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# Fault Identification Using Normalized Horizontal Tilt Angle (TDX)Case Study of Menanga Fault as The Reason of Swarm Earthquake in Pesawaran-Lampung, 2021 January

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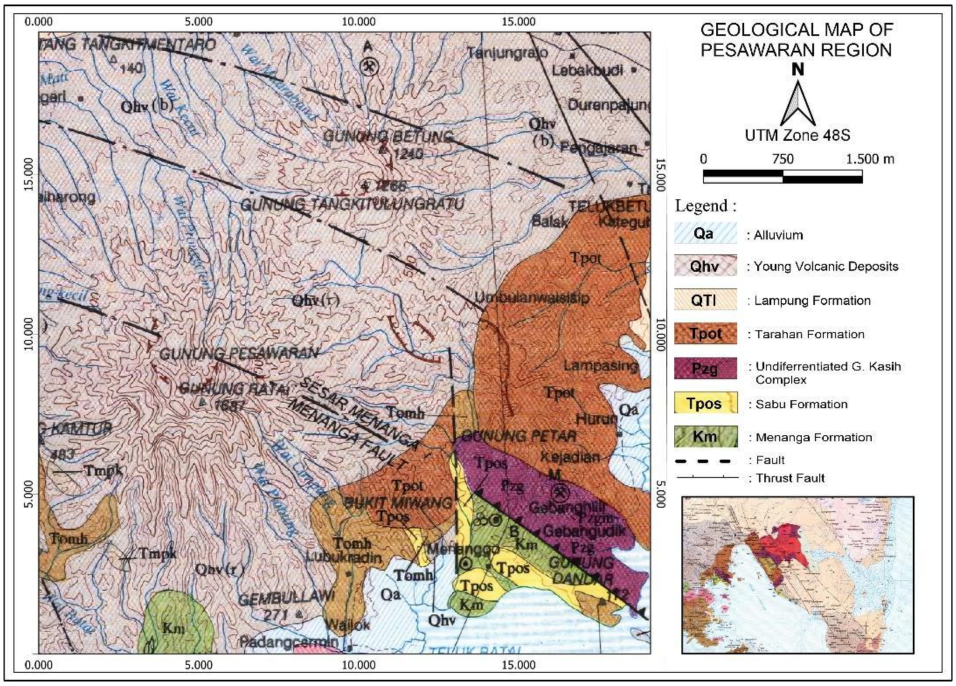
***ABSTRACT**: A series of low-magnitude earthquakes rocked Pesawaran in January 2021. These earthquakes occurred continuously in a high tempo but it is not accompanied by a large-magnitude main earthquake so that it was indicated as a swarm earthquake. This study aims to identify the structure of the Menanga Fault which caused the swarm earthquake. The method used in this study is the magnetic method using a Normalized Horizontal Tilt Angle (TDX) filter. Based on the interpretation results, it is found that there is a continuity of the Menanga Fault from the Northwestto Southeast directions. Menanga Fault is reverse fault. It is hoped that these results could be used as a reference for disaster risk maps.*
***KEYWORDS:** Pesawaran,Earthquake,MenangaFault,Swarm.*

## I. INTRODUCTION

Earthquakes are natural disasters that we cannot avoid, earthquakes are the output of a mechanism that occurs below the earth's surface in the form of plate movements that result in a sudden release of energy in the form of seismic waves. The impact of an earthquakes itself will be very destructive depends on the magnitude of the earthquake and the location of the epicentre [28]. The topic of discussion in this study is swarm earthquake. Swarm earthquakes is an increase in the number of earthquakes in a certain time span without high scale earthquakes which generally occurs in volcanic areas or fault areas or in areas where stress concentrations occur. According to [1] an earthquake is classified as a swarm earthquake if the earthquakes is not accompanied by a major earthquake with a large destructive magnitude. According to seismological researchers, the process of the occurrence of this swarm earthquakes is not exactly known because the earthquake has a different mechanism compared to earthquakes in general that occur due to faults or megathrust [2]. Meanwhile in megathrust subduction areas, swarms tend to occur repeatedly and occur between large earthquake fault areas and occur in areas with low accumulation of interseismic strain [3]. Several things have been proposed as the cause of the swarm earthquake, one of them are the release of medium tectonic strain energy that occurs between the instantaneous release of tectonic strain energy during large earthquakes, slow earthquakes and silent earthquakes [4]. Swarm earthquakes is the impact of an active fault that is creeping. This creeping fault can cause earthquakes with small but shallow magnitudes and have relatively high earthquake frequencies so that they can be considered as swarm [5].

The process of the occurrence of this earthquake is also has the correlation with the process of continents forming because it involves plate shifts. The subduction of the Indian Ocean plate boundary which was subducted under the Eurasian plate during the Cenozoic Period is indicated to be the cause of the rotation on Sumatra Island in a clockwise direction to Java Island [6]. This resulted in a change in the location of the island of Sumatra, which initially trended West - East to Northwest - Southeast [7]. According to [8] the normal fault that forms the fault segment is a geological structure that is commonly formed on the island of Sumatra. Conditions like this make the Sumatra region has a fairly high potential for natural disasters.One of the correlations is the Menanga Fault which is indicated to be the cause of the swarm earthquake in Pesawaran. Based on the geological map sheet of Tanjung Karang, the research area is a Young Volcanic Deposit (Qhv b). This Young Volcanic Sediment (Qhv b) was unconformably deposited above the Undifferentiated G. Kasih Complex (Pzg) which consists of metamorphic-sedimentary and igneous rocks consisting of schist, quartzite, and gneiss as can be seen in Figure 1. [9]. According to [10] the Menanga Fault itself is located in the southern part of Mount Betung. This fault is a normal fault that cuts Mount Pesawaran. This fault is formed due to compressional forces and is indicated as the cause of the swarm earthquake.




**Pesawaran Regional Geological Map [9]**

Previously study, Nurfitriana [11] was collected relocation of hypocenter data from BMKG station whichcan beconcludedthatswarm earthquake at Pesawaran in January 2021 was the activity of the Menanga Fault. On the other hand, Nurfitriana [29] also conducted a gravity acquisition in the same area as this research in Mount Ratai, Pesawaran which the result is the Menanga Fault is located at about 500 m of Southeast from the inferred Menanga Fault by Mangga [9] with the dipping orientation of Menanga Fault is heading to North-East. But from the research [29] there is still lack of information about the other section of Menanga Fault because it only did one slicing. Hence, we conducted this research with 3 slicing use magnetic anomaly with the aim of subsurface modeling.

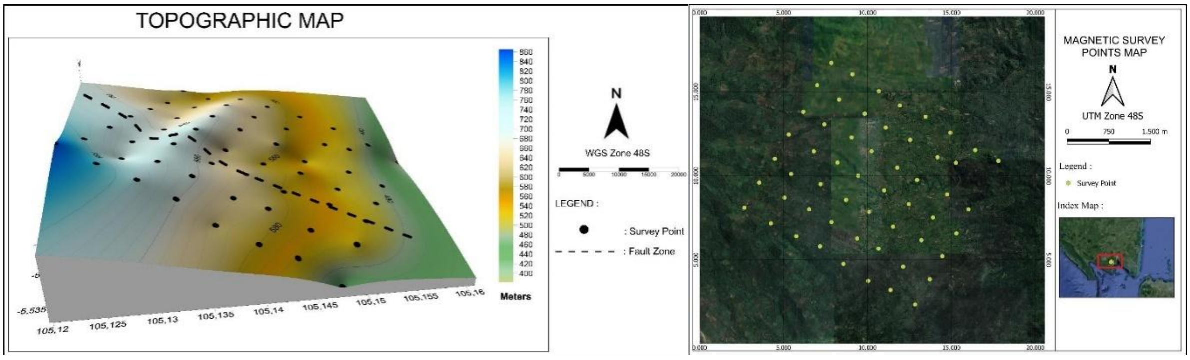
## II. METHODS

Research related to faults requires comprehensive geophysical and geological data because changes in the structure below the earth's surface occurred due to changes in soil and rock mass loads. Both on the earth's surface and in the earth's subsurface [30]. To identify subsurface structures due to these events, several geophysical methods can be used, one of which is the magnetic method. In collecting data to conduct this research is to use the magnetic method which is a geophysical method to measure the contrast of the magnetic field intensity on the earth's surface [12]. Magnetic methods can be used to determine the depth and surface structure, measurements can be obtained easily for local and regional studies [13]. The difference or contrast in the intensity of the measured magnetic field will be applied as a parameter for interpreting the distribution of magnetic properties of rocks below the earth's surface as a basis for estimating geological conditions in the study area. The magnetic method is also influenced by variations in the direction and magnitude of the rock magnetization vector [26]. The magnetic method and the gravity method have many similarities, but in general the magnetic method is more complex. The difference between the magnetic method and the gravity method is th't the magnetic field is dipole while the gravitational field is monopole. Another difference is caused by the variable direction of the magnetic field where the gravity field is always in the vertical direction while the magnetic method is horizontal [14] [15] [16]. This is true because the magnetic method is time dependent and the gravity method does not depend on time [17]. In addition, magnetic methods are commonly used in studies of geological structures that can be used as disaster mitigation [18] [19].

Generally, Lampung area is located in convergent zone with the India-Australia plate subducting the Sunda (Eurasia) plate on the west side of Sumatra. These subductions resulted a series of volcanoes in the central part of Sumatra Island and the presence of the Great Sumatran Fault with a rightward movement as a result of the oblique type of subduction [3]. Pesawaran is one of the districts in Lampung Province that has some geologic features which is two dormant volcanoes (Mount Ratai and MountBetung); a lineament estimated as the Menanga Fault; and geothermal manifestations in the form of hot wells and silica [20].

In this geomagnetic study, a Normalized Horizontal Tilt Angle (TDX) filter is used. The Normalized Horizontal Tilt Angle (TDX) filter is an anomaly enhancement based on the results of the total number of derivatives on the x-axis and y-axis magnetic anomalies [21][31]. In the Normalized Horizontal Tilt Angle (TDX) method, the anomaly boundary is described based on the maximum value of the magnetic anomaly from the TDX results [22]. Therefore, this method can identify the presence of a geological structure boundary. The geological structure can be in the form of folds or faults, in this case it is to determine and identify the Menanga Fault. Faults can be deformed so that there can be changes in the direction and position of the fault due to the presence of compression or strain forces. It is also influenced by the nature of the rock in the fault area, whether it is brittle or ductile [23][27].

## RESEARCH AREA




**Topography of the Research Area**

The acquisition design for this research is the acquisition design for the magnetic method in the Mount Pesawaran area with a total of 58 points of measurement in the research area of 3.5 km x 3.5 km and the distance between points as far as 500 meters. The map of the research area in the form of topographic maps and measurement points can be seen on picture above.

## DATA PROCESSING

Data that processed in this research was collected using GSM-19T Proton Magnetometer that lend from Geophysics Laboratory of Institute Technology of Sumatera. Following are the procedure performed in processing the data in this study [24] [17]:

1. Magnetic Data Correction

This procedure aims to obtain the appropriate magnetic field anomaly value by correcting the magnetic field data measured at each location point by making daily (diurnal) corrections and IGRF (International Geomagnetic Reference Field) corrections.

2. Creating Total Magnetic Intensity Map (TMI)

After obtaining the TMI value from the reduction between the average anomaly value, daily correction and IGRF correction, the TMI value is then gridded to obtain a total magnetic anomaly map or TMI map.

3. Creating Reduce to Pole Map (RTP)

Reduce to Pole needs to be done with the aim of facilitating the interpretation of field data because the magnetic anomaly dipole nature will complicate the interpretation of field data due to the asymmetrical pattern. The results of Reduce to Pole will produce a magnetic anomaly distribution centered on one pole.

4. Spectral Analysis

Spectral analysis is used to estimate the depth of anomalous sources below the surface. The results of the spectral analysis in the form of distance estimation can be used as a distance parameter in the continuity process. This stage is carried out with a Fourier transform process on a predetermined path. The Fourier transform itself is a process of converting the distance function into a wavenumber function.

5. Separation of Regional and Residual Anomaly

Anomalies Magnetic anomaly separation is carried out due to data that still has residual anomaly values, regional anomalies, and noise so that filtering to produce a contour map that is clean of noise. In this study, the separation of these anomalies using Gaussian Filter and Continuation upwards. Gaussian filter is a process of separating regional and residual anomalies. This filter is included in the low pass filter which is based on the Gaussian probability distribution function.

6. Normalized Horizontal Tilt Angle (TDX) Analysis

This TDX filter will display the boundary of the structure of a magnetic anomaly which will be represented by the maximum value of the anomaly in the TDX results. Therefore, geological structures in the form of faults can be easily identified with this filter.

7. 2D Forward Modeling

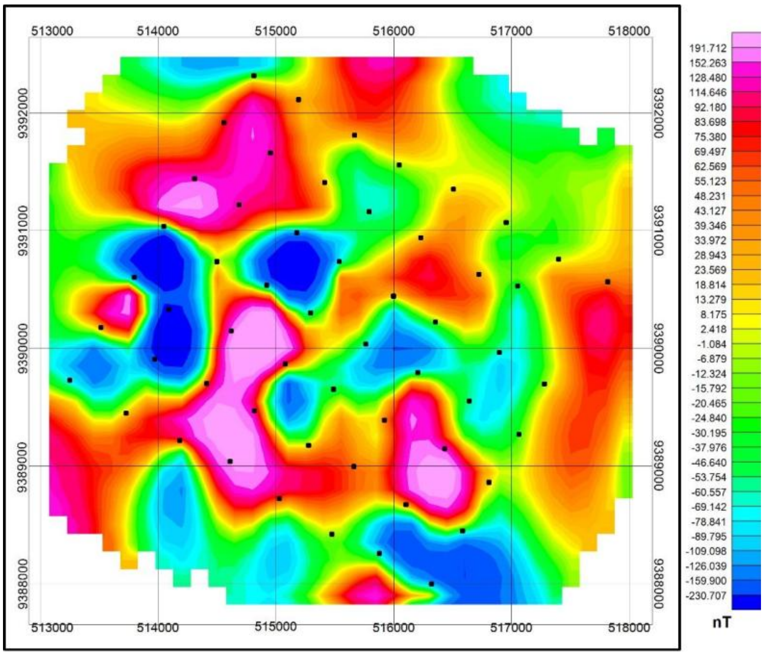
Forward modeling is the process of estimating the subsurface model in the research area based on data calculations from theoretical results observed on the earth's surface with certain parameters. This process is done by making a subsurface model to get a response that matches the observation data or field data. The match is represented in the form of a misfit or error. The smaller the misfit, it can be said that the condition of the model that has been made can represent the actual shape of the underground surface. However, in carrying out forward modeling, regional geological information is needed in the research area.

In general, interpretation of geomagnetic data is divided into two, namely qualitative and quantitative interpretation. Qualitative interpretation is based on the anomalous contour pattern of the magnetic field sourced from the distribution of magnetized objects or subsurface geological structures while the quantitative interpretation aims to determine the shape or model and depth of anomalous objects or geological structures through mathematical modeling [25].

The data that has been obtained is then processed according to the magnetic data processing procedure, namely by making daily corrections and IGRF (International Geomagnetic Reference Field) to then obtain the TMI value which is then plotted to obtain the distribution of magnetic anomalies in the study area. However, the distribution of anomalies on the TMI map is still dipole so it is difficult to interpret, therefore the TMI data is processed by making a Reduce to Pole (RTP) correction and then filtering the RTP data until the expected data is obtained, such as regional and residual zone maps, spectral analysis. In this study, no continuation was carried out, because the residual map was sufficiently representative for slicing. Then in doing slicing and modeling this research uses a Normalized Horizontal Tilt Angle (TDX) filter to facilitate the determination of the structural boundary of the Menanga Fault, because the TDX filter is represented by the maximum anomaly value.

## III. RESULT AND DISCUSSION

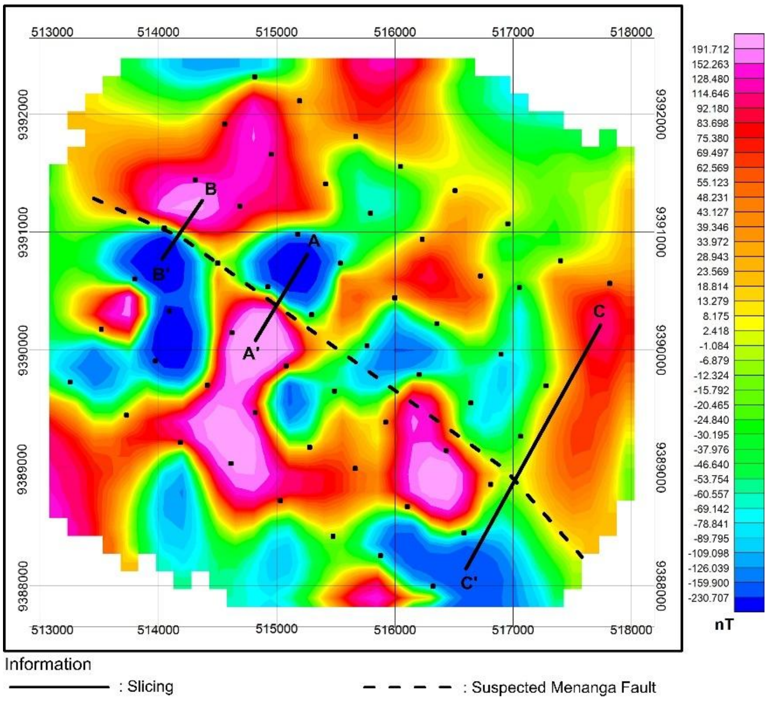
Data processing generally gives the final result in the form of modelling of the slicing form of 2D modelling. The modelling trajectory is generally sliced on the residual map, in this study slicing was carried out on the residual map. This thing is done because the purpose of this study was to see the structure of the Menanga Fault so that a map that could better represent the shallow anomaly was needed, in this case the residual map is more suitable to be used because it is better to see the source of the shallow anomaly using a residual map.




**MAGNETIC RESIDUAL MAP**

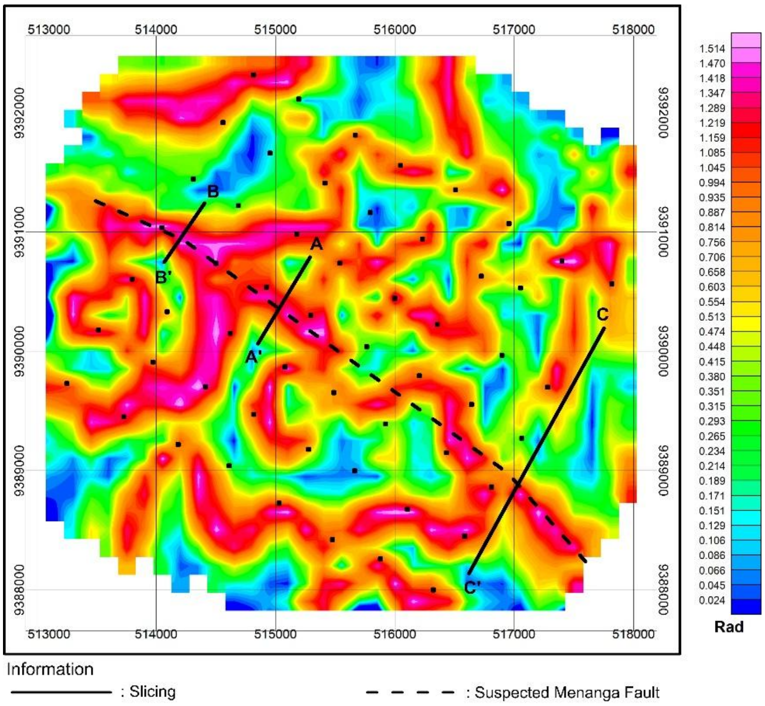
Residual anomaly is an anomaly that is has shallow depth and caused by objects associated with high frequency. From picture above, it can be identified that the residual anomaly map has anomalous values ranging from -230.7 nT to 191.7 nT. The low anomaly has a range of values from -230.7 nT to -69.1 nT and is represented by blue color. Furthermore, the moderate anomaly has anomalous values ranging from -60.6 nT to 48.2 nT which is represented by green to yellow colors, then the high anomaly has a value range from 55.1 nT to 191.7 nT which is represented by orange to pink color. There is a contrast anomaly in the center of the residual map which is suspected to be the structure of the Menanga Fault which is indicated to be the cause of the swarm earthquake that occurred in Pesawaran in January, 2021. The distribution of anomalies on this map is quite low considering the high elevation of the measurement area and the influence of from the Young Volcanic Deposits (Qhv) Formation.

In order to make the 2D forward modelling in this research, three slicing was carried out to identify and visualize the subsurface shape of the Menanga Fault so that its structure could be identified. Future modelling results for the three slicing areas are based on the A-A', B-B' and C-C' trace. The three modelling trajectories are in a straight line so that it is expected to represent the overall shape of the Menanga Fault in the research area. The three modelling trajectories are in the direction from Northeast to Southwest with each track length for Line A-A' as far as 1650 meters, then B-B' trajectory with a line length of about 450 meters and Line C-C' with a length of 2340 meters. Each line has a depth of up to 500 meters. The modelling trajectory can be seen in picture below.



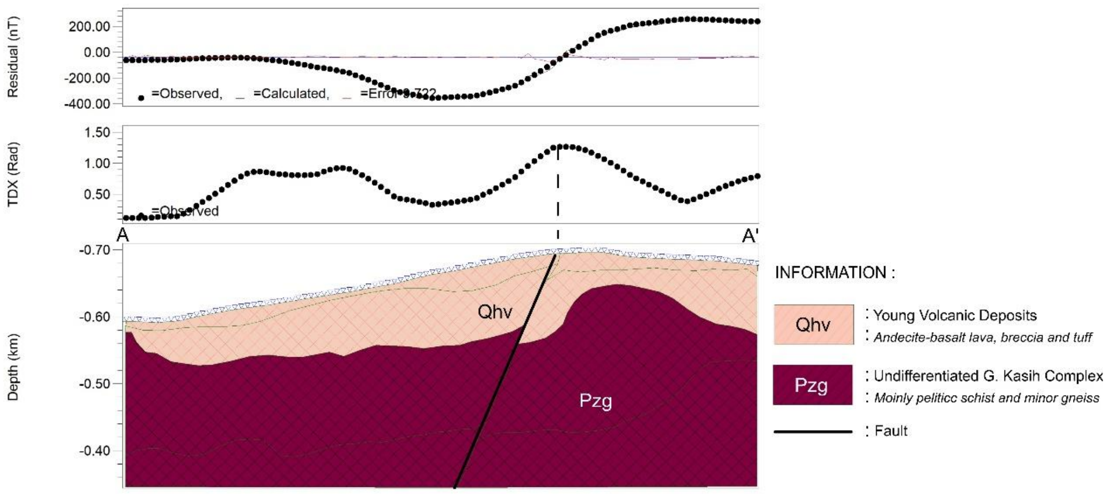

**RESIDUAL MAP WITH SLICING LINE**

Normalized Horizontal Tilt Angle (TDX) is an anomaly of enhancementbased on the total number of derivatives on the x-axis and y-axis magnetic anomalies. This filter can display the boundary of the magnetic anomaly structure which is represented by the maximum value on the TDX anomaly distribution map. Based on this TDX analysis, the structure limits can be seen at the maximum anomaly as can be seen in the picture with the anomaly range on this TDX map from 0.024 rad to 1.514 rad. The boundary of the structure represented by the high anomaly which is represented by red to pink color with a range of 1,045 rad to 1,514. Then the moderate anomaly is represented by green, yellow and orange with a range from 0.171 rad to 0.994 rad. The low anomaly is represented by blue color with anomaly values from 0.024 rad to 0.151 rad. When making the models, the Normalized Horizontal Tilt Angle graph will be correlated with the residual anomaly graph and geological map so that later accurate future modeling results will be obtained.



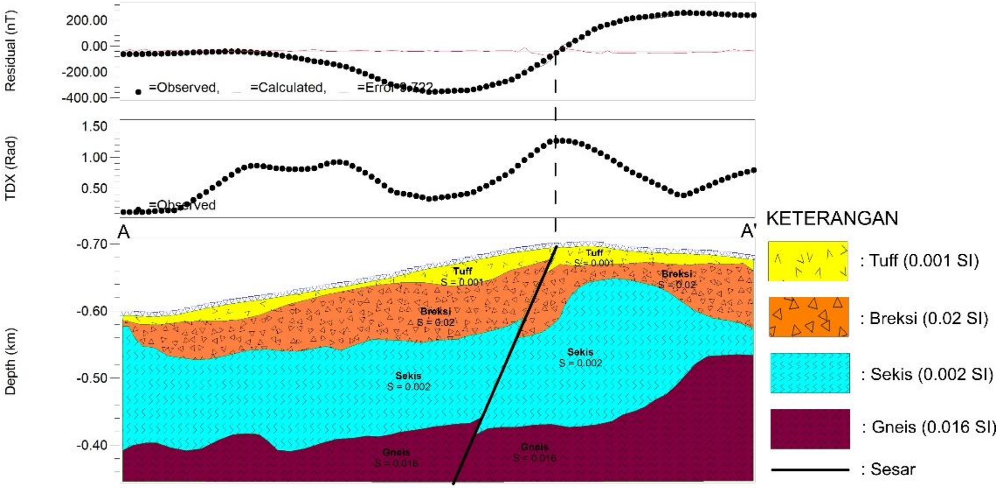

**NORMALIZED HORIZONTAL TILT ANGLE(TDX)**

Forward modeling on the Line A-A' is carried out by slicing or making a trajectory of about 1650 meters perpendicular to the predicted fault in the direction of the Northeast-Southwest on the residual map as shown inpicture above. Based on the Normalized Horizontal Tilt Angle(TDX) graph which is correlated with residuals and regional geological maps, the modeling on the Line A-A' can identify normal faults that experiencing continuity from a depth of about 450 meters from below ground surface to ground surface. The results of the modeling can be seen in picture of belowwhere based on the regional geological map, the research area is located in the Qhv and Pzg rock formations. Qhv itself is a Young Volcanic Deposit with rock units in the form of lava (andesite-basalt), breccia and tuff, then for Pzg itself it is an Undifferentiated G. Kasih Complex with rock units of pelitan schist and a little gneiss. Based on the modeling results on line A-A', it can be identified that the Menanga Fault is a reverse fault and there are 4 rock layers. Reverse fault is a fault in which one of the rock blocks has shifted upwards and the other rock blocks have moved downwards. In other words, the fault is said to be a reverse fault if the hanging wall of the fault pushes upwards and then the foot wall remains in its lower position with a slope of not more than 45 degrees.



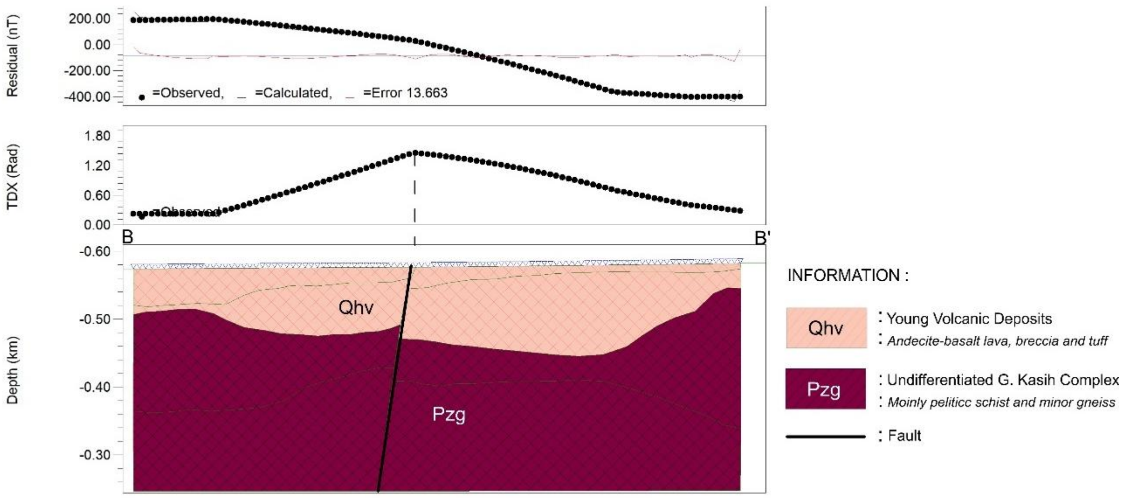

**LINE A-A' MODELING WITH ROCK FORMATION**

Line A-A’ has the highest altitude from all the slicing trajectories as we can see on the topographic map. It looks like a folded section in the slope of Mount Pesawaran. The rock layers on Line A-A’ that identified as one of Menanga Fault’s track which in the Young Volcanic Deposits (Qhv) and Undifferentiated G. Kasih Complex (Pzg) formation are Tuff, Breccia, Schist and Gneiss. The tuff rock layer is the topmost rock layer and is the youngest with a susceptibility value of 0.001 SI with a layer thickness of approximately 30 meters, then for the second layer in the form of a Breccia rock layer with a susceptibility value of 0.02 SI with a thickness of about 100 meters at a depth of 130 meters below surface. The first and second layers are including in the Young Volcanic Deposits (Qhv) formation. Then for the third layer is a layer of Schist rock with a susceptibility value of 0.002 SI with a layer thickness of up to 200 meters at a depth of 310 meters below the surface and the fourth layer is identified as a Gneiss rock layer with a susceptibility value of 0.016 SI at a depth of 400 meters below the ground surface, the thickness of the fourth layer it reaches more than 180 meters below ground level. This has differences in the Line B-B' and C-C' because the lithological boundaries are not absolute so that they will be different at every different point even though they are still in the same area.



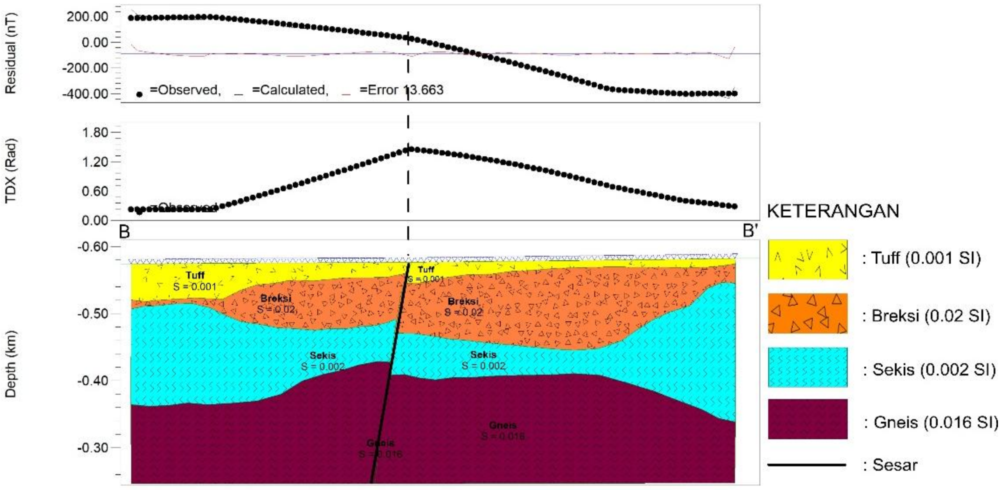

**LINE A-A’ MODELING WITH LITHOLOGY SYMBOL**

In the Line B-B', it can be seen that the Menanga Fault structure is a reverse fault but with dipping direction towards Northeastsame as on the Line A-A’. Even based on the residual map the location of the high anomaly and the low anomaly on both the Line B-B' and A-A' are opposites but it cannot be the guidance to determine the type of the fault and the dipping direction of the fault. The Line B-B’has lower altitude compared to Line A-A’ which is the highest Line that sliced in this research. We can see that the dipping angle of the structure in Line B-B’ is steeper than on the Line A-A’ which possibly caused by the difference of the altitude. The higher altitude caused the structure to have slope strike.



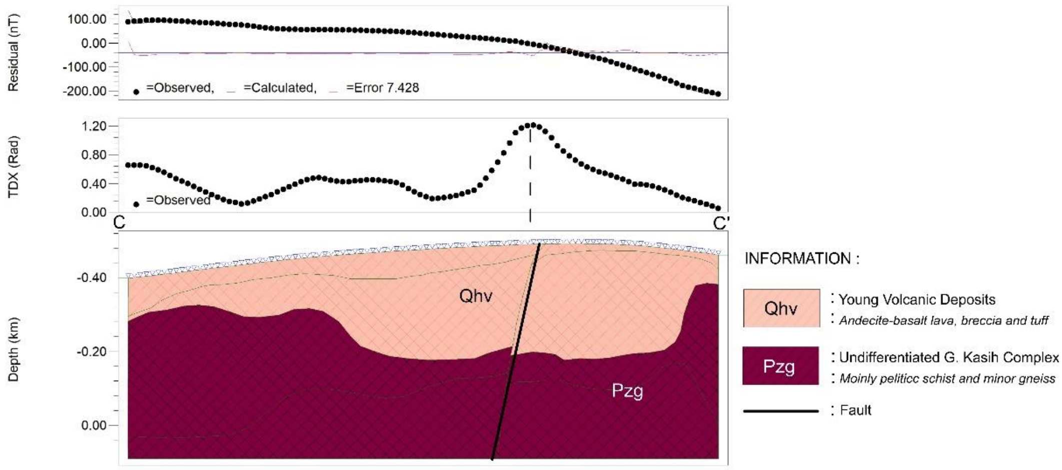

**LINE B-B’ MODELING WITH ROCK FORMATION**

The rock layers on the Line B-B' are still the same as the rock layers on the Line A-A' as shown in Figure 3.6 where the first layer is a tuff rock layer with a thickness varying from 20 meters to 80 meters, then the second layer is a breccia rock with a thickness of up to 110 meters. at a depth of about 200 meters. The first and second layers are layers of Young volcanic Deposits (Qhv) Formation. The third and fourth layers are the Undifferentiated G. Kasih Complex (Pzg) Formation where the third layer has a thickness of 40 meters to 150 meters at a depth of about 200 meters. The fourth layer has a thickness of 80 meters to about 150 meters at a depth of approximately 400 meters.



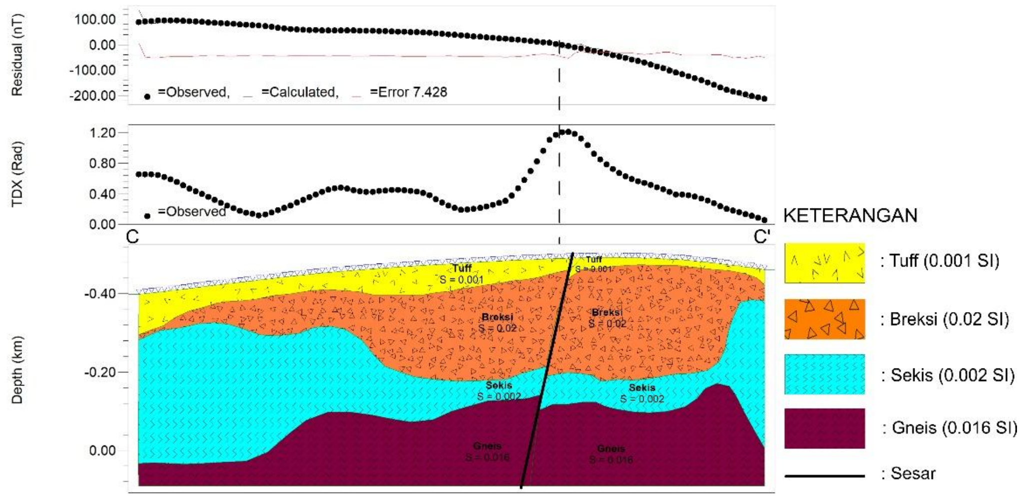

**LINE B-B' MODELING WITH LITHOLOGY SYMBOL**

Line C-C' is the outer most line carried out in this study for modeling. This line is in a lower topography than the Line B-B' track even the Line B-B' in a valley from the folded section on Line A-A'. From the Line C-C', it can be identified that the Menanga Fault structure has the same dip direction as in the Line B-B' which is directing to Northeast as can be seen on picture below. Menanga Fault has the continuity from the Line B-B' through the Line C-C' which indicate the existence of this fault which previously only a suspected or inferred fault. The rock structure also must be highlighted because it should be identified whether the rock has ductile characteristics or not. This is absolutely necessary because it is very strong that the movement of the Menanga Fault is what causes the swarm earthquaketo occur so that with further research we can identify it more comprehensively with the aim of mitigating natural disasters because we can never predict the occurrence of natural disasters, therefore efforts to mitigation.



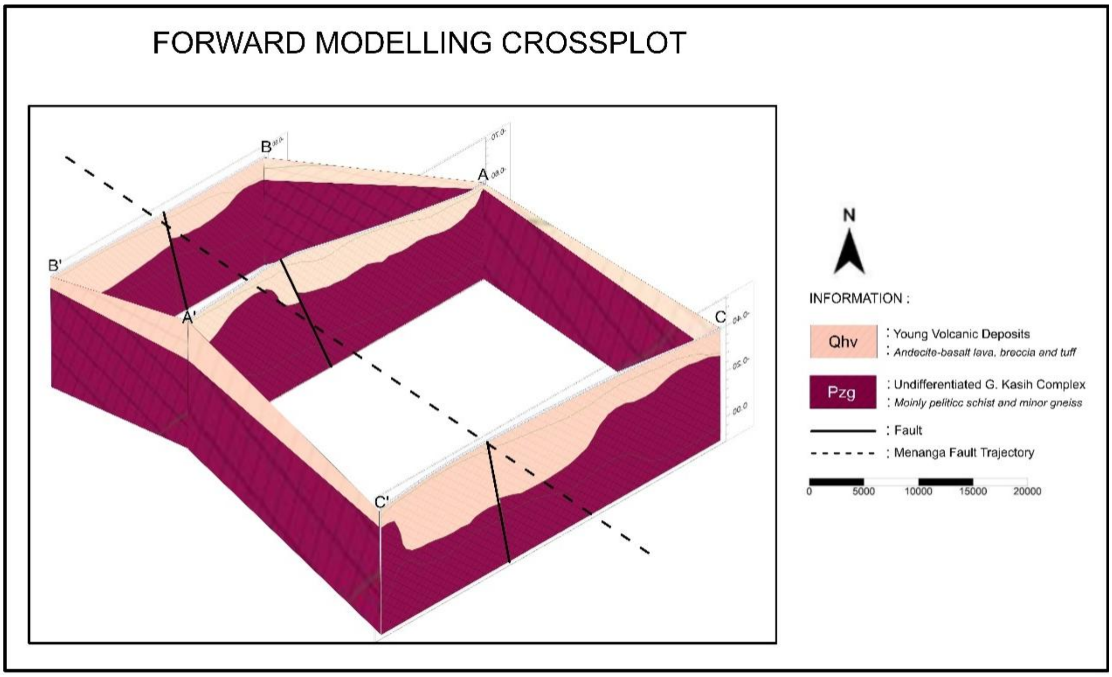

**LINE C-C' MODELING WITH ROCK FORMATION**

The rock layer structure on the Line C-C' can be identified that the tuff rock layer has a thickness of up to 15 - 40 meters at a depth of 40 meters, then the breccia rock layer has a thickness of up to 60 meters at a depth of up to 200 meters below ground level. Meanwhile, the schist and gneiss layers have varying depths from 15 meters to 80 meters at a depth of up to 400 meters below the ground surface. The cross-section of this lithology can be seen below.




**LINE C-C' MODELING WITH LITHOLOGY SYMBOL**

From the cross plot below, it can be identified that the dip direction of the Menanga Fault is heading to Northeast. This indicate that the Menanga Fault have a continuity from the Line C-C' toward B-B' which correlated with the bottom structure of Menanga Fault based on geological map.This result proves that the Menanga Fault which caused swarm earthquake in Pesawaran in January, 2021 and justified by Nurfitriana et al [11, 29].




**CROSSPLOT MODELING**

## IV. CONCLUSION

Based on cross plot forward modelling, Menanga Fault proven as the causes of swarm earthquake in Pesawaran, 2021. The Menanga Fault itself has direction from the Northwest to Southeast.This fault is reverse faultconsists of four layers of rock including layers of Tuff, Breccia, Schist and Gneiss with variety depth and thickness.

**SOME OF THE ADVANAGES FROM THE ABOVE RESULTS**

a) 3 slicing area gives more information about the continuity ofMenanga Fault
b) Could be used as a reference for disaster risk maps.

## V. ACKNOWLEDGEMENT

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