Indonesian Physical Review

Volume 4 Issue 3, September 2021

P-ISSN: 2615-1278, E-ISSN: 2614-7904

Identification of Horst and Graben Structural Patterns Using Gravity and *Second Vertical Derivative* (SVD) Methods in The Lubuksikaping Area of West Sumatera

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ARTICLE INFO

Article info:
Received: 28-06-2021
Revised: 12-09-2021
Accepted: 26-09-2021

Keywords:
Gravity Method; SVD; Structural Patterns; Lubuksikaping

How To Cite:
Zulkaromi, M., Setiadi, I., Suharno, Mulyatno, B.S., Haerudin, H., Ferucha, I. (2021). Identification of Horst and Graben Structural Patterns Using Gravity and Second Vertical Derivative (SVD) Methods in The Lubuksikaping Area of West Sumatera. Indonesian Physical Review, 4(3) pp 153-165

DOI:
https://doi.org/10.29303/ipr.v4i3.118

ABSTRACT

The Lubuksikaping area is located between the main fault branching of Sumateran Fault so, there are many quite complex structures. This research was conducted to determine the structure pattern of the high (horst) and low (graben) that formed in the sub- surface of the Lubuksikaping area, West Sumatera. This research uses gravity data which will then be carried out by spectral analysis, upward continuation, separation of regional and residual anomalies, and Second Vertical Derivative (SVD) analysis. Furthermore, 2D forward modeling is carried out to determine the correlation between the 2D subsurface forward modeling and the resulting SVD graph. Based on the analysis of the regional anomaly map, the measured low anomaly is due to the area in the form of a structural valley formed due to the activity of the Sumatera Fault, while the high is thought to be a structural hill (horst) that forms an elongated mountain range and separated by graben. In addition, based on the analysis of the residual anomaly map, the low anomaly indicates the presence of a depositor (graben), whereas the high anomaly is indicated as the presence of rocks with high-density contrast values . and is interpreted as a horst structure. Based on the analysis of the horst and graben patterns in the residual Bouguer anomaly, there is elevation zone (horst) that are northwest and northeast on the residual map and it is known that there are 3 graben structures in Lubuksikaping, namely Panyabungan Graben, Rao Graben and Sumpur Graben with relative northwest-southeast direction. The 2D models of paths A-A' and B-B' show faults that are located relatively the same as SVD graph obtained from the residual SVD anomaly map.

Introduction

The Lubuksikaping area and its surroundings are part of the Bukit Barisan Mountains path. This research area is located on the Lubuksikaping Sheet, which is in Kuantan

Formation, Panti Formation, Silungkang Formation, Ulai Granite Intrusion, Undefined Volcanic-Sediment, and Quaternary Sediment, as shown in Figure 1. The landscapes in the area of this study were built by a hilly landscape structure, the rest of the volcanic cone, cone volcanoes, valleys structure, as well as alluvial plain [1]. The shape of structure was identified using the method gravity method. To determine the subsurface structure using the gravity method, it is necessary to get the data processing of the gravity anomaly indicates differences in density in the subsurface, which is Bouguer anomaly who will then do the separation of residual and regional anomalies in research area. The gravity anomaly pattern obtained will then be used to determine the pattern of the high (horst) and low (graben) structures in the Lubuksikaping area assisted by Second Vertical Derivative (SVD) analysis. The graben in the Lubuksikaping area tends to be northwest-southeast as seen in the Panyabungan (Panyabungan Graben), Rao (Rao Graben) and Lubuk Attitude (Sumpur Graben) areas referred to as the Sumatran Fault System. This fault is thought to have been active since the Oligocene [2].

Second Vertical Derivative (SVD) was carried out to bring out the shallow effects of regional influences and to determine the boundaries of existing structures in the research area. Furthermore, 2D forward modelling will be carried out which correlated with the SVD analysis results to determine the boundaries of the existing structures in the research area. The general principle of forward modeling is to minimize the difference between observation anomalies to reduce ambiguity [3]. This modeling is a process of calculating data from theoretical results that will be observed on the earth's surface if the model parameters are known. Often the term forward modeling is used for the trial-and-error process. It is hoped that from this trial-and-error process, a model that matches the response with the data is obtained [4]. Based on the information from gravity data and derivative analysis, it is hoped that it can be used to model subsurface geological fault structures in the Lubuksikaping area, West Sumatera.

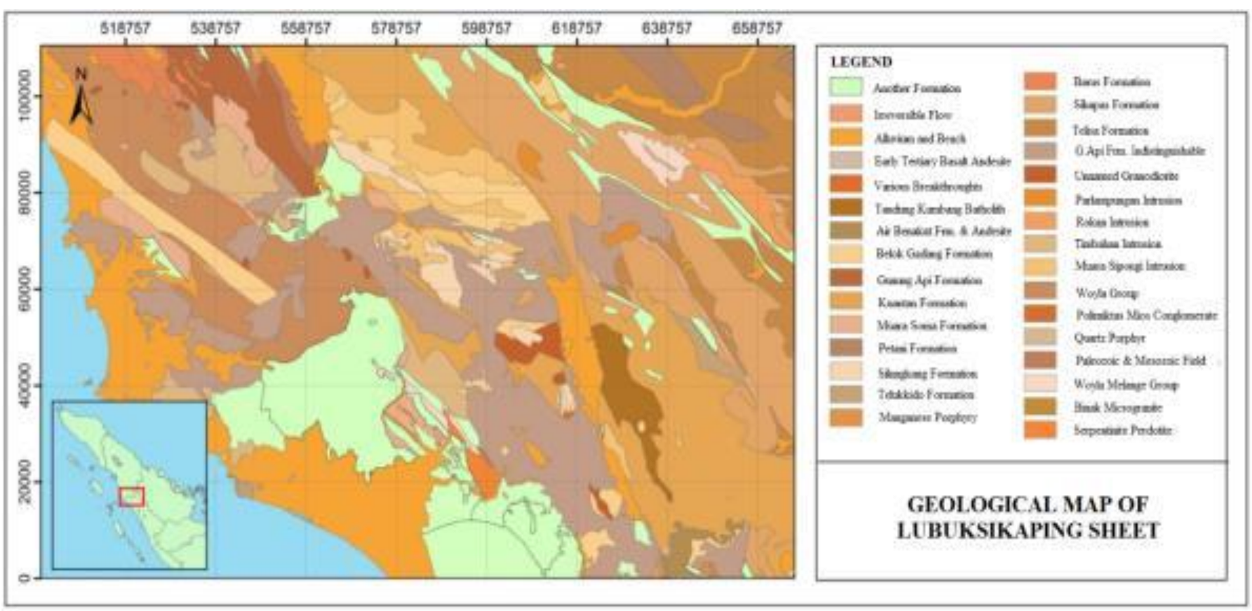

Figure 1. Geological map of research area [5].

Theory and Calculation

Gravity method is one of the methods in geophysics that is used for investigating the subsurface conditions based on differences in the density of the surrounding area (ρ = g/cm^3). The gravity method measures a certain gravitational field to determine the lateral density of subsurface rocks. Differences in density values can be caused by differences between the distance from the center of the earth to the surface and differences in topography. This can give rise to various values of the gravitational field on the earth's surface. The spatial variation in gravity arises because of the heterogeneity of the earth's mass [6]. The shape and magnitude of the gravity anomaly are influenced by subsurface density, depth, horizontal area, and magnitude. The appearance of gravity anomaly is caused by density contrast, rock depth, and anomalous dimensions [7].

The gravity method has a high element of ambiguity. The ambiguity is caused by the density and depth of the rock as a source of anomalies. To reduce the ambiguity factor, one way that can be done is to estimate the depth using spectral analysis [8]. Spectral analysis is carried out by transforming the Fourier path that has been determined on the complete Bouguer anomaly contour map. Spectrum analysis uses the Fourier transform principle by converting data from the space domain to the wave number domain. The gradient of the spectrum analysis graph is proportional to the depth of field of the anomaly, where a gradient with a large value reflects a regional anomaly while a gradient with a smaller value reflects a residual anomaly [9].

In this study, 1D spectral analysis was used by slicing and digitizing the map using 4 km (Δx) on 10 tracks. Then spectral analysis of all cross sections was carried out to determine the depth of field of deep and shallow anomalies. The depth of field anomalies in this case expressed by the value of the slope (gradient) of the log power spectrum (Ln Amplitude) to frequency (k), one of which is as shown in Figure 2 which is a graph of the relationship between Ln A and k on track 1.

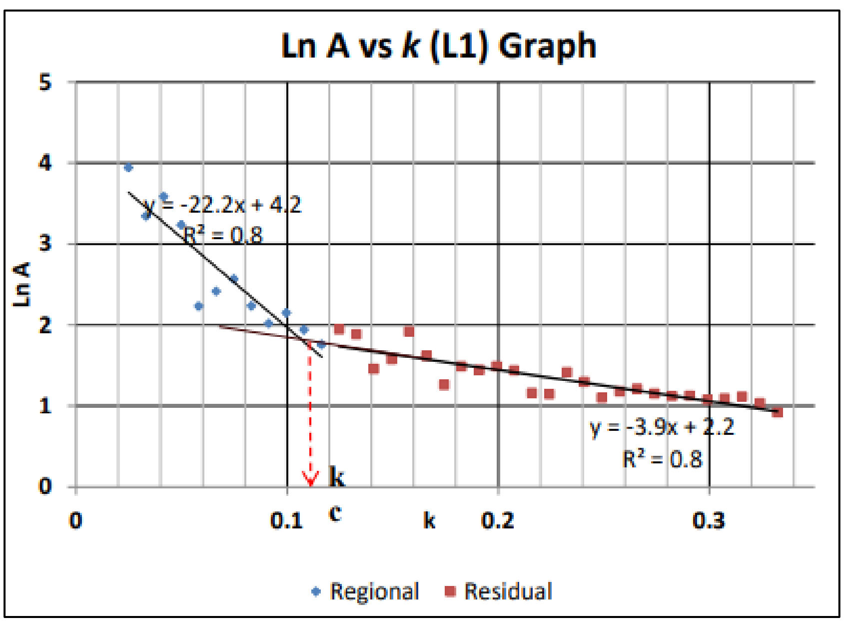

Figure 2. Relationship between Ln A and k on track 1

Second Vertical Derivative (SVD) was carried out to bring out the shallow effects of regional influences and to determine the boundaries of existing structures in the research area. The effectiveness of Second vertical derivative (SVD) analysis in improving gravity data that otherwise would appear very [10]. SVD analysis of gravity data is widely used to describe and mapping faults in subsurface exploration [11] and general geological mapping [12, 13]. On the SVD curve, the presence of a fault will be indicated by a value of 0 (zero). Theoretically, this method is derived from Laplace's equation [14]

$$\nabla^2 \Delta g = 0 \tag{1}$$

where

$$\nabla^2 \Delta g = \frac{\partial^2(\Delta g)}{\partial x^2} + \frac{\partial^2(\Delta g)}{\partial y^2} + \frac{\partial^2(\Delta g)}{\partial z^2} \tag{2}$$

So, the equation becomes,

$$\frac{\partial^2(\Delta g)}{\partial x^2} + \frac{\partial^2(\Delta g)}{\partial y^2} + \frac{\partial^2(\Delta g)}{\partial z^2} = 0 \tag{3}$$

$$\frac{\partial^2(\Delta g)}{\partial z^2} = -\left[\frac{\partial^2(\Delta g)}{\partial x^2} + \frac{\partial^2(\Delta g)}{\partial y^2}\right] \tag{4}$$

From those equations, the Second Vertical Derivative of a surface gravity anomaly is the same as the negative of its second-order horizontal derivative which is more practical to work with. In this study, the author uses the SVD filter calculated by Elkins (1951) [15]. The Second Vertical Derivative (SVD) filter with the Elkins operator is shown in the following Table 1.

Table 1. SVD Filter Operators According to Elkins (1951) [16]

		Operator Filter SVD		
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

Experimental Method

This research begins with obtaining raster data on the Bouguer anomaly map in the Lubuksikaping area. Then, the map is digitized so that it can be processed digitally. The research flow chart can be seen in Figure 3. Then, make a Slice on the Bouguer Anomaly Map for Spectral Analysis Process. In this process, a graph of lnA vs *k* is made, to estimate the depth of the anomaly gravity and calculate cutoff points. Cutoff number will be used to calculate the window width to be used for regional anomaly filtering. Then the Upward Continuation stage was carried out on the Bouguer Anomaly Map and continued with making a residual anomaly map. The next stage is the Second Vertical Derivative analysis carried out on the residual anomaly map which has been obtained. Then forward modeling will be carried out which will produce a 2D model which will then be interpreted for the geological fault pattern.

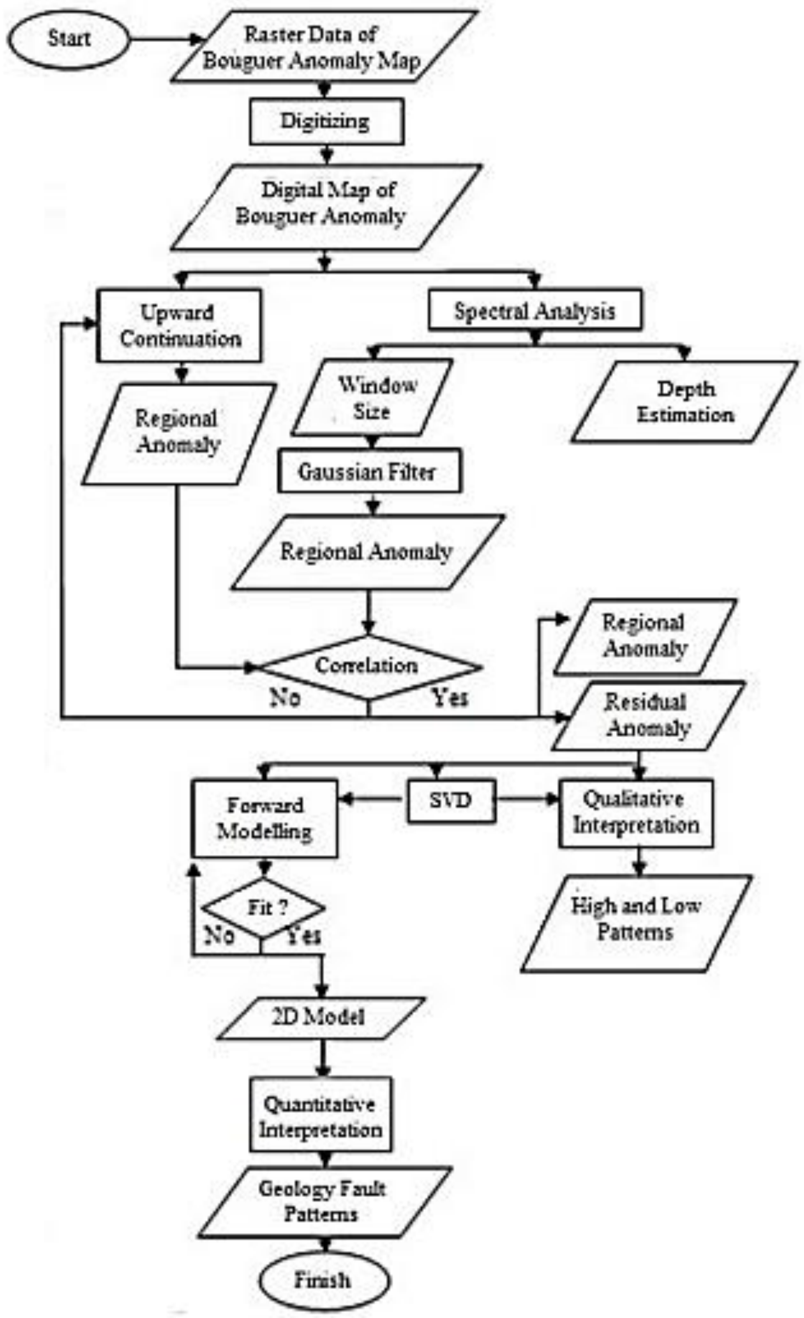

Figure 3. Research Flow Chart

Result and Discussion

Based on the regional anomaly map of research area shows the anomalous value range of -17 to 21 mGal, as shown in Figure 4. The low anomaly is shown in dark blue and light blue with a range of values between -17 to -5 mGal. Low anomalies located on the northern area of research and in the late southeast direction relative northwest southeast. Moderate anomalies are shown in green and yellow with values ranging from -5 to 1 mGal. Moderate anomaly is found in the middle and on the southwest coast. Meanwhile, high anomalies are shown in red and pink with values ranging from 1 to 21 mGal. High values spread on the west and east sea area of research that extends to the direction of relative northwest southeast.

This regional anomaly pattern describes the influence of the rock structure in a deeper position, the scale of the crust to the lower crust (lower crust). The low anomaly is thought to be caused because the area is a structural valley. The structure of the valley created by the Sumateran Fault activity. The high anomaly is suspected as a hill structure (horst). In this high area it forms elongated mountains, separated by grabens. The constituent rocks consist of meta-volcanic and meta-sedimentary as well as intrusive rocks. This causes the anomalous response to be high.

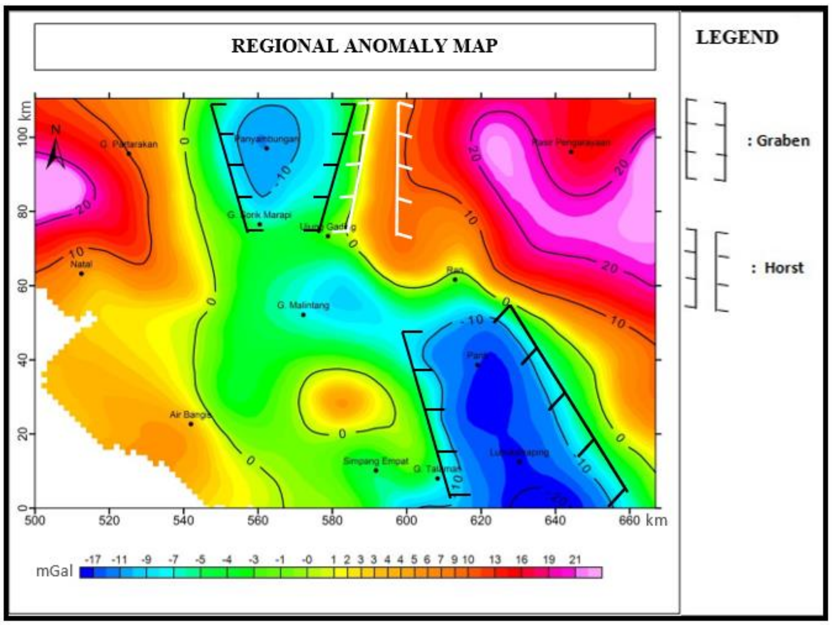

Figure 4. Regional anomaly map of the research area.

Meanwhile, residual anomalies map shows a more complex anomaly pattern than regional anomaly because describes anomalous patterns with shorter wavelengths which reflects the effect of the shallower anomalous object, as shown in Figure 5. Residual anomaly obtained have anomalous small difference values range between -6 mGal up to 6 mGal. This anomaly pattern is divided into three categories which is low, moderate, and high anomalies. Low anomaly value between -6 mGal up to - 2 mGal with a contrast of dark blue to light blue which indicates the existence of rocks with low density contrast, which is interpreted as a deposenter (graben). The moderate anomaly has an anomaly value of -2 mGal until 2 mGal with a green to yellow color contrast, this anomaly is transition area from low to high anomly that occupies almost the entire research area. While highly anomalous values between 2 mGal to 5 mGal with a contrasting red to pink color that indicates the presence of rocks with high contrast density values. The high anomaly value shown from this anomaly is interpreted as a horst structure.

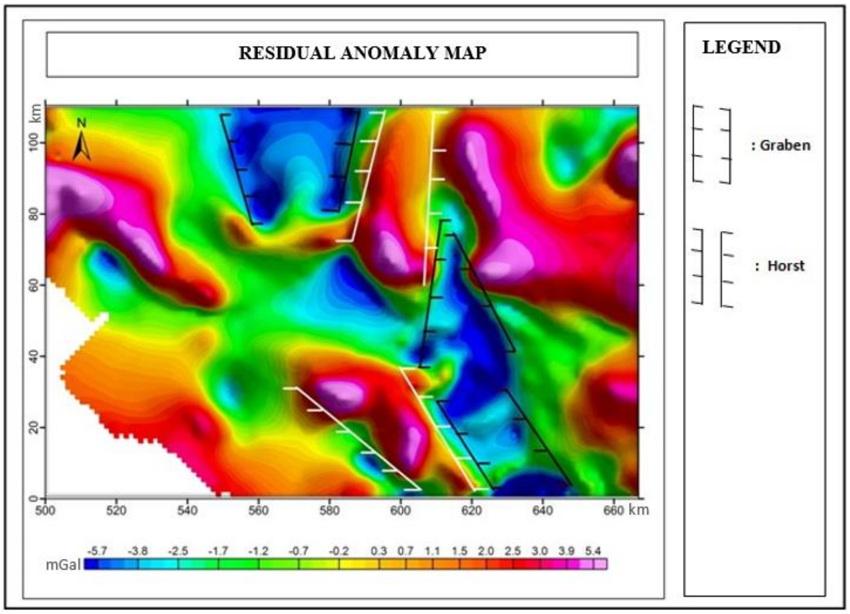

Figure 5. Residual anomaly map of the research area.

Based on Figure 6, the northwest and northeast areas on the residual map are interpreted as elevation zones. Generally, the rocks that make up this high zone are transformed, sedimentary, and breakthrough rocks. The ridges of the hills are controlled by fault and fold structures. Fault structures generally trending northwest-southeast to follow the general pattern of Sumateran Fault, while some are trending east-west. In the east, folding and fault structures develop, while in the west there is no visible folding structure. The valley area is in the north extending to the southeast. This low zone is interpreted as a graben area located between the branches of the Sumateran Fault which forms a graben pull apart bassin. This graben tends to be northwest-southeast as seen in the areas of Panyabungan (Panyabungan Graben), Rao (Rao Graben) and Lubuksikaping (Sumpu Graben).

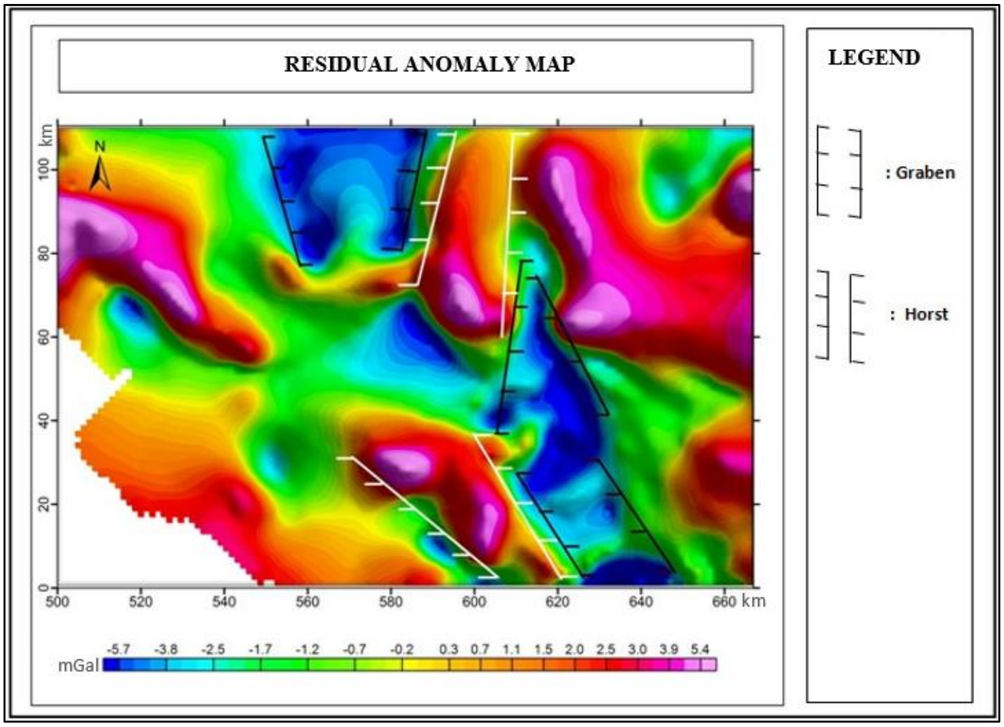

Figure 6. Residual anomaly map showing horst and graben patterns in the study area.

In this study, derivative analysis was performed on the residual anomaly map. The SVD contour map is based on the basic principles and calculation techniques of Elkins (1951). The residual SVD contour with a value of 0 which is depicted by a dotted line indicates the presence of a shallow fault structure or fault in the study area. On the SVD map, the dotted line residual anomaly is found in almost all research areas. This is in accordance with geological information where the study area is interpreted as a graben area located between the branching of the Sumateran Fault. The Sumateran Main Fault System is interpreted as a magmatic pathway from Sumatera tectonic. So that many structures appear in the form of a complex fault.

On the residual anomaly SVD map shown in Figure 7, the blue line is the fault obtained from the geological map, while the red line is the fault from the SVD analysis. The location and direction of the fault is relatively the same as the fault on the geological map which has a northwest-southeast direction. The residual SVD map of the study area shows the distribution of faults centered in areas with low residual anomaly values. The area is traversed by 2 major faults, namely the Lubuksikaping Fault and the Pungkut-Barilas Fault which are also responsible for the formation of the graben in the vicinity. The faults contained in the residual SVD map are used to help interpret the elevation pattern, graben pattern, and 2D modeling.

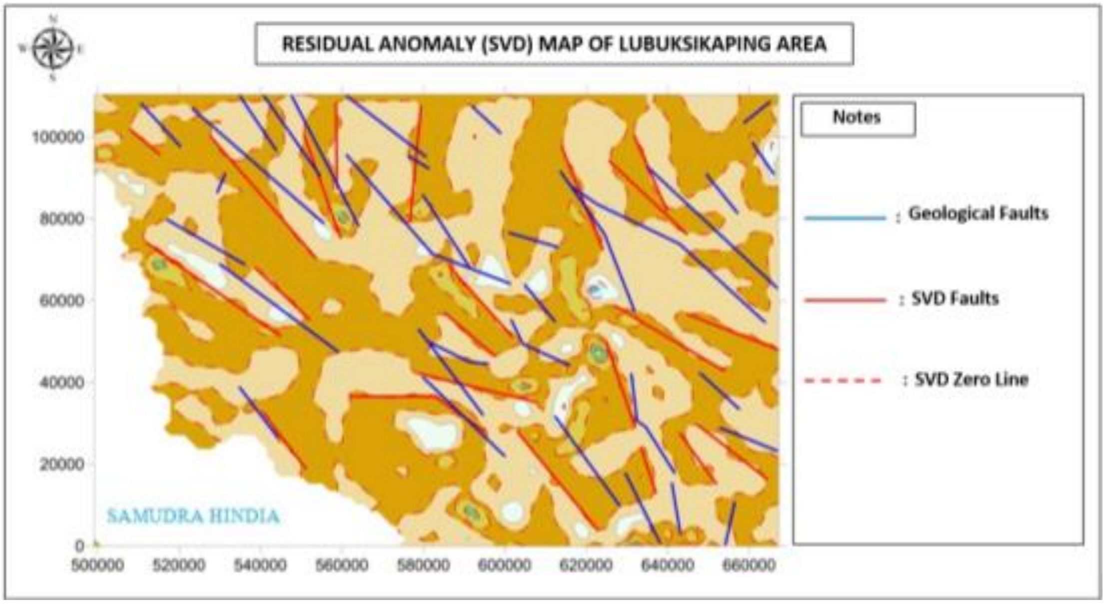

Figure 7. Residual anomaly SVD map using Elkin Filter.

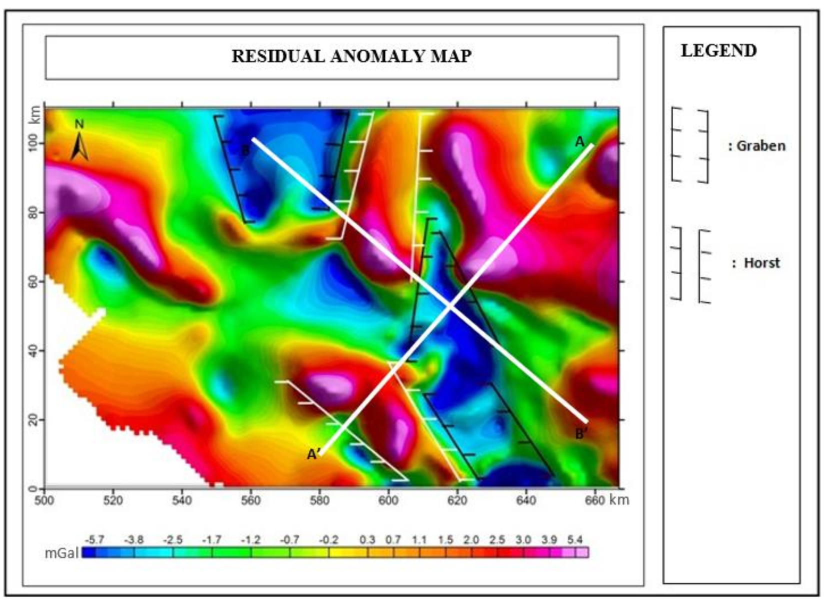

Figure 8. Cross section on residual anomaly map for subsurface modeling.

Forward modelling is performed on residual anomaly map, to bring up the superficial effects. So, it can be known the model of the subsurface in detail and shallow faults can be interpreted in subsurface models. On this study using two cross-sections at residual anomaly (Figure 8), there are A-A' and B-B' cross-section to determine the pattern of lower and highs. The A-A' cross-section is elongated with a relative northeast–southwest direction perpendicular to the fault direction in the study area, while the B-B' cross-section extends in a northwest-southeast relative direction.

Fault location determination is assisted by information from the SVD line graph. Based on the profile that has been made **(**Figure 9**),** the fault structure is shown when the anomaly value is at the zero point. The 2D model of the A-A' cross-section shows faults that are relatively like the SVD graph obtained from the residual SVD anomaly map. The 2D B-B' cross-section model shows faults that are located relatively the same as the SVD graph obtained from the residual SVD anomaly map. From the subsurface geological model (Figure 10) it is known that the B-B' cross section crosses 1 high and 2 valleys. The low anomalies response in the Panyambungan Area is interpreted as the Panyambungan Graben depression zone and then filled with layers of sedimentary rock. The appearance of the high anomaly on the residual map is caused by the uplift of the bedrock by the reverse fault. The valley area around the Rao Area is a normal fault zone that creates a half graben structure. The anomalies response appears slightly elevated to the east of the Lubuksikaping Area due to layers of old sedimentary rock that came to the surface.

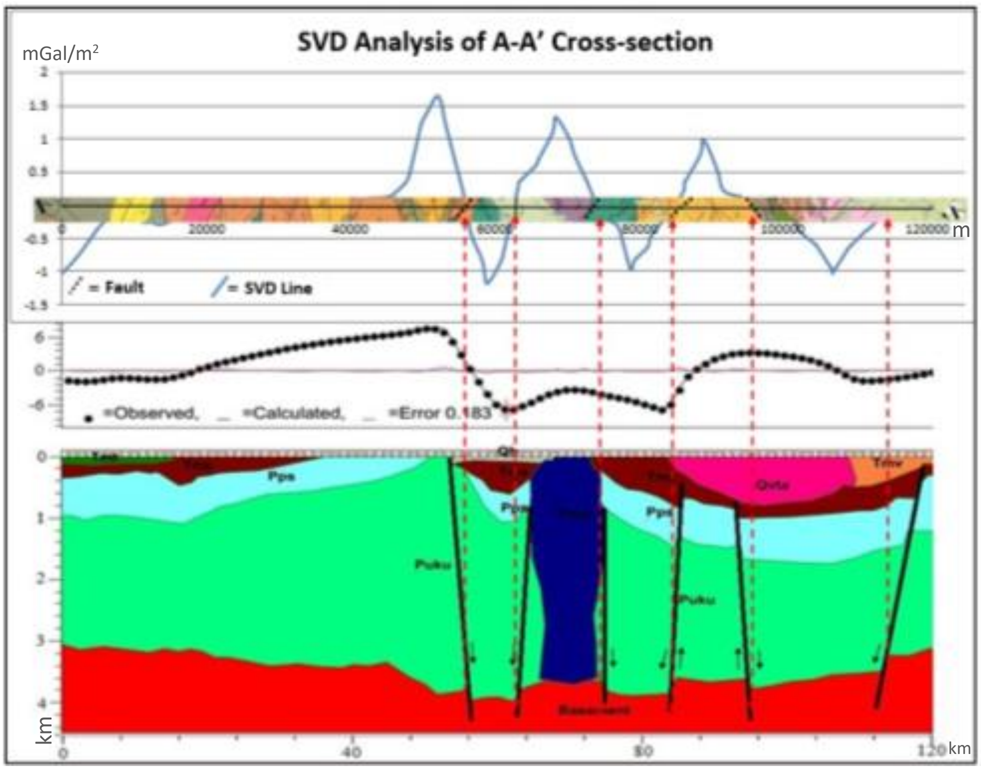

Figure 9. Determination of fault path A-A' based on SVD analysis.

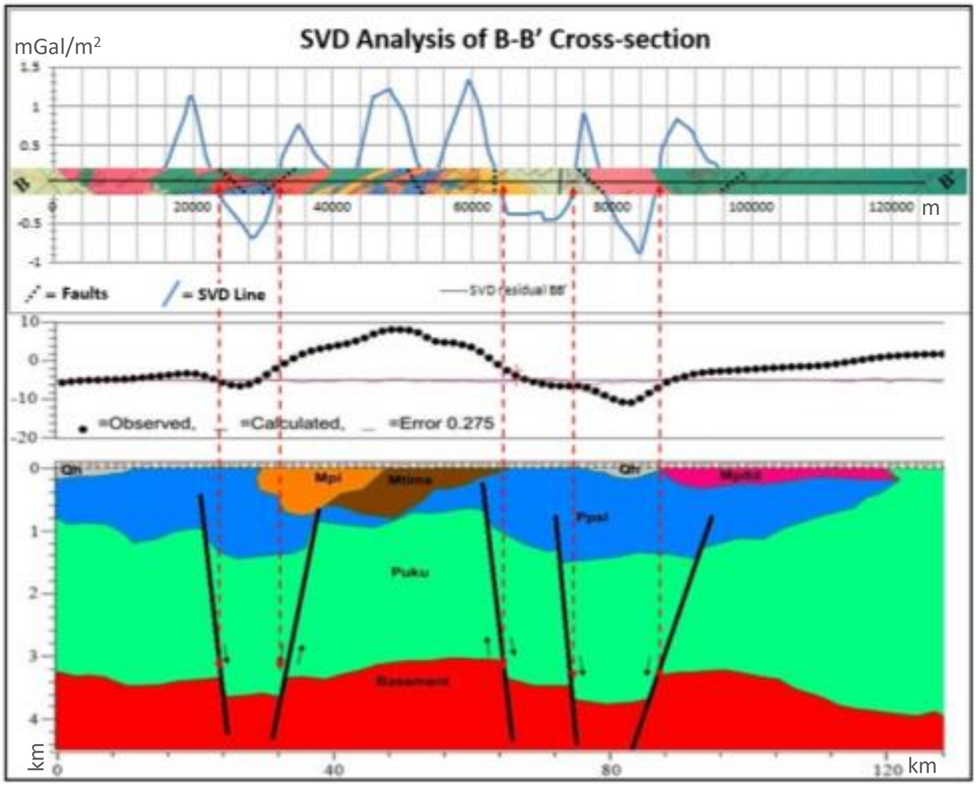

Figure 10. Determination of fault path A-A' based on SVD analysis.

Conclusion

The conclusions obtained from this research, firstly based on the analysis of regional anomaly map of the study area, it is known that low anomalies caused by that area forms of valley structure that is created as a result of Sumateran Fault activity. While high anomalies are predicted as a hill structure (horst) that forms an elongated mountains and is separated by graben. The other conclusion is based on the analysis of the residual anomaly map of the study area, low anomalies indicated the presence of a depocentre (graben). Meanwhile, highly anomalies indicated as the presence of rocks with high contrast density values and is interpreted as a structural horst.

Refer to the analysis of horst and graben patterns on residual Bouguer anomalies, there is a height zone (horst) with northwest and northeast trend on residual anomaly map and it can be known there are three graben structures in Lubik Sikaping Area, such as Panyabungan Graben, Rao Graben, and Sumpur Graben in a relatively northwest-southeast direction. It also can be concluded the 2D model of the A-A' cross-section and B-B' cross-section model shows faults that are located relatively the same as the SVD graph, it is known that the B-B' cross section crosses 1 high and 2 valleys. The low anomalies response in the Panyambungan Area is interpreted as the Panyambungan Graben depression zone and then filled with layers of sedimentary rock. The appearance of the high anomaly on the residual map is caused by the uplift of the bedrock by the reverse fault.

Acknowledgment

The authors would like to thank the Geological Survey Center Bandung, West Java, for the opportunity and permission to access data in this research and all parties who have provided advice and support for this research.

References

[1] Lumbanbatu, U.M. 2009. Morfogenetik Daerah Lubuksikaping Provinsi Sumatera Barat. *JSDG* Vol. 19 No. 2 April 2009.

[2] Verstappen, H. T. 1985. Applied Geomorphological Survey and Natural Hazard Zoning, ITC Syllabus. The Netherlands. 37 pp.

[3] Andari, W., Karyanto., & Kurniawan, R. 2019. Identifikasi Batas Sub-Cekungan Hidrokarbon Menggunakan Analisis Shd (*Second Horizontal Derivative)* Dan Svd *(Second Vertical Derivative)* Berdasarkan Korelasi Data Gayaberat Dan Seismik. *Jurnal Geofisika Eksplorasi* Vol. 5/No. 1 Maret 2019: 60-74.

[4] Grandis, H. 2009. *Pengantar Permodelan Inversi Geofisika*. Himpunan Ahli Geofisika Indonesia, pp. 93-100.

[5] Rock N.M.S., Aldiss D.T., Aspden J.A., Clarke M.C.G., Djunuddin A., Kartawa W., Miswar, Thomson S.J., & Whandoyo R. (1983). *Geology Map of Lubuksikaping* scale 1: 250,000, Sumatera. Geology Research Center.

[6] Handayani L. & Wardhana D.D. (2017). Gravity Exploration for Groundwater and Bedrock Topography in Serang, Banten. *Geological and Mining Research*, 27(2), pp.157–167.

[7] Murti M.D. & Nurhasan. (2016). Two-Dimensional Modeling of Gravity Data in the Lembang Fault Zone. *SKF 2016 Proceedings*. Bandung, pp.305–314.

[8] Setiadi I., Setyanta, & Widijono B.S. (2010). South Sumatera Sediment Basin Delineation Based on Gravity Data Analysis. *Journal of Geological Resources*, Vol. 20, No. 2, Pages: 93-106.

[9] Apriani M., Julius A.M., Joseph M., Heryanto D.T., & Marsono A. (2017). *Estimation of Sediment Thickness with Power Spectral Analysis on Gravity Anomaly Data in DKI Jakarta*. Jakarta: BMKG Earthquake and Tsunami Center.

[10] Sumintadireja, P., Dahrin, D., & Grandis, H. 2018. A Note on the Use of the Second Vertical Derivative (SVD) of Gravity Data with Reference to Indonesian Cases. *Journal of Engineering and Technological Science,* Vol. 50, No. 1, 2018, 127-139.

[11] Sarkowi, M. Identification of Structures in Ulubelu Geothermal Field Based on SVD Data Analysis of Bouguer Anomaly. *Jurnal Sains MIPA,* 16(2), pp. 111-118, 2010.

[12] Ali, Y.H., Azimi, A. & Wulandari, A. Mapping of Nusa Laut Fault Based on Nusa Laut August-September 2015 Earthquake Hypocenters and Gravity Data. *Proceedings of National Seminar on Physics and its Applications,* Universitas Padjadjaran, pp. FB11-FB18, 2015.

[13] Hartati, A. Identification of Fault Structure Based on Derivative Analysis of Gravity in Celebes Island, Undergraduate Final Project, Universitas Indonesia, 2012.

[14] Telford W.M., Geldart L.P., Sheriff R.E., & Keys D.A. (1976). *Applied Geophysics.* Second Edition. Cambridge University Press. Cambridge.

[15] Elkins, T.A. (1951). The Second Derivative Method of Gravity Interpretation. *Geophysics* v.23, pp. 97-127.

[16] Parsneau, H.P. 1970. *The Development of Two-Dimensional Digital Operators for the Filtering of Potential Data.* Montreal: Department of Mining Engineering and Applied Geophysics.