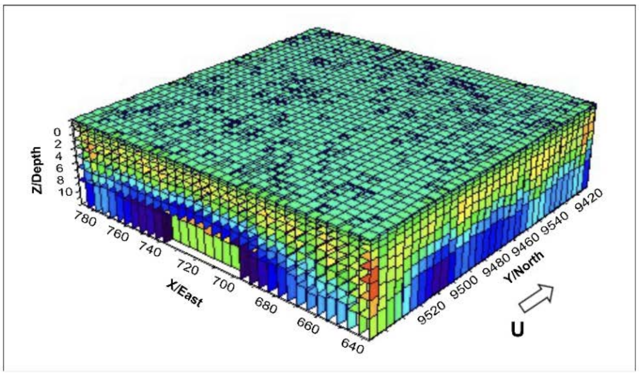
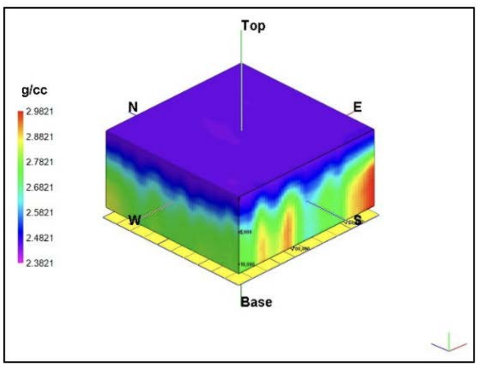
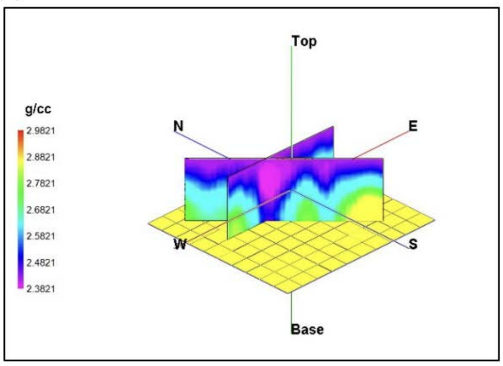


Figure 8. Line section and 2D Modeling of Line BB'



(a)





(b) (c)

Figure 9. *Rockwork* 3D Modeling

analysis is based on the second derivative having a value of zero. Along the AA' path, two types of normal faults were identified, where the maximum SVD anomaly value is greater than the minimum anomaly. It can also be identified that there are two thrust faults where the minimum SVD anomaly value is greater than the maximum anomaly.

Along the BB' path, four types of normal faults were detected, with the maximum SVD anomaly value exceeds the minimum anomaly. Furthermore, two thrust faults where the minimum SVD anomaly value exceeding the maximum anomaly.

Figure 9a display the result of 3D inversion modeling using Grablox software, while Figures 9b and 9c show the results of 3D inversion using Rockwork software. The 3D inversion modeling results indicate that sediments shown in blue are at a depth of 0 – 5000 m with a density value of 2.3 g/cc – 2.5 g/cc. Meanwhile, the basement is shown in green to red at a depth of 5000 to 12000 m with a density value of 2.6 g/cc – 2.9 g/cc. Gravity modeling aimed to identify structures in the study area and determine the depocenter depth of sub-basins in the Sunda Asri Basin. Where there are several interesting basin with a thickness of up to 6000 m.

The existence of basement height structures and several sedimentary sub-basin shows quite interesting data for the development of the existing petroleum system in the Sunda Asri Basin. Petroleum system information indicates that the study area is a hydrocarbon producing sedimentary basin, which is in the Talang Akar Formation with the main reservoir consisting of sandstones. The gravity study results in the Sunda Asri Basin provide additional geoscientific information, particularly regarding structural patterns, sedimentary sub-basins and subsurface geological models, which are expected to become additional data for the next stage of oil and gas exploration in the Sunda Asri basin.

CONCLUSIONS

The results of the spectral analysis show that the average depth of the bedrock of the Sunda Asri basin is 2.75 km. Based on the optimal polynomial filter, the delineation of sub-basins reveals the presence of 14 sedimentary sub-basins in the Sunda Asri basin. The structural pattern, as determined using qualitative analysis, demonstrates a relatively southwest-northeast and north-south direction. The first layer was modeled with an average density of 2.37 g/cc, comprising claystone, sandstone, shale, and limestone. The second layer, with an average density of 2.28 g/cc, consists of limestone, claystone, shale, silt, and sandstone. The third layer, with a density value of 2.02 g/cc, includes claystone, sandstone, and a small amount of coal. Lastly, the basement, located at the bottom, is composed of metamorphic rock with an average density value of 2.71 g/cc. The analysis of the selected paths using the Second Vertical Derivative (SVD) technique reveals the presence of normal fault structures and several thrust faults. The existence of basement high structures and several sedimentary sub-basin indicates an attractive structure for the development of the existing petroleum system in the Sunda Asri basin.

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