J E M T
Journal of Earth and Marine Technology
homepage URL: ejurnal.itats.ac.id/jemt

The detailed geological investigation in Kadidia geothermal field and surrounding areas, Nokilalaki District, Sigi Regency, Central Sulawesi Province

Irwan Firmansyah *[1], Siswandi [1], Sachrul Iswahyudi [1], Dudi Hermawan [2], Santia Ardi Mustofa [2]
[1] Department of Geological Engineering - University of Jenderal Soedirman, Purwokerto, Indonesia
[2] Pusat Sumber Daya Mineral Batubara dan Panas Bumi – Badan Geologi, Bandung, Indonesia
*e-mail: irwangeologist@yahoo.com

Article info
Received:
December 20, 2021
Revised:
February 18, 2022
Accepted:
March 15, 2022
Published:
March 31, 2022

Keywords:
Granite intrusion,
Napu formation,
stratigraphy

Abstract
The need for alternative energy other than fossil energy is felt to be increasingly urgent for the fulfillment of domestic electrical energy. In meeting the demand for electricity, the government needs to investigate alternative geothermal energy, to find out the potential for geothermal energy to provide electricity. The realization of this policy is that the government conducts an integrated geothermal investigation to find prospective geothermal areas that can be developed as electric power. Nokilalaki District, Sigi Regency, Central Sulawesi Province is one area that has geothermal potential in Indonesia. The Kadidia geothermal area, Sigi Regency, Central Sulawesi Province is one of the volcanic geothermal fields that have good potential and needs to be investigated further, especially on geological conditions that affect the presence of geothermal energy. The research method used is the method of analyzing the results of field observations. From the observations, it can be concluded that the geomorphology of the research area is divided into Tongoa hills, Nokilalaki Granite Intrusions, Kamamora Hills, and Kadidia Alluvial Plains. The stratigraphy of the study area from old to young consists of Breccia, Sandstone, Granite Intrusion A, Granite Intrusion B, Granite Intrusion C, and Alluvial Plain. The geological structure of the study area consists of the Kamamora sinistral shear fault and the Kadidia dextral shear fault. The geological history of the study area begins in the early Miocene which is the beginning of the movement of the Palu - Koro fault.

1. Introduction

The need for alternative energy other than fossil energy is felt to be increasingly urgent for the fulfillment of domestic electrical energy [1]. In meeting the demand for electricity, the government needs to investigate alternative geothermal energy, to find out the potential for geothermal energy to provide electricity [2]. The realization of this policy is that the government conducts an integrated geothermal investigation to find prospective geothermal areas that can be developed as electric power[2]. Nokilalaki District, Sigi Regency, Central Sulawesi Province is one area that has geothermal potential in Indonesia. The Kadidia geothermal area, Sigi Regency, Central Sulawesi Province is one of the volcanic geothermal fields that have good potential and needs further investigation [3]–[5]. The presence of geothermal energy is certainly influenced by geological conditions such as geomorphology, stratigraphy, and developing geological structures [6]–[8]. This study aims to determine the geological conditions of the environment so as to obtain an overview of the ongoing process and predict future conditions so that the best actions can be taken so as not to cause negative impacts.

2. Methodology

This research begins with a literature review or study by observing reading from sources such as books, e-books, and journals written by several experts. Then field observations were made to obtain actual information in the field. Next, analyze the observations using geomorphological analysis, petrographic analysis, age analysis, geological structure analysis, and spectral analysis.

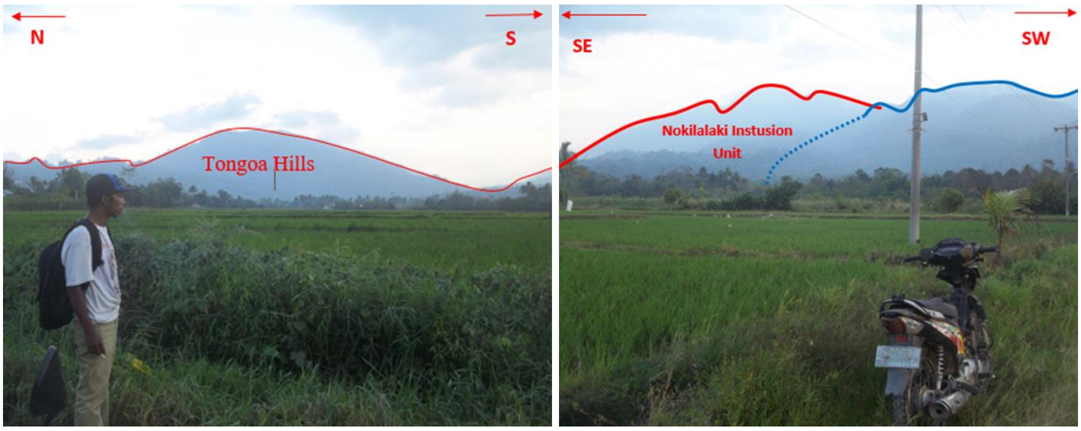

Figure 1. The field figure of typical Tongoa hills (left), the field figure of typical Nokilalaki intrusion unit (right)

3. Results

3.1. Geomorphology of the research area

The research area is divided into 4 geomorphological units [9], namely the Tongoa Hills Unit, the Nokilalaki Intrusion Unit, the Kamarora Hills Unit, and the Kadidia Alluvial Plain Unit.

3.1.1 Tongoa Hills Unit

This unit covers 25% of the research area (figure 1 left). On the geomorphological map, this unit is marked by a light blue color in the northeast - east of the map. Characterized by the morphological appearance of steep slopes with very tight contours, located at an elevation of 1125 – 800 meters above sea level. This unit has a trellis flow pattern. The geomorphic stage is characterized by a "V" river shape and cliffs that characterize a young river, then undergo vertical and lateral erosion, the bend of the river is still determined by lithological resistance and the morphological boundary of the two mountains. The exogenous process is in the form of periodic erosion so that it makes the formation as it is now. Lithology is composed of igneous and sedimentary rocks.

3.1.2 Nokilalaki Granite Intrusion Unit

This unit covers 10% of the study area (figure 1 right). On the geomorphological map, this unit is marked in red in the south-eastern part of the map sea. It is characterized by the appearance of steep hills with dense contours, located at an elevation of 1425 – 750 meters above sea level. This unit has a trellis flow pattern. The geomorphic stage is characterized by a "V" river shape which characterizes as a young river, then experiences vertical and lateral erosion, the bend of the river is still determined by lithological resistance and the morphological boundary of the two mountains. The exogenous process is in the form of periodic erosion so that it makes the formation as it is now. Lithology is composed of igneous rock.

3.1.3 Kamarora hills unit

This unit covers 25% of the research area (figure 2 left). On the geomorphological map, this unit is marked in dark blue in the southern part. It is characterized by the appearance of steep hills with dense contours, at an elevation of 1175 – 700 meters above sea level. This unit has a trellis flow pattern. The geomorphic stage is characterized by a "V" river shape which characterizes as a young river, then experiences vertical and lateral erosion, the bend of the river is still determined by lithological resistance and the morphological boundary of the two mountains. The exogenous process is in the form of periodic erosion so that it makes the formation as it is now. Lithology is composed of igneous and sedimentary rocks.

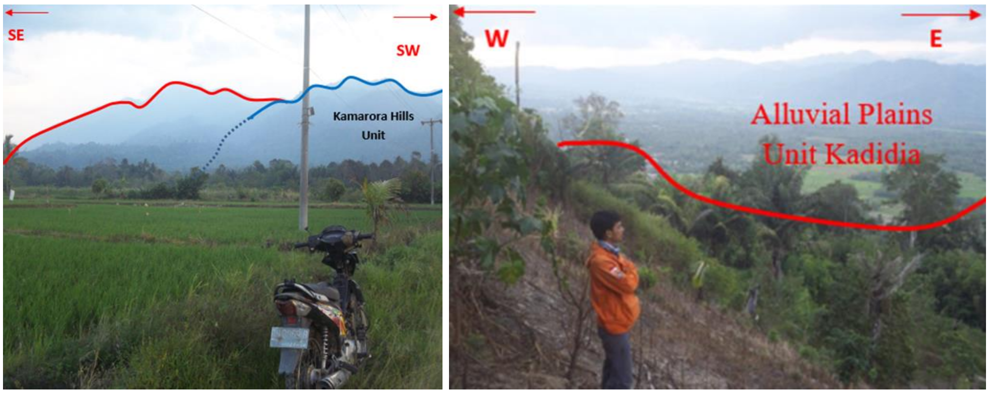

Figure 2. The figure of the morphologic unit of Kumamora Hills (left), The figure of the morphologic unit of the Kadidian Alluvial Plain

3.1.4 Kadidia Alluvial Plain Unit

This unit covers 40% of the research area (figure 2 right). On the geomorphological map, this unit is marked in Gray in the center and north. Characterized by the appearance of plains with very loose contours from the middle to the north, very gentle slopes with very loose contours, located at an elevation of 675 – 575 meters above sea level. This unit has a trellis flow pattern. The geomorphic stage is characterized by the shape of the river "U" which is characterized as an adult river, then experiences vertical and lateral erosion, the bend of the river is still determined by lithological resistance and the morphological boundary of the two mountains. The exogenous process is in the form of periodic erosion so that it makes the formation as it is now. Lithology is composed of Alluvial Units.

3.2. Stratigraphy of the research area

Based on the geological cross-section, the stratigraphic sequence of the Kadidia area and its surroundings is sorted from oldest to youngest (see figure 5). The Breccia unit (see figure 3 left), this unit occupies ± 14% of the research area. petrographic analysis to see the appearance of the breccia fragments obtained characteristics including thin slices of plutonic igneous rock, light grey in color, inequigranular, phaneritic, crystal size 0.01 – 2 mm euhedral - subhedral shape. Crystals in the form of, quartz, biotite, muscovite, hornblende. Mineral composition: 40% quartz, 25% biotite, 10% feldspar, 10% albite, 10% chlorite, 5% opaque minerals. In the classification of [10], [11] these rocks are included in the greywacke.

The sandstone unit (see figure 3 right), this unit occupies ± 26% of the research area. Then a petrographic analysis was carried out to see the appearance of the sandstone, the characteristics include thin slices of sandstone, blackish grey in color, crystal size 0.01 – 2 mm euhedral - subhedral shape. Crystals in the form of quartz, plagioclase, chlorite, opaque minerals. Mineral composition: 45% quartz, 30% plagioclase, 20% chlorite, 5% opaque minerals. In the classification of [7], [8] the rock is included in the Greywacke.

Figure 3. The field appearance of the breccia unit (left), the classification of the breccia's matrix (right)

Figure 4. The appearance of the Granite intrusion A (left), the appearance of the Granite intrusion B (middle), The appearance of the Granite intrusion C (right)

Granite intrusion A (see figure 4 left), this unit occupies ± 6% of the research area. Then a petrographic analysis was carried out to see the appearance of the granite, the characteristics included: thin slices of plutonic igneous rock, light grey in color, inequigranular, phaneritic, crystal size 0.01 – 2 mm euhedral - subhedral shape. Crystals in the form of, quartz, biotite, muscovite, hornblende. Mineral composition: 50% quartz, 25% biotite, 10% feldspar, 10% albite, 5% opaque minerals. In [12] classification, these rocks belong to the Granitoids.

Granite intrusion unit B (see figure 4 middle), this unit occupies ± 4% of the research area. Then a petrographic analysis was carried out to see the appearance of the granite (Appendix F). The characteristics include thin slices of plutonic igneous rock, light grey in color, inequigranular, phaneritic, crystal size 0.01 – 2 mm euhedral - subhedral shape. Crystals in the form of, quartz, biotite, muscovite, hornblende. Mineral composition: 40% quartz, 25% biotite, 10% feldspar, 10% albite, 10% chlorite, 5% opaque minerals. The granite in the study area and its surroundings is megascopic characterized by grey lithology. In [12] classification, these rocks belong to the Granitoids.

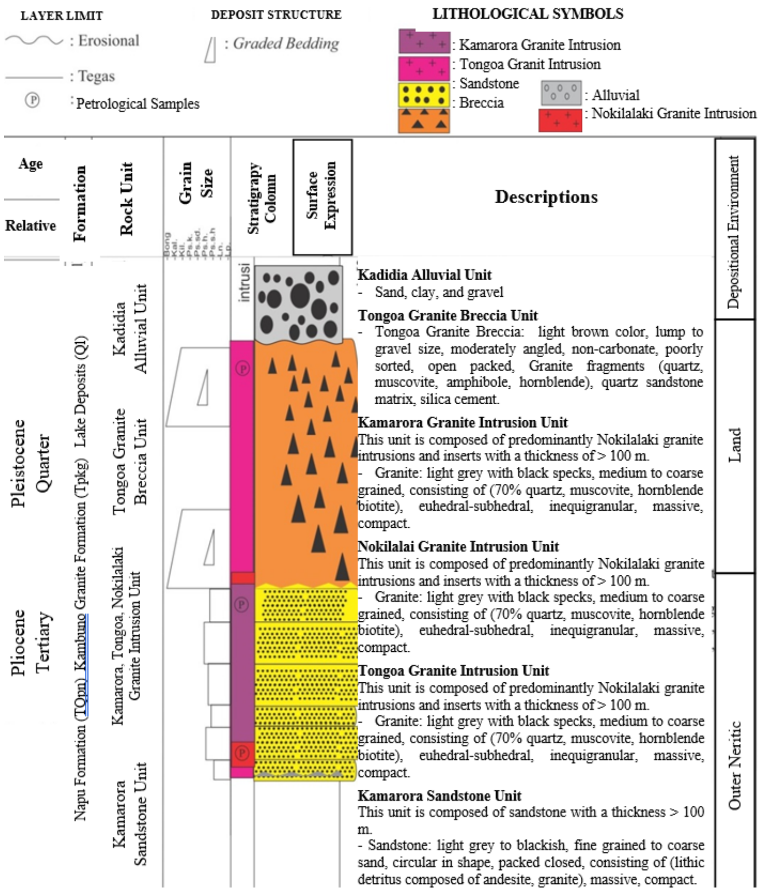

Figure 5. The simplified stratigraphy of the study area

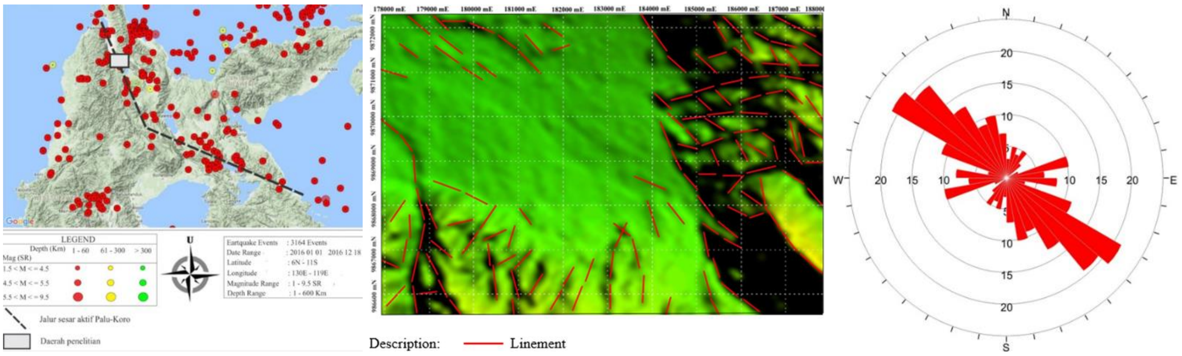

Figure 6. The earthquake event distribution [13] (left), the fault fracture distribution of the study area (middle), the rose diagram of the detected fault and fractures (right)

Granite intrusion unit C (see figure 4 right), this unit occupies ± 9% of the research area. Then a petrographic analysis was carried out to see the appearance of the granite, the characteristics included: thin slices of plutonic igneous rock, light grey in color, inequigranular, phaneritic, crystal size 0.01 – 2 mm euhedral - subhedral shape. Crystals in the form of, quartz, biotite, muscovite, hornblende. Mineral composition: quartz 35%, biotite 25%, feldspar 15%, albite 15%, opaque minerals 10%. In [12] classification (1978), the rock belongs to the Granite Adamellite [2].

Alluvial unit (see figure 2 right), the alluvial plains in the study area and its surroundings are megascopic characterized by whitish to brownish ash color, medium – lumpy sand grain size, round – angular grain shape. The distribution of this unit occupies ± 41% of the study area, this alluvial plain unit is located in the northern part which is marked by a grey color on the map covering the Kadidia area. The thickness of this rock unit is >135 m.

3.3. Geological structure of the study area

Analysis of the geological structure in the research area is carried out using an indirect and direct approach (see figure 6). Based on the indirect approach using GDEM2ASTER imagery [14], it is seen that there is a straightness pattern, namely the straightness that is oriented relatively NW-SE in the N 315^0 E direction. Meanwhile, for direct observations made in the field, it is found that the structure in the study area cannot be measured for shear fracture or tensional. fracture because the outcrop was not found, then most of the rock was weathered, covered in vegetation, and had difficult access.

3.3.1. Kamora sinistral shear fault

This fault is in the Kamarora river, where the river has a trellis river flow pattern as an indication of structural traces (Figure 7). Based on field observations, no shear fracture or tensional fracture data were found, because many outcrops are weathered, covered with vegetation, and difficult to access. In the field, a morphological pattern was found that indicated the appearance of the fault, which was in the form of a steep cliff.

Figure 7. The field appearance of the Kamora sinistral shear fault (left), the field appearance of the Kadidia dextral shear fault (right)

3.3.2. Kadidia dextral shear fault
This fault is in the Kadidia River. This river has a trellis river flow pattern as an indication of structural traces. Based on field observations, no data on shear fractures or tensional fractures were found, because many outcrops are weathered, covered with vegetation, and difficult to access.

3.4. The geological history of the study area
The following is a description of the geological processes that take place in the research area. At the age of 145 – 72.1 million years ago (Cretaceous), there was the deposition of Latimojong formation sediments as basement rocks in the study area, with the depositional environment estimated as the shallow sea to land, the source of sediment supply comes from Latimojong volcano [15]

At the age of 23.03 million years, ago (early Miocene) was the beginning of the movement of the Palu-Koro fault as a result of the subduction movement between Sundaland and the Australian Microplate and the fault remains active until now [16]. This fault also causes metamorphism in the rocks of the Latimojong formation [17].

At the age of 5.46 - 3.21 million years ago (early Pliocene) the formation of granitic magma as an intrusion, in the literature it is known as a mylonitic granitoid medium [15]. In the research area, it is exposed as the Tongoa Granite Intrusion Unit.

At the age of 3.07 – 1.76 million years ago (late Pliocene) there was the formation of granitic magma as an intrusion, in the literature it is known as fine granitoid with poor biotite [15]. In the research area exposed as the Kamarora Granite Intrusion unit.

At the age of 3.6 – 2.58 million years ago (Pliocene – Pleistocene Boundary) there was the formation of granitic magma as an intrusion, in the literature known as fine granitoid with poor biotite [7], the reappearance of this granitic intrusion was due to faults. Palu – Koro is still active, so the flow of granite magma is controlled following the pattern of the Palu – Koro fault as a magma movement gap. In the research area, it is exposed as the Nokilalaki Granite Intrusion Unit. The activation of the Palu – Koro fault until now has caused the formation of horsts and grabens [18], [19], but in the study area, it is a graben. The graben pattern in the study area is revealed as an expected fault pattern.

4. Conclusion
Based on the results of research in Kadidia Village and its surroundings, several conclusions can be drawn, the geomorphology of the research area is divided into 4 units, namely: Tongoa Hills, Nokilalaki Granite Intrusion, Kamarora Hills, and Kadidia Alluvial Plain. The stratigraphy of the study area consists of six rock units in order from oldest to youngest, namely: Breccia, Sandstone, Granite Intrusion A, Granite Intrusion B, Granite Intrusion C, and Alluvial Plain. The geological structure of the pinnacle area is in the form of the sinistral Kamarora shear fault and the Kadidia dextral shear fault. The geological history of the study area begins with the early Miocene, which is the beginning of the movement of the Palu - Koro fault which is still active today. In the late Miocene, breccia units were exposed as products with gravel to boulders and very fine to coarse sandstone units. Formation of granitic magma as an intrusion, in the study area, exposed as granite intrusion unit A. In the late Pliocene, the formation of granitic intrusion unit B, and at the age of 3.6 – 2.58 million years ago (Pliocene – Pleistocene Boundary) is the reappearance of this unit. granite C intrusion due to the influence of the Palu – Koro fault which is still active so that the flow of magma-granite is controlled following the pattern of the Palu – Koro fault as a magma movement gap. Then the unit above it is deposited alluvial unit as a product of weathering.

References:
[1] "Direktorat Jenderal EBTKE - Kementerian ESDM." https://ebtke.esdm.go.id/post/2022/02/19/3090/sekjen.esdm.sinergi.dan.kolaborasi.kunci.percepatan.pengembangan.ebt (accessed Mar. 03, 2022).

[2] "Direktorat Jenderal EBTKE - Kementerian ESDM." https://ebtke.esdm.go.id/post/2022/02/16/3086/bertemu.world.bank.menteri.esdm.paparkan.peta.jalan.transisi.energi.indonesia (accessed Mar. 03, 2022).
[3] A. Wibowo, M. Nurhadi, Y. Rezky, and D. Hermawan, "Penentuan kesamaan reservoar sistem panas bumi Kadidia dan Kadidia Selatan Kabupaten Sigi, Provinsi Sulawesi Tengah," *scholar.archive.org*, Accessed: Mar. 03, 2022. [Online]. Available: https://scholar.archive.org/work/atbvguvccjc75jvdd4ekopqbqq/access/wayback/http://buletinsdg.geologi.esdm.go.id/index.php/bsdg/issue/download/BSDG%20Vol%2010%20No%202/pdf_17#page=54
[4] M. Nurhadi, … Y. R.-B. S., and undefined 2015, "Penentuan kesamaan reservoar sistem panas bumi Kadidia dan Kadidia Selatan Kabupaten Sigi, Provinsi Sulawesi Tengah," *buletinsdg.geologi.esdm.go.id*, Accessed: Mar. 03, 2022. [Online]. Available: http://buletinsdg.geologi.esdm.go.id/index.php/bsdg/article/view/142
[5] S. H. Mahmud, "Analisis geologi dan geokimia untuk keprospekan panas bumi daerah Kadidia Selatan, Kecamatan Nokilalaki, Kabupaten Sigi, Povinsi Sulawesi Tengah," 2017, Accessed: Mar. 03, 2022. [Online]. Available: http://eprints.upnyk.ac.id/11653/
[6] J. K.-E.-S. Reviews and undefined 1971, "A review of the geotectonic theories and tectonic maps of Indonesia," *Elsevier*, Accessed: Mar. 03, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/0012825271900067
[7] H. Darman, "An Outline of The Geology Indonesia," *Journal of Chemical Information and Modeling*, 2000, doi: 10.1017/CBO9781107415324.004.
[8] R. W. van Bemmelen, "The Geology of Indonesia. General Geology of Indonesia and Adjacent Archipelagoes," *Government Printing Office, The Hague*. 1949. doi: 10.1109/VR.2018.8447558.
[9] B. Brahmantyo and Bandono, "Klasifikasi Bentuk Muka Bumi untuk Pemetaan Geomorfologi pada Skala 1:25.000 dan Aplikasinya untuk Penataan Ruang," *Geoaplika*, 2006.
[10] F. J. Pettijohn, *Sedimentary Rocks (third edition)*, 3rd ed. San Francisco: Harper & Row Publishers, 1975.
[11] F. J. Pettijohn, P. E. Potter, and R. Siever, "Sand and Sandstone," *Soil Science*, 1974, doi: 10.1097/00010694-197402000-00013.
[12] M. J. le Bas and A. L. Streckeisen, "The IUGS systematics of igneous rocks," *Journal of the Geological Society*, 1991, doi: 10.1144/gsjgs.148.5.0825.
[13] "Artikel: Kajian Distribusi Gempa Terhadap Gerak Patahan Palu Koro | BMKG." https://www.bmkg.go.id/artikel/?p=kajian-distribusi-gempa-terhadap-gerak-patahan-palu-koro&lang=ID (accessed Mar. 03, 2022).
[14] F. R. Widiatmoko, R. H. K. Putri, and H. L. Sunan, "The Relation of Fault Fracture Density with the Residual Gravity; case study in Muria," *Journal of Earth and Marine Technology (JEMT)*, 2021, doi: 10.31284/j.jemt.2021.v1i2.1743.
[15] T. O. Simandjuntak, Surono, and J. B. Supandjono, "Geological Map of The Poso Quadrangle, Sulawesi, Scale 1:100,000," Bandung, Indonesia, 1997. Accessed: Mar. 03, 2022. [Online]. Available: https://drive.google.com/drive/u/2/folders/1OvNQrXwNKNjKyWpIgvvh
[16] P. Bird, "An updated digital model of plate boundaries," *Geochemistry, Geophysics, Geosystems*, 2003, doi: 10.1029/2001GC000252.
[17] R. Soeria-Atmadja, R. C. Maury, H. Bellon, H. Pringgoprawiro, M. Polve, and B. Priadi, "Tertiary magmatic belts in Java," *Journal of Southeast Asian Earth Sciences*, 1994, doi: 10.1016/0743-9547(94)90062-0.
[18] F. R. Widiatmoko *et al.*, "Possibility of geothermal offshore in Sangihe archipelago, northern part of Sulawesi, Indonesia," *IOP Conference Series: Materials Science and Engineering*, 2021, doi: 10.1088/1757-899x/1010/1/012004.
[19] F. R. Widiatmoko *et al.*, "Possibility of geothermal offshore in Sangihe archipelago, northern part of Sulawesi, Indonesia," 2021. doi: 10.1088/1757-899X/1010/1/012004.