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Identification of potential hydrocarbon traps using the gravity method in the Bengkulu basin

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Abstract

A sedimentary basin is a depression where sediment deposits accumulate and can act as a reservoir for the sedimentation and maturation of sediments containing hydrocarbons. The Bengkulu Basin is one of the forearcs in Indonesia. The Bengkulu Basin is one of the basins with the potential to have hydrocarbon reserves marked by an oil show in the Padang Capo village. Exploration to find a basin or hydrocarbon trap can be done using the gravity method. This method is often used to study the structure, bedrock, rock intrusion, and sedimentary basins based on variations in the earth's gravitational field due to lateral density differences which are known as anomalies gravitational. Determination of the existence of a hydrocarbon trap structure is carried out by derivative analysis, namely First Horizontal Derivative (FHD) and Second Vertical derivative (SVD) graphs and 2D modeling using forward modeling. The results of the analysis of the FHD and SVD graphs with 2D modeling show synchronous results. Where the analysis of the FHD and SVD graphs in the study area found many fault structures and folds. The study area is dominated by the fault type of thrust fault. In the 2-dimensional modeling of the research area where there is an oil show, it is found that there is a rising fault structure and the presence of anticline and syncline structures that could act as hydrocarbon traps.

Keywords: Bengkulu basin, gravity, FHD, SVD and traps

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1 Introduction

A sedimentary basin is a depression in which sediment deposits accumulate and can act as a container for the deposition and maturation of sediments containing hydrocarbons (Boggs, 2006). Hydrocarbons come from *organic* matter contained in sediments. Such organic matter consists of microalgae and deposited microorganisms. During the deposition process, the material continues to be buried with sediment, the material is damaged due to the oxidation process. The rest of the material left behind contains kerogen which during sediment deposition due to high pressure and temperature for a very long time, turns into hydrocarbons by the thermal cracking process (H.M Petroleum Engineering, 2016).

Tectonically, Sumatra Island was formed due to a collision with the Indo-Australian Plate which plunged into the Eurasian Plate. Pulunggono (1992) divided the subduction system of Sumatra Island into three changes in the direction of subduction which led to the formation of three main fault patterns, namely faults with a northwest-southeast direction in the Late Jurassic-Cretaceous in the compressional phase, North-South direction in the Late Cretaceous-Early Tertiary in the tensional phase and in the Northeast–Southwest direction in the Middle Miocene – Recently in the compressional phase. In Tertiary – Recently there has been an oblique meeting of plates at a speed of 5-7 cm/year which then forms an angle of N 025 ^{o}E in the southern part of Sumatra and N 031 ^{o}E in the northern part of Sumatra so that the main fault forming the island of Sumatra is formed with the movement of the strike-slip fault (Semangko Fault) (Newcomb and McCann, 1987). As a result of the meeting of the plates also causes the formation of space in the form of half grabens, horsts, and fault blocks which then form tertiary basins consisting of forearc basins and back arcs.

The Bengkulu Basin is one of the tertiary sedimentary rock basins on the island of Sumatra which is included in the forearc basin. The Bengkulu Basin is located in the west of Sumatra Island to the northeast of this basin bounded by the Bukit Barisan mountains. Geologically, the research area is included in the geological map of the Bengkulu sheet and the geological map of the manna sheet. The possibility of hydrocarbon presence in the Bengkulu Basin is quite large. This is shown by the emergence of oil seepage in Kampung Padang Capo Village (Heryanto. R. 2006).

Gravity is one of the geophysical methods used to describe the geological structure of the subsurface. This method is often used to study structures, bedrocks, rock intrusions, and sedimentary basins based on variations in the earth's gravitational field due to lateral density differences which are then known as gravitational anomalies (Sarkowi, 2014). Based on the convergence process, it is always accompanied by crustal deformation, causing a mass deficit which is immediately offset by the shedding of the parent rock to fill the basin, forming clastic sedimentary rocks called sedimentation basins. Because the relative mass density is smaller than 2.67g/cc, the anomalous value of gravity in the basin area becomes negative (Setyanta and Setiadi, 2010).

The Petroleum System is a concept that includes all the different elements and processes of Petroleum Geology (SKK MIGAS, 2016). Oil and gas are formed in a sedimentary basin through important processes and elements, namely: source rock (parent rock) which has kerogen that can produce a hydrocarbon, reservoir rock (reservoir rock) is a rock that is able to store fluid or hydrocarbons, trap (trap) serves to trap a hydrocarbon so that it cannot move one example of a trap is faulting and folding, Cap rock is a rock that has poor permeability. Investigation of a basin and elements of this petroleum system can be done by geophysical surveys, one of which is the gravity method (gravity). Therefore, research was conducted on the application of the gravity method (gravity) to identify potential hydrocarbon traps in the Bengkulu basin.

2 Reserch Methods

A. Geology Research Area

The Bengkulu Basin is one of the *forearc* basins in Indonesia. Forearc basin means a basin that is positioned in front of a volcanic path (*fore-arc; arc* = volcanic path). Based on various geological studies, it is agreed that the Bukit Barisan Mountains (in this case the volcanic arc) began to rise west of Sumatra in the Middle Miocene. Its influence on the Bengkulu Basin was that before the Middle Miocene there was no forearc of the Bengkulu Basin because at that time the arc itself did not exist. Before the Middle Miocene or Paleogene, the Bengkulu Basin was still the westernmost part of the South Sumatra Basin. In the period after the Middle Miocene or Neogen, after the Barisan Mountains rose, the Bengkulu Basin was separated from the South Sumatra Basin. From then on, the Bengkulu Basin became the forearc basin and the South Sumatra Basin became the backarc basin.

Figure 1. Map of the Bengkulu Basin (simplification of Gafoer et al., 1992 and Amin et al., 1994).

The Bengkulu area is occupied by rocks included in the Barisan Column (Upstream Formation, deep breakthrough rocks, Bal Formation, Ranau Formation, and volcanic rocks) and the Bengkulu Column (Seblat, Lemau, Simpangaur, and Bintunan Formations, as well as Quaternary volcanic rock units). The distribution of these rocks is presented in Figure 2 and the stratigraphic columns of the Bengkulu Basin as shown in Figure 3. Geology of the Bengkulu Basin has been widely published by previous writers, including Gafoer et al. (1992), Amin et al. (1994), Yulihanto et al. (1995), Guntoro and Djajadiharja (2005), and Heryanto (2005, 2006 a,b & 2007a,b).

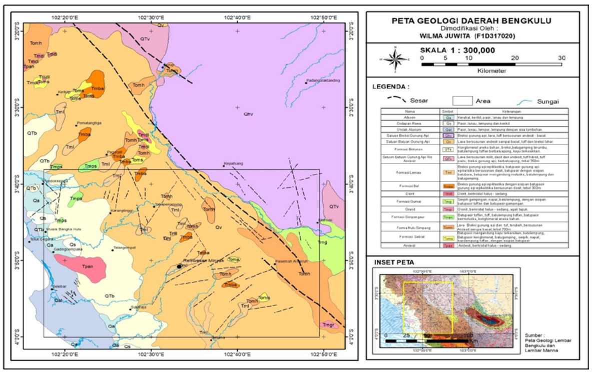

Figure 2. Map of Research Areas (Simplification of SHP Map of Indonesia and Pusgen 2017).

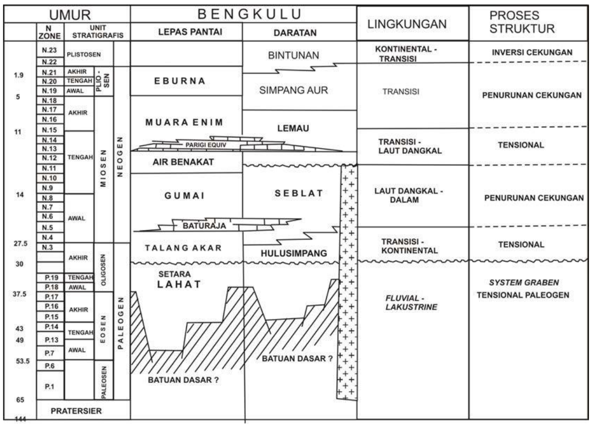

Figure 3. Stratigraphic Correlation of Offshore and Inland Areas in the Bengkulu Basin (modification of Yulihanto et al., 1995).

Faults

Faults (faults) are cracks in the earth's rocks caused by vertical or horizontal sliding movements so that there is relative movement in rock blocks in the area. Active faults are faults that moved 10,000 years ago. Potentially active faults are faults that moved 2 million years ago, while inactive faults are faults that never moved 2 million years ago (Massinai, 2015).

There are three types of faults, namely horizontal faults, ascending faults, and descending faults. In addition to these three types, there is also a type of fault which is a combination of horizontal faults and ascending/descending faults called oblique faults.

A.) Strike-slip fault
is a fault whose movement is parallel, the left block is relatively shifted in the opposite direction to the right block.

B.) Thrust Fault
is a fault where one of the rock blocks shifts upward and the other part of the block shifts downward along the plane of the fault. In general, the ascending fault plane has a slope smaller than 45°.

C.) Normal Fault
is a fault that occurs due to the shift of rock blocks due to the influence of gravitational forces. In general, normal faults occur as a result of the loss of force influence so that the rock goes to a balanced position.

Petroleum System

In oil and gas exploration activities in a basin, it usually takes some elements and processes in a system that is thought to contain a hydrocarbon, this system is usually called the Petroleum System. Where in the petroleum system includes several important elements, namely, Source Rock (Main Rock), Reservoir Rock, Trap, and Cap Rock (Protective Rock).

Elements in a petroleum system

A.) Source Rock
Source Rock is a sedimentary rock deposit that contains enough organic matter to be able to produce oil and natural gas when the deposit is buried and heated, usually, the rock included in the parent rock is shale or carbonate rock.

B.) Reservoir Rock
Reservoir Rock is a rock that has high porosity and permeability properties that can store and drain hydrocarbons to the place of accumulation of a hydrocarbon, generally rocks that include rock reservoirs are sandstone.

C.) Trap
The trap is a layer geometry condition that traps a hydrocarbon in a rock reservoir so that the hydrocarbon does not escape/migrate from the rock reservoir and accumulate in the rock reservoir. There are several types of hydrocarbon traps, namely:

a.) Structural Traps
A structural Trap is a trap that occurs due to deformation in a layer to form a fold caused by tectonic events, this trap is the trap most often found.

b.) Stratigraphic Trap
Stratigraphy traps are traps that are affected by vertical and lateral layers and also due to misalignment in the lithology of a reservoir layer.

c.) Combination Trap
Combination Traps are mixed traps between structural traps and stratigraphic traps.

D.) Cap Rock
Cap Rock is a type of rock that has porosity and permeability properties that are small or inversely proportional to the nature of rock reservoirs, this protective rock has a function so that hydrocarbons in the rock reservoir do not migrate again to the ground surface, hydrocarbon migration events to the ground surface are commonly called oil seep.

Gravity Method

The gravity method has the principle of measuring variations in the earth's gravitational field caused by differences in the density of subsurface rocks (Reynolds, 2011). The gravitational method is based on Newton's Law of Gravity which states that the force of attraction between two objects is proportional to the mass of both objects and inversely proportional to the square of the distance between the centers of mass of the two objects (Jacobs et. al., 1974). The equation of Newton's law stating the gravitational relationship is as follows:

$$F(r) = G\frac{m1m2}{r^2} \quad (1)$$

Information
F(r) = attractive force (N)
m1 and *m2* = mass of object one and mass of object two (kg)
r = distance between two objects (m)
G = universal gravitational constant (6.67 x 10-11 m3 kg-1s-2)

Gravity measurements emphasize changes in gravity values due to density contrast below the surface. Therefore, correction is needed to eliminate these factors (Telford et al., 1990).

A.) Free-air correction (CFA) expressed by equation (h as the altitude of measurement position):

CF = 3.086 h (2)
Information:
CF = Correction Free Air
h = Datum point height (m)

B.) Bouguer correction is used to reduce the value of gravity due to the presence of rock mass between measurement points at a height of h meters against MSL. So that the measured gravity value is greater than the value of gravity that should be on the equipotential surface (Andrian &; Jefri, 2018).

CB = 0.000419.Δhρ (3)
Information:
CB = bouguer correction (mgal)
Δh = difference in height of the measurement point with datum (m)
ρ = density (kg/m3)

C.) Terrain correction, the influence of materials around both materials above and below the measurement point also contributes to the measurement results at the measurement point so that topographic corrections must be made, especially if the measurement field has irregular topography such as mountain chains, or hills (Suhadiyatno, 2008). According to Reynold (1997), it can be calculated by the following formula:

$$TC = Gp\theta\left[(r2 - r1) + \sqrt{r1^2 + z^2} - \sqrt{r2^2 + z^2}\right] \quad (4)$$

Information:
TC = terrain correction (mgal)
G = is a Universal constant
ρ = rock mass density (kg/m3)
θ is the angle formed by the compartment (degrees)
r1 = radius of inner circle (m)1
r2 = radius of outer circle (m)2
z = hill height/valley depth (m)

D.) Bouguer's Complete Anomaly is a gravitational anomaly value obtained after correcting the observational gravity value. CBA values are a combination of regional anomalies and residual (local) anomalies. The value of CBA is obtained from the following equation:

CBA = Gobs - Gn + GF - CB +TC (5)
Information:
CBA is a complete Bouguer anomaly (mGal)
SBA is simple bouguer anomaly (mGal)
TC is terrain correction value (mGal)

Furthermore, processing uses several filters, namely:

E.) Spectrum analysis is one of the tools of the gravity method that utilizes the equation of the Fourier transform (time domain to frequency domain). The Fourier transform is used to mathematically transform data from a spatial gravitational anomaly amplitude function to a gravitational anomaly amplitude function in the frequency domain or in the sense of determining the depth of the subsurface anomaly based on the Fourier transform (Andrian &; Jefri, 2018).

F.) Moving Average *Window Filter* is a method or separation technique that if analyzed from the spectrum will resemble a low pass filter so that the output of this process is a low frequency of Bouguer anomaly which will represent a deeper depth (regional) because this low frequency has a deeper penetration. Furthermore, the residual anomaly is obtained by constricting the regional anomaly from Bouguer's anomaly.

G.) Derivative Analysis

The First Horizontal Derivative (FHD) or First Horizontal Derivative, also known as Horizontal Gradient, is a method used to determine the location of horizontal contrast density boundaries from gravity data. FHD of gravity anomalies caused by a body tends to reveal the edges of that body. FHD be calculated using the following approach

$$FHD = \frac{g_{(i+1)} - g_{(i)}}{\Delta x} \quad (6)$$

Information:

$g_{(i+1)}$ = gravity anomaly value of data at (i+1) (mgal)

$g_{(i)}$ = gravity anomaly value of data at (i) (mgal)

$\Delta x =$ difference between the distance on the path (m)

Second Vertical Derivative (SVD) is used to surface sources of anomalies that are superficial. SVD is an analysis that has the property of a high pass filter, which can describe local anomalies associated with shallow structures so that the value can be used to identify the type of fault in the area including ascending or descending faults (Hartati, 2012). The calculation of Second Vertical Derivation (SVD) is expressed in the equation:

$$SVD = \frac{g_{(i+1)} - 2g_{(i)} + g_{(i+1)}}{\Delta x^2} \quad (7)$$

Gravity Data GGMPlus

GGMplus is a gravitational field model based on data from the GRACE satellite, GOCE satellite, EGM2008, and topographic gravity. GGMplus provides five gravitational field functions, namely gravitational acceleration, gravity disturbance, north-south and east-west vertical deflection, and quasi-geoid altitude. The GRACE and GOCE gravity satellites measure Earth's gravitational field with passive measurements. Passive measurements take advantage of the natural response from the source by using Satellite to Satellite Tracking (SST) mode relative to the Earth. SST mode utilizes two satellites, namely gravity satellites and Global Positioning System (GPS) satellites to determine the position of satellites in measuring the earth's gravitational field. In this study, the data used were gravity disturbance and geoid data as elevation.

Figure 4. GRACE satellite system and GPS (http://www.csr.utexas.edu/grace/).

3 Results and discussion

The research is in the Bengkulu basin. The Bengkulu basin is one of the forearc basins. The Bengkulu Basin is enclosed by two fault systems, namely the Mentawai Fault and the Sumatran Fault. The process of unification and separation of the Bengkulu Basin from the South Sumatra Basin can be studied and observed in the Paleogene, the stratigraphy of both basins is almost the same. Both developed graben systems in several places. The Bengkulu Basin contained Graben Pagar Jati, Graben Kedurang-Manna, and Graben Ipuh (at the same time in the South Sumatra Basin at that time there were grabens Jambi, Palembang, Pematang, and Kepahiang) But after Neogen, the Bengkulu Basin entered a deeper basin than the South Sumatra Basin, evidenced by the development of massive carbonate reefs in the upper Miocene that were almost equivalent in age to the Parigi carbonate in West Java.

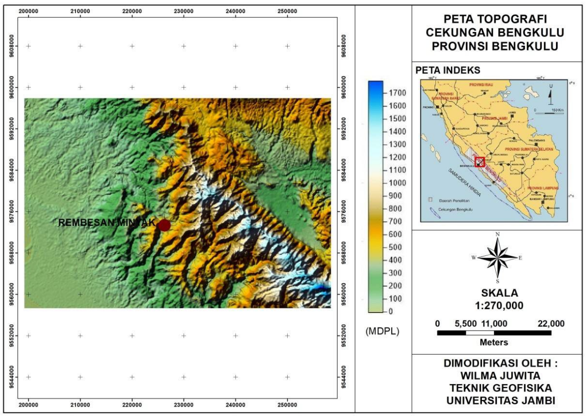

Figure 5. Topographic Map of the Research Area.

3.1 Bouguer's anomaly

Bouger anomaly often referred to as *Complete Bouguer Anomaly* (CBA) is a gravitational acceleration anomaly that is influenced by the density of mass below the Earth's surface that has been corrected.

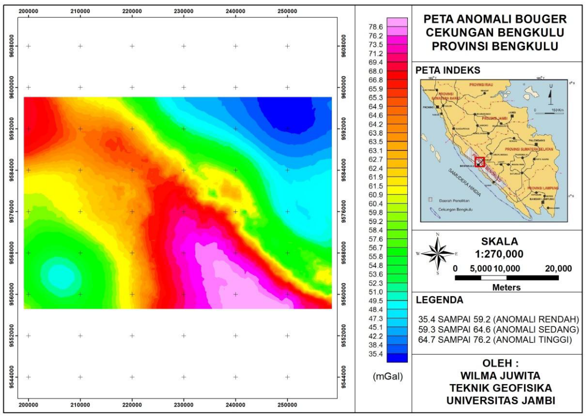

Figure 6. Map Complete Bouguer Anomaly.

The Complete Bouguer anomaly (CBA) map still contains components of regional anomalies and residual anomalies. CBA anomaly values ranging from 35.4 to 76.2 (mGal) indicate that there are differences in subsurface structure that vary depending on subsurface lithology that will provide different density responses. Low anomalies with values of 35.4 to 59.2 (mGal) were in the Northeastern and Southwest parts of the study area with those indicated by dark blue to green colors. The moderate anomaly with values of 59.3 – 64.4 (mGal) is indicated by a yellow to reddish-orange color. High anomalies with values of 64.7 to 76.2 (mGal) are indicated by red to pink colors in the Southeast-South and Northwest parts. From the anomaly value of CBA, it can be predicted that one of the Bengkulu sub-basins is in the Northeast and Southwest parts of the study area.

3.2 Spectrum Analysis and Moving Average for Anomaly Separation

Spectral analysis is performed to estimate window width as well as depth estimation of gravity anomalies. Spectrum analysis is carried out by transforming the Fourier line that has been determined on the CBA map. Moving average window filter is a method or separation technique that when analyzed from the spectrum will resemble a low pass filter so that the output of this process is a low frequency of Bouguer anomalies that will represent deeper depths (regional).

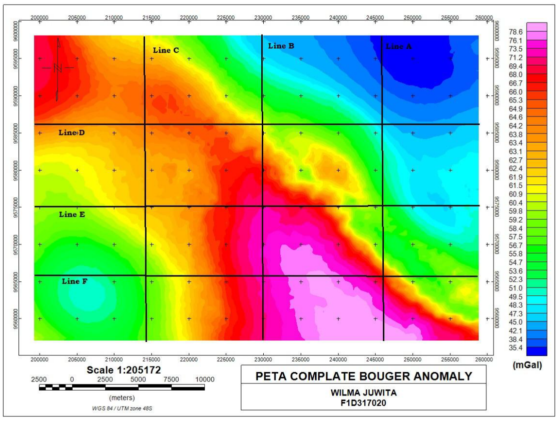

Figure 7. *Slice* Specral Analysis.

Table 1. Results of Spectral Analysis Results (Spectral Analysis).

Line	Regional	Residuals	N
A	-21516	-3151.5	38.333
B	-21778	-3532.1	38.624
C	-25248	-3893.7	36.066
D	-23355	-3464.3	39.582
E	-25465	-3583	39.097
F	-28257	-3560	43.211
Average	**-24269.8**	**-3530.77**	**39.152**

3.3 Regional anomalies

Anomaly Regional is obtained by doing a low pass filter process with a window width value of 39 x 39. Regional anomaly describes deeper subsurface structures. On the regional anomaly map, low anomaly values range from 37.2 – 59.1 mGal. Medium anomalies with values ranging from 59.2 – 64.2 mGal and high anomalies with values ranging from 64.4 – 73.3 mGal.

In the south-to-northwest regional anomaly shows high anomaly values of 64.3 mGal to 73.3 mGal. This indicates that there is a lithology of rocks that have a large density. Based on regional geology where the southern part of the study area is related to the formation of the Breksi unit of Andesite to basalt volcanoes. The formation is thought to originate from leaf hills and cold hills with a thickness of around 300m. The high anomaly with values of 61.5 mGal to 68.2 mGal located in the northwest of the study area indicates high density. Where in the northwestern part of the study area is associated with the Bitunan Formation (conglomerate, breccia, reef limestone, tufa clay, pumice, scraped wood) and the Simpang aur Formation (conglomerate, breccia, tufa sandstone, mollusk-containing claystone with lignite inserts).

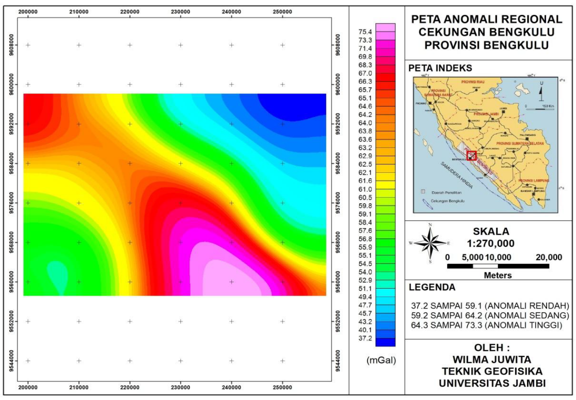

Figure 8. Regional Anomaly Map.

3.4 Residual anomalies

Residual anomaly is obtained by doing grid math in the data gridding section. Where the CBA grid is subtracted from the Regional grid so that the residual anomaly map grid is obtained. In Figure 9, low anomalous values range from -3.6 to -0.3 mGal with color indications that are blue to green. Moderate anomalies with values ranging from -0.2 to 0.9 mGal indicated by yellow to orange colors. High anomalies range from 0.10 to 4.1 mGal indicated by red to pink color.

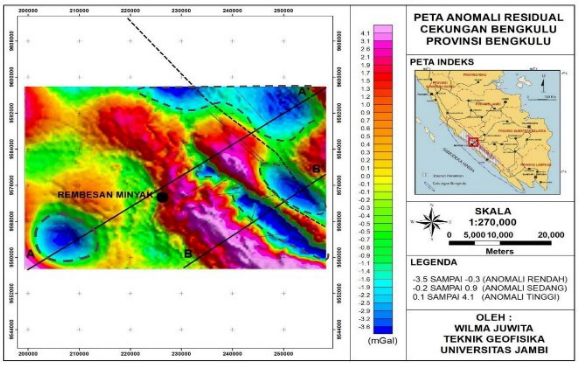

Figure 9. Fault Overlay Residual Anomaly Map.

High anomalies in residual anomalies indicate the presence of host structure. These rocks are used as a barrier between sub-basins with one another. While low anomalies indicate the presence of a graben structure. So that based on the residual anomaly map, it can be interpreted that there are 4 indications of the Bengkulu sub-basin contained in the research area. This is in accordance with the statement of Supriyani E and Tatang P (2020) stating that through residual maps, qualitative delineation of sub-basins can be carried out by looking at their anomalous patterns. The existence of sub-basins is characterized by The existence of low-value anomalous surrounded by high-value anomalous patterns.

The sub-basin contained in this study area was formed due to collision activity between the Australian Indian plate and the Sunda microplate then caused the formation of Graben as a sedimentary basin. Each sub-basin is bounded by an elevation characterized by a high anomalous value. The presence of height can potentially be an anticline.

Filter Derivative

Derivative analysis is used to determine boundaries and determine the type of fault. To get this, First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) were carried out from the Complete Bouguer anomaly Map. Where this derivative filter is a highly fast filter that can pass anomalies that have high frequencies that will strengthen the noise value. So a fast filter band is done to reduce the high-frequency Bouguer anomaly. From the results of the bandpass filter, the first horizontal derivative and second vertical derivative filters are carried out which aim to increase the frequency of low-frequency Bouguer anomaly.

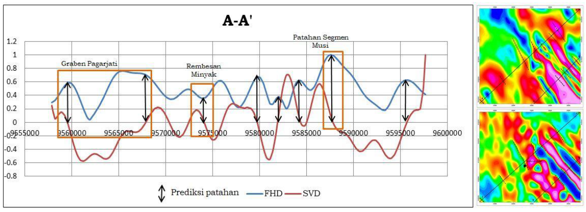

Figure 10. FHD and SVD Graphics A-A trajectories.

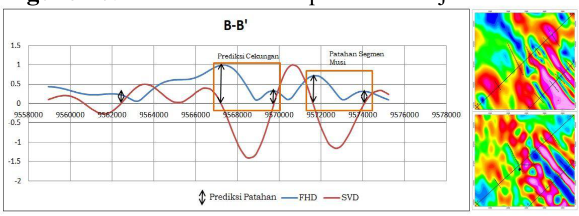

Figure 11. FHD and SVD Graphics Cross B-B'.

On the FHD and SVD maps, 2 passes of slicing are carried out. The slice data contains information on latitude, longitude, FHD values, and SVD values. The latitude or longitude values are plotted into the curve on the x-axis, while the FHD and SVD values as the y-axis as shown in the FHD and SVD graphs below. Then the FHD and SVD curves are juxtaposed for analysis. The existence of faults is seen from the FHD curve while finding out the type of fault is seen by the SVD curve. Analysis of the prediction of a fault on the FHD graph is determined from the maximum peak and minimum peak values limited by the SVD curve which is 0 or close to 0.

In the FHD and SVD graphs that have been carried out, a graben zone in the study area is flanked by 2 types of rising faults. Both FHD and SVD chart analysis of the study area found many fault zones. The type of fault that dominates is the type of ascending fault. The type of ascending fault is determined from the absolute value of the maximum SVD is smaller than the absolute value of the minimum SVD. An oil seepage found in the Kampong Padang Capo area in the analysis of the derivation chart is controlled by a rising fault.

2 Dimensional Modeling

2D modeling is a forward modeling stage. Forward modeling is a process to describe a state below the earth's surface that provides a response that matches observational data or field data. Thus the model that has been made is considered to have represented subsurface conditions in the study area.

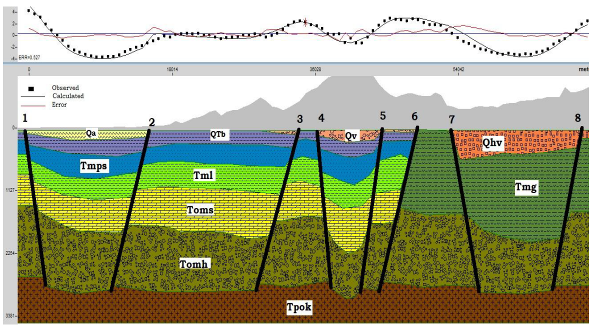

Figure 12. 2D Model of A-A' Trajectory.

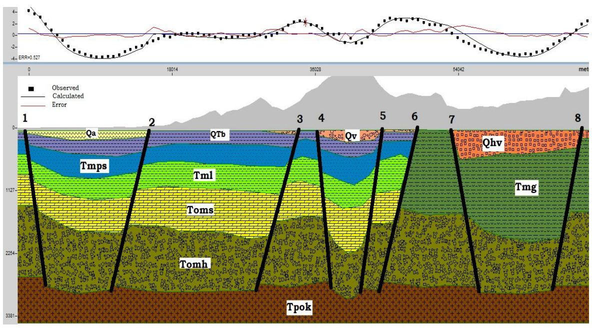

Figure 13. 2D Model of B-B Trajectory.

In 2-dimensional modeling of A-A' trajectories that describe the shape of the subsurface, this shows the same response as fault analysis in FHD and SVD graphs. There are many fault zones in this modeling result with an A-A line error value of 0.527 and a B-B trajectory of 0.607. 2D modeling consists of seven layers. Where the top formation is a quaternary deposit in the form of an Alluvium Formation consisting of chunks, sand, silt, mud, and clay. This Alluvium Formation (Qa) is the youngest unit revealed in the regional geology of the Bengkulu basin area and has an average density value of 1.8 gr/cc. Volcanic rock unit formation (Qv) consisting of andesite to basalt, tuff, and lava breccia with an average density value in this formation is 2.2 gr/cc. Volcanic Breksi Formation (Qhv) consists of volcanic breccia, lava, and tuff arranged andesite to basalt with an average value in this formation is 2.3 gr/cc.

The second layer is the Bitunan Formation (QTb) with rock lithology, namely tufa rocks, polymeric conglomerates, tuffs, and tufa clays with lignite inserts and plant remains. The Bitunan Formation has an average density of 2.26 gr/cc. The third layer is the Simpangaur formation (Tmps) with lithology of conglomerate sandstones, sandstones, mudstones containing mollusks, and tufa sandstones. The Simpangaur Formation has an average density of 2.36 gr/cc. The fourth layer is the Lemau Formation (Tml) with lithology of claystone, limestone, coal, sandstone, and conglomeration. The Lemau Formation has an average density of 2.38 gr/cc. The fifth layer is the Seblat Formation (Toms) with interspersed rock lithology of claystone, limestone, and siltstone with sandstone inserts and conglomeration. The Seblat Formation has an average density of 2.45 gr/cc. The sixth layer, the Upstream formation (Tomh), consists of lava, volcanic breccia, and tuff, changing from andesite to basalt. The upstream formation has an average density of about 2.7 gr/cc. The seventh layer is the Kikim formation (Tpok) which consists of volcanic breccia, tuff, lava with sandstone inserts, and claystone having an average density of 3 gr/cc.

Then also in 2-dimensional modeling the Gumai formation was exposed to the surface. The Gumai Formation (Tmg) consists of napalm limestone shale, claystone with tufa sandstone inserts, and limestone sandstone. The Gumai formation has an average density of 2.35 gr/cc. This formation is revealed at the end of the A-A trajectory in the Kapahiang area. Before the separation between the Bengkulu basin and the South Sumatra basin, the Kapahiang area was a graben of the South Sumatra basin. The 2-dimensional modeling carried out also found a low in the Kapahiang area.

Based on 2-dimensional modeling and derivative analysis, it shows that at the beginning of the A-A’ trajectory, there is a graben where in the map of the Bengkulu basin the area is a teak fence graben flanked by two rising faults. The oil seepage area shows that there is a fault near the seepage area, this is in accordance with the analysis of FHD and SVD graphs which show the type of fault in the form of an ascending fault. The existence of a horst and graben structure parallel to the Sumatran fault indicates a folding. So the assumption is that oil seepage that occurs in Padang Capo Village comes from a graben close to the Sumatran fault controlled by the rising fault. In the book Oil and Gas Geology written by Sukandarrumidi (2013), rising faults can act as a trap element and are usually always associated with folds.

The regional geological map of the Bengkulu sheet, shows an oil seepage in the Lemau formation. Petrographic analysis and SEM analysis conducted by Heryanto R (2007b) showed that Seblat Formation sandstones have an average secondary porosity value of 3.63% and Lemau Formation sandstones with an average porosity value of 2.73% which shows that Seblat Formation and Lemau sandstones have the same porosity. While the Seblat Formation limestone with an average value of less than 3% is one of the reservoir rocks. This is also evidenced by the discovery of an oil show in the Arowana 1 well, offshore drilling of Bengkulu, found in volcanic clastic rocks, namely sandstone and dolomite limestone. Wiyanto B, et al (2021) hydrocarbon prospects in the Gumai formation of the Bandar Jaya sub-basin, the main reservoir is sandstone, while the main reservoir is limestone. In regional geology and stratigraphy of the Bengkulu sheet where the Baturaja Formation and Gumai Formation are equivalent to the Seblat Formation in the Bengkulu basin.

However, 2-dimensional modeling shows that there are many layers of rock formations that can act as overburden so as to inhibit a hydrocarbon from migrating. An overburden is ordinarily impermeable in the form of solid clay. In the research of Heryanto R (2007b) in petrographic and SEM analysis solid and impermeable claystone are found as inserts, both in the Seblat Formation and Lemau Formation depending on where the reservoir rocks themselves are located. Batulempung is also found in Bitunan formations.

4 Conclusion

Based on the Residual Anomaly map of the Bengkulu basin shows low anomalous values ranging from -3.6 to -0.3 mGal, medium anomalies with values of -0.2 to 0.9 mGal, and high anomalies with values of 0.1 to 4.1 mGal. Low anomaly values indicate the presence of Graben structures and high anomalies indicate the presence of horst structures. The existence of a horst and graben structure indicates a folding with anticline and syncline types and then also many ascending faults are found in the study area. Among the horst and graben structures and faults, it is expected that some are hydrocarbon traps. In addition to structural traps, hydrocarbon traps are also found originating from rock formations that act as caprocks.

Glossary of Terms and Symbols

Symbol	Definition	Unit
FHD	First Horizontal Derivative	(mGal/m^2)
SVD	Second Vertical Derivative	(mGal/m^2)
GGMPlus	Global Gravity Model Plus	
SST	Satellite To Satellite Tracking	
GPS	Global Positioning System	
CBA	Complete Bouger Anomaly	(mGal)
Qa	Alluvium Formation	
Qv	Volcanic Rock Unit	
Qhv	Volcano Breccia Unit	
QTb	Bitunan Formation	
Tmps	Simpang Aur Formation	
Tml	Lemau Formation	
Toms	Seblat Formation	
Tomh	Upper Simpang Formation	
Tpok	Kikim Formation	
Tmg	Gumai Formation	
SEM	Scanning Electron Mickroscope	

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Reference

Amin, T. C., Kusnama, Rustandi, E., & Gafoer, S. (1994). Geology of the Manna and Enggano sheets, Sumatra, scale 1:250,000. Center for Geological

Research and Development.

Andrian and Jefri. 2018. Basement Structure Mapping Using Energy Spectral Analysis – Multi Window Test (ESA-MWT) Method of Gravity Data in North Sumatra Basin. University of Indonesia. Jakarta

Boggs, Jr. S. 2006. Principle of Sedimentology and Stratigraphy 4th edition, pp. 550-553, Pearson Education, inc., Upper Saddle River New Jersey.

Gafoer, S., Amin, T. C., & Pardede, R. 1992. Geological map of the Bengkulu sheet, Sumatra, scale 1:250,000. Center for Geological Research and Development.

Guntoro, A., dan Djajadiharja Y.S., 2005, Tectonic Scenario of the Sumatra Fore-Arc Basin in Relation to the Formation of Petroleum Systems., International Conference on Geology, Geotechnology and Mineral Recources of Indochina (GEOINDO 2005) 28-30 November 2005, Khon Kaen, Thailand.

Hartati, A. 2012. Identification of Fault Structure Based on Derivative Analysis of Gravity Method in Sulawesi Island. FMIPA UI Vol. **30**. Jakarta.

Heryanto, R. (2005). Research report on hydrocarbon resources in the Bengkulu Basin, Bengkulu. Center for Geological Research and Development, Geological Agency, Ministry of Energy and Mineral Resources.

Heryanto, R. (2006a). Characteristics of the Seblat Formation in the South Bengkulu area. Jurnal Sumber Daya Geologi, 16, 179–195.

Heryanto, R. (2006b). Provenance of sandstones in the Lemau Formation of the Bengkulu Basin. In Proceedings of the National Seminar on Indonesian Geology: Dynamics and Its Products. Center for Geological Survey, Bandung, December 5–6, 2006.

Heryanto, R. (2007a). Diagenesis of sandstones in the Lemau Formation of the Bengkulu Basin and its potential as a hydrocarbon reservoir rock. Mineral dan Energi, 5, 58–70.

Heryanto. R. (2007b). Possible Hydrocarbon Presence in the Bengkulu Basin. Indonesian Journal of Geology. Vol **2**. No. 3. 199-131.

H.M Petroleum Engineering. 2016. Petroleum System. UPN Veterans. Yogyakarta.

Jacobs, J. A., R. D. Russell, and J. T. Wilson. 1974. Physics And Geology: New York: McGraw: Hill Book Company.

Massinai and Muhammad A. 2015. Tectonic Geomorphology. Science Library. Yogyakarta.

Newcomb K. R. and McCann, W. R., 1987. "Seismic History and seismotectonics of the Sunda Arc". Journal of Geophysical Research, Vol. **92**, No. B1, pp 421-439. American Geophysical Union.

Pulunggono, A., Agus H.S., Kosuma, C.G. 1992. Pre-Tertiary and Tertiary Fault Systems as a Framework of the South Sumatra Basin; A Study Of Sar-Maps. Proceedings Indonesian Petroleum Association, **21**, p340 – 360.

Reynolds, J. M. 2011. An Introduction to Applied and Environmental Geophysics. John Wiley & Sons.

Sarkowi, M. 2014. Exploration of Gravity. Graha Ilmu.

Setyanta. B and Setiadi I. 2010. Structural patterns and geodynamics of the Bula Basin, based on gravity anomaly. Journal of Geological Resources. Vol. **20**.

SKK MIGAS. 2016. Work Procedure Guidelines on Geological and Geophysical Engineering. Jakarta. Number: PTK-061/SKKO0000/2016/S0

Suhadiyatno. 2008. Modeling of three-dimensional gravity methods using Matlab. FMIPA UI. Jakarta

Sukandarrumidi. 2013. Oil and Gas Geology For Beginner Geologists. Gadjah Mada University Press. Bulaksumur. Yogyakarta.

Supriyana E and Tatang P. 2020. Correlation of Kemite and Melawi Basins Based on Analysis of Gravity Data. Oil and Gas Technology Research and Development Center (LEMIGAS). Vol. 54.No. 1. Jakarta.

Telford, W. M., W. Telford, L. Geldart, R. E. Sheriff, and R. Sheriff. 1990. Applied geophysics. Cambridge University Press.

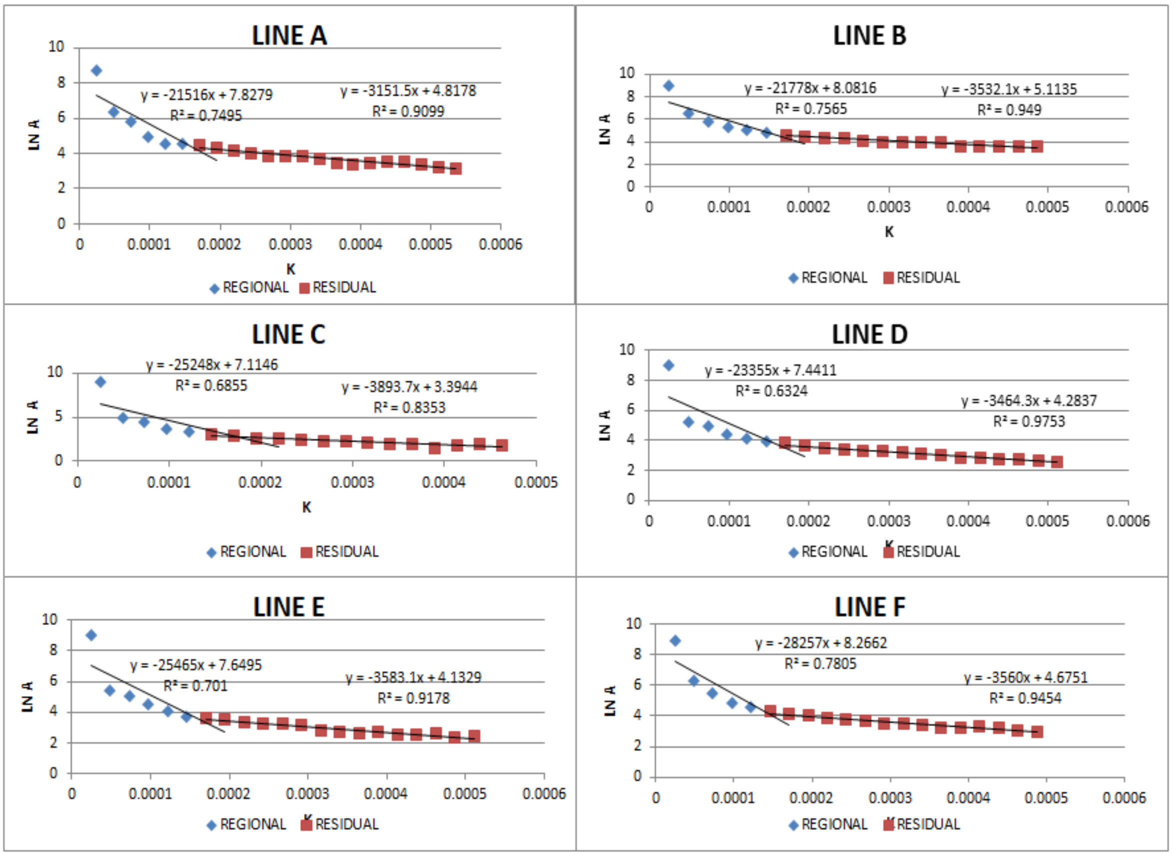
Wiyanto B, Taufan J, Sulistiyono, Hendhy P, Yuli W, and Diana P. 2021. Hydrocarbon Potential of Bandarjaya Sub-Basin, Lampung Province. LEMIGAS Publication Sheet. Vol. 43. No. 1. Jakarta.

Yulihanto, B., Situmorang, B., Nurdjajadi, A., & Sain, B. (1995). Structural analysis of the onshore Bengkulu Forearc Basin and its implication for future hydrocarbon exploration activity. In Proceedings of the 24th Annual Convention of the Indonesian Petroleum Association. Indonesian Petroleum Association.

ATTACHMENT

Elkins (1951)				
0.0000	-0.0833	0.0000	-0.0833	0.0000
-0.0833	0.0667	-0.0334	-0.0667	-0.0833
0.0000	-0.0334	+1.0668	-0.0334	0.0000
-0.0833	-0.0667	-0.0334	-0.0667	-0.0833
0.0000	-0.0833	0.0000	-0.0833	0.0000

Appendix I. Elkins SVD Coefficient Filter (1951).



Appendix II. k vs Ln curve a Specral Analysis.

Slice A-A'					
No	FHD (mGal/m^2)	SVD (mGal/m^2)	SVD Mak (mGal/m^2)	SVDMin (mGal/m^2)	Fault Type
1	0.571	0.032	0.128	-0.537	Thrust
2	0.702	0.02	0.209	-0.539	Thrust
3	0.593	0	0.148	-0.201	Thrust
4	0.638	0.055	0.205	-0.525	Thrust
5	0.351	-0.028	0.676	-1.175	Normal
6	0.588	-0.003	0.676	-0.328	Normal
7	0.982	0.029	0.517	-0.527	Thrust
8	0.62	-0.018	0.187	-0.527	Thrust

Appendix III. Results of FHD and SVD Chart Analysis A-A Trajectories.

Slice B-B'					
No	FHD (mGal/m^2)	SVD (mGal/m^2)	SVD Mak (mGal/m^2)	SVDMin (mGal/m^2)	Fault Type
1	0.246	0.009	0.471	-0.144	Normal
2	0.992	0	0.398	-1.408	Thrust
3	0.307	-0.0 05	0.963	-1.408	Thrust
4	0.702	-0.059	0.963	-1.159	Thrust
5	0.314	0	0.319	-1.159	Thrust

Appendix IV. Results of FHD and SVD Chart Analysis B-B Trajectory.

Rock Type	Density (gr/cm3)	Average density (gr/cm3)
Sedimentary Rocks		
Alluvium	1,96 – 2,00	1,98
Chalk	1,20 – 2,40	1,92
Soil	1,53 – 2,60	2,00
Clay	1,63 – 2,67	2,21
Gravel	1,70 – 2,40	2,00
Sand	1,70 – 2,30	2,00
Sandstone	1,61 – 2,76	2,35
Shale	1,77 – 3,20	2,40
Limestone	1,93 – 2,90	2,55
Dolomitte	2,28 – 2,90	2,70
Igneous rocks		
Rhyolite	2,35 – 2,70	2,52
Andesite	2,40 – 2,80	2,61
Granite	2,50 – 2,81	2,64
Diorite	2,72 – 2,99	2,85
Lavas	2,80 – 3,00	2,90
Basalt	2,70 – 3,30	2,99
Gabbro	2,70 – 3,50	3,03
Metamorphic rocks		
Graywacke	2,60-2,70	2,65

Slate	2,70-2,90	2,79
Amphibolite	2,90-3,04	2,96
Eclogite	3,20-3,54	3,37
Metamorphic	2,40-3,10	2,74

Appendix V. The value of rock density according to Telford et al (1990).