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2D INVERSION MODELING OF OIL AND GAS BASINS USING GRAVITY DATA IN TAMBELANG DISTRICT

PEMODELAN INVERSI 2D CEKUNGAN MINYAK DAN GAS MENGGUNAKAN DATA GRAVITASI DI KECAMATAN TAMBELANG

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Abstract. Pertamina Hulu Energi discovered a new source of oil and gas reserves in Tambelang, Bekasi Regency, which was named East Pondok Aren (EPN-001). These oil and gas reserves have great potential based on the oil flow test in the second Drill Stem Test. The drill data needs to be correlated with other supporting data such as geophysical methods to ensure the accuracy. Therefore, this research was conducted to examine the subsurface structure of oil and gas reserves in EPN-001 through 2D inversion modeling using the gravity method. Gravity satellite data was taken via the GGMPlus website with a total of 23,898 data in the form of gravity disturbance, geoid, and topography, so only terrain and bouguer corrections were carried out to get the Complete Bouguer Anomaly value. The research results show low anomaly values from -0.4463 – (-0.0339) mGal which are thought to be associated with alluvium lithology and the Lower Cibulakan Formation. In the 2D model, it can be seen that the drilling point in the Lower Cibulakan Formation layer has a density contrast value of -0.002 – 0.001 g/cc at a depth of 2590 m, and is known to be a reservoir that stores hydrocarbon reserves in the research area.

Abstrak. *Pertamina Hulu Energi menemukan sumber cadangan minyak dan gas baru di Tambelang, Kabupaten Bekasi, yang diberi nama East Pondok Aren (EPN-001). Cadangan minyak dan gas bumi tersebut sangat berpotensi berdasarkan uji aliran minyak bumi pada Drill Stem Test kedua. Data bor tesebut perlu dikorelasikan dengan data pendukung lainnya seperti metode geofisika untuk dapat memastikan keakuratannya. Oleh karena itu, penelitian ini dilakukan untuk melihat struktur bawah permukaan cadangan minyak dan gas di EPN-001 melalui pemodelan inversi 2D menggunakan metode gravitasi. Data* *satelit gravitasi diambil melalui website GGMPlus dengan jumlah sebanyak 23.898 data berupa gravity disturbance, geoid dan topografi, sehingga hanya dilakukan koreksi terrain dan bouguer untuk mendapat nilai Anomali Bouguer Lengkap. Hasil penelitian menunjukkan nilai anomali rendah berkisar -0.4463 – (-0.0339) mGal diduga berasosiasi dengan litologi alluvium dan formasi Cibulakan Bawah. Pada model 2D, terlihat bahwa drilling point yang terdapat di lapisan Formasi Cibulakan Bawah memiliki nilai kontras densitas -0.002 – 0.001 g/cc pada kedalaman 2590 m, dan diketahui sebagai reservoar yang menyimpan cadangan hidrokarbon di daerah penelitian.*

1. INTRODUCTION

Petroleum reserves in 2019 decreased by 49.75%, while natural gas reserves decreased by 42.98% compared to 2018 (Directorate General of Oil and Gas, 2021). Based on data from the Ministry of Energy and Mineral Resources (ESDM), oil reserves in Indonesia are only available for 9.5 years and natural gas for 19.9 years, assuming no new reserves are discovered (Rahmayanti et al., 2021). As a result, continuous oil production and oil reserves will increasingly run out, causing the oil exploration process to stop, resulting in old wells (Rosid et al., 2020). Meanwhile, it is important to continue oil and gas exploration in an effort to increase and maintain hydrocarbon production rates in Indonesia (Prasetiyohadi et al., 2022).

Therefore, steps are needed to increase the amount of energy reserves. One way is to optimize existing reserve potential through exploration and drilling activities in oil and gas fields, both those that have been operated previously and the discovery of new sources that have not been exploited (Dewi et al., 2020); (Purnama et al., 2020). However, in reality, the average oil and gas production achievement in the last two years has decreased due to a decline in natural reservoir performance and also the absence of new reserves that would replace reserves that continue to be produced (Directorate General of Oil and Gas, 2019).

PT Pertamina Hulu Energi (PHE) discovered a new source of oil and gas reserves in the Tambun Field WKP, Tambelang District, Bekasi Regency, West Java. The new reserve discovered is called East Pondok Aren (EPN-001) which is proof of a new concept in the form of a stratigraphic trap in the Lower Cibulakan Formation, Ciputat Sub Basin, and is included in the onshore North West Java Basin (CNN Indonesia Team, 2023).

Drilling of the East Pondok Aren (EPN)-001 exploration well was started on August 18, 2023. As a result, EPN-001 succeeded in showing that the flow of oil in the second Drill Stem Test (DST) was 402 Barrels of Oil Per Day (BOPD) and gas reached 1,00 million standard cubic feet per day or Million Standard Cubic Feet per Day (MMSCFD) at a depth of 2,590 meters measured depth (mMD) (Ira, 2023).

To utilize the energy potential of oil and gas, accurate data analysis is needed by optimizing the exploration stages in more depth. Apart from the drilled well data that has been obtained, other supporting data is also needed to see the condition of subsurface structures such as geological data and data from gravity method measurements. Gravity method is one of the geophysical methods used to find out conditions below the earth's surface by measuring force field variations weight of the earth.

The method used in hydrocarbon estimation was also revealed by Sota (2011) in this research on estimating fault structures using the gravity method. According to this research, the presence of faults can be associated with hydrocarbon traps. One of the methods used is the gravity method, which was chosen for reasons of response sensitivity, cheap economically and technically in the field. The gravity method is very appropriate to use for estimating fault locations because this method is able to detect differences in density contrast of rock bodies. Significant differences in rock density contrast indicate that the zone is a fault zone (Sarkowi et al., 2023).

The gravity method is known to be able to describe subsurface geological structures very well and has been widely used to identify faults, and hydrocarbon prospect structures in oil and gas basins. Therefore, this method is very suitable for oil and gas exploration in the East Pondok Aren (EPN-001) field, Bekasi Regency, which is located in the North West Java Basin.

2. LITERATURE REVIEW

2.1. Petroleum System

In oil and gas exploration activities in a basin, several elements are usually needed in a system which is thought to contain hydrocarbons, this system is usually called the Petroleum System. Where the petroleum system includes several important elements, namely, source rock, reservoir rock, cap rock, trap and migration (Setyowiyoto et al., 2007; Permana, 2020).

2.1.1. Source Rock

There are three main source rocks in the North West Java Basin, namely lacustrine clay (oil-prone) which is reflected by the Banuwati Formation or Jatibarang Formation; deltaic fluvial coal and clay (oil and gas) reflected by the Upper Talang Akar Formation; and marine clay (bacterial gas) which is reflected by the Parigi Formation and Cisubuh Formation.

2.1.2. Reservoir Rock

The reservoir rocks in the Cibulakan Formation are primarily composed of sandstones, which have good porosity and permeability. These sandstones were deposited in a variety of environments, including fluvial, deltaic, and shallow marine settings. The Upper Cibulakan Formation often contains the best reservoir quality sands.

2.1.3. Cap Rock

The covering layer is an impermeable layer that can inhibit or cover the passage of hydrocarbons. The formation that acts as the main covering layer is the Cisubuh Formation, because this formation has impermeable lithology making it suitable as a barrier for hydrocarbons to migrate further.

2.1.4. Trap

The trap types in all petroleum systems in the North West Java Basin are very similar. This is caused by the tectonic evolution of all sedimentary basins along the southern boundary of the Sunda Craton, so that the types of geological structures and trapping mechanisms are almost the same. The main geological structures are wide anticlinal domes and traps of tilted fault blocks. In some areas with reservoir reef build-up, stratigraphic traps also play a role.

2.1.5. Migration

In the North West Java Basin, the main channels for lateral migration are mostly sandstone gaps that have a north-south orientation of the Talang Akar Formation, similar to the orientation of sandstone systems in the Main or Massive members (Upper Cibulakan Formation). In this case, the fault becomes the main channel for vertical migration with fast transport.

2.2. Regional Geology

The North-West Java Basin is one of 128 sedimentary basins and is known as a hydrocarbon basin. This basin is estimated to have reserves of 2.3 BBOE oil and 1.17 BBOE gas. The North West Java Basin is influenced by a north-south trending block faulting system which is divided into grabens or several sub-basins from west to east, namely the Ciputat sub-basin, the Pasir Putih sub-basin and the Jatibarang sub-basin (Setiadi & Pratama, 2018). The North West Java Basin has an age range from the Middle Eocene to the Quaternary. The regional startigraphic sequence from oldest to youngest is Bedrock, Jatibarang Formation, Lower Cibulakan Formation (Talang Akar, Baturaja), Upper Cibulakan Formation (Massive, Main, Pre -Parigi), Parigi Formation and Cisubuh Formation (Narpodo, 1996).

Sources of new oil and gas reserves in Tambelang District are included in the Cibulakan Formation. The Cibulakan

Formation consists of interbedded shale with sandstone and limestone. This formation is divided into two members, namely Upper Cibulakan members and Lower Cibulakan members. The division of these members is based on differences in depositional environments, where the Lower Cibulakan member is a transitional (parallic) deposit, while the Upper Cibulakan member is a neritic deposit (Narpodo, 1996). Overall, the Cibulakan Formation is Early Miocene to Middle Miocene in age (Rohmana et al., 2019).

If seen from the regional geological map (**Figure 1**), the research area is included in floodplain deposits. Generally, these floodplain deposits are dominated by alluvial deposits such as silt and mud, although fine sandstone occasionally appears which was deposited by stronger currents at the peak of the flood. The rate of deposition is generally very low, ranging between 1 and 2 cm of silt-clay layer per flood period (Center for Water Resources Education and Training, 2017).

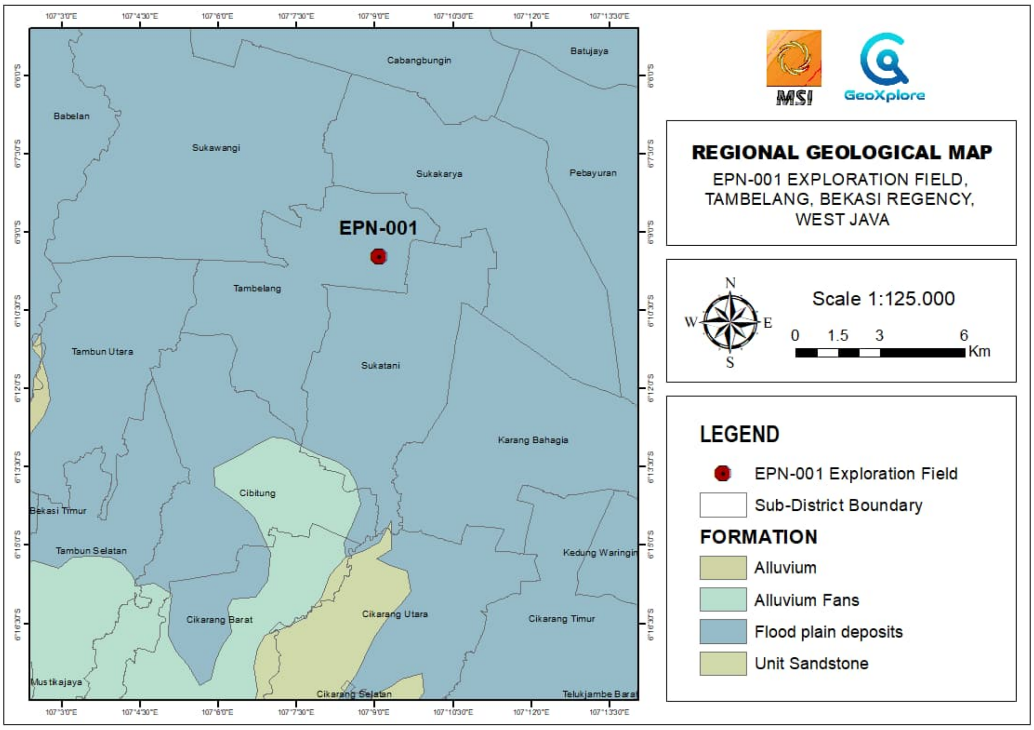

Figure 1. Geology of the Research Area (Ratman & Gafoer, 1998).

2.3. Gravity Method

The gravity method is a geophysical method that can describe subsurface geology based on variations in the earth's gravitational field caused by density differences between rocks (Pellokila et al., 2018; Firdaus & Setianto, 2018; Permana et al., 2023). This method has the advantage that it can provide quite detailed information about the geological structure and density contrast of rocks (Kurniawan et al., 2022). Knowledge of subsurface structures is important for planning exploration steps for oil and gas, geothermal and other minerals (Agussalim, 2019).

The basic principle of this gravitational method is to use Newton's law of gravity which states that the force of attraction between two points having masses m_1 and m_2 which are separated by a distance r, then the equation can be written:

$$\vec{F}(r) = G\frac{m_1 m_2}{R^2}\hat{r} \qquad (1)$$

F is the force exerted between two particles with masses m_1 and m_2, r is the distance between two particles, $\hat{r}$ is the unit vector of m_1 and m_2, and G is the universal gravitational constant (6.6732×10^{-11} Nm^2/kg^2) (Rizkiani & Rustadi, 2019).

2.4. Inversion Modeling

Inversion modeling is a field data processing process that involves mathematical and statistical solving techniques to obtain useful information regarding the distribution of subsurface physical properties (Sudrajad et al., 2024). In the inversion process, field data is analyzed by performing curve fitting between the mathematical model and field data (Sihombing et al., 2018). In determining this inversion process, an initial model is needed in the form of average rock density (Maimuna et al., 2022).

The aim of the inversion process is to estimate previously unknown rock physical parameters. The inversion problem is formulated as an optimization problem where the object function of the model density is minimized, according to boundary conditions within an error tolerance (Hiden et al., 2019). Inversion modeling is carried out by optimizing the singular value decomposition approach to gravity anomalies. This technique is based on the linear inversion technique. The result of this inversion modeling is the distribution of rock density in two dimensions and is a picture of the subsurface of the research area (Setiadi & Pratama, 2018).

3. METHODS

The research location is in the EPN-001 oil and gas drilling field in Tambelang District, Bekasi Regency, West Java with an area of around 1174.27 km^2 (**Figure 2**). The data used is gravity satellite data taken via the GGMPlus website with a total of 23,898 data consisting of gravity disturbance (gd), geoid, and topography.

GGMplus (Global Gravity Model plus) is a combination of GRACE and GOCE satellite gravity data, EGM2008 short-wavelength topographic gravity effects at a resolution of about 200 m for all terrestrial and nearshore regions of the Earth between ±60° latitude (Hirt et al., 2013). Gravitational disturbance data in GGMPlus is defined as the difference between Earth's gravity and normal gravity at the same point (Perozzi et al., 2021). And for the geoid it is the equipotential surface of the earth's real gravitational field that passes under the topographic mass and coincides with the mean sea level.

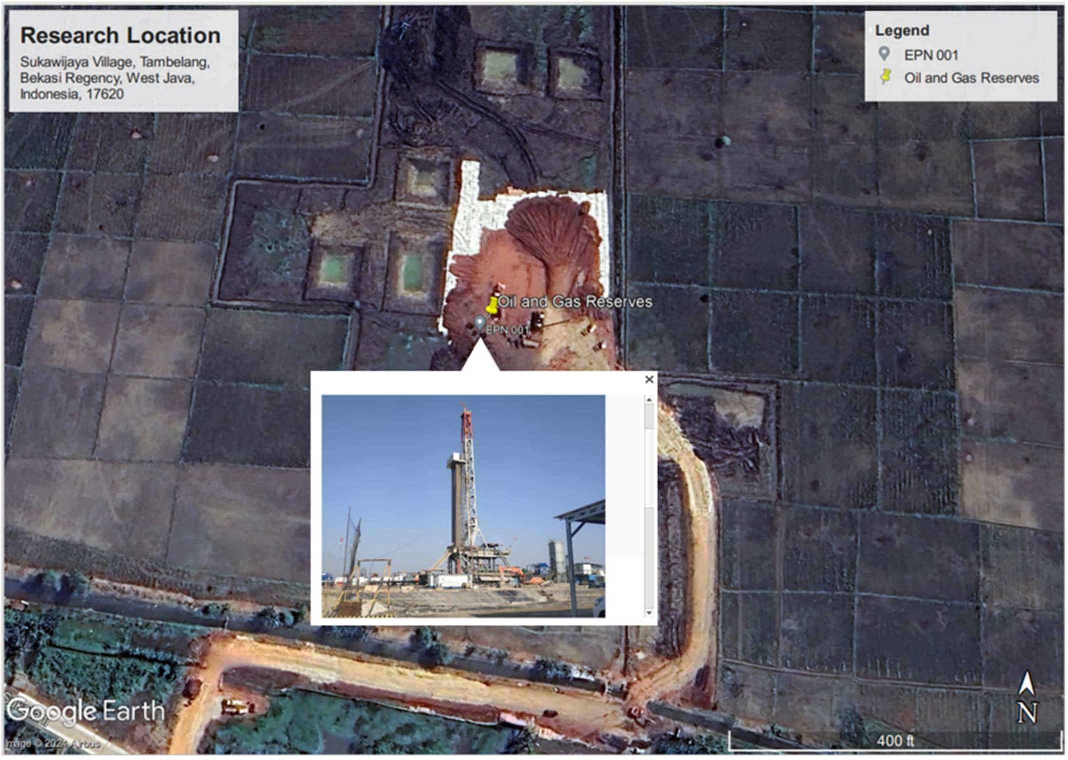

Figure 2. Research Location.

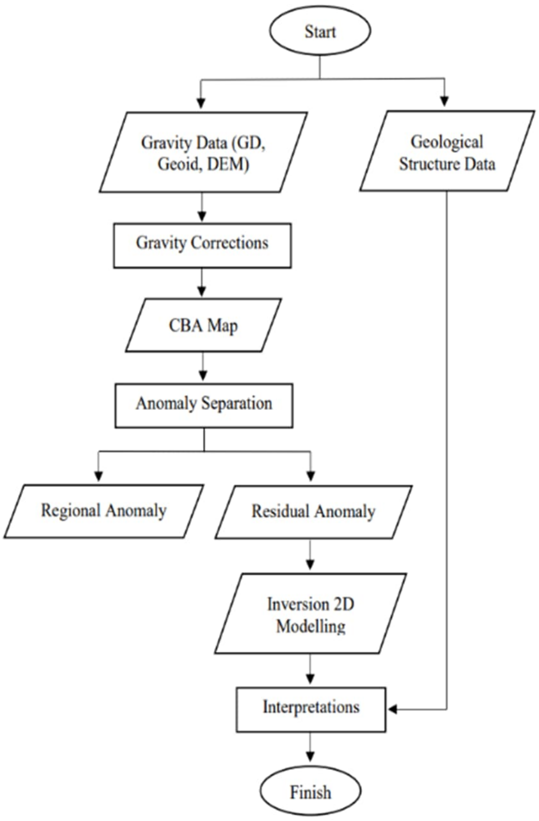

Figure 3. Research Flow Chart.

4. RESULTS & DISCUSSION

4.1. Topography Map

On the topographic map of the research area, it can be seen that the research area has topographic values ranging from 0.02 – 27.65 m above sea level. The northern part of the research area has low topographic values ranging from 0.02 - 2.01 m because it is closer to the sea, so the topographic value is very low, in the southern part of the research area it has high topographic values ranging from 6.46 - 27.65 m. The topography of this study area is classified as lowland morphology (**Figure 4**).

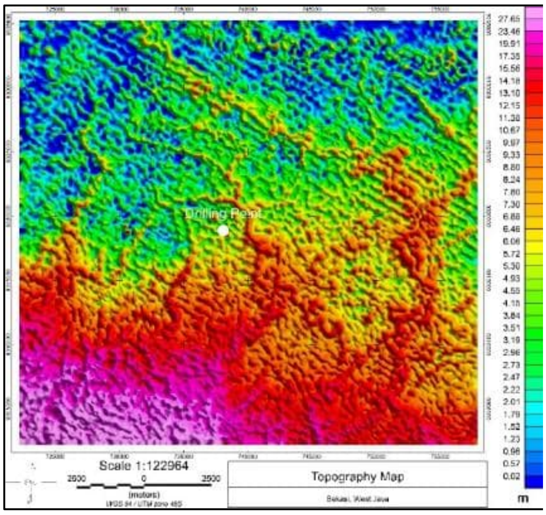

Figure 4. Topography Map.

4.2. Complete Bouguer Anomaly Map

On the CBA map, the research area has gravity field anomaly values ranging from 36,860 – 53,342 mGal. The high anomaly has a value of 42,934 - 53,342 mGal, located in the northern and western parts of the study area which is thought to be associated with volcanic rock deposits. The low anomaly has a value of 36,860 – 42,461 mGal, located in the south to east and a little in the north which is thought to be associated with alluvium lithology and the Lower Cibulakan Formation which is the target of research (black polygon) (**Figure 5**).

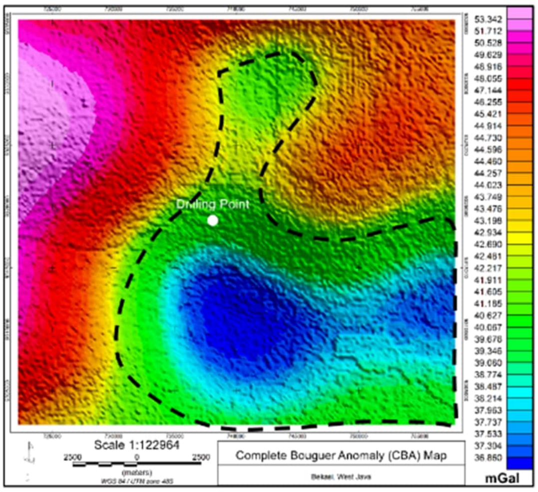

Figure 5. Complete Bouguer Anomaly Map.

This CBA map still has quite high ambiguity because the anomaly that is read is a combination of residual anomalies and regional anomalies, so this CBA map needs to be separated from the anomalies in order to eliminate this ambiguity.

4.3. Regional Anomaly Map

In the regional anomaly map the research area has anomaly values ranging from 36,817–53,623 mGal, it can be seen that the contour is smoother and has similarities to the CBA map. This is because regional anomalies describe very deep subsurface conditions, where the layers and rocks in the deep zone have homogeneous properties.

The high anomaly has values ranging from 42,941-53,623 mGal in the northern and western parts of the study area. This high anomaly is thought to be associated with deep volcanic rock deposits. The low anomaly has values ranging from 36,817–42,179 mGal in the south to east and slightly in the north of the research area. This low anomaly is thought to be associated with alluvium lithology and the Lower Cibulakan Formation in the inner zone which is the research target (**Figure 6**).

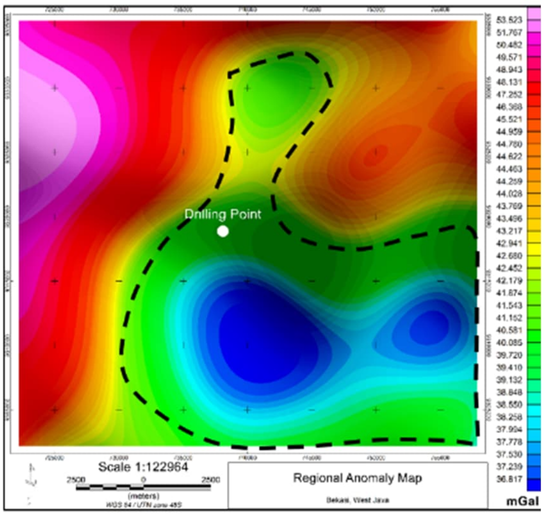

Figure 6. Regional Anomaly Map.

4.4. Residual Anomaly Map

In the residual anomaly map, the research area has an anomaly value of -0.4463 – 0.3055 mGal. It can be seen that the contour of the residual anomaly is more varied and slightly rougher when compared to regional anomalies. This is because residual anomalies describe shallow subsurface conditions or close to the ground surface, where the layers and rocks in the shallow zone have heterogeneous properties.

The high anomaly has a value of 0.0056 - 0.3055 mGal which is located in the western, central and eastern parts of the study area which extends from north to south. This high anomaly is thought to be associated with volcanic rock deposits. The low anomaly has a value of -0.4463 – (-0.0339) mGal which is located in almost all parts of the study area (**Figure 7**). This low anomaly is thought to be associated with alluvium lithology and the Lower Cibulakan Formation, where in this formation there is drilling point EPN-001 which is the target of this research. Based on the residual anomaly map, a 2D model section will then be carried out.

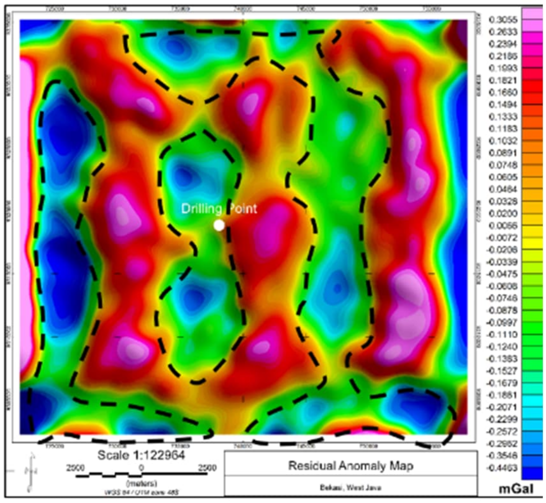

Figure 7. Residual Anomaly Map.

4.5. 2D Inversion Modeling

4.5.1. Section A-A'

In the 2D gravity model section A – A' which trends west to east with a depth of 4000 m with a root mean square error model value of 0.6, it can be seen that there are 3 lithologies or formations that make up the subsurface of the research area. The cap rock layer has a density contrast value of 1.5 – 1.8 g/cc at a depth of 0 – 2500 m which functions to resist the flow of oil and gas fluids to the surface. Layers consisting of volcanic rock have a density contrast value of 2.6 – 2.8 g/cc at a depth of 0 – 4000 m. The last layer, namely the Lower Cibulakan Formation, has a density contrast value of 2 – 2.3 g/cc at a depth of 2500 – 4000 m. This layer is thought to be a reservoir that stores hydrocarbons below the surface which is the target of this research (**Figure 8**).

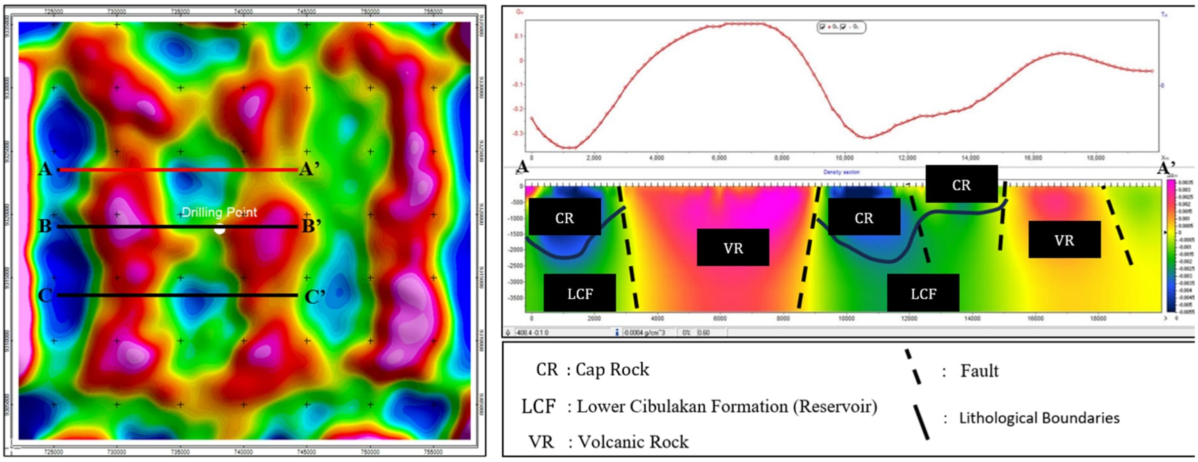

Figure 8. 2D Gravity Inversion Model Section A-A'.

4.5.2. Section B-B'

In the 2D gravity model section B – B', the drilling point cuts from west to east in the research area at a depth of 4000 m with a model root mean square error value of 0.39. The result is that there are 3 lithologies or formations that make up the subsurface of the research area. The cap rock layer has a density contrast value of 1.5 – 1.8 g/cc at a depth of 0 – 2500 m. Layers consisting of volcanic rock have a density contrast value of 2.6 – 2.8 g/cc at a depth of 0 – 4000 m. The last layer, namely the Lower Cibulakan Formation, has a density contrast value of 2 – 2.3 g/cc at a depth of 2500 – 4000 m. The Lower Cibulakan layer is thought to be a reservoir that stores hydrocarbons below the surface, where it can be seen that the drilling point that produces oil and gas fluids is at a depth of 2590 m (**Figure 9**).

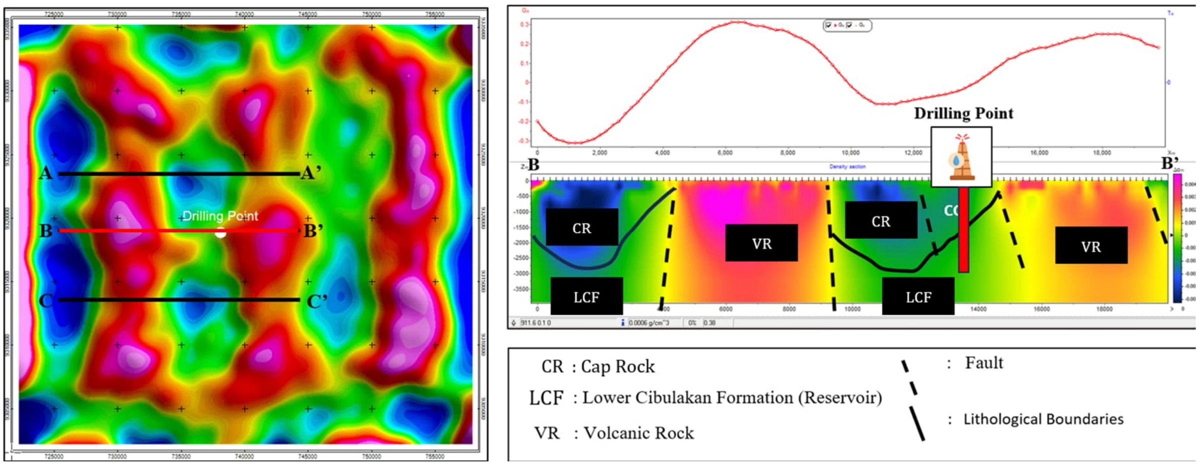

Figure 9. 2D Gravity Inversion Model Section B - B'.

4.5.3. Section C-C'

In the 2D gravity model section C – C' which trends west to east with a depth of 4000 m with a root mean square error model value of 1.19, it can be seen that there are 3 lithologies or formations that make up the subsurface of the research area. The cap rock layer has a density contrast value of 1.5 – 1.8 g/cc at a depth of 0 – 4000 m which functions to resist the flow of oil and gas fluids to the surface. Volcanic rock layers have a density contrast value of 2.6 – 2.8 g/cc at a depth of 0 – 4000 m. The last layer, namely the Lower Cibulakan Formation, has a density contrast value of 2.6 - 2.8 g/cc at a depth of 2500 – 4000 m. This layer is thought to be a reservoir that stores hydrocarbons below the surface which is the target of this research (**Figure 10**).

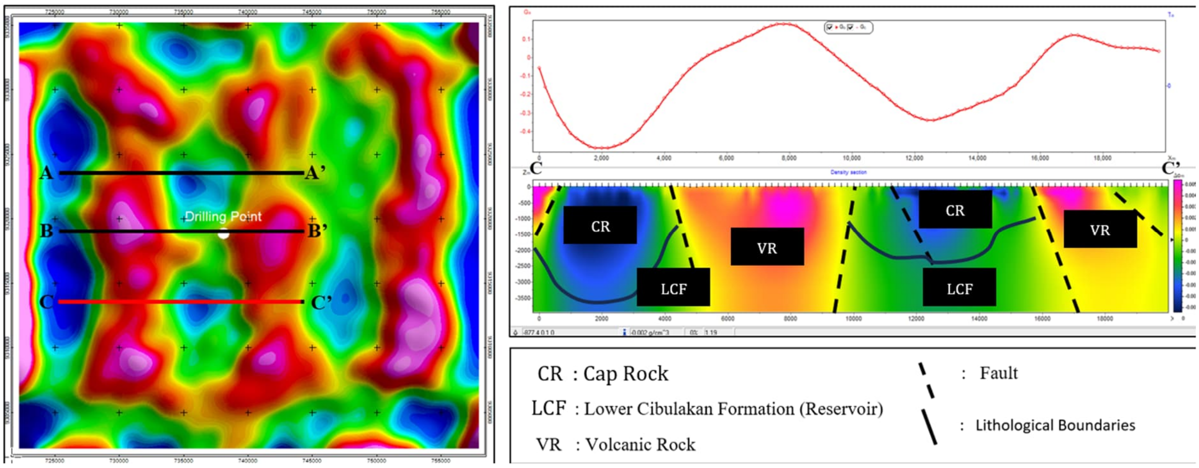

Figure 10. 2D Gravity Inversion Model Section C - C'.

5. CONCLUSIONS

Based on the residual anomaly map, the low anomaly has a value of -0.4463 – (-0.0339) mGal which is located in almost all parts of the study area. This low anomaly is thought to be associated with alluvium lithology and the Lower Cibulakan Formation, where in this formation there is drilling point EPN-001 which is the target of this research.

In the three sections of the 2D model with a depth of 4000 m, there are 3 lithologies or formations that make up the subsurface of the research area. The cap rock layer has a density contrast value of 1.5 – 1.8 g/cc at a depth of 0 – 2500 m, the volcanic rock layer has a density contrast value of 2.6 – 2.8 g/cc at a depth of 0 – 4000 m, and in the Lower Cibulakan Formation layer has density contrast value 2 – 2.3 g/cc at a depth of 2500 – 4000 m. The Lower Cibulakan Formation is thought to be a reservoir, where the drilling point at a depth of 2590 m and produces oil and gas fluids which are visible in the 2D model section B - B'.

At the exploration stage, it is very important to collaborate with several geophysical methods to obtain more accurate and easier results at the data interpretation stage, especially the gravity method to support seismic data in oil and gas exploration where it is quite difficult to see density parameters.

To increase oil and gas exploration, various strategies can be implemented. The following is a potential strategy, namely Utilizing Geological and Geophysical Data by Building and maintaining a comprehensive database of geological and geophysical data to make it easier to identify potential areas.

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