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Preliminary Research for Fault Identification as Disaster Mitigation in Sumbawa Besar Using Geophysics and Geology Methods.

Sayidatina Hayatuzzahra *[1], Adella Ulyandana Jayatri [1], Rita Desiasni [2]
[1] Mining Engineering Department, Sumbawa University of Technology, Indonesia
[2] Metallurgy Engineering Department, Sumbawa University of Technology, Indonesia
*E-mail: sayidatina.hayatuzzahra@uts.ac.id

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Abstract
Faults are conditions under which rocks are displaced from their original positions. Its presence is closely related to its high tectonic activity. Fault movement can trigger earthquake disasters. Therefore, various studies on faults are important for carrying out disaster mitigation efforts. This study aims to identify the existence of faults in Sumbawa Besar as a disaster mitigation effort. The method used was a combination of geophysical methods and geological field observations. Geophysical methods include the average shear wave method (VS30) and the gravity method. The geological method consists of direct geological observations (geomorphology and structural geology) in the research area. The results of research based on geophysical methods, namely the gravity method, showed that in the research area, there were indications of thrust faults, which were then strengthened by VS30 analysis, which showed the existence of weak zones along the suspected fault lines. The results of field data collection and geological data analysis show that no surface fault characteristics were found in the research area.

1. Introduction

Indonesia has high active tectonic activity. The geographical conditions located in the area where the world's three main plates meet, namely the Indo-Australian Plate, Eurasian Plate, and Pacific Plate, result in this region having a complex tectonic structure. One of the consequences is that there are many faults or what are known as faults. Faults/fractures are conditions under which rocks are displaced from their original positions [1]. Faults can trigger earthquakes. One example is the phenomenal earthquake that occurred on Lombok Island periodically throughout August 2018, which was caused by the activity of the Flores Back Arch Thrust. The earthquake resulted in large material losses, and 560 people died [2]. Therefore, identifying the presence of fault/fault structures in an area is critical. The Sumbawa Island is an important area for identifying faults. This island is in the eastern part of Lombok Island, which is also in the Flores Back Arch Thrust Zone. This includes areas that have an active tectonic setting because they are located in the Mediterranean mountain range, which is close to the collision zone of the Indo-Australian plate, which is submerged under the Eurasian plate [3]. Therefore, there are many geological structures in the form of faults on mainland Sumbawa Island. This fault can trigger an earthquake. One of the earthquakes that occurred on the island of Sumbawa, which was caused by a fault, was an earthquake that occurred on June 13, 2020, with a magnitude of 5.3 SR which occurred in the southern part of the Plampang sub-district. This earthquake shock was experienced at the IV MMI in Sumbawa. This earthquake showed the influence of shallow active faults [4]. Therefore, research on faults in the Sumbawa area is important for disaster mitigation. This fault stretches in a northeast-southwest direction and could become a threat in the future if it experiences movement. Apart from threatening life and safety, it can potentially damage the infrastructure above it. Therefore, identifying faults in this area is an early disaster mitigation strategy. It is hoped that the results of this research can serve as a reference for mitigating surface disasters, for example, by creating evacuation routes in areas that are prone to be affected.

2. Methodology

This study was conducted by correlating geophysical methods with geological data. The geophysical methods used consisted of the gravity method and the mean shear wave method (VS30). The gravity method is widely used to study faults. This method can map rock structures based on variations in gravitational acceleration values caused by differences in the rock density below the surface. The gravity data in this research uses satellite image data obtained from TOPEX which is downloaded via https://topex.ucsd.edu/cgi-bin/get_data.cgi. Data were downloaded at geographic positions -8.370146355269949 to -8.642619921572 South Latitude and 117.30342864990236 to 117.54272460937501 East Longitude. The downloaded data consisted of latitude, longitude, Free Air Anomaly (FAA), and topographic data. Gravity data analysis begins by performing Bouguer correction and terrain correction on FAA data to obtain a complete Bouguer anomaly (CBA) [5]. The CBA results create a contour map, which is then filtered to separate regional anomalies and residual anomalies. Next, the residual anomaly obtained from the filtering results is subjected to a Second Vertical Derivative analysis or what is known as second vertical derivative (SVD) to determine the type of fault structure. The results of the analysis relate to the superficial effects of local nature. To determine the type of fault/fault, slicing can be performed across the zone suspected to be a fault. The criteria for the fault types are as follows [6]:

$$\left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{max} > \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{min} \quad \text{for normal fault (1)}$$

$$\left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{max} < \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{min} \quad \text{for thrust fault (2)}$$

$$\left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{max} \approx \left|\frac{\partial^2(\Delta g)}{\partial z^2}\right|_{min} \quad \text{for strike-slip fault (3)}$$

The shear wave velocity Vs is an indicator of the dynamic properties of soil and rock and is related to the shear modulus (μ), which depends on the strain level. It is important to know the shear wave speed (Vs) in an area because the Vs value indicates the earthquake vibration response, which is predicted to be higher in the event of an earthquake rupture. This method uses data originating from https://earthquake.usgs.gov/data/vs30/ then the Vs30 value of the research area will be interpolated at each measuring point in the research area to produce a distribution map of USGS VS30 values based on the research area. The next step is to determine the USGS VS30 value at each geological survey measuring point, by plotting the measurement points on a map and digitizing each measuring point.

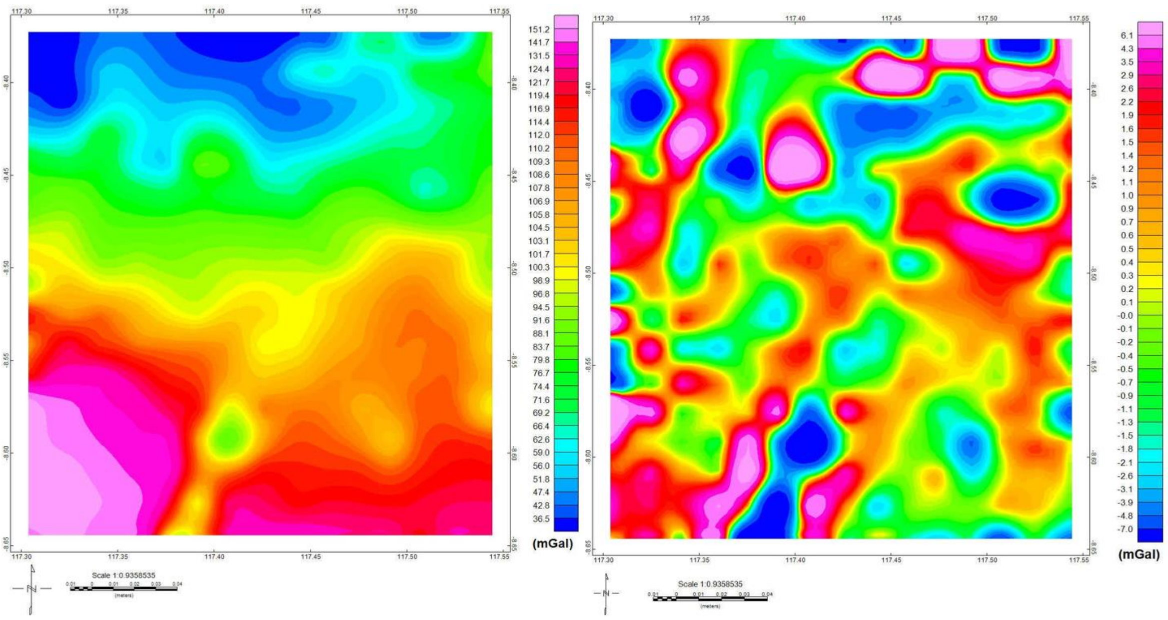

Figure 1. Complete Bouguer Anomaly Map (left), Residual Anomaly Map (right)

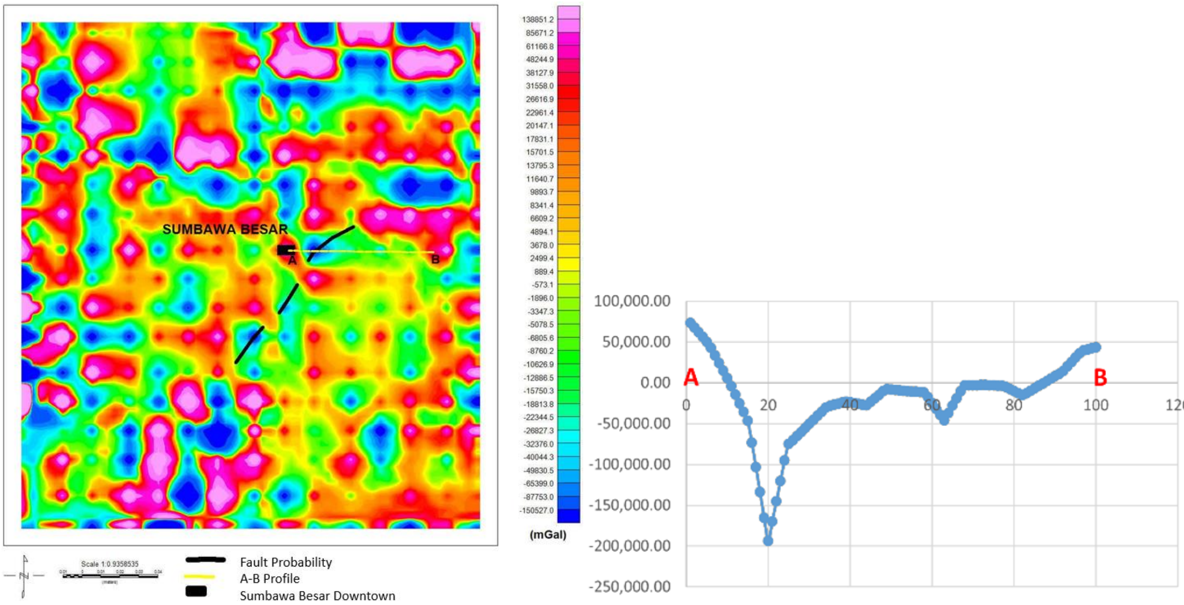

Figure 2. Second Vertical Derivative Anomaly Map (left), Slicing A-B (right)

The geological data used in this research included geomorphological and geological structure data. Geomorphological data consists of observations of natural landscapes, such as fault scarps, terrace deposits, river alignment patterns, and morphotectonic calculations, while observations of geological structures consist of measurements of bedding planes, joints, folds, and faults found in the field.

3. Results and discussions

3.1. Gravity Method

The complete Bouguer anomaly (CBA) in Figure 1 (left) is the result of Bouguer correction and terrain correction on the Free Air Anomaly (FAA) data. The range of anomaly values ranges from 36.5 mGal to 151.2 mGal with low anomaly patterns marked in dark blue and high anomaly patterns marked in pink. CBA consists of a combination of regional and residual anomalies. Therefore, to obtain the target anomaly (residual anomaly), it was necessary to separate the anomaly.

Anomaly separation to obtain the target anomaly in Image 1(right) was performed using a Gaussian filter. This filter is generally used to process the data obtained from satellite imagery [7]. The resulting anomaly contour pattern appears to have a shorter wavelength than the complete Bouguer anomaly contour pattern. Short wavelengths show typical characteristics of local residual anomalies [5]. This was caused by a shallow mass anomaly below the surface [8]. The anomaly value ranges from -7.0 mGal – 6.1 mGal. The research area was dominated by low anomalies flanked by high anomalies in the northern part of the residual anomaly map. The patterns of high and low anomalies were influenced by the density of rocks below the surface. Rocks with a high density tend to produce relatively high-gravity anomalies.

Second Vertical Derivative (SVD) analysis was performed to identify the presence and type of fracture. In general, the presence of a fault is indicated by an SVD anomaly value of zero [9]. Indications for the existence of a fault are also marked by a low anomaly flanked by two high anomalies [10]. In Figure 2 (left), it can be seen that the bold black dotted line is interpreted as the presence of a fault, while the yellow dotted line AB is an incision that cuts perpendicular to the fault. Based on this interpretation, the fault trends northeast-southwest. The AB incision results shown in Figure 2 (right) were used to identify the fracture type. The graphic results show that the maximum value was lower than the minimum absolute value. This shows that the fault is a thrust fault [11][9].

Table 1. Relationship between soil class, VS30, and slope [12]

Class	VS30 (m/s)	Slope (m/m) *active tectonic*	Slope (°) *active tectonic/volcanic area*
E	<180	$<1,0\times10^{-4}$	$<5,7\times10^{-3}$
D	180-240	$1,0\times10^{-4} - < 2,2\times10^{-3}$	$5,7\times10^{-3} - < 0,126$
	241-300	$2,2\times10^{-3} - < 6,3\times10^{-3}$	0,126 – < 0,361
	301-360	$6,3\times10^{-3} - < 0,018$	0,361 – < 1,031
C	361-490	0,018 – < 0,050	1,031 – < 2,86
	491-620	0,050 – < 0,10	2,86 – < 5,7
	621-760	0,10 – 0,138	5,7 – 7,86
B	>760	> 0,138	>7,86

3.2. Result of USGS Active Tectonic VS30 Seismic Wave Shear Velocity Mapping

Mapping results of the VS30 value obtained from the standard topographic slope of a location. In detail, it was explained that the USGS had carried out global VS30 mapping on the entire surface of the earth to estimate the magnitude of earthquake wave amplification in an area to predict ground movements in the event of an earthquake. This method was introduced by Allen and Wald 92007) by proposing the determination of VS30 based on the slope value of the topography [12], as shown in Table 1. Allen and David (2007) explained that USGS VS30 values throughout the world have been compiled based on VS30 data obtained from direct measurements. (primary) and slope data from topography (gradient) were obtained from the GTOPO30 satellite imagery with a resolution of up to 1 km [12]. In practice, at each VS30 measurement point, the slope of the topography was also measured. This measurement was only performed by the USGS Team in several countries. VS30 data is based on the VS30 active tectonic/volcanic area. This empirically shows the relationship between VS30 and the slope of the topography in various regions and is used as an initial reference (standardization) for making global-scale VS30 maps. Therefore, for areas outside the USGS VS30 measurement area, the VS30 value was calculated based on slope standards created from empirical results of VS30 measurements and topography in the USGS Team's measurement area; thus, the USGS VS30 standard is VS30 data describing the soil (lithology) of the local area. The relationships between soil class, Vs30, and slope are shown in Table 1.

Based on the explanation above, USGS Vs30 determination was performed in the research area. The USGS VS30 used in this research is the VS30 active tectonic/volcanic area because the research area is one of the areas whose existence is influenced by active tectonic plate activity, causing the formation of a series of volcanoes in this area (high topography).

The characteristics of Vs30 around the Sumbawa fault are very important because they provide information about seismic hazards in the area where the Sumbawa fault passes. The characteristics of Vs30 around the Sumbawa fault line can be seen in the map of the relationship between Vs30 and the topographic slope shown in Figure 1. Based on the map around the Sumbawa fault, it was 180 -750 m/s. The Vs30 Active tectonic map in Figure 1 passing through the Pungkit area has shear wave velocity values at a maximum depth of 30 m (Vs30), ranging from 180 to 430 m/s. Moyo District distributed shear wave velocity values at a maximum depth between 200 and 600 m/s. Based on the USGS Vs30 distribution, the Sumbawa fault cuts through the Sumbawa region at a shear-wave speed (Vs30) of 180 -600 m/s. This condition has a high seismic vulnerability, especially in areas with a low Vs30 distribution. This means that, geotechnically, soil conditions can be estimated using the average shear wave velocity parameter (Vs30). In hard soil types (with a higher Vs30 value), vibrations experience low amplification (low amplification). Low amplification of earthquake vibrations results in less damage than thick-seated soil with soft soil (with a lower Vs30 value). Areas with lower Vs30 values are at a higher risk of earthquake threats [13]. According to Yen-bin [14], the speed of seismic waves passing through rocks depends on the hardness of the rock. The softer the rock, the lower the speed of seismic waves in the rock.

Figure 3. VS30 USGS active tectonic

According to Wald and Allen (2007), areas with steep topographic slopes are still composed of lithology (types of rock) that are hard, dense and have not experienced weathering processes, so they are thought to have high shear wave velocities [12]. In principle, various geological materials originating from high gradients (mountain peaks) experience erosion to depositional processes at lower topographies (plains). The grain size decreased during the erosion process. Rocks that have experienced a decrease in grain size easily experience weathering and reduce their rigidity (compactness).

3.3 Geology Method.

Lithological mapping carried out in the research area concluded that two lithologies constitute the research area, namely Coral Limestone from the coral limestone (Ql) formation and Volcanic Breccia from the Old Volcanic Rock (Tlmv) formation. Coral limestone is grouped into monomictic breccia, where the rock fragment, matrix, and cement are composed of the same material which is crystalline limestone, with a fragment size of approximately 2 mm-32 cm. This rock also contains numerous coral fossils. This lithology spreads from the southeast to the northeast of the study area, namely, in the Olat Langko ridge (Figure 4).

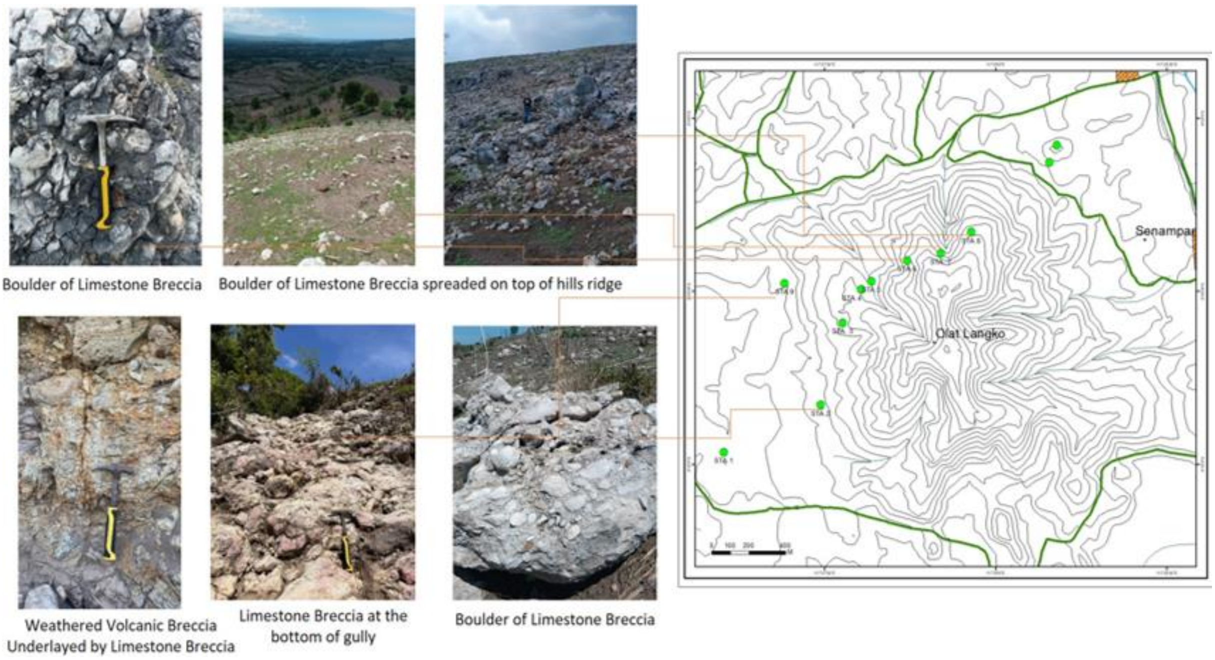

Figure 4. Distribution of lithology in the research area.

Table 2. Mountain front sinuosity index

Active Tectonism	Moderate to slightly active tectonism	Tectonically Inactive
1,2 - 1,6	1,8 - 3.4	2,0 - 7,0

In general, the Old Volcanic Rock formations in the study area are composed of Volcanic Breccia interbedded with tuffs. This unit occupies part of the southeastern region of the study area and is unconformably overlain by coralline limestones (Figure 4). Megascopically, the volcanic breccia in the study area is brownish-grey in color, with a hypocrystalline texture. These rocks have poor sorting and closed packing, with fragments in the form of andesite and basalt rocks, ranging from pebbles to boulders (3–83 cm).

Morphotectonic analysis was performed in the study area. Morphotectonic studies have correlated landforms with structural geological conditions [15]. Bull and Fadden (1977) formulated a method to calculate morphotectonics by calculating the value of Mountain front sinuosity by using the following formula as written below[16] :

$$Smf = Lmf/Ls$$

where: Lmf is the length along the mountain-piedmont junction;
Ls is the overall length of the mountainfront

Using the formula above, Bull & Fadden [16] provided the following classification as listed in Table 2. The results of the calculation of the mountainfront sinuosity in the research area are shown in Table 3, where the value obtained is 1.911 which indicates that the research area is included in an area with a moderate level of tectonism.

Olat Langko, the main focus of the research area, is an outlier hill. Sembroni et al define an outlier as an area composed of younger rocks surrounded or isolated by older rocks[17]. Outliers can generally form owing to erosion (uplift erosional outliers) and geological structures (structural outliers). The results of morphotectonic analysis in the research area show a moderate tectonic level, but no morphological characteristics such as changes in river flow patterns, terrace deposits, or fault scarps were found, which indicated the presence of faults in the research area. Therefore, it is very likely that outliers in the research area were caused by erosional uplift.

The only factor that indicated the existence of geological structures in the research area was the presence of joints (Figure 5). However, the presence of these joints does not indicate the existence of a geological structure because the numbers are not representative, and other structural data, such as rock bedding areas, fault areas, brecciation, and other accompanying structures, were not found.

Based on the results of observations from geomorphological data and geological structure data, it can be concluded that there are no characteristics of surface faults found in the research area.

Table 3. Calculation result of Mountain front sinuosity

Length along the mountain-piedmont junction (Lmf)	The overall length of the mountain front (Ls)	Mountain front sinuosity (Smf)
3,25 km	1,70 km	1,911

Figure 5. Joint found at Volcanic Breccia at Field Stop 2 of the research area

4. Conclusion

Analysis using the Second Vertical Derivative (SVD) found an anomaly that indicated the presence of a fault which was classified as a thrust fault, while the results of analysis using the VS30 method showed that there was a weak zone in the area around the anomaly. Despite the geophysical analysis which stated that there were indications of faults in the research area, based on geological observations in the field, no characteristics were found that indicated the presence of faults in the research area.

Several things that are recommended to be done in the research area include; 1) carrying out 3D modeling to estimate the depth of the fault, 2) verifying the existing data with several other data, such as reflection seismic data and micro-seismicity distribution to confirm the existence and level of activity of the thrust fault,) carry out primary data collection to identify VS30 and microseismic to identify subsurface amplitudes.

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