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The 2D resistivity modelling on north sumatran fault structure by using magnetotelluric data

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Abstract. Aceh is the region that some parts of the Sumatran Fault System (GSF) pass through. The existence of faults has implications for earthquake events. To understand the impact of seismic activities that occur along the fault, it is necessary to do fault mapping and geometry modelling. In this study, magnetotelluric geophysical methods were used to describe 2D resistivity structures in the northern Sumatran. A geophysical survey using magnetotelluric method was done to image 2D resistivity model along the northern part of the fault. The measurement was carried out two lines, with a length of the profile is 92 km and 114 km, consisting of 14 measurement points across the fault, with distances between tracks ranging from 10 - 15 km. 2D resistivity models were generated by using the Reduce Basic Occam (REBOCC) code. From the resulted model, it can be interpreted as indications of the existence of the Aceh Segment and Segment Seulimeum Faults. In-line C, there are two locations indicated by faults, namely Saree area associated with the Seulimeum segment and the Jantho area associated with the Aceh segment and line D in the geographic area is associated with the Aceh segment. From the resulted model, the Sumatran Fault in the northern part of Aceh was divided into two segments as shown in the model.

1. Introduction

Aceh is located on the Sumatra Fault active fault line that extends 1900 km and reaches the Andaman islands. The Sumatra Fault Formation occurs due to the subduction of the Indo-Australian Plate below the Eurasian Plate which moves at a speed of 50-70 mm/year, this zone has a slope of as much as 12° [1][2]. The Sumatra fault consists of 20 segments starting from the south with a small strike-slip and rising to the north end of Sumatra Island. History The Earthquake in Sumatra Fault with a magnitude of 6.5 to 7.7 has been well documented since 1980. Besides that, an earthquake with magnitude 9 at the subduction zone also occurred in 2004 but the disaster was also affected by aftershocks in several other segments of Sumatran Fault [2] Thus as an effort to reduce disaster risk, it is necessary to do research on geometry from the Sumatra Fault, especially on Aceh segment and Seulimeum segment.

The Magnetotelluric (MT) method has been widely applied to study various fault structures, [3] studied fault systems in northern Japan, this method has also been used to map Altyn Tagh Fault, India-Asia structures [4]. On the other hand, the MT method is also used to estimate local structures and faults in geothermal fields [5][6]. This MT method provides information on electrical

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conductivity ranging from the crust that is only a few meters to the upper mantle with a depth of hundreds of kilometers, the depth of this method depends on the frequency used [7].

Research on Sumatran fault geometry has been carried out, for example, [8] uses the electrical resistivity method for estimating shallow faults at the Seulimum segment. In addition, [9] has used the MT method for geometry mapping of the Sumatra segment Aceh and Seulimum fault structures based on Occam's 2D inversion modeling. Occam's algorithm is an inversion method which is very widely used in various electromagnetic non-plane wave data, especially the MT method [10] but this inversion was developed by Siripunvaraporn & Egbert in 2000 [11] which faster calculation called Occam's Inversion Reduced Base. As an effort for reducing the risk disaster from the earthquake, the 2D magnetotelluric was modeling using the REBOCC inversion for imaging the fault structure. The results of the modelling can explain the geometrical structure of the North Sumatra Fault; Aceh and Seulimeum segments based on the distribution of resistivity values.

2. Background and geological setting
Based on the geological map (Figure. 1), in general, the geological structures of the island of Sumatra are composed of Tertiary sedimentary rocks located above metamorphic rocks, and some places are penetrated by mafic and ultramafic igneous rocks. In the eastern part of Sumatra, there are basins consisting of shale sediments, Miocene-Pleistocene volcanic sediments. Physiographically, the Sumatra region is formed by two mountain ranges that are almost parallel, both separated by a graben zone which forms a fairly wide valley path [12]. From the type of lithology in the western part of Sumatra, it is dominated by Jurassic-Cretaceous limestone, meanwhile, in the eastern part of Sumatra, it is dominated by sand and clay in Tertiary-Neogene age [13][14].

Figure 1. Simplified geologic map of the study area, modified from David Fernández-Blanco, et al., 2016.
3. Theory and method

The Magnetotellurics (MT) method is a passive electromagnetic geophysical method used to investigate the electrical resistivity distribution of the Earth. This method measures the electromagnetic induction of the earth by utilizing variations in the geomagnetic fields that occur naturally. It is possible to know the structure of the conductivity of the earth from several tens of meters to hundreds of kilometers. In the MT method, the horizontal component of the electric field \( E \) and the magnetic field \( H \) are measured simultaneously as a function of time and converted to the frequency domain using Fourier transformation. This process is carried out to obtain the resistivity value below the study area. The horizontal component of the electric and magnetic fields is related to the tensor impedance \( Z \) given by:

\[
E = ZH 
\]

The tensor impedance in a more complex form can be written for real numbers \( X \), and imaginary \( Y \) is

\[
Z = X + iY
\]

For 2D earth reviews, there are two components in the MT method, the electric field impedance component parallel to the electric strike direction is transverse electric (TE) and the magnetic field component parallel to the strike direction of the rock is called transverse magnetic (TM) mode. Data obtained from the MT method in the form of apparent resistivity \( \rho_a \) as a function of frequency \( f \), is given by

\[
\rho_a = \frac{1}{\mu_0 \omega} \left| \frac{E_i}{H_i} \right|^2
\]

while phase

\[
\varphi = \tan^{-1} \left| \frac{E_i}{H_i} \right|
\]

Where \( \mu \) is a magnetic permeability of free space, and \( \omega \) is the angular frequency from the source. The apparent resistivity shows information of subsurface resistivity as a function of depth. While the phase data can also help interpret the resistivity model, a value below 45° indicates a resistor at depth while 45° indicates a conductor object below the surface [7]. The depth of penetration of the skin depth electromagnetic field depends on the frequency and electrical conductivity of the medium through which it can be mathematically written:

\[
\delta = \frac{500 \sqrt{\rho}}{f}
\]

Where \( \rho \) is the resistivity of the medium, and \( f \) is the exploration frequency in Hertz. The equation shows that the penetration depth in the MT method is not only influenced by the frequency but also by the material’s resistivity in the observation area.

The MT data acquisition was carried out since 2010 - 2014 using Phoenix Instrument equipment, and the data was measured by cutting the Sumatra Fault consisting of two trajectories which had 14 measurement points with distances between points ranging from 5 - 10 km covering the area of Aceh Jaya district, Aceh Besar, Pidie, Pidie Jaya and Bireun. Geographically it is in coordinates between 4°48'50" LS to 5°18'90" LS, and 95°28'80" BT to 96°47'60" BT. In modeling magnetotelluric data, the apparent resistivity and phase values are obtained from the transferred frequency function of time series data. To get the value in the frequency domain obtained by using Fast Fourier Transform (FFT), so that the magnetic field and electric field data are obtained in the frequency function. The frequency range obtained varies from one point to another, which is between 1.34 - 320 Hz, with the number of frequencies, obtained varying at each measurement point. The apparent resistivity and phase values in the XY direction indicate the direction of the electric field measured in the direction of the measurement path and the magnetic field perpendicular to the direction of the path, also known as the
electric transfer mode (TE), while the apparent resistivity and phase in the \( XY \) direction indicate the magnetic field in the direction of the track and the electric field is perpendicular to the direction of measurement, also called magnetic transfer (TM). Before 2D Magnetotelluric data modeling is performed, it is necessary to test the quality of apparent resistivity and phase data in TE and TM modes. Furthermore, modeling is done using code Reduced Base Occam's Inversion (REBOCC) from Siripunvaraporn and Egbert [11].

4. Result and discussion

The results of measurements in the field obtained the data in the form of electric fields \( (E) \) and magnetic fields \( (H) \) forms. The measurement of electric field data is carried out by using four electrodes in two directions \( Ex \) and \( Ey \). While the measurement of magnetic fields is done by using coils in three directions \( Hx, Hy, \) and \( Hz \). The frequency range obtained varies from one point to another, which is between 1.34 - 320 Hz, with the number of frequencies, obtained varied at each measurement point. Figure 2 shows the value of apparent resistivity and phase in the \( X_y \) direction as TE mode and \( Y_x \) direction as TM mode. The value of apparent resistivity is relatively low at high frequencies and relatively high at low frequencies. In the frequency range 16.2 - 320 Hz, it shows a low resistivity value, while in the frame frequency 2 - 11 Hz shows a high resistivity value. Phase data also show the same information, assuming 1D frequency range 66 - 320 Hz with phase values above 45° describing conductive zones and phases below 450 with frequencies of 2.34 - 57 Hz with phase values below 45° indicating resistive zones.

![Figure 2. Apparent resistivity data and TE, TM phase mode at C5 point measurement. (a) A comparison between TE and TM. (b) Magnetic response on TE and TM mode.](image-url)

Magnetotelluric data modeling was carried out using REduced Base OCCam's Inversion (REBOCC) developed by [11] with further development by Siripurvaraporn and Egbert [10] to be able to produce
a more smooth 2D resistivity model. The inversion results at line C have a length of 90 km and a D track with a length of 114 km. Measurement of data on both tracks that cut off the northern Sumatra fault line directly affects the distribution of resistivity values on the resulted model.

The result of a resistivity model inversion at line C (Figure 3) shows the existence of two Sumatran fault structures; Aceh and Seulimum segments. The distribution of subsurface resistivity values between C2 and R1 can be interpreted as a Sumatra fault structure of the Acehnese segment. While the difference in resistivity values that contrast between R1 and C1 are interpreted as the location of the existence of the Seulimum segment fault structure. In geological structure, these active segment areas are dominated by rocks originated by volcanic eruptions; andesite volcanic rocks up to dacite, buoyant breccias, tuffs, conglomerates, and dust flows. The inversion model on path D (Figure 4) shows the distribution of resistivity value correlates with the Sumatra fault structure. The distribution of the resistivity value distribution, which is very contrast between the R3 and R4 zones can be interpreted as a Sumatra fault structure indicated by a dashed line.

![Figure 3](image1.png)

**Figure 3.** Subsurface resistivity based on 2D inversion, the distribution at line C shows a cut line survey on Aceh segment (C3) and Seulimum segment(C4).

![Figure 4](image2.png)

**Figure 4.** A Resistivity value distribution on the 2D magnetotelluric model in line D. Measurement lines is carried out by cutting the Sumatera fault structure between Aneuk Manyak and Geumpang.

Based on the 2D modelling from both profiles, the Sumatran fault structure can be interpreted between resistive and conductive blocks, where the difference of the two blocks is caused by the resistivity of the rocks in the subsurface.
5. Conclusion
Based on the result, it can be interpreted as indications of the existence of the Aceh Segment and Segment Seulimeum Faults. In-line C, there are two locations indicated by faults, namely Saree area associated with the Seulimeum segment and the Jantho area related to the Aceh segment. In Line D in the geographic area is associated with the Aceh segment. The Sumatran Fault in the northern part of Aceh was divided into two segments as shown in the model. The indications of Sumatra fault in Aceh and Seulimeum segments can be used as a reference for earthquake risk management in Aceh Province. However, for more comprehensive results, several MT measurement is needed to produce a clear structure of Sumatran fault.

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