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Delineation of the Subsurface Structures in the Central Sumatra Basin (Indonesia) through Bouguer Gravity Data

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Sumatra Island,
Bouguer gravity anomaly,
Tilt,
Half-Distance,
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Abstract: This study presents the delineation of the boundaries of the subsurface structures and the potential hydrocarbon areas located in the eastern part of the central Sumatra basin using Bouguer gravity data. The existence of the high gravity anomalies in the eastern part displayed in this sedimentary basin takes attention. It could be said that the sedimentary basins in the region have a great importance for hydrocarbon potential. Therefore, investigation of the reason for these high anomalies is required for the region. To this end, gravity anomalies have been processed by advanced potential field methods such as the power spectrum analysis method and tilt method. The average depths of the deep and shallow causative sources have been calculated as 23.71 km and 1.61 km, respectively. Furthermore, the boundaries of the causative sources have been determined utilizing the tilt method. The tilt map has shown that the reason for these high anomalies could be the bedrock composed of high-density material rising upwards, considering the tectonic background of the region. This study has determined that the depths of the causative bodies in the region are approximately 11.2 km, 7.8 km, and 13.2 km from north to south, respectively. As a result, it could be said that such sources with deep roots could be prospective for hydrocarbon maturation.

Bouguer Gravite Verileriyle Orta Sumatra Havzasındaki (Endonezya) Yeraltı Yapılarının Belirlenmesi

Anahtar Kelimeler
Sumatra adası,
Bouguer gravite anomalisi,
Tilt,
Yarı-mesafe,
Dalma-batma zonu

Öz: Bu çalışma, Bouguer gravite verilerini kullanarak Sumatra merkez havzasının doğu kısmında yer alan yeraltı yapılarının sınırlarının ve potansiyel hidrokarbon alanlarının belirlenmesini sunmaktadır. Bu sedimanter havzanın doğu kesiminde yüksek gravite anomalilerinin varlığı dikkat çekmektedir. Bölgedeki tortul havzaların hidrokarbon potansiyeli açısından büyük öneme sahip olduğu söylenebilir. Bu nedenle bölge için bu yüksek anomalilerin nedeninin araştırılması gerekmektedir. Bu amaçla gravite anomalileri, güç spektrumu analiz yöntemi ve tilt yöntemi gibi ileri potansiyel alan yöntemleriyle işlenmiştir. Derin ve sığ nedensel kaynakların ortalama derinlikleri sırasıyla 23,71 km ve 1,61 km olarak hesaplanmıştır. Ayrıca tilt yöntemi kullanılarak anomaliye neden olan yapıların sınırları da belirlenmiştir. Tilt haritası, bölgenin tektonik arka planı dikkate alındığında bu yüksek anomalilerin nedeninin yukarıya doğru yükselen yüksek yoğunluklu malzemeden oluşan ana kaya olabileceğini göstermiştir. Yapılan çalışmada bölgedeki anomaliye neden olan cisimlerin derinliklerinin kuzeyden güneye doğru sırasıyla yaklaşık 11,2 km, 7,8 km ve 13,2 km olduğu tespit edilmiştir. Sonuç olarak kökleri derin olan bu tür kaynakların hidrokarbon olgunlaşması açısından umut verici olabileceği söylenebilir.

1. Introduction

Sumatra Island presents a very complex structure as it is located at the junction of many tectonic plates. The region is located at the boundary between the Indian/Australian tectonic plate and the Eurasian tectonic plate. Moreover, the subduction zone has been developed in this region due to the subduction of the Indian Plate beneath the Sunda Plate. The speed of this movement has been determined as 50 to

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70mm/year [1, 2]. The subduction zone southwest of Sumatra is determined as a part of a long convergent belt and plate-tectonics models have been created by references [3 and 4] for the region. The subduction of the Indian Plate beneath the Sunda Plate has caused the development of a volcanic arc that has intensive seismic activity. Furthermore, this movement has caused the development of many fault systems in the region. One of the prominent faults in the region is the Great Sumatran Fault which is a dextral strike-slip fault. This fault, which is 1900 km long, extends along the island of Sumatra (Fig.1).

Many basin structures have been developed with the tectonic evolution in the region. These basins located on Sumatra Island are gathered into three groups: north, central, and south Sumatra basin. The central basin, which is one of the largest tertiary sedimentation basins on the island, has a crucial importance in terms of hydrocarbon production. This basin is located in the back-arc basin region, and it extends NW-SE direction due to the tectonic background in the region [5]. The study area, which is the subject of this study, is located at the southeast end of the central basin. On the other hand, Sumatra Island has crucial importance in producing hydrocarbon and has current resources of almost 28, 15, and 6.7 billion barrels of oil equivalent in the north, central, and south Sumatra Basin, respectively [6-8]. Especially, the production in the central basin has been sourced from Oligocene-Miocene clastics [8].

The tectonic features of the southern Sumatra region have been investigated using multichannel reflection seismic profiles [9]. The hydrocarbon prospect in the west Sumatra forearc basin was explored utilizing well data and it was stated that the forearc region may have gas hydrate potential [10]. Also, the geological properties of the offshore central Sumatra basin have been interpreted utilizing the topex satellite data. [11] The results obtained from the spectral analysis showed that the average sedimentary thickness is 2.1 km in this region. Furthermore, they calculated the density values of the sedimentary rocks and granitic rocks as 2.35 and 2.67 gr/cm3, respectively. Susantoro et al. [12] explored heavy oil potential in Central Sumatra Basin by using remote sensing, gravity, and petrophysics data. They revealed the lineaments in Sumatra extended in NW-SW and N-S directions. In addition, they determined that there is a continuity between subsurface and surface lineament features. The study showed that these lineaments provide contact between reservoirs and surface water resources facilitating heavy oil generation. Reference [13] delineated the sub-basin structures in the eastern part of the central Sumatra basin based on the gravity, seismic, and well dataset. Also, they investigated the high and low anomaly pattern in Sumatra Island and it is considered that these values could be caused by a lifting of the bedrock. Furthermore, they determined the top depth of the bedrock is approximately 750m sea level while the deep depth of the bedrock is approximately 1500m below sea level. As can be seen from the above-mentioned studies, the region has a crucial importance in terms of hydrocarbon production. Hence, it could be said that every study carried out in the region will provide a great contribution to the literature.

As can be seen from the abovementioned tectonic and geological background, this study plays an important role in understanding the subsurface structures and their boundaries in the region due to the basins including hydrocarbons. There are many studies [14-18] carried out for the north and south basins, but the studies including the central basin are limited. In this context, it could be possible to say that the current study will fill the gap in the literature. The study area, which is characterized by high Bouguer gravity anomalies, is located at the southern end of the central basin (see Fig.1). The region has a crucial importance due to tectonic features. Hence, to reveal the boundaries of the structures in this region, advanced potential field data techniques (power spectrum analysis and tilt method) have been applied to the Bouguer gravity data in the current study.

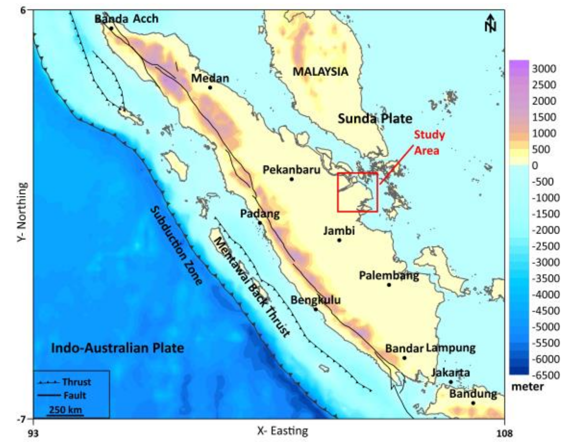

Figure 1. Bathymetric and topographic map of the Sumatra Island and its vicinity [19]

2. Material and Method

This section contains the free air and Bouguer gravity datasets used in the study and the methods applied to these datasets. The methods used in the current study are comprehensively described in the literature. However, it is briefly summarized in this paper.

2.1. Material

The free air and Bouguer gravity datasets, which are a part of the WGM project [20], are provided by the Bureau Gravimetrique International (BGI) and the support of the United Nations Educational Scientific and Cultural Organization (UNESCO). These data contain high-resolution terrain corrections that take into account the contribution of most surface masses (atmosphere, land, oceans, etc.). The free air anomaly map is widely used for geological interpretation of deep water. As can be seen from Fig. 2, the regions located along the subduction zone (namely Sunda trench) have displayed negative anomaly values (-20 to -150 mGal). The highest values of the free-air anomalies reached up to 300 mGal (in Fig. 2) have been seen over the volcanic arc region trending NW-SE (in the central part of the study region). The free air anomaly map of the region has some similarities to the isolines of the bathymetric map. In other words, there is a close correlation between bathymetry and free-air gravity anomalies.

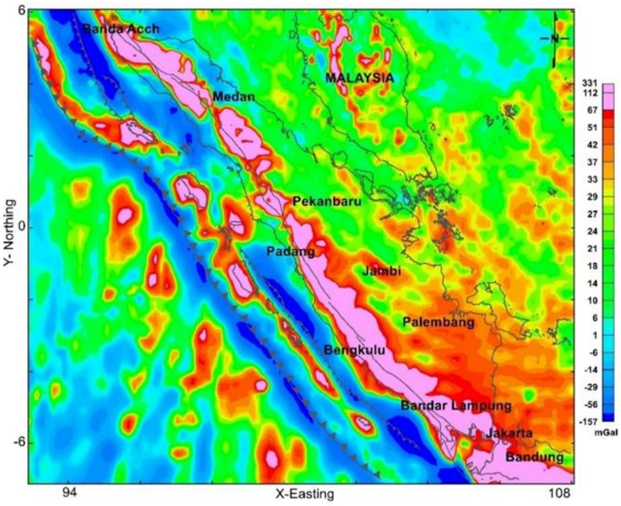

Figure 2. Free air anomaly map of the Sumatra Island and its vicinity

As well known, the Bouguer anomaly over continents displays generally negative anomalies, especially over mountain ranges while the positive Bouguer anomalies are observed over oceans. The variation of these anomalies depends on the thickness of the earth's crust [21]. In other words, the continental crusts are presented by thick, low-density crust whereas the ocean basins are presented by thin, high-density oceanic crust. To obtain Bouguer gravity anomalies, Bouguer and terrain corrections have been applied to the data. The Bouguer correction density has been taken as 2.67 g/cm3 during the application. The constituted Bouguer map is given in Fig. 3. As can be seen from Fig. 3, the gravity anomalies gradually decrease from the ocean to the subduction zone. This is associated with the variation in the thickness of the earth's crust mentioned above. Furthermore, these gravity anomalies have reached maximum gravity anomaly values (approximately 400 mgal) in the fore-arc island and the volcanic arc region in Sumatra Island. On the other hand, the basin regions located on Sumatra Island are characterized by low gravity anomalies. Especially, the eastern part of this basin, which is selected as the study area in the current study (see Fig. 4), takes attention due to the existence of the high gravity anomalies. The low gravity anomalies in the central Sumatra basin exhibit a range of 120 to 240 mGal (see Fig. 3). The Bouguer gravity anomaly map of the study area, enlarged to better see the anomaly values, is given in Figure 4. To determine the reason for these high gravity anomalies and the boundaries of these causative bodies, advanced potential field methods such as power spectrum analysis and tilt method have been applied to these data.

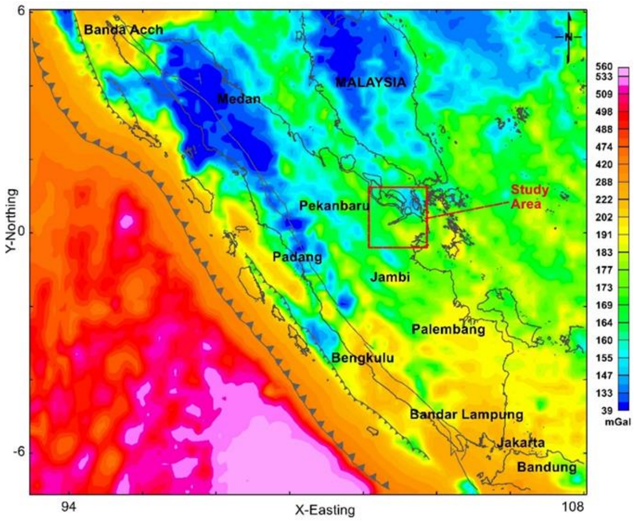

Figure 3. Bouguer gravity anomaly map of the Sumatra Island and its vicinity

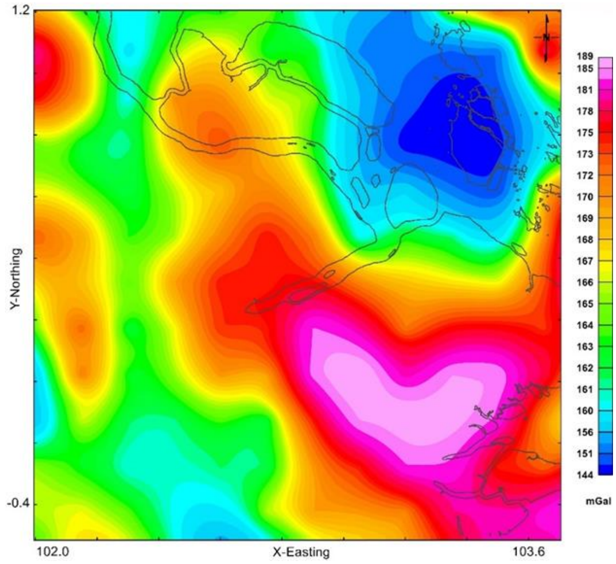

Figure 4. The Bouguer gravity anomalies of the enlarged study area. This enlarged area is shown in Fig. 3.

2.1. Methods

2.1.1 Power spectrum analysis

The Bouguer gravity anomalies are composed of two components: regional and residual anomalies.

Regional anomalies present the anomalies caused by the deep-seated bodies. These regional anomalies are characterized by long wavelength and low amplitude anomalies. The residual anomalies present the anomalies caused by the shallow bodies. These anomalies are characterized by the short longwave and high amplitude anomalies. The power spectrum developed by reference [22] is widely used to separate the anomalies from each other. This method based on the FFT transform allows the researcher to calculate the average depths of these causative bodies. The method uses the graph obtained by the logarithmically averaged power spectrum versus the wave number, and the average depths of the structures that cause anomalies are calculated. In this study, the power spectrum method has been applied to Bouguer gravity data and calculated the average depths of these bodies. Applying the power spectrum method, three segments whose depths vary between 23.71 km and 1.61 km have been determined for the region. The average depth of the regional anomalies caused by the deep sources has been calculated as 23.71 km while the average depth of the shallow sources (residual anomalies) has been calculated as 1.61 km (Fig. 5).

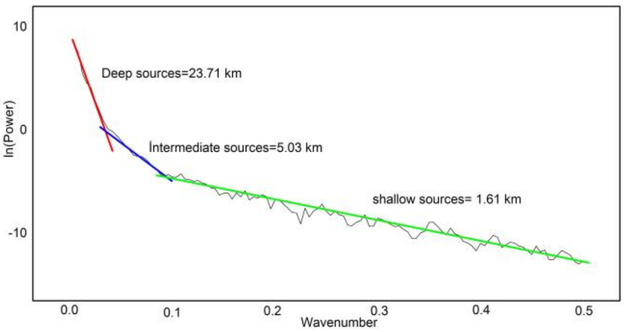

Figure 5. The radially averaged power spectrum graph

2.1.2 Tilt method

The tilt angle derivative technique is widely used for defining trends and boundaries of causative bodies and mapping shallow basement structures. This method is based on the arctangent function of the horizontal and vertical derivative of the potential field data as follows;

$$Tilt = \arctan\left[\frac{\frac{\partial f}{\partial z}}{\sqrt{(\frac{\partial f}{\partial x})^2+(\frac{\partial f}{\partial y})^2}}\right] \qquad (1)$$

where, $\frac{\partial f}{\partial x}$, $\frac{\partial f}{\partial y}$ and $\frac{\partial f}{\partial z}$ are the derivative of the Bouguer gravity data in the x, y and z- directions, respectively [23]. The tilt amplitudes vary between -$\pi/2$ and + $\pi/2$. The zero contours reflect the boundaries of the structures while maximum values are located over the causative bodies in this method. After developing the tilt method, the half-distance method was proposed by [24]. According to this method, the half-distance between ±π/4 Radians (±45°) contours allows us to estimate the source depth for vertical contacts. In this study, we have applied the tilt method to the first vertical derivative of the Bouguer gravity data in order to delineate the boundaries of the causative sources. The reason for the application to the first vertical derivative of Bouguer anomalies is explained by the Poisson relation [25]. The tilt map is given in Fig. 6. Looking closer at Fig. 6, the existence of high amplitudes takes attention in the central part of the map. The boundaries of these causative sources have been emphasized by applying the tilt method. The constituted map has shown that the causative bodies extend to the northern part of the region. The red and green lines indicate the -π/4 and + π/4 Radians contours, respectively. Similarly, the black short-dash lines show the zero contour. According to the tilt-distance method, the depth of the causative bodies located in the southeastern part of the map is calculated as 13.2 km while the depth of the structure located in the central part of the map is calculated as 7.8 km.

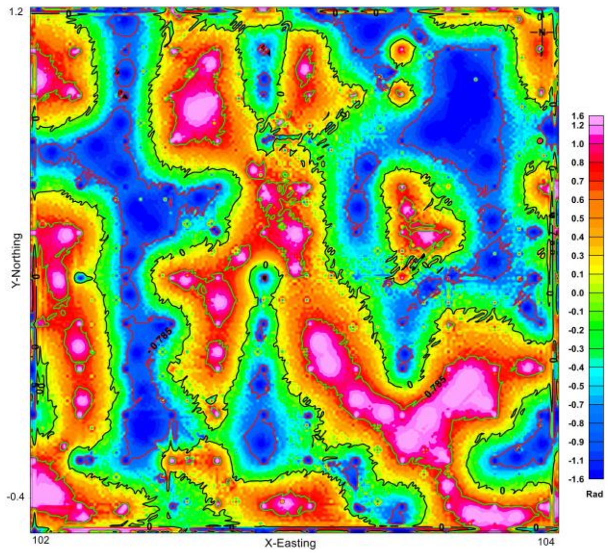

Figure 6. Tilt map of the study region. Zero contour represents the boundaries of the structure

3. Result and Discussion

This study aims to delineate the boundaries of the causative sources located in the eastern part of the central Sumatra basin. This sedimentary basin includes hydrocarbon production fields. Therefore, it can be said that revealing the structures located in this region has a crucial role for economic reasons. To this end, gravity anomalies have been analyzed and the tilt method, which is one of the boundary analysis methods, has been applied to these data to delineate the boundaries of the causative sources in the region. The study area is located between the central Sumatra basin and south Sumatra basin and this region could be evaluated as a range region. Therefore, considering the tectonic background in the region, it could be thought that the high gravity anomalies have resulted from the bedrock composed of high-density material rising upwards. After delineating the boundaries of this structure, the tilt map has shown that the map shows that the anomaly located in the northern part of the Bouguer map has been caused by two separate structures. Furthermore, the upper depths of this high have been calculated as 11.2 km, 7.8 km, and 13.2 km, from the north to south direction, respectively utilizing the half distance method (distance between $\pm\pi/4$ radians). On the other hand, the boundaries of the basin located in the western part of this high have been clearly determined with the current study. In conclusion, the delineation of the sub-surface structure plays a key role in surveying hydrocarbon prospecting. Thus, it could be said that the current study is a basement for seismic studies that will be carried out in the future.

Acknowledgement

We thank to the Bureau Gravimetrique International (BGI) and the support of the United Nations Educational Scientific and Cultural Organization (UNESCO) for gravity data.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

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