ISSN: 2579-5821 (Print)
ISSN: 2579-5546 (Online)
URL address: http://journal.unhas.ac.id/index.php/geocelebes
DOI: 10.20956/geocelebes.v8i2.34588

Jurnal Geocelebes Vol. 8 No. 2, October 2024, 132 – 141

Identification of Sub-Fault Zone Using Magnetotelluric Inversion (Case Study: Ketaun Fault, Lemeu Village, Lebong Regency)

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Manuscript received: 24 April 2024; Received in revised form: 10 June 2024; Accepted: 26 June 2024

Abstract

Lemeu Village, Lebong Regency, borders the Bukit Barisan Mountain range and is crossed by the Ketaun Fault, which causes a high level of seismic activity, so it is necessary to conduct research on the potential existence of the Ketaun sub-fault as one of the efforts to mitigate natural disasters such as earthquakes. The Magnetotelluric method utilises the earth's natural electromagnetic field, which is used to determine the distribution of resistivity in the subsurface using the ADU-07e Magnetotelluric tool with two horizontal electrical sensors (Ex, Ey) and three horizontal (Hx, Hy) and vertical (Hz) magnetic sensors and uses seven research points with an interval of 1 km. Data processing uses MAPROS software to convert data from the time domain to the frequency domain and ZONDMT2D to obtain subsurface resistivity values. The results obtained from this study are 2D magnetotelluric cross sections showing a zone with low resistivity values between research points P4 and P5 which is thought to be a new fault zone with resistivity values ranging from 1.3 – 6.1 Ωm from a depth of 2.5 km to a depth of 10 km. The zone is assumed to be a new fault that is a branch of the Ketaun fault.

Keywords: Fault; Lebong; Magnetotelluric; Resistivity.

Citation: Rahmawati, N.I., Farid, M., Hadi, A.I. & Al Ansory, A.R. (2024). Identification of Sub-Fault Zone Using Magnetotelluric Inversion (Case Study: Ketaun Fault, Lemeu Village, Lebong Regency). *Jurnal Geocelebes*, 8(2):132–141, doi: 10.20956/geocelebes.v8i2.34588

Introduction

Bengkulu Province is one of the provinces on the island of Sumatra that the Bukit Barisan crosses. According to Geology, Bukit Barisan was formed due to the subduction pressure of the Indo-Australian Tectonic Plate that penetrates under the Eurasian Tectonic Plate and moves at a velocity of 50-70 mm/year (Mulyati et al., 2020). This causes Bengkulu Province to have a high level of seismic activity due to the plate movement (Hadi & Brotopuspito, 2016).

Another result of the plate movement is that Indonesia is divided into many regions bounded by many active fault lines. Fractures in rocks that experience movement are referred to as faults. Faults usually form paths or lines, but they can also form fault planes or single fractures (Supartoyo et al., 2019).

Faults are divided into normal fault, reverse fault, strike-slip fault. Based on the activity level, faults are classified into active and inactive faults (Firdaus et al., 2016). One of the active faults in Indonesia is the Sumatra fault. The Sumatra fault cuts through the Bukit Barisan mountain range along 1,900 km, starting from the Sunda Strait to the Aceh region and the Andaman Sea (Lubis et al., 2019). The Sumatra fault was formed as a result of subduction between the Indo-Australian and Eurasian plate (Arisbaya et al., 2016).

The Sumatra fault is divided into several segments with varying segment lengths ranging from 60 km to up to 200 km (Natawidjaja, 2018). This makes Sumatra a lot of active faults. One of the active faults in Sumatra is the Ketaun fault. The Ketaun fault stretches from Ketaun, Lebong, Tes to Muaraaman along 85 km and 20 km wide. It has a northwest-to-southeast orientation direction and upward movement characteristics (Sieh & Natawidjaja, 2000).

Faults cause earthquakes that affect local tectonic geological conditions (Muflihah, 2014). One of the tectonic hazards is the people who live on the island of Sumatra, especially the Bengkulu Province, especially the North Bengkulu and Lebong Regencies, which are crossed by the Ketaun Segment Sumatra fault (Ardiansyah, 2018).

Lemeu Village in Lebong Regency is directly adjacent to the Bukit Barisan Mountains. These mountains are at the epicenter of active faults and are in an earthquake-prone zone (Bahri et al., 2022). In 1943, a large earthquake with a magnitude of M=7.4 occurred on the Ketaun segment and caused considerable damage to the Tes District to Muara Aman District. Another earthquake occurred in 1952 with M=6.8 (Syaputra et al., 2023). When viewed from the location of the main segment, the Ketaun segment, it is a land fault that has potential to damage in the event of a natural disaster earthquake even though the magnitude is not too large, the depth is shallow and close to settlements and community activities (Rais, 2021). So, it is necessary to research the existence of potential sub-faults in the Ketaun segment that have not been mapped as one of the disaster mitigation efforts to minimize the risk of fatal damage.

One of the geophysical methods used to determine the presence of sub-faults is the Magnetotelluric (MT) method because it is considered capable of detecting subsurface structures up to approximately 8,000 meters (Wulandari et al., 2017). This is because MT method measurements use low frequencies to detect to a greater depth than other methods. On the other hand, the top depth of the Sumatra fault is around 3 km (PUSGEN, 2017). Previous research on fault identification using the MT method was conducted by Arisbaya et al. (2023) to identify the possibility of an active fault in Garut, West Java. The MT method also mapped the Altyn Tagh fault, an Indian-Asian structure (Zhang et al., 2015). In addition, the MT method can estimate local structures and faults of geothermal fields.

This research is expected to provide comprehensive information on the existence of potential unmapped sub-faults to monitor the movement of these plates to minimize losses and impacts caused by earthquake natural disasters.

Materials and Methods

According to Van Bemmelen (1949), the physiographic zone of Sumatra is grouped into four parts, the Bukit Barisan Mountains, Semangko Fault, Tigapuluh Mountains, and undulating lowlands. The research location in Lemeu Village is included in the Bukit Barisan Mountains zone with physiographic conditions formed in the form of hills with narrow valleys composed of tertiary sedimentary rocks (Adrianda & Sutriyono, 2022). The Regional Geological Condition of Lebong Regency can be seen in Figure 1.

Based on the Geological map of Bengkulu sheet in (Al Ansory et al., 2023), fault structures that can be found in the geological structure of the study area include: joint, Air Putih slip fault and Batang Ketaun fault which have the age of late Miocene, when the main force moves relatively north-south, which is the time of formation of geological structures in the study area (Putra et al., 2017).

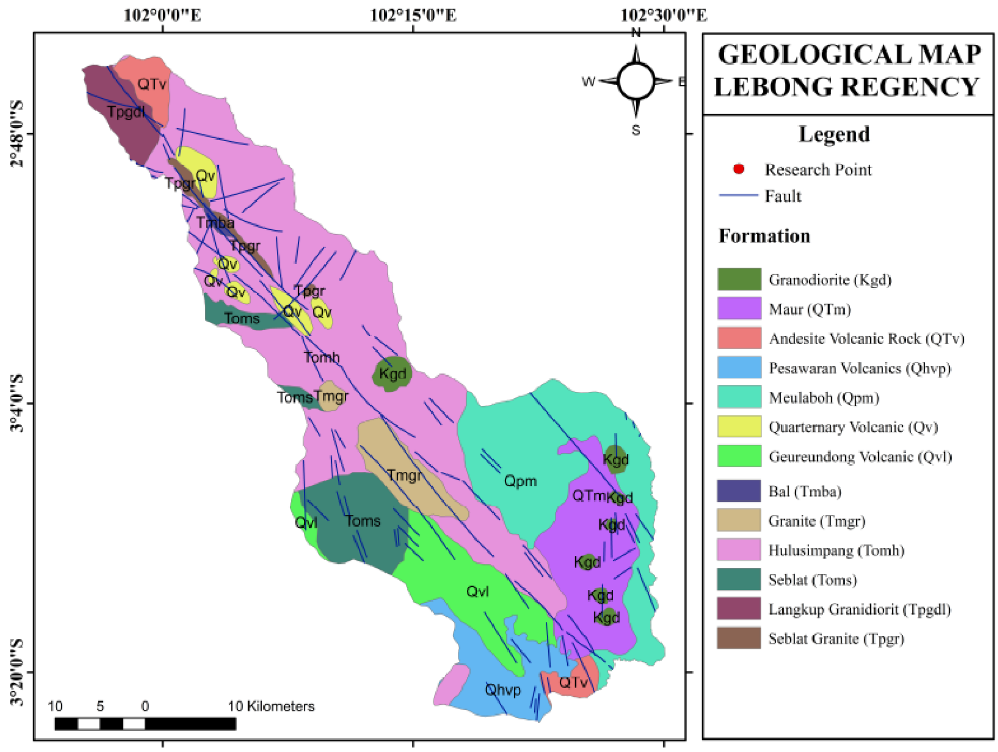

Figure 1. Regional Geological Map of Lebong Regency (Modified from ESDM, 2023).

Lebong Regency regionally has several rock formations, which are the Simpangaur Formation, which is composed of breccia and conglomerate, the Bintunan Formation, which is dominated by conglomerate, breccia, and claystone, the Hulusimpang formation which consists of lava, tuff and breccia, the Lemau Formation which is dominated by breccia and the Seblat Formation is dominated by sandstone and carbonate. At the research location, Lemeu Village, Lebong Regency, the Hulusimpang Formation is composed of lava, tuff and volcanic breccia and is composed of andesite to basalt rocks of Late Oligocene to Early Miocene age.

MT method is a geophysical exploration method that uses the earth's natural electromagnetic field to determine the conductivity distribution in the subsurface (Harahap et al., 2022). According to the frequency and duration of recording, the MT method has a reasonably deep penetration. If using a small frequency with a relatively long recording duration, the depth reached is also getting deeper up to 8 km. That is the reason of MT method can be used to determine the subsurface structure (Rizal et al., 2019).

MT method measures the orthogonal or perpendicular components of the electric (Ex, Ey) and magnetic (Hx, Hy, Hz) fields at the Earth's surface in the time domain (Setyani, 2017). Figure 2 shows a typical MT setup, with the Earth's naturally varying magnetic field as the source of a wide and continuous spectrum of electromagnetic waves. The internal coordinate system measures the electric field horizontally orthogonal and the magnetic field vertically and horizontally orthogonal (Muttaqien & Nurjaman, 2021).

The MT method utilizes the natural electromagnetic (EM) field to determine the earth's subsurface structure based on the electrical properties of rocks at relative depths (including the earth's mantle) within the earth (Hidayat et al., 2016). The MT method can describe subsurface resistivity by looking at the nature of the rock. The MT method's depth reached is inversely proportional to the signal frequency used (Türkoğlu et al., 2015).

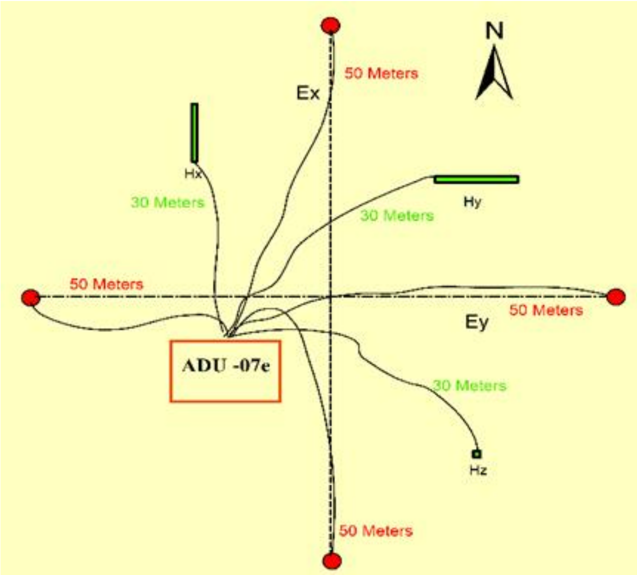

Figure 2. MT arrangement in internal coordinate system (Al Ansory et al., 2023).

These EM fields are generated by complex physical processes with a very wide frequency spectrum, ranging from 10-5 Hz to 104 Hz. Variations in the EM field at low frequencies of less than 1 Hz are caused by the interaction of the earth's permanent magnetic field with wind containing electrically charged particles, causing variations in the EM field. Furthermore, variations above 1 Hz are caused by meteorological activities such as lightning, which create EM waves that travel between the ionosphere and the earth (Fitrida et al., 2015).

To find out the nature of EM waves, the general equation is used, which is Maxwell's equation (Fitzpatrick, 2010).

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (1)$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (2)$$

$$\nabla \cdot D = q \quad (3)$$

$$\nabla \cdot B = 0 \quad (4)$$

Where :
$\vec{E}$: Electric field (Volt/m)
B : Flux or magnetic induction (Weber/m^2 or Tesla)
H : Magnetic field (Ampere/m)
J : Current density (Ampere/m^2)
D : Electrical displacement (Coulomb/m^2)
q : Current charge density (Coulomb/m^3)

Result and Discussion

This research was conducted in Lemeu Village, Lebong Regency using seven measurement points and a 1 km intervals. Figure 3 shows the map of the research location. The results of MT measurements in Lemeu Village, Lebong Regency are shown in the time series in Figure 4. The time series of electric field data has good quality because at the time of measurement, further data processing is carried out by MAPROS software. MAPROS software can reduce data.

That deviate from the main data pattern. As a result, only data with good quality will be processed using MAPROS. Figure 4 shows the measurement results for 16 hours taken with a low frequency (128 Hz) with a recording time of 13 hours because small frequencies are more susceptible to noise, therefore the recording time is longer, medium frequency (1024 Hz) with a recording duration of 2 hours, high frequency (4096 Hz) with a recording time of 1 hour because the frequency used is large.

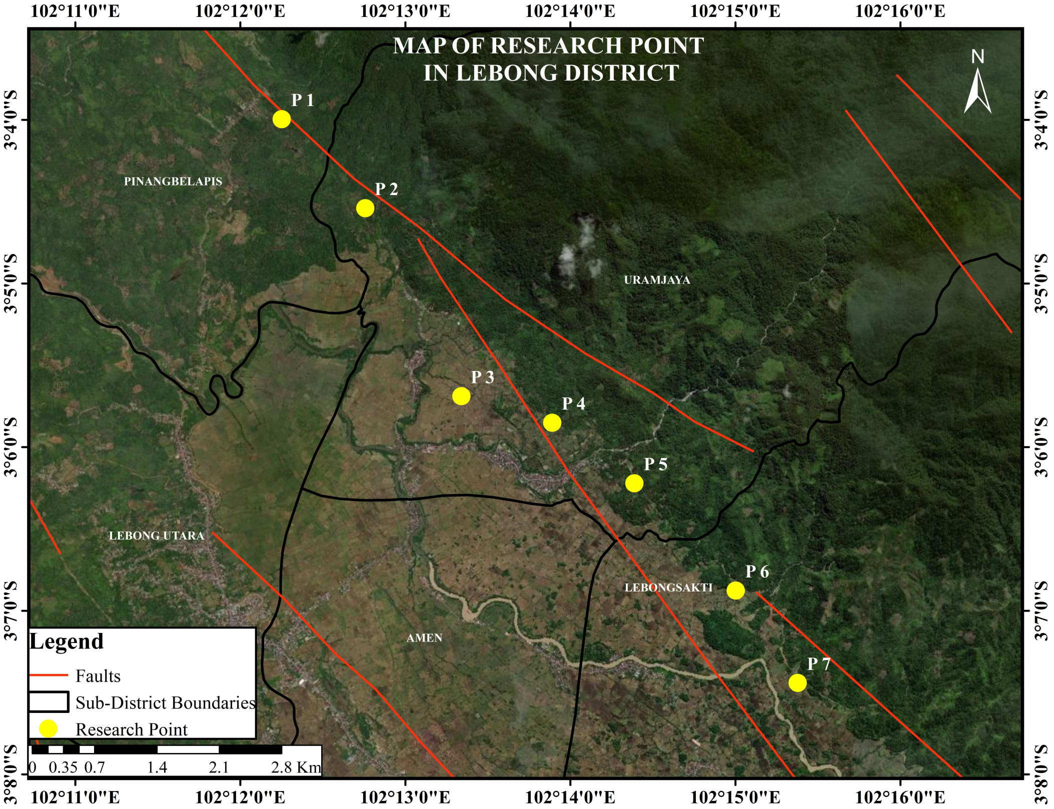

Figure 3. Map of MT research location.

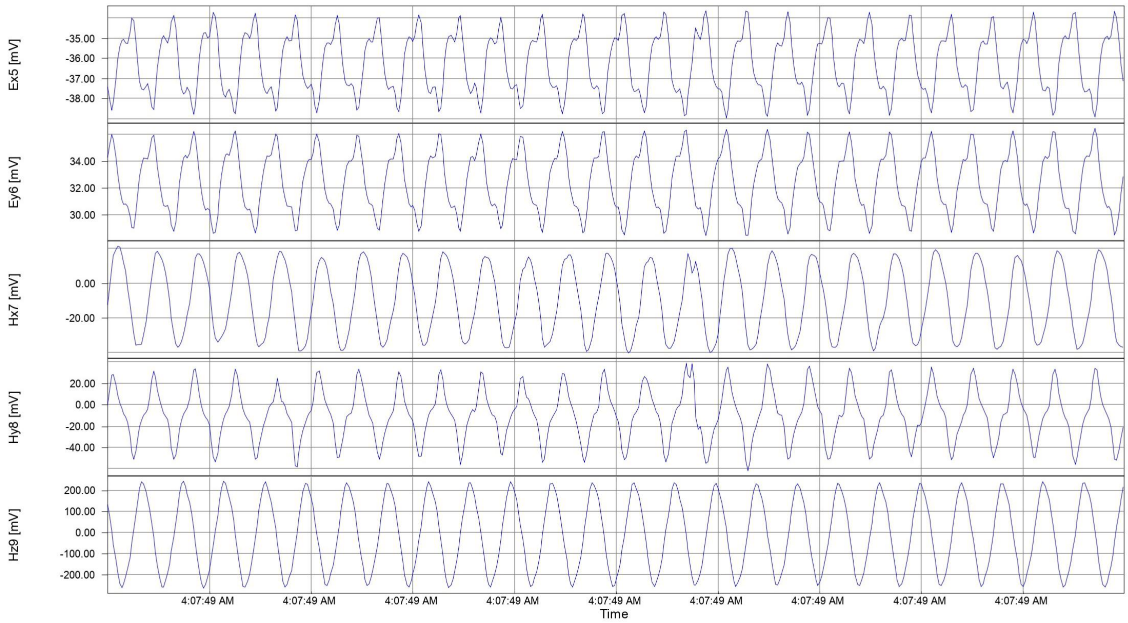

Figure 4. Time series data.

Figure 5 shows the connectivity between resistivity value and depth, from the two figures there is a difference at P5 which shows an anomaly and indicates that the zone is a fault zone because of the low resistivity value. In Figure 6 shows three 2D cross-sections of resistivity values, cross-section 1 is field data with apparent resistivity values, cross-section 2 is a calculation model between field data and model data generated by ZONDMT2D software, and cross-section 3 is the result of the actual resistivity value. The 2D resistivity model shows that the resistivity value is related to the type of rock that is there.

Research that has been conducted around this location by Al Ansory et al. (2023) which from the results of his research shows resistivity values ranging from 0.2 Ωm to 700 Ωm which from the results of the cross section shows the potential pattern of geothermal and from the results of Al Ansory et al. (2023) shows a 2D cross section of resistivity values that differ significantly when compared to this research.

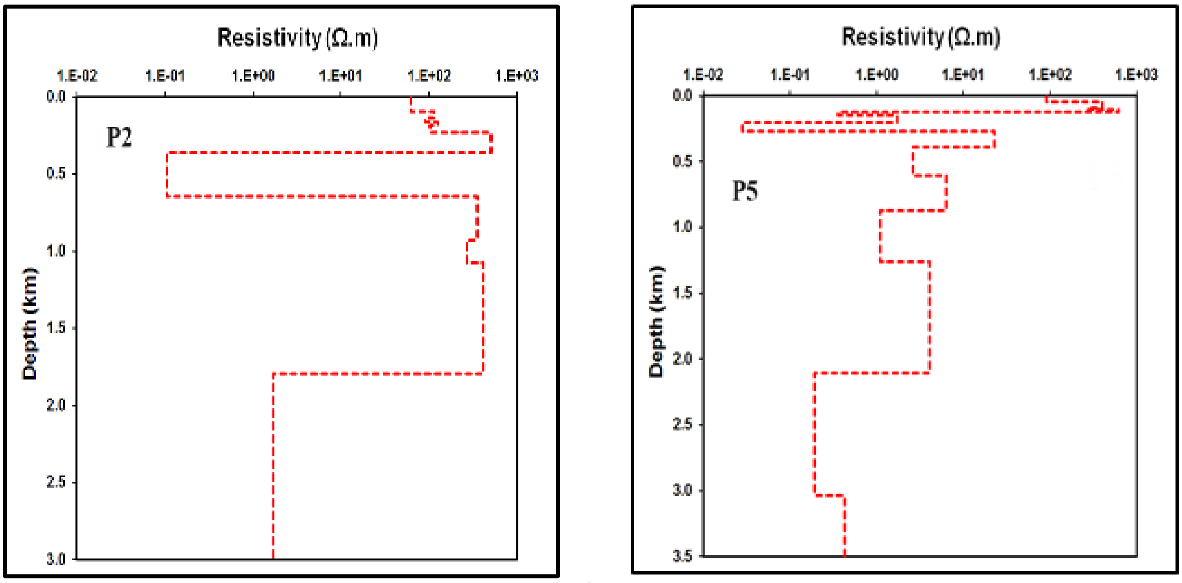

Figure 5. Connectivity of resistivity value with depth.

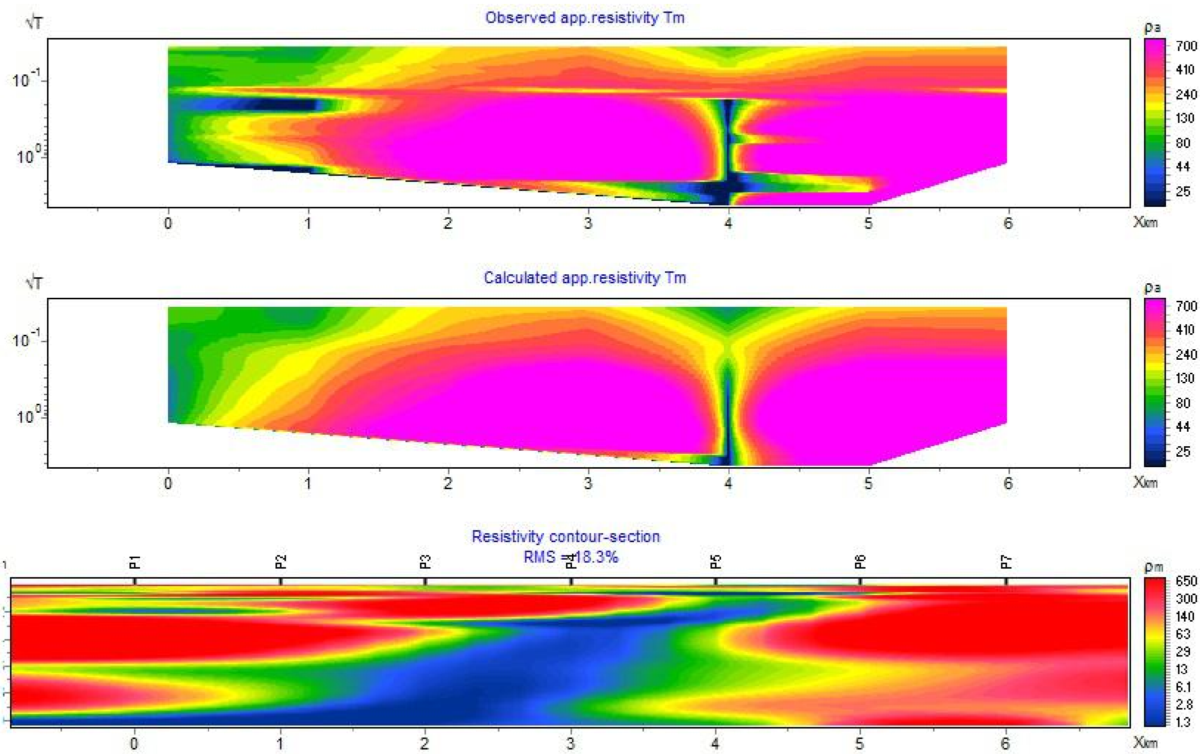

Figure 6. 2D cross-section model resistivity value.

The 2D resistivity cross-section model shows varying resistivity values, starting from 1.3 Ωm to 650 Ωm. According to Gafoer et al. (1992), the resistivity value can be classified into three groups: low, medium, and high resistivity. Low resistivity (1.3 – 6.1 Ωm) is shown in blue color which is thought to be a caprock layer or an overlaying layer at a depth of 0.75 km. In this research area, an andesitic lava rock type was identified where this rock has undergone alteration. Some of the alterations are in the form of volcanic breccia and tuff so that they can experience fractures. Medium resistivity with resistivity values ranging from 10 - 80 Ωm is colored green to yellow and is thought to be a reservoir. The red color shows high resistivity values with resistivity values around 140 – 650 Ωm which is thought to be a hot rock layer.

The 2D cross section shows an anomaly structure in the measurements at points P4 and P5. The structure has a resistivity value that changes significantly and shows a low resistivity value of 1.3 - 6.1 Ωm which is thought to be a fault zone (Telford et al., 1990). The presence of a fault zone can generally be identified as a conductive zone by the presence of a fracture that has the potential to be filled with fluid, causing the resistivity value in the fracture to have a low resistivity value while the bedrock or basement is characterized by a resistive zone (Pratama et al., 2021). When the measurement depth is at 2.5 km, the layer is fractured which has the potential for an unmapped Ketaun sub-fault zone (Figure 7). The fault zone can be formed from the parent fault, which is the Ketaun fault, which interacts with magma intrusion, causing fluid to seep into the fractures which are then heated by the hot rock layer and produce low resistivity values.

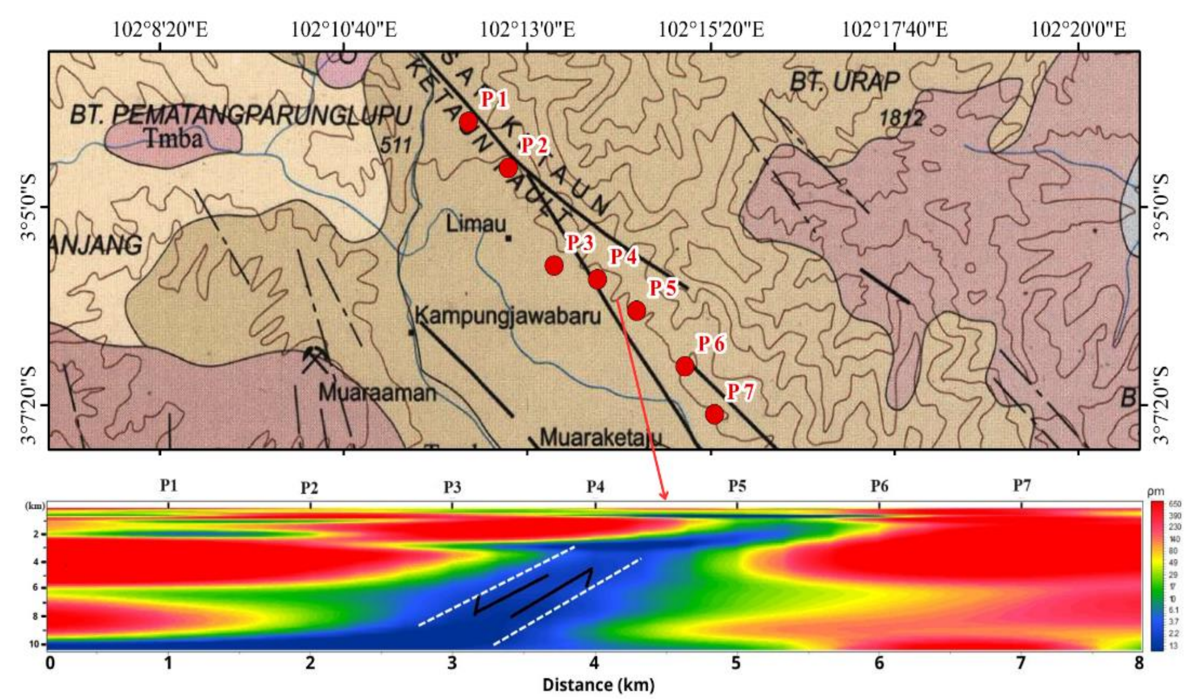

Figure 7. 2D model identified as the presence of a fault zone.

Conclusion

Based on the research conducted in Lemeu Village, Lebong Regency, on the Ketaun segment, it is concluded that the 2D MT cross section shows a zone with low resistivity values between research points P4 and P5, which is thought to be a new fault zone with resistivity values ranging from 1.3 – 6.1 Ωm from a depth of 2.5 km onwards. The zone is assumed to be a secondary fault that is a branch of the Ketaun fault. This shows that this study can map geological structures suspected to be new faults.

Acknowledgements

Thanks to the Geophysical Laboratory of Bengkulu University for giving permission to use geophysical equipment for acquisition purposes, so that the survey in this study can be carried out.

Author Contribution

The preparation of this research journal, each author is divided into several job desks for collecting literature sources and preparing journals by Nurul Ilmi Rahmawati. Making research survey design, data processing by Nurul Ilmi Rahmawati and Andre Rahmat. Observers and supervisors in writing this journal are M. Farid and Arif Ismul Hadi.

Conflict of Interest

The authors declare that the data published in the manuscript has no conflict of interest to any parties.

References

Adrianda, R. S., & Sutriyono, E. (2022). Kajian Struktur Geologi Daerah Muaro, Kabupaten Sijunjung, Sumatera Barat. *Jurnal Geomine*, 10(3), 209–219. https://jurnal.teknologiindustriumi.ac.id/index.php/JG/article/view/1283

Al Ansory, A. R., Raihana, H., Pritama, V. L., Saputri, W., Maghribi, F. B., Farid, M., Hadi, A. I., Harlianto, B., & Sugianto, N. (2023). Delineasi Nilai Resistivitas Di Lapangan Panas Bumi Tambang Sawah Menggunakan Metode Magnetotellurik. *Buletin Sumber Daya Geologi*, 18(3), 145–154. https://doi.org/10.47599/bsdg.v18i3.386

Ardiansyah, S. (2018). *Analisis Gempabumi Merusak Kabupaten Lebong- Bengkulu 6 Desember 2017*.

Arisbaya, I., Mukti, M. M., Handayani, L., Permana, H., & Schnabel, M. (2016). Tabuan-Panaitan Ridge, Trace of Sumatran Fault in the Sunda Strait based on Geophysical Data Analysis. *Prosiding Pemaparan Hasil Penelitian Geoteknologi LIPI*, I-33–I-39.

Arisbaya, I., Wijanarko, E., Warsa, W., Sumintadireja, P., Sudrajat, Y., Handayani, L., Mukti, M. M., & Grandis, H. (2023). Magnetotellurics (MT) and Gravity Study of a Possible Active Fault in Southern Garut, West Java, Indonesia. *International Journal of Geophysics*, *2023*, 4482074 https://doi.org/10.1155/2023/4482074

Bahri, S., Hanif, M. F., Prihatiningrum, A., & Islam, M. (2022). Perilaku dan Ketahanan Struktur Rumah Vernakular Desa Gunung Alam Lebong terhadap Gempa Bumi. *Jurnal Inersia Teknik Sipil*, *14*(1), 1–10. https://ejournal.unib.ac.id/inersiajurnal/article/view/18357

ESDM, P. S. G. (2023). *SHP Peta Geologi Lebong*.

Firdaus, M. W., Setyawan, A., & Yusuf, M. (2016). Identifikasi Letak Dan Jenis Sesar Berdasarkan Metode Gayaberat Second Vertical Gradient Studi Kasus Sesar Lembang, Kota Bandung, Jawa Barat. *Youngster Physics Journal*, 5(1), 21–26. https://ejournal3.undip.ac.id/index.php/bfd/article/view/10629

Fitrida, S. M., Sampurno, J., Ivansyah, O., & Kholid, M. (2015). Identifikasi Struktur Bawah Permukaan Berdasarkan Metode Magnetotellurik di Kawasan Panas Bumi Wapsalit Kabupaten Buru Provinsi Maluku. *Positron*, 5(1), 11–18. https://doi.org/10.26418/positron.v5i1.9733

Fitzpatrick, R. (2010). Maxwells equations and the principles of electromagnetism. *Laxmi Publications, Ltd.*

Gafoer, S., Amin, T. C., & Pardede, R. (1992). *Geologi lembar Bengkulu, Sumatera*, Pusat Penelitian dan Pengembangan Geologi.

Hadi, A. I., & Brotopuspito, K. S. (2016). Estimasi Kedalaman Bidang Batas Sesar dari Data Gravitasi di Daerah Rawan Gerakan Tanah (Studi Kasus: Sesar Sumatra Segmen Musi Bengkulu). *SIMETRI*, *Jurnal Ilmu Fisika Indonesia*, 2(2), 2207-37–2207-42. https://jsimetri.wordpress.com/wp-content/uploads/2016/07/j-simetri-v2-no2-2016-07-arifunib-37-42.pdf

Harahap, Z. A., Haryanto, A. D., Firmansyah, Y., & Alfadli, M. K. (2022). Determinasi Zona Reservoir Dengan Data Magnetotelurik Di Zona Prospek Panas Bumi Telaga Ngebel, Jawa Timur. *Padjadjaran Geoscience*, 6(2), 803–811. https://jurnal.unpad.ac.id/geoscience/article/view/41415

Hidayat, A. R., Junursyah, L. G., & Asep, H. (2016). Analisis Deret Waktu Untuk Peningkatan Kualitas Data Magnetotelurik (Studi Kasus Lapangan Geothermal). *Proseding Seminar Nasional Fisika dan Aplikasinya*, *November*, 1–10.

Lubis, A. M., Butarbutar, D. C., Suhendra. S., & Samdara, R. (2019). Investigasi Sudut Pergerakan Sesar di Musi Kepahiang dengan Menggunakan Metode Geolistrik. *Jurnal Meteorologi dan Geofisika*, 20(2), 67–72. https://doi.org/10.31172/jmg.v20i2.543

Muflihah, I. (2014). Distribusi Dan Pola Sesar Daerah Kepala Burung (Papua Barat). *Jurnal Neutrino*, 6(2), 91–98. https://doi.org/10.18860/neu.v0i0.2588

Mulyati, R., Suryana, V. A., & Wulandari, D. A. (2020). Identifikasi Sesar Aktif Terhadap Pembangunan Bendungan Di Provinsi Aceh (NAD). *Ruang Teknik Journal*, 3(1), 94–98. https://jurnal.umsb.ac.id/index.php/RANGTEKNIKJOURNAL/article/view/1684

Muttaqien, I., & Nurjaman, J. (2021). Two-Dimensional Inversion Modeling Of Magnetotelluric (Mt) Synthetic Data Of A Graben Structure Using SimPEG. *RISET Geologi dan Pertambangan*, 31(1), 1–12. https://doi.org/10.14203/risetgeotam2021.v31.1121

Natawidjaja, D. H. (2018). Updating active fault maps and sliprates along the Sumatran Fault Zone, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 118(1), 012001. https://doi.org/10.1088/1755-1315/118/1/012001

Pratama, R., Resta, I. L., Farid, F., & Joni, W. (2021). Identifikasi Lapisan Bawah Permukaan Daerah Prospek Panas Bumi Songa-Wayaua Berdasarkan Metode Magnetotelurik. *Jurnal Meteorologi dan Geofisika*, 22(2), 45–53. https://doi.org/10.31172/jmg.v22i2.786

PUSGEN. (2017). *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017 (Map of Indonesia Earthquake Sources and Hazards in 2017)*. Pusat Studi Gempa Nasional.

Putra, I. D., Nasution, R. A. F., Harijoko, A. (2017). Aplikasi Landsat 8 Oli/Tirs Dalam Mengidentifikasi Altrasi Hidrotermal Skala Regional : Studi Kasus Daerah Rejang Lebong dan Sekitarnya, Provinsi Bengkulu. *Prosiding Seminar Nasional Kebumian Ke-X*, 10, 1812–1826.

Rais, L. N. (2021). Analisis Bencana Gempa Bumi Dan Mitigasi Bencana Di Daerah Kertasari. *Jurnal Samudra Geografi*, 4(2), 14–19. https://doi.org/10.33059/jsg.v4i2.3773

Rizal, M., Ismail, N., Yanis, M., Muzakir, M., & Surbakti, M. S. (2019). The 2D resistivity modelling on north sumatran fault structure by using magnetotelluric data. *IOP Conference Series: Earth and Environmental Science*, 364(1), 012036. https://doi.org/10.1088/1755-1315/364/1/012036

Setyani, A. (2017). *Investigasi bawah permukaan segmen cibeber zona sesar cimandiri, jawa barat dengan metode audio magnetotelurik (amt)*. Universitas Islam Negeri Syarif Hidayatullah Jakarta.

Sieh, K., & Natawidjaja, D. (2000). Neotectonics of the Sumatran fault, Indonesia. *Journal of Geophysical Research: Solid Earth*, 105(B12), 28295–28326. https://doi.org/10.1029/2000jb900120

Supartoyo, S., Suntoko, H., Bondan, A., & Alhakim, E. E. (2019). Analisis Morfotektonik dan Pemetaan Geologi pada Identifikasi Sesar Permukaan di daerah Plampang, Pula Rakit, Provinsi Nusa Tenggara Barat. *Jurnal Pengembangan Energi Nuklir*, 21(1), 45–52. http://dx.doi.org/10.17146/jpen.2019.21.1.5461

Syaputra, E. W., Refrizon, R., & Zakariya, H. (2023). Identifikasi Sesar Segmen Ketahun Berdasarkan Metode First Horizontal Derivative (FHD) dan Second Vertical Derivative (SVD) Data Anomali Gaya Berat GGMplus. *Jurnal Fisika Unand*, 12(4), 598–607.

Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). *Applied Geophysics*. Cambridge University Press.

Türkoğlu, E., Unsworth, M., Bulut, F., & Çağlar, İ. (2015). Crustal structure of the North Anatolian and East Anatolian Fault Systems from magnetotelluric data. 241, 1–14. https://doi.org/10.1016/j.pepi.2015.01.003

van Bemmelen, R. W. (1949). *The Geology of Indonesia*, The Hague.

Wulandari, J. C., Gaffar, E.Z., Zulaikah, S., N. A. P. (2017). *Penentuan Struktur Litologi Daerah Panasbumi Probolinggo Menggunakan Metode Magnetotellurik (MT)*.

Zhang, L., Unsworth, M., Jin, S., Wei, W., Ye, G., Jones, A. G., Jing, J., Dong, H., Xie, C., Le Pape, F., & Vozar, J. (2015). Structure of the Central Altyn Tagh Fault revealed by magnetotelluric data: New insights into the structure of the northern margin of the India-Asia collision. *Earth and Planetary Science Letters*, 415, 67–79. https://doi.org/10.1016/j.epsl.2015.01.025