GEOPHYSICAL INVESTIGATION OF GEOTHERMAL MANIFESTATION IN SUNGAI MEDANG USING ELECTRICAL RESISTIVITY AND GRAVITY METHODS

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ABSTRACT

This study investigates the geothermal manifestation in Sungai Medang, located within a volcanic arc depression zone of the Sungai Penuh Basin, formed by right-lateral movement along the segmented Siulak Fault. The exploration approach combined electrical resistivity and gravity methods to delineate subsurface features associated with hydrothermal activity. The electrical resistivity survey employed a dipole–dipole configuration with 25-meter spacing over a 400-meter line and the complementary gravity data from the Topex/Poseidon satellite altimetry were processed into Simple Bouguer Anomaly (SBA) maps. Resistivity survey revealed low-resistivity zones (11.6–99.1 Ωm), interpreted as hydrothermal fluid pathways and altered volcanic formations aligned with known fault traces, particularly the Siulak Fault segment. The gravity data indicated NW–SE trending density contrasts. Spectral analysis identified residual anomalies (~1.5 km depth) consistent with shallow sedimentary infill and structural depressions, while deeper regional anomalies (~38.7 km) reflected basement variations. The spatial correlation of resistivity lows, gravity lows, and surface manifestations suggests active geothermal upflow along structurally controlled zones. This study highlights the importance of integrating geophysical datasets for geothermal resource evaluation and offers a methodological framework applicable to similar underexplored regions in Indonesia and beyond.

Keywords: *Gravity method; Electrical resistivity method; Resistivity; Geothermal manifestation; Sungai Medang*

INTRODUCTION

Sumatra Island is part of the Indonesian archipelago that lies along the active volcanic arc known as the "Ring of Fire" (Hamilton, 1979). The chain of volcanoes on Sumatra has given rise to numerous geothermal surface manifestations, which are closely linked to the tectonic activity of the segmented Sumatran Fault System (SFS) (Natawidjaja, 2017). Despite a theoretical geothermal potential of 5845 MWe and a proven reserve of 4975 MWe, only 12 MWe is currently in operation, making Sumatra's geothermal utilization the lowest compared to Java and Sulawesi, despite Sumatra having higher resource availability (Kasbani, 2009; Simandjuntak, 1986).

Kerinci Regency, located in the central part of the Barisan Mountains, is one of Sumatra's geothermal hotspots. It hosts several well-known manifestations, including Semurup hot springs, Lempur hot springs, and geysers at Grahosikai and Grahobuangit. These features are part of the Kerinci-Lempur geothermal field operated by Pertamina (Badan Geologi, 2012; Muraoka et al., 2010). The geothermal systems in this region are typically volcano-tectonically controlled, strongly influenced by both the Siulak Fault segment and nearby volcanoes such as Mt. Raya, Mt. Kunyit, Mt. Tujuh, and Mt. Kerinci (Kasbani, 2009; Muraoka et al., 2010). These geothermal occurrences are distributed linearly along the Sumatran Fault Zone and associated Quaternary volcanic centers within the Bukit Barisan Physiographic Zone (Kasbani, 2009).

Tectonically, Sumatra forms part of the Sundaland Block, an extension of the Eurasian Plate (Simandjuntak, 1986; Hamilton, 1979). The tectonic evolution of Sumatra has been driven by the subduction of the Indo-Australian Oceanic Plate beneath the Eurasian Continental Plate, which has produced extensive magmatic arc volcanism and complex crustal deformation patterns (Hamilton, 1979; Carlile & Mitchell, 1994; Hall, 1997, 2002). Indonesia's magmatic arcs are known to host geothermal systems and mineralization zones, with

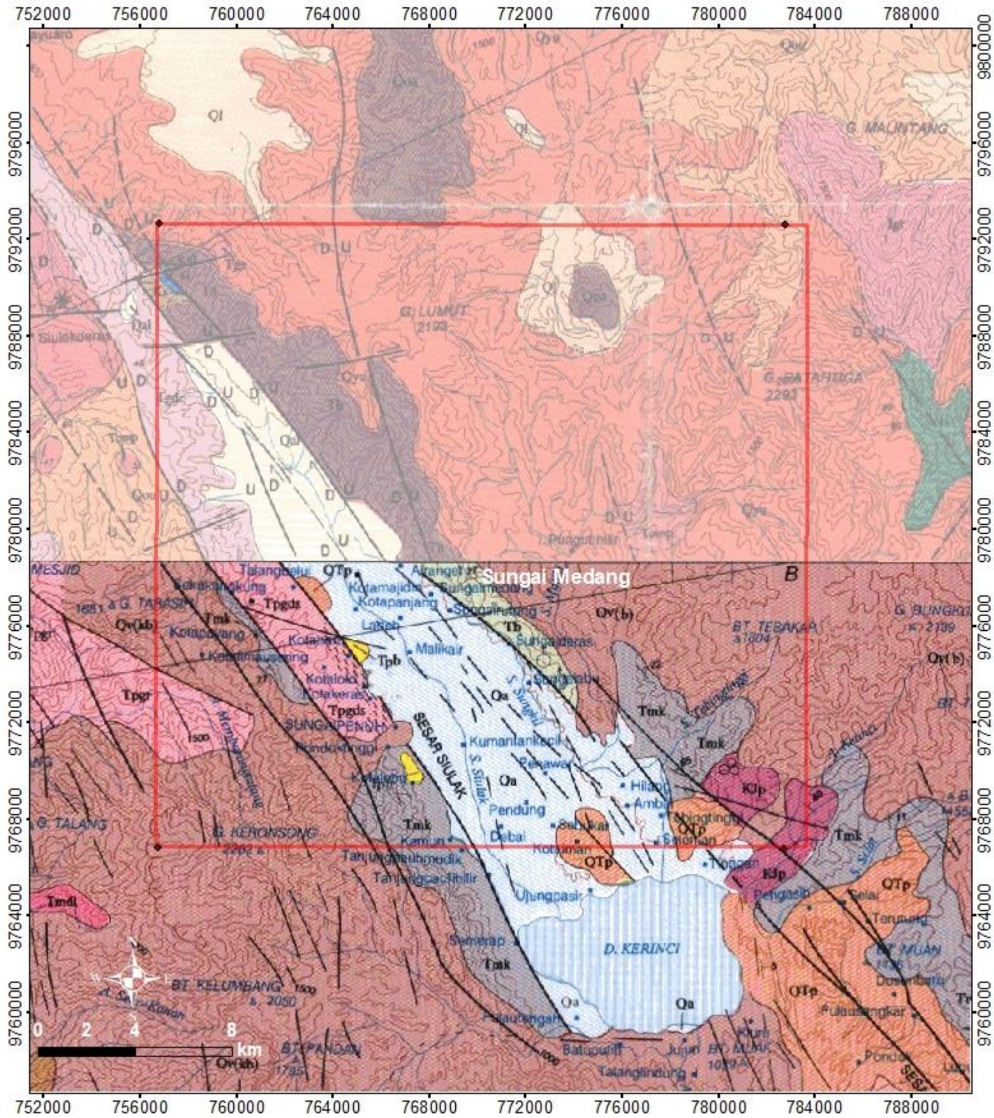

Figure 1. Regional Geology of the Geothermal Manifestation Area in Sungai Medang and Surroundings (Kusnama et al., 1992). The focus of this study is indicated by the red box.

the Sunda-Banda Arc being one of the most prominent. Kerinci, as part of this arc, represents an important geothermal zone where fault-volcano interaction plays a key role in geothermal circulation (Muraoka et al., 2010).

From a physiographic perspective, Kerinci Regency lies within the Barisan Mountain Zone and the Sumatran Fault Zone (Van Bemmelen, 1949). This positioning places it within a structurally complex terrain. The region's stratigraphy consists of Jurassic–Cretaceous basement rocks (e.g., Peneta Formation, composed of tuffaceous shale, slates, and limestones), overlain by Tertiary volcanic and intrusive rocks (e.g., Kumun Formation, granites, and granodiorites), and capped by Quaternary volcanic products (e.g., Pengasih Formation, andesitic-basaltic volcanic units, and alluvial deposits) (Kusnama et al., 1992; Rosidi et al., 1996).

The geothermal manifestation study in Sungai Medang, one of geothermal manifestation spot in Kerincy Regency, utilized integrated geophysical techniques, including electrical resistivity and gravity surveys, to investigate subsurface anomalies. The measurement locations are illustrated in Figure 1, focusing on the red box area of interest. Although this study primarily employs electrical resistivity and gravity methods, it is recognized that other geophysical techniques such as seismic and magnetotelluric (MT) surveys play vital roles in geothermal exploration. Seismic analysis, for instance, is essential for understanding fault segmentation and structural deformation, with studies such as Sefiyanti et al. (2024), Gemilang

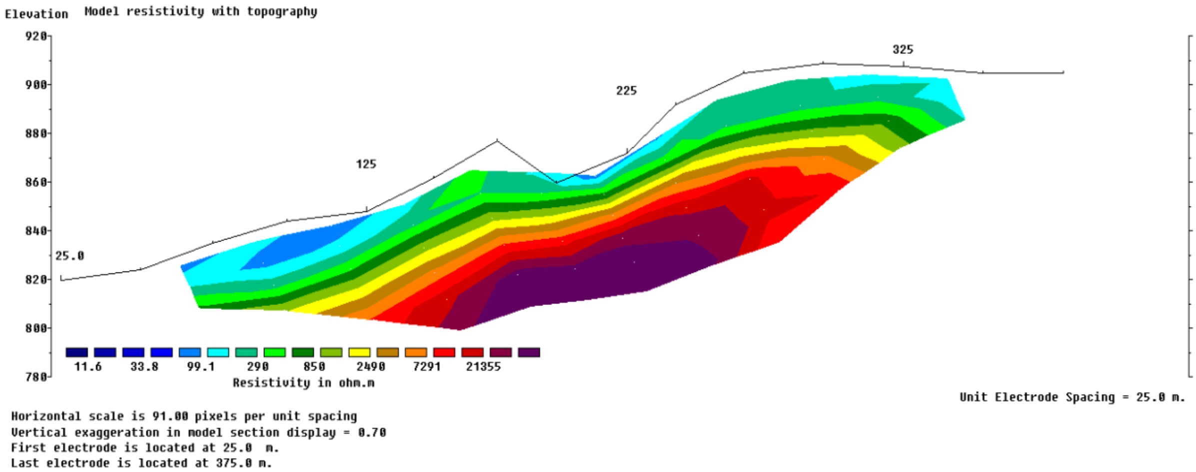

Figure 2. 2D Resistivity Cross-Section

(2024) and Resta et al. (2021) in the Kerinci region providing valuable frameworks for assessing active tectonics. Similarly, MT methods have proven effective in detecting deep conductive zones associated with geothermal reservoirs, as demonstrated in the Songa-Wayaua geothermal prospect by Pratama et al. (2021). Nevertheless, this research focuses specifically on the integration of resistivity and gravity data to delineate subsurface structures and hydrothermal pathways in the Sungai Medang geothermal area.

The gravity method, widely used in geothermal exploration, is instrumental in defining lithological variations and identifying deep structural features such as faults, horsts, and grabens that are often associated with hydrothermal systems (Mulugeta et al., 2021; Soengkono et al., 2013). Gravity data in this study were derived from the Topex/Poseidon satellite, particularly the Free Air Anomaly (FAA) dataset. FAA is corrected for elevation to account for gravitational differences due to topographic height, with further reduction into Simple Bouguer Anomaly (SBA) maps using a reference density (Telford et al., 1990).

In addition, electrical resistivity surveys, one of the most frequently used methods in geothermal prospecting, were applied to identify hydrothermal fluid zones characterized by low resistivity signatures. Numerous studies have confirmed the effectiveness of resistivity in mapping clay caps, fault zones, and geothermal aquifers (Mahardika et al., 2020; Mulugeta et al., 2021; Soengkono et al., 2013).

METHOD

This study adopts an integrated geophysical approach using electrical resistivity imaging and gravity anomaly mapping to investigate the geothermal characteristics of the Sungai Medang region. Both methods are non-invasive, cost-effective, and capable of revealing critical subsurface features such as hydrothermal alteration zones, structural weaknesses, and lithological contrasts-essential parameters in geothermal prospecting. Electrical resistivity methods are widely used for subsurface characterization due to their sensitivity to changes in fluid content, lithology, and porosity. Recent studies demonstrate their application in environmental and energy contexts, such as detecting groundwater contamination (Meng et al., 2024; Dewi et al., 2020) and mapping coal seams (Resta & Novrianti, 2023; Bharti et al., 2022). In geothermal exploration, resistivity surveys are especially useful for delineating clay caps, fracture zones, and hydrothermal upflow pathways (Domra Kana et al., 2015; Anderson et al., 2000).

Subsurface investigation through resistivity measurements involved the dipole–dipole configuration, chosen for its superior lateral resolution in detecting near-surface anomalies, utilizing a 400-meter survey line with 25-meter electrode spacing. Current and potential dipoles were repeated five times, with electrodes implanted 10–15 cm into the ground. Electrical resistivity data were acquired using a resistivity meter and processed through Res2Dinv software to generate 2D pseudo sections. The resulting models provided the lateral and vertical distribution of resistivity values, with resistivity interpreted using the rock classification.

The gravity method was employed to map subsurface density contrasts that correlate with geological structures such as faults, basement uplifts, and sedimentary basins. In geothermal settings, gravity anomalies can highlight features that either facilitate or impede the migration of hydrothermal fluids. This study used secondary gravity data sourced from Topex/Poseidon satellite altimetry, made available through the UC San Diego gravity server (http://topex.ucsd.edu/cgi-bin/get_data.cgi). The satellite employs radar altimetry to measure the Earth's surface elevation with high precision, especially in oceanic and coastal regions (USGS, 1997). The data set included: Geographic coordinates (X, Y), Free Air Anomaly (FAA) values, and Surface topography.

FAA values, which account for elevation variations, were corrected to obtain the Simple Bouguer Anomaly (SBA) using a reduction density of 2.6 g/cm³. This correction process eliminates the gravitational effect of topography, allowing a clearer view of subsurface mass distribution. The average distance between data points was approximately 2 kilometers, enabling regional-scale interpretation with moderate resolution.

In geothermal exploration, such gravity-electrical resistivity overlaps often mark permeable zones where deep fluid circulation is possible. Furthermore, residual anomalies were used to isolate shallow targets, while spectral filtering helped differentiate regional tectonic trends from local geothermal structures.

RESULTS AND DISCUSSION

The 2D resistivity model generated from the dipole–dipole survey reveals subsurface resistivity variations along a northwest–southeast trending line located near the Sungai Medang manifestation zone. The inversion results provide imaging down to a depth of approximately 300 meters. As shown in Figure 2, resistivity values range from 11.6 Ωm to 21,355 Ωm, indicating substantial geological heterogeneity.

The low-resistivity zones (11.6–99.1 Ωm), illustrated in dark to light blue, are interpreted as conductive layers potentially associated with hydrothermal fluids. These anomalies are likely caused by a combination of geological and hydrological factors, including faults and fracture systems, changes in lithology and rock formation, presence of conductive pore fluids.

According to Telford et al. (1990), these resistivity values correspond to clay-rich volcaniclastics or saturated fractured zones, typical features in geothermal settings. The alignment of these conductive zones with the interpreted fault trace suggests the presence of structural controls on upward fluid migration. This correlation is further supported by gravity anomaly data, which show structural segmentation in the same area. The conductive anomalies are interpreted as active pathways for deep thermal fluids to rise toward shallow aquifers, resulting in observable hot spring manifestations at the surface.

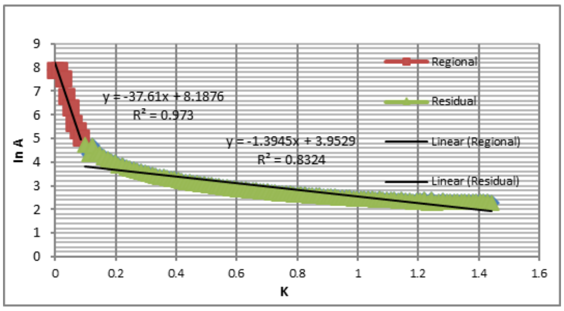

Figure 3. Spectral Analysis Graph

The gravity survey, aimed at detecting weak structural zones and density contrasts, used satellite-derived Free Air Anomaly (FAA) values. These were corrected using a Bouguer reduction with a standard density of 2.6 g/cm³ to produce the Simple Bouguer Anomaly (SBA) map. The SBA values across the study area range from −54.9 to 13.1 mGal, reflecting both vertical and horizontal density variations in the upper crust. The anomaly pattern is dominated by a NW–SE trend, mirroring regional tectonic trends such as the Sumatra Fault System. Notably, high gravity anomalies correspond to dense intrusive or basement rocks, low anomalies (−54.9 to −20.9 mGal) suggest low-density lithologies such as volcanic infill or sedimentary grabens. The contrast between high and low gravity zones indicates lithological boundaries and fault-controlled segmentation in the subsurface. This provides evidence of graben-type structures and intrusive–sedimentary contacts, which are important in geothermal reservoir formation and recharge dynamics.

To estimate the depth of anomaly sources, spectral analysis was applied to the Bouguer anomaly data. The resulting log power spectrum plots (Figure 3) show two distinct linear segments, regional anomalies correspond to long-wavelength, deep sources (~38.7 km depth) and residual anomalies represent short-wavelength, shallow structures (~1.54 km depth). The cut-off wave number (KC) was used to define the spatial filtering window, allowing the construction of separate regional and residual anomaly maps.

A prominent negative residual anomaly (−20.9) to (−1.0) mGal) was identified near the geothermal manifestation zone (Figure 4). This anomaly coincides with a volcanic alteration zone of the Bandan Formation (Tb), the Siulak Fault segment, and the flanks of Mt. Lumut volcanic center. The negative anomaly is interpreted as resulting from a density contrast between low-density alluvium and pyroclastic fill (e.g., from the

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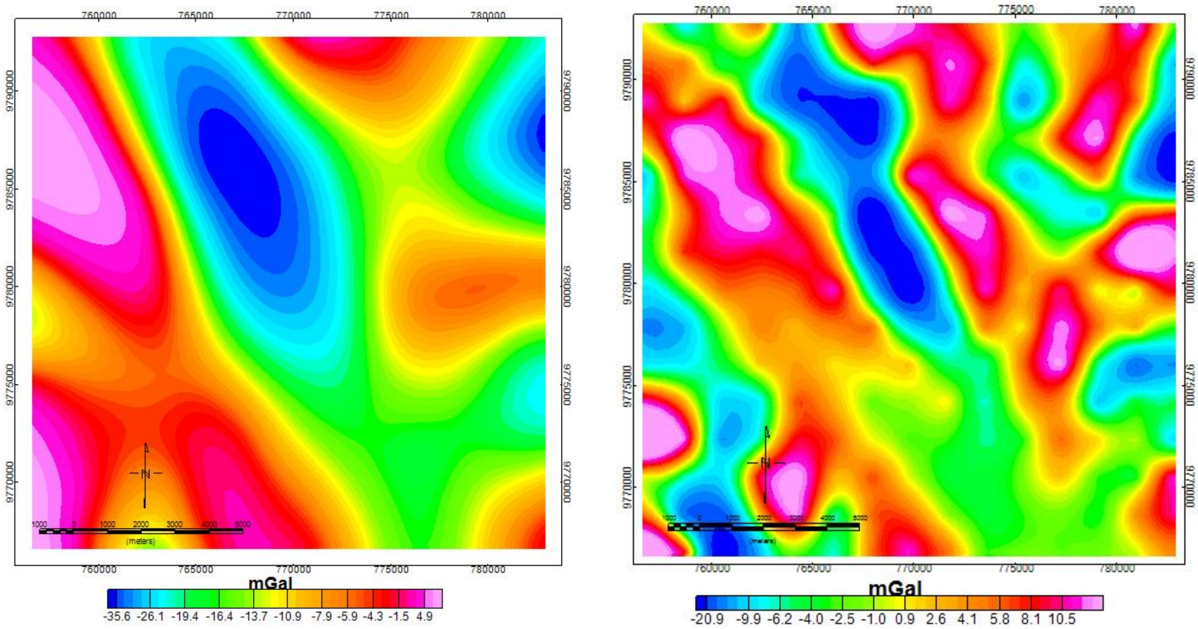

Figure 4. (Left) Regional Anomaly Map and (Right) Residual Anomaly Map

Bandan Formation) and adjacent denser lithologies such as granites of the Seblat Formation and granodiorites of the Sungai Penuh Formation.

Structural analysis shows this anomaly aligns with NE and NW-trending fault segments, reinforcing the idea that these structures control fluid upwelling and surface geothermal manifestations. The geometry and alignment of the residual anomalies indicate fault zones acting as preferential pathways for hydrothermal fluid migration.

The results of both geophysical datasets highlight a strong correlation between structural segmentation and geothermal upflow. The low-resistivity zones, aligning with gravity low anomalies, reflect conductive and low-density pathways that enable vertical migration of hydrothermal fluids. These results strongly support the conclusion that the geothermal activity at Sungai Medang is governed by a complex interplay between fault segmentation, volcanic architecture, and lithological layering, similar to structural controls observed in the Humenné Unit from Jacko et al. (2022).

CONCLUSIONS

The resistivity survey successfully delineated subsurface zones with low resistivity values ranging from 11.6 to 99.1 Ωm, which were interpreted as hydrothermal fluid pathways or altered zones rich in conductive minerals such as smectite. These anomalies coincided spatially with surface manifestations, including hot springs and hydrothermal alteration features, and were aligned with known fault traces, particularly the Siulak Fault segment. This alignment suggests that the faults act as conduits for fluid ascent, facilitating geothermal activity near the surface.

Gravity data further supported these findings. The Simple Bouguer Anomaly (SBA) values varied from −54.9 to 13.1 mGal, with significant negative residual anomalies observed in areas surrounding the manifestation zone. These low-density anomalies are interpreted as resulting from young volcanic infill and sedimentary grabens, which act as thermal reservoirs. Spectral analysis of the gravity data indicated that regional anomalies were sourced from depths of approximately 38.7 km, while residual anomalies, more closely tied to geothermal processes, were located at depths of about 1.54 km. These findings provide a stratified understanding of the subsurface and support the interpretation of multi-level geothermal potential.

Based on these findings, it is recommended that future geothermal exploration in similar geological settings adopt an integrated geophysical approach early in the exploration process. Electrical resistivity methods should be prioritized for imaging shallow hydrothermal systems, while gravity surveys can provide essential information about deeper structures and lithological contrasts. Spectral filtering techniques should also be employed to differentiate regional tectonic influences from shallow geothermal features. The methodological synergy observed in this study reduced interpretive ambiguity and increased the reliability of subsurface models, thereby improving the likelihood of successful drilling.

In a broader context, the Sungai Medang case highlights the importance of structural-geological integration in geothermal exploration. Areas with significant fault segmentation and Quaternary volcanic activity, such as those found throughout the Bukit Barisan of Sumatra, are especially well-suited for this approach. Given the high cost of drilling and the exploration risk associated with geothermal development, especially in developing regions, the cost-effective nature of these geophysical methods makes them highly suitable for early-stage prospecting and resource evaluation.

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DAFTAR PUSTAKA

Anderson, E. B., Crosby, D. B., & Ussher, G. N. (2000). Bulls-eye! – Simple resistivity imaging to reliably locate the geothermal reservoir. In Proceedings of the World Geothermal Congress 2000 (pp. 909–914).

Badan Geologi. (2012). Data dan Informasi Panas Bumi Indonesia. Pusat Sumber Daya Geologi, Kementerian Energi dan Sumber Daya Mineral.

Bharti, A. K., Prakash, A., Verma, A., Oraon, J., Chaudhary, D. K., Kumar, S., & Singh, K. K. K. (2022). Mapping of decades-old underground coal mine workings using electrical resistivity tomography. Journal of Earth System Science, 131(4), 258.

Carlile, J. C., & Mitchell, A. H. G. (1994). Magmatic arcs and mineralization in Indonesia. Journal of Geochemical Exploration, 50(1–3), 91–142. https://doi.org/10.1016/0375-6742(94)90022-1

Dewi, I. K., & Resta, I. L. Juventa.(2020). Aplikasi Geolistrik Konfigurasi Wenner dalam Mendeteksi Pencemaran Air Tanah Akibat Gambut pada Desa Sungai Terap. *Journal Online of Physics*, *6*(1), 44-51.

Domra Kana, J., Djongyang, N., Raïdandi, D., Nouck, P. N., & Dadjé, A. (2015). A review of geophysical methods for geothermal exploration. Renewable and Sustainable Energy Reviews, 44, 87–95. https://doi.org/10.1016/j.rser.2014.12.026

Gemilang, R., Syawalia, N., Resta, I. L., Adhitya, B., Efendi, A., Sitompul, J., … & Setiawan, R. A. (2024). Identification Of Site Class Using Microtremor Hvsr Measurements in Tanah Kampung District. Journal Online of Physics, 9(3), 60-65.

Hamilton, W. (1979). Tectonics of the Indonesian region (U.S. Geological Survey Professional Paper 1078).

Hochstein, M. P., & Browne, P. R. L. (2000). Surface manifestations of geothermal systems with volcanic heat sources. In H. Sigurdsson (Ed.), Encyclopedia of Volcanoes (pp. 835–855). Academic Press.

Hochstein, M. P., & Sudarman, S. (2008). History of geothermal exploration in Indonesia from 1971 to 2000. Geothermics, 37(3), 220–226.

Hochstein, M. P., & Sudarman, S. (2015). Indonesian volcanic geothermal systems. In Proceedings of the World Geothermal Congress, Melbourne, Australia, 19–25 April 2015 (pp. 1–2).

Jacko, S., Babicová, Z., Thiessen, A. D., Farkašovský, R., & Budinský, V. (2022). The use of multi-geophysical methods to determine the geothermal potential: A case study from the Humenné Unit (The Eastern Slovak Basin). Applied Sciences, 12(2745). https://doi.org/10.3390/app12052745

Kasbani. (2009a). Tipe sistem panas bumi di Indonesia dan estimasi energinya. In Prosiding Hasil Kegiatan Lapangan Pusat Sumber Daya Geologi, PMG–Badan Geologi (pp. 64–69). Bandung.

Kasbani. (2009b). Sumber daya panas bumi Indonesia: Status penyelidikan, potensi dan tipe sistem panas bumi. In Prosiding Hasil Kegiatan Lapangan Pusat Sumber Daya Geologi, Badan Geologi (pp. 4–11). Bandung.

Kusnama, Pardede, Mangga, H. M., & Sidarto. (1992). Peta Geologi Lembar Sungai Penuh dan Ketaun Skala 1:250.000. Pusat Penelitian dan Pengembangan Geologi.

Loke, M. H. (2004). Tutorial: 2D and 3D electrical imaging surveys. Retrieved from http://www.geotomosoft.com/

Mahardhika, R., Said, Y. M., Resta, I. L., & Mastur, A. K. (2020). Identifikasi Keberadaan Manifestasi Daerah Panasbumi Gunung Sumbing, Jangkat Berdasarkan Interpretasi Data Landsat 8 dan Geolistrik.

Jurnal Geologi dan Sumberdaya Mineral, 21(4), 207-215.

Meng, J., Hu, K., Wang, S., Wang, Y., Chen, Z., Gao, C., & Mao, D. (2024). A framework for risk assessment of groundwater contamination integrating hydrochemical, hydrogeological, and electrical resistivity tomography method. *Environmental Science and Pollution Research*, *31*(19), 28105-28123.

Mulugeta, B. D., Fujimitsu, Y., Nishijima, J., & Saibi, H. (2021). Interpretation of gravity data to delineate the subsurface structures and reservoir geometry of the Aluto–Langano geothermal field, Ethiopia. *Geothermics*, *94*, 102093.

Muraoka, H., Takahashi, T., Sundhoro, H., Dwipa, S., Soeda, Y., Momita, M., & Shimada, K. (2010). Geothermal systems constrained by the Sumatran Fault and its pull-apart basin in Sumatra, Western Indonesia. Proceedings of the World Geothermal Congress, 2–9.

Natawidjaja, D. H. (2017). Updating active fault maps and slip rates along the Sumatran Fault Zone, Indonesia. Earth and Environmental Science Conference Series, 118, 2–10.

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.

Resta, I. L., Apriliyani, D. P., Nasri, M. Z., & Dewi, I. K. (2021, April). Deterministic seismic hazard analysis for assessing earthquake hazard in Sungai Penuh and Kerinci Regency. In Journal of Physics: Conference Series (Vol. 1876, No. 1, p. 012016). IOP Publishing.

Resta, I. L., & Novrianti, R. (2023). Identifikasi Lapisan Batubara Menggunakan Metode Geolistrik Konfigurasi Schlumberger Di Lapangan X Kecamatan Bulian Kabupaten Batanghari. Journal Online of Physics, 8(2), 82-89.

Rosidi, H. M. D., et al. (1996). Atlas Geologi Sumatera. Pusat Penelitian dan Pengembangan Geologi.

Sefiyanti, F., Amin, S. S., Resta, I. L., Hamdi, H., Astuti, P., Fauziyah, A. A., ... & Harahap, I. A. (2024). Identifikasi Kerentanan Tanah Dan Percepatan Tanah Menggunakan Metode Mikrotremor Di Kawasan Kayu Aro Barat. Journal Online of Physics, 10(1), 88-93.

Simandjuntak, T. O. (1986). Tectonic development of the Indonesian region. Geological Research and Development Centre, Bandung.

Soengkono, S., Bromley, C., Reeves, R., Bennie, S., & Graham, D. (2013). Geophysical techniques for low enthalpy geothermal exploration in New Zealand. Exploration Geophysics, 44(3), 215–227. https://doi.org/10.1071/EG13036

Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). Applied Geophysics (2nd ed.). Cambridge University Press.

UCSD. (2019). Topex/Poseidon gravity satellite data. Retrieved from http://topex.ucsd.edu/cgi-bin/get_data.cgi

Van Bemmelen, R. W. (1949). The geology of Indonesia (Vol. 1A). Government Printing Office.