Magnetic Anomaly Patterns Using Trend Surface Analysis Application (TSA) on Marine Geology Mapping in The Balikpapan Waters (Map Sheet 1813–1814), East Kalimantan

Pola Anomali Magnetik dengan Menggunakan Aplikasi "Trend Surface Analysis" (TSA) pada Pemetaan Geologi Kelautan, Lembar Peta 1813-1814, Perairan Balikpapan, Kalimantan Timur

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ABSTRACT: The application of Trend Surface Analysis (TSA) method an geological and geophysical research in map sheets 1813-1814, Balikpapan Waters and its surrounding, shows the significant value of residual anomaly. The magnetic disseverance of regional and total anomaly value obtained the negative anomaly between -50 nT and -350 nT and positive anomaly between +50 nT and +400 nT. The contour of total and regional anomaly shows the magnetic properties of rocks which characterizes the geological arrangements of the research areas. Residual anomaly yielded from the 2nd order value of regional anomaly might be correlated with the formation of basin structures in the central and northern parts of research area, which is interpreted as a part of Kutai Basin.

Key words : TSA method, magnetic anomaly, geology and geophisics, Balikpapan Waters.

ABSTRAK: *Penerapan metode TSA dalam penelitian geologi dan geofisika di Lembar Peta 1813-1814, Perairan Balikpapan dan sekitarnya menunjukkan nilai anomali sisa yang cukup signifikan. Hasil pemisahan nilai anomali magnet regional dan anomaly total diperoleh nilai anomali yaitu antara -50 nT dan –350 nT dan anomali positif antara +50 nT dan +400 nT. Kontur anomali total dan anomali regional memperlihatkan sifat kemagnitan batuan yang mencirikan tatanan geologi daerah penelitian. Anomali sisa dihasilkan dari nilai anomali regional orde ke 2, kemungkinan berkaitan dengan pembentukan struktur cekungan di bagian tengah dan utara daerah penelitian yang ditafsirkan sebagai bagian dari Cekungan Kutai*

Kata kunci : *metode TSA, anomali magnet, geologi dan geofisika, Perairan Balikpapan.*

INTRODUCTION

Information on geophysical data, especially on marine magnetics at Balikpapan Waters, and its surroundings were relatively inadequate. Thus, magnetic methods utilized in geophysical researchs are expected to contribute preliminary data to determine the form of magnetic anomalies in Balikpapan Waters and its surroundings.

Analysis of magnetic anomalies using Trend Surface Analysis (TSA) in Balikpapan Waters, East Kalimantan, is a part of activity of geological and geophysical mapping that systematically conducted by Marine Geological Institute (MGI). The purpose of this study is to determine both regional and residual total magnetic anomalies pattern, which can well describe geological structure of the seabed surface.

By applying a method Trend Surface Analysis (TSA) from the calculation magnetic intensity total it is expected that the application of this method can show trend regional anomaly and residual. Furthermore, both of these anomaly pattern will support the geological structures interpretation of the study area.

This method is one of the oldest of mathematical technique which is used by geologists to conduct an interpretation of geological data and oil reserves that was applied in Moruga, Trinidad and Leduc Reefs, Alberta Basin, Canada (Wharton, 1993). One of the challenges that was faced by geologists in petroleum industry by applying TSA is to achieve optimum result in decision making. Analysis TSA can be used to define the geometric 3D models. This modelling have been done at several exploration activities and as a result the more oil reserve in complicated geological condition was found.

Polynomial equations and linear resultant produced a graphical representation of a mathematical equation (Davis, 1986). Mathematical methods used to separate these data are represented as maps and residual trend maps. The exodus of the application of this method served in contour map and a three-dimensional shape (3-D).

The research area is located at Balikpapan Waters and its Surrounding, between 1 15' and 2 45' South, 116 30' and 117 05' East, map sheet 1813-1814 (Figure 1).

Water depths of study area ranges from 15 to 65 meters, and more deeper toward the east and southeast of study area (Ilahude et al, 1999).

Application of magnetic methods in the study area was conducted simultaneously with continuous measurement of sea water depth (sounding). Generally, the track lines had been applied to get a good data and had been carried out by using MGI research vessel, Geomarin I. Balikpapan port was managed to be the starting point of measurement, as well as the base station of the research.

Principlly, magnetic method derived from magnetic induction in the core of the earth's magnetic field and permanent magnetization, which generally have different directions and intensities, and partially magnetized from the crystallization process (Telford et al, 1974). Therefore, the magnetic anomaly value obtained was either a combination of both or the result of pure induction. If the directions of permanent magnetic field and magnetic induction were similar, the value of magnetic anomaly will amplify and vice versa.

Magnetic data processing was based on magnetic intensity measurement to depict the pattern of magnetic anomalies in the study area. Thus, the coordinate position of longitude and latitude, and magnetic field intensity of the area will be acquired.

Measured magnetic field intensity is the sum value of main earth magnetic field, variations in earth magnetic field that related with variations in rock magnetic susceptibility, remanent magnetic field, and variations due to sun activity. Magnetic field intensity data are strongly influenced by earth's magnetic variations, which related to the variations in rock's magnetic susceptibility, generally known as local magnetic anomaly.

TSA is one of the polynomial methods which can depict geographic model of magnetic anomaly pattern in large scale. This method is a mathematical model of linear regression in polynomial coordinates of X and Y. Based on the applying this model, the obtained pattern of magnetic anomalies can describe the whole geology order in the area.

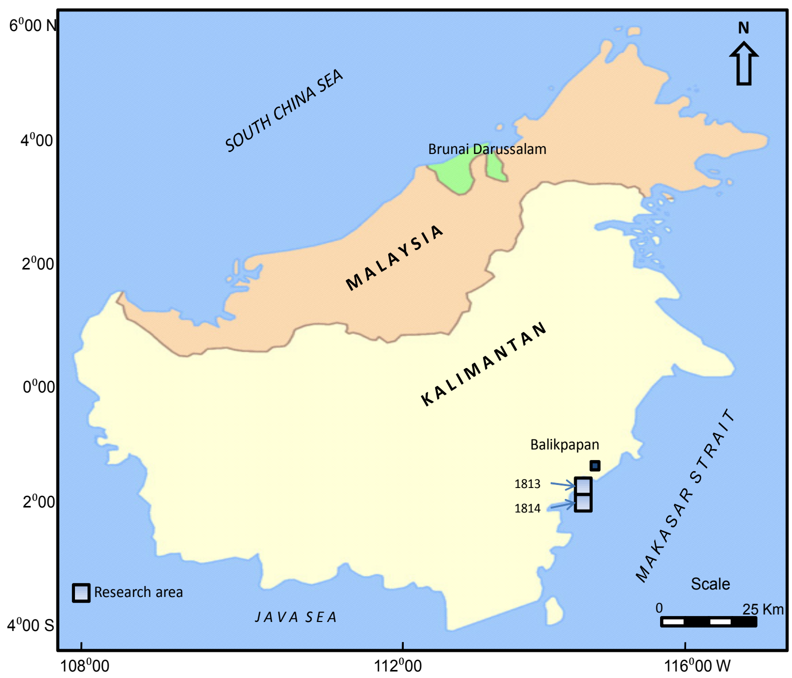

Figure 1. The research area in Balikpapan Waters and its surrounding, map sheet 1813-1814 (Ilahude et al, 1999)

Magnetic anomalies analysis in this paper will stress on the shape of anomalies as a result of applied TSA method, which can describe the pattern of regional and residual anomalies. Regional magnetic anomaly is a response from relatively deep source anomalies, while residual magnetic anomaly is a response from shallow source anomalies. It is expected that both residual and regional pattern of anomalies can more be visible.

Regional and residual anomalies pattern is obtained by applying TSA method from magnetic intensity calculation, may address comprehensive interpretation of geological structure in the research area.

Polynomial and linear resultant equations generated were graphical representations of mathematical equations (Davis, 1986). This mathematical method was applied to classify represented data as trend and residual map. Its output will be presented in a contour map of total magnetic anomalies of regional and residual.

The main objective of this study is to map total magnetic anomalies, of regional and residual in Balikpapan and its surrounding waters, and to refine the form of anomalies along the trajectories, by applying TSA method. This method is utilized to depict the order of residual anomaly patterns from reduced total and regional anomalies.

Geologically, the study area is a part of Sampanahan Sheet, Balikpapan, East Kalimantan. This is a relatively stable geological structure formed by nearly north-south direction of anticline and syncline (Heryanto et al, 1994). Thrust-faults and normal-faults with almost northeast-southwest direction were generally easy to observe in this area.

Tectonic activity in this particular area, were allegedly occurred since the Jurassic ultramafic, radiolarian chert and schist (Heryanto et al, 1994). During the Early Pliocene, granodiorite breakthrough occurred, followed by uplifting, erosion, and leveling. This activity lasted until the Eocene, forming land deposition of Tanjung Formation. Later in Oligocene, pool of sea occurred, yielding the limestones of Berai Formation. This activity was occurred simultaneously

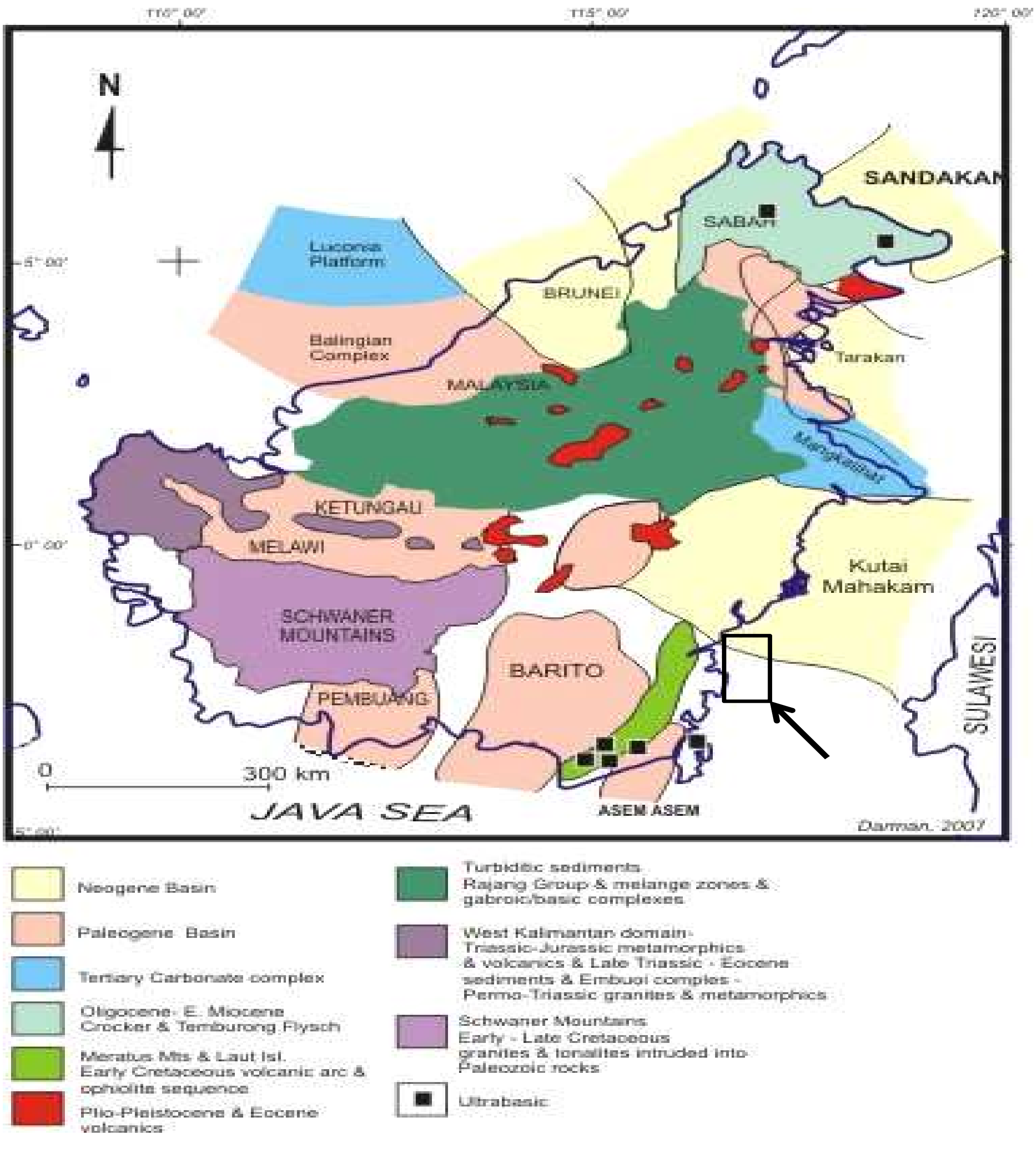

Figure 2. Geological Map of Kalimantan (Darman, 2007)

with classic sediment deposition of Pamaluan Formation. During the Middle Miocene, sea shrinkage were occurred and formed Warukin and Pulau Baling Formations. In Late Miocene, the deposition ceased with the uplifting and forming of Meratus, Barito, Kutai, and Pasir Basins. In the Pliocene – Plistocene, the leveling that deposited Dahor Formation occurred.

At the northern part of study area shows that Neogen Basin is called the Kutai Mahakam Basin (Figure 2). This area as potential area for hydrocarbon exploration, because some field on Kutai Mahakam Basin is produced the oil and gas.

METHODS

Magnetic intensity data from the sea were collected using a marine magnetometer system of *G-877 geometrics* model and proton procession model *G-856*. These magnetic sensor devices were pulled from the back of the ship, at a distance of three-times the length of it. Devices were operated simultaneously with 4 knots average of ship cruising speed. To determine the position of field data collection, integrated satellite navigation system was utilized by using *C-Nav* model of *DGPS Receiver* satellite. The data was received every two seconds and digitally processed using *Hypack Software* program.

To obtain the magnetic anomaly value, reduction of magnetic intensity effects due to Earth's magnetic field was performed. The value of measured magnetic intensity (T_{obs}) was corrected to the datum of global magnetism (International Geomagnetic Reference Field/IGRF) and to daily variation of magnetic intensity (vh), thus the total magnetic anomaly value was obtained in nano Tesla (nT) units.

According to Telford, et al, (1990), the value of total magnetic intensity around magnetized rocks formulated as follows :

$$\Delta \mathbf{T} = \mathbf{T_{obs}} - \mathbf{T_{IGRF}} \pm \mathbf{T_{VH}} \quad \text{.......................................} (1)$$

ΔT = *Total magnetic anomaly*
T_{obs} = measured magnetic intensity
T_{IGRF} = theoretical magnetic intensity according to IGRF at T_{obs} measurement station
T_{VH} = magnetic intensity due to daily variations

Total magnetic anomaly data was processed into the form of matrix calculation to obtain the value of regional magnetic anomaly using the 2nd order of Trend Surface Analysis (TSA), formulated by Krumbein (1963) with polynomial numbers as follows:

$$f(x_i,y_i) = b_0 + b_1x + b_2y + b_3x^n + b_4xy + b_5y^n \quad \text{.........} (2)$$

$f(x_i,y_i)$ = regional anomaly
b = polynomial constant
x_i = the x-coordinates in each observation station
y_i = the y-coordinates in each observation station
n = order

Total magnetic anomaly is the sum total of regional anomaly and residual anomaly, which can be mathematically written as follows :

$$T = f(x_i,y_i) + R_s \quad \text{..} (3)$$

T = total magnetic anomaly value
R_s = residual anomaly
$f(x_i,y_i)$= regional anomaly

Thus, residual anomaly (R_s) can be obtained from the difference between regional anomaly and total magnetic anomaly :

$$R_s = f(x_i,y_i) - T \quad \text{...} (4)$$

The value of regional and residual magnetic anomaly was analyzed using Surfer-8 Software to acquire the magnetic anomaly contour map.

RESULTS

Magnetic Track Line

The application of TSA method in geological and geophysical research at Balikpapan waters and its surrounding, 1813-1814 map sheets, showing significant value of residual anomaly. The magnetic disseverance of regional and total anomaly value obtained the anomaly between -50 nT and -350 nT and positive anomaly between +50 nT and +400 nT. The results which is obtained from the field measurement is the total magnetic field data which is still under the influence of external magnetic field components.

These influences were caused by magnetic field originating from the moon movements and the earth's temperature conditions, so the total anomaly data which were obtained needed to be corrected with the fluctuations of daily magnetic field variations. In this study, the research trajectory was drawn north-south and east west directions, with crosscheck line in the southern part of research area with southwest-northeast directions (Figure 3). Analysis of magnetic anomalies was conducted using *ΔT* formulations to obtain the total anomaly values, whereas the value of regional anomaly was obtained using the TSA method. Meanwhile, the residual anomaly was obtained from the reduction of total anomaly values in the entire trajectory. From the results of total, regional, and residual magnetic anomaly, an anomaly contour was drawn to see the pattern (trend) of those three kinds of magnetic anomalies in Balikpapan and its surrounding waters.

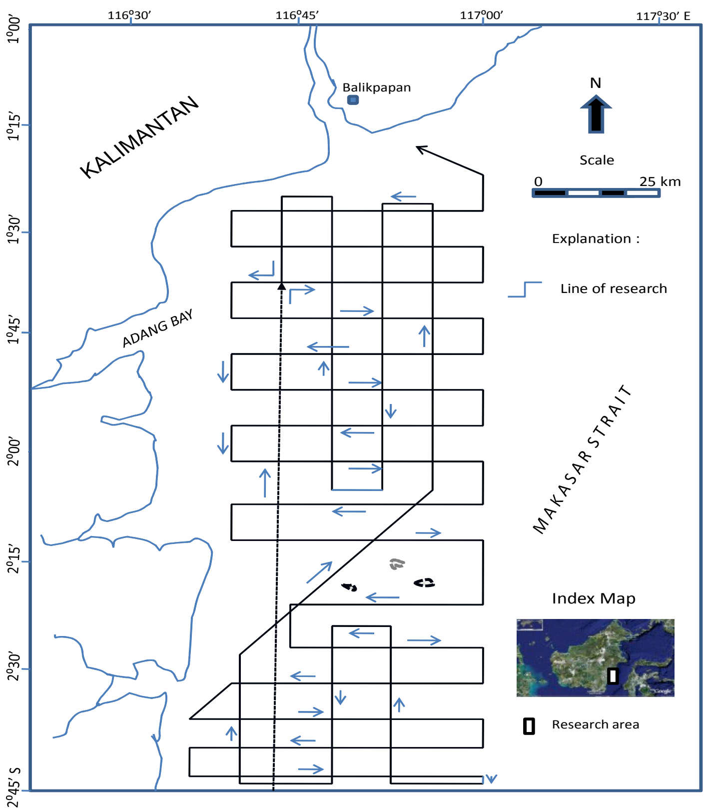

Figure 3. Drawn trajectory of magnetic survey in Balikpapan Waters and its surrounding (Ilahude et al, 1999).

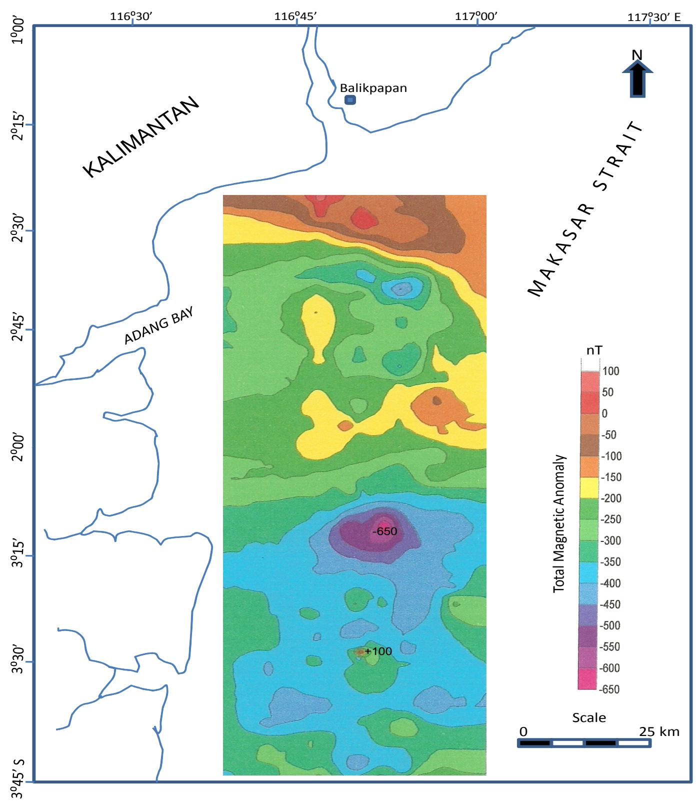

Figure 4. Total magnetic anomaly contour of Balikpapan waters and its surrounding

Total Magnetic Anomaly

Total magnetic anomaly values are obtained after correction to IGRF and variation of daily magnetic intensity were done. Distribution of total magnetic intensity gave the insight of its anomaly values between -650 nT and 100 nT. The contour of total magnetic anomaly was dominated by negative magnetic anomaly located in the central and northern part of research areas. The pattern of total magnetic anomaly contour is obtained as a resultant of magnetic intensity components which assumed to be associated with igneous rocks containing either high or low susceptibility.

The distribution of total magnetic anomalies was determined into two separate groups: between +50 nT and +100 nT belongs to positive anomaly group, while from -50 nT and -650 nt belongs to negative anomaly group. Through this distribution, positive anomalies +100 nT were located in the southern part of research areas, marked with pink colored notation. These anomalies were presumed to be related with geological structures in the area, and also an influence of magnetic rocks derived from volcanic rocks of Meratus. In the other hand, negative anomalies -650 nT formed a circle in the central of research area, that was interpreted as a non-magnetic rocks with low susceptibility, suspected to be sedimentary rocks.

The drawn total magnetic anomaly contour shows that the pattern of negative anomalies from -50 nT to -650 nT which are located in northern, central, and southern part of the research area, were presumed to be the part of deep layer of Kutai Basin structure see (Figure 4).

Regional Magnetic Anomaly

Group of low magnetic anomalies were scattered along the northern to the southern part of research area. To acquire the regional magnetic anomaly values, 2nd order of TSA formulation was applied by substituting the value of total magnetic anomaly at all magnetic trajectories. Separation using TSA-order method yields two regional anomalies depicted below.

The values of regional magnetic anomalies range from -150 nT to -410 nT. Regional magnetic anomalies were dominated by negative anomaly groups. This condition showed that the lithological order of its component rocks were dominated by sedimentary rocks with low magnetic susceptibility (Figure 5). This anomaly regional distribution magnetic delineates globally by layers of deeper rock, while anomalous total and anomalous delineates remaining layers of rock more shallow.

Residual Magnetic Anomaly

To acquire the residual anomaly values, reduction of total to regional magnetic anomaly values were carried out. From the results of the reduction, distribution of residual magnetic anomaly can be determined into another two groups as follows: negative anomaly ranged between -50 nT and -350 nT, and positive anomaly ranged between +50 nT and +400 nT (Figure 6). Generally, the pattern of this residual anomaly in several locations indicates some similarities to the total magnetic anomaly pattern (See Figure 4).

This form of similarity occurs since the residual anomaly is a reflection of magnetic basal rocks at a shallow sea depths. In the southern part of the research area, the occurence of positive anomalies were relatively high (+400 nT). It is suspected that high value of positive anomalies were related to polarization effect of magnetic rocks which was deformed by geological structure of the area, while the negative anomaly values were suspected as the part of Kutai Basin (See Figure 2).

DISCUSSION

From the analysis of regional anomaly by using the TSA method shows that anomaly great in map residual not preclude the possibility anomaly caused by the influence of weathered rock magnetic the volcanic rocks of Meratus. While the low magnetic anomaly allegedly sedimentary rock is non magnetic in relatively shallow depth.

To scatter anomalous value of residual value were obtained a picture that anomaly occupy the southern part of the study area with yellow color, notation brown to red, reflecting sensorial magnetic of bedrock has high susceptibility. The estimatetion of positive catter anomalous will associated with volcanic rocks that derived from

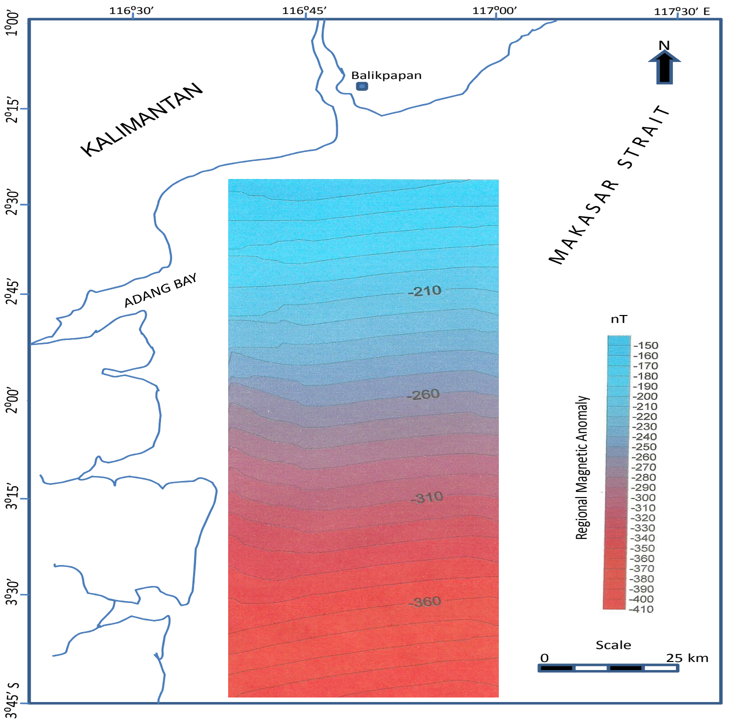

Figure 5. Regional magnetic anomaly contour of Balikpapan Waters and its surrounding

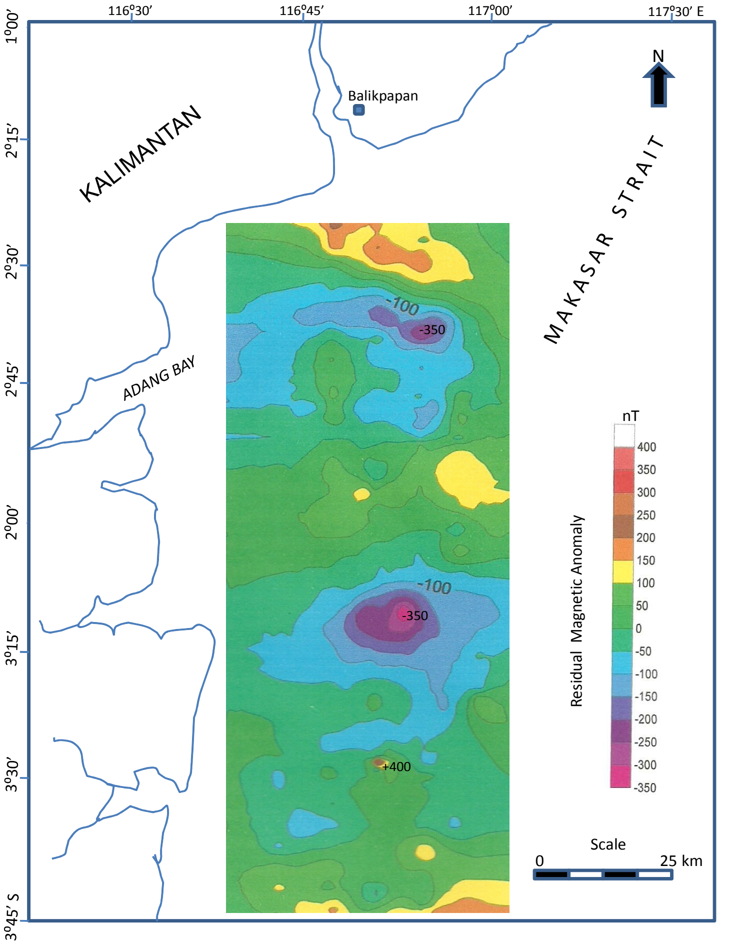

Figure 6. Residual magnetic anomaly contour of Balikpapan Waters and its surrounding

Volcano Meratus. While anomalous negative in northern and central regions will represent the sedimentary rock, even though the sedimentary rock some time will represent by low magnetic nature. Another possibility the relative low magnetic anomaly can also be caused by igneous rock or rock acidic metamorphic. From the application of the TSA method, the patterns of residual sensorial anomalous magnetic reflecting magnetic bedrock susceptibility that have a high anomaly, whereas at some places the negative anomalies is also found. To reduce this negative anomaly of the relation lithologi in the sedimentary rock of study area is not magnetic interpretation of Kutai Basin.

Based on the result of TSA method application show that the sedimentary deposits is thick and wide enough. This condition is indicated by regional negative anomaly map (Figure 5).

The difference in positive and negative anomaly value, on each map is presented by a colour in order to make easy interpretation. The interpretation of TSA method will show us the lithology and order bedrock as apart of sediment of the Kutai Basin.

CONCLUSIONS

Application of TSA method yields a significant magnetic anomalies pattern that is considered to be highly related to geological structure under the seabed. Residual anomalies separate the root cause of anomalies in the deeper layer, and high value of magnetic anomaly with large dimensions were depicted in the regional and residual magnetic anomalies. Positive anomalies found in the southern part of the research area were assumed due to the magnetic rocks derived from Meratus peaks. These anomalies were the source of relatively shallow anomalies which related to high magnetic susceptibility in the southern part of research area. In the northern and central part of it, negative residual magnetic anomalies were found and assumed to be low susceptibility rocks which interpreted as the part of Kutai Basin.

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REFERENCES

[1] Davis, G.V., 1986, *Numerical Methods in Engineering and Science*, *London*, Proc. Conf. p. 213.

[2] Heryanto, R., Supriatna, S., Rustandi, E., Baharudin, 1994, *Peta Geologi Lembar Sampanahan*, Kalimantan, PPPG.

[3] http://en.wikibooks.org/wiki/Darman, 2007, in The Geology of Indonesia/Kalimantan/ 2011.

[4] Ilahude, D., Usman, E., Ibrahim, A., Setyanto, A., Salahudin, M., Setyadi, D., Rachmat, B., 1999, Penyelidikan Geologi dan Geofisika Kelautan Daerah Perairan Kalimantan Timur, Lembar Peta 1813-1814, *Laporan Intern Pusat Penelitian dan Pengembangan Geologi Kelautan, Bandung.*

[5] Krumbein, W.C., 1963, Confidence intervals on low-order polynomial trend surfaces, *Journal Geophysical Research,* 68, 5869-5878.

[6] Telford, W. M., Geldart, L. P., Sheriff, R.E. Keys, D.A., 1974, *Applied Geophysics*, Cambridge University Press, London-New York-Melbourne.

[7] Telford, W. M., Geldart, L. P., Sheriff, R.E., 1990, *Applied Geophysics*, Cambridge University Press, Cambridge, Second Edition.

[8] Wharton, S.R., 1993, An Integrated Approach to the Study of Pliocene Gros Morne Reservoir Sands For Developing Play Concepts, *Moruga East Field, Trinidad.*