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Geological Structure Identification in Geothermal Manifestation of Lamongan Volcano Complex: A Magnetic Data Analysis Approach

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Abstract. The Tiris area in the Lamongan Volcano Complex, Probolinggo, East Java, is estimated to be an area with geothermal potential in Indonesia. This is indicated by the existence of several hot springs along the Tancak River, forming a continuous line with a distance about 20–50 m between each hot spring. Segaran hot springs are one of the hydrothermal manifestations that can indicate the presence of geothermal potential in this location. Some previous research has shown the existence of subsurface geological structures around Segaran hot springs in a northwest-southeast direction. However, the identification of geothermal manifestations in this location is limited, so magnetic data can help identify subsurface geological structures to confirm the geothermal potential in this area. A significant contrast in horizontal magnetic anomalies indicates the existence of subsurface geological structures. To delineate the boundaries of the magnetic anomaly, the first horizontal derivative and second vertical derivative were applied. To determine the depth of the magnetic anomaly, located Euler deconvolution was used. The integration of these three transformations on the magnetic data is sufficient to interpret the position, direction, and depth of subsurface structures in the research area. The results show the position of dominant lineament in the Lamongan Volcano Complex through Segaran hot springs is a northwest-southeast orientation. These results align with the dominant orientation from the density lineaments analysis performed based on the Digital Elevation Model Nasional (DEMNAS). Building from previous research, the existence of fault structures correlated with Segaranhot springs can improve the indication of geothermal potential in the Lamongan Volcano Complex, especially in the Tiris area.

Key words:
Derivative analysis,
Euler deconvolution,
Fault structure;
Segaran hot springs, East Java.

Апстракт. Област Тирис у комплексу вулкана Ламонган (Проболинго, Источна Јава), представља подручје са геотермалним потенцијалом у Индонезији. На то указује постојање неколико топлих извора дуж реке Танцак, који су поређани у низу са растојањем од око 20–50 m између сваког извора. Топли извори Сегаран су једна од хидротермалних манифестација која може указивати на присуство геотермалног потенцијала на овој локацији. Нека претходна истраживања су показала постојање подземних геолошких структура око ових извора са правцем пружања

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северозапад-југоисток. Међутим, идентификација геотермалног потенцијала на овој локацији је ограничена, тако да геомагнетни подаци могу помоћи у идентификацији подземних геолошких структура како би се потврдио геотермални потенцијал у овој области. Значајне разлике у хоризонталним магнетним аномалијама указују на постојање подземних геолошких структура. Да би се оконтуриле границе магнетне аномалије, примењене су хоризонталне и вертикалне деривације. За процену дубине магнетне аномалије коришћена је Ојлерова деконволуција. Интегрисана примена ове три промене на магнетним подацима омогућава тумачење положаја, правца и дубине подземних структура у области истраживања. Резултати показују да оријентација доминантних раседних структура у комплексу вулкана Ламонган прати топле изворе Сегаран правцем пружања северозапад-југоисток. Ови резултати су у сагласности са доминантном оријентацијом анализе густине структура изведене на основу Digital Elevation Model Nasional (DEMNAS). На основу претходних истраживања, постојање раседних структура у корелацији са топлим изворима Сегаран, може побољшати индикацију геотермалног потенцијала у комплексу вулкана Ламонган, посебно у области Тириса.

Кључне речи
Деривациона анализа,
Ојлерова деконволуција,
раседна структура,
топли извори Сегаран,
Источна Јава.

Introduction

Indonesia has 28,910 MWe of geothermal potential spread across several locations, but its utilization only reached 1,533.5 MWe in 2016 and increased to 1,948.5 MWe in 2018 (Darma et al., 2020; Pambudi, 2018). The Tiris area, located in the Lamongan Volcano Complex, Probolinggo, East Java, is estimated to be one area with geothermal potential in Indonesia. Based on data from the Ministry of Energy and Mineral Resources in 2017, this location has geothermal potential with an area of 299 km^2 with fumarole and hot springs manifestations (Sidik & Harmoko, 2022). A survey conducted by Hitay Rawas Company found that the geothermal power potential in Tiris is approximately 147 Mwe (Wiyono et al., 2022). One of the hydrothermal manifestations that can indicate the existence of geothermal potential in this location is the Segaran hot springs (Deon et al., 2015; Ilham & Niasari, 2018; Siombone et al., 2021). There are several hot springs besides the Segaran hot spring that form a continuous line with a distance about 20 – 50 m between hot springs along the Tancak River (Siombone et al., 2021).

The Lamongan Volcano Complex (LVC) is an active volcano that last erupted in 1898 and had multiple localized earthquakes in 1925, 1978, 1985 and 1988–1989 (Carn, 2000). The location of geothermal manifestations in the LVC categorizes this potential area as a volcano-hosted type (Purnomo & Pichler, 2014). Based on data from the Ministry of Energy and Mineral Resources, the Lamongan Volcano Complex is composed of lavas, fine tuffs to lapilli, lahars, and volcanic breccias resulting from the eruption of Mount Lamongan, the youngest vent in the complex (Suharsono & Suwarti, 1992; Carn et al., 1999). The location of this hot spring is close to one of the maars in the Lamongan Volcano Complex, Ranu Segaran, which is composed of grayish-orange fine ash to lapilli deposits and has a cross-bedding structure (Gurusinga et al., 2023). Based on previous research, Nugrohoet al. (2020) interpreted the presence of lineaments in the Lamongan Volcano Complex with dominant directions of northwest–southeast and southwest-northeast using morphometric analysis. On the other hand, Aziz et al. (2018) identified a geological structure with a northwest-southeast and west-east orientation using satellite gravity methods around the Lamongan Volcano Complex. The fault type near Segaran hot springs is a normal fault based on analysis with the second vertical derivative (SVD) filter.

Research from Siombone et al. (2021) managed to describe the subsurface conditions around Segaran hot springs using the gravity method inversion. The inversion performed on the residual anomaly data

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provides a 3D subsurface model with a depth of 1000 m. Based on the subsurface model, there are four rock layers interpreted as lapilli tuff, tuffaceous breccia, volcanic breccia, and intrusion of basalt. Fault structure was found near the hot springs, passing through three layers over intrusion of basalt to a depth of around 150 m. Another research from Supriantoet al. (2020) showed different results. The inversion of gravity data did not indicate any intrusion of basalt and the geological structure was interpreted down to a thousand meters of depth. However, these results align with the magnetic data inversion results. The geological structure interpreted from the gravity data is associated with low susceptibility values, indicating a high-temperature zone.

The identification of geothermal manifestations in this area is limited, and further geophysics surveys are needed. One such method is using magnetic surveys to identify subsurface geological structures. In his research, Basantaray & Mandal (2022) used magnetic and gravity methods in a non-volcanic hot spring zone to describe the subsurface structure and its influence on geothermal activity. They used Euler deconvolution analysis to estimate the depth of the anomaly source. Moreover, Mekkawi et al. (2022) combined magnetic and magnetotelluric methods to evaluate geothermal potential by identifying the structure through derivative analysis and Euler deconvolution. Similarly, Balogun (2022) conducted an analysis using aeromagnetic data to reduce the risk of subsurface geological structures. Building on previous research that identified geological structures and lineaments in the Lamongan Volcano Complex, this research aims to identify the position, direction, and depth of subsurface geological structures with magnetic method approach. Magnetic data was collected around the Segaran hot spring as one of the geothermal manifestations in the Lamongan Volcano Complex. These results will enhance the understanding of geothermal potential in the area where the Segaran hot spring manifestation is located.

Research Area

The Lamongan Volcano Complex is located on the peninsula of East Java and lies in a broad depression between the massifs of Tengger–Semeru and Iyang–Argupura, around 200 km above the Wadati-Benioff zone (Carn et al., 1999; Carn & Pyle, 2001). Stratigraphically, the Lamongan Volcanic Rocks (Qvl) are composed of lava, fine tuffs to lapilli, and volcanic breccia, which are the result of the Mount Lamongan eruption based on the Geological Map of the Probolinggo Quadrangle from the Ministry of Energy and Mineral Resources as shown in Figure 1 (Suharsono & Suwarti, 1992). Lamongan Volcano itself is a young volcano that has separated from Tarub Volcano, an older eruption period, due to the northwest-southeast orientation of the geological structure (Carn, 2000; Yudiantoro et al., 2019). The Geological Map of the Lamongan Volcano Area from the Center for Volcanology and Geological Hazard Mitigation in 1986 shows that Mount Lamongan's younger eruptions cover the western and southern slopes of the main cone (Bronto, 1986 in Agustin, 2020). These eruptions include lava groups from the main cone eruption, lava from side eruptions, pyroclastic deposits, and lahar deposits. The eruption of Mount Tarub dominates the eastern slope of the main cone, consisting of lava groups from the main cone eruption, lava from side eruptions, and pyroclastic deposits. Deon et al. (2015) analyzed rock samples taken from several locations around Mount Lamongan. The results showed that the lava is basaltic with major mineral plagioclase and minor minerals olivine and pyroxene.

Other than from the eruption of the main cone, there are rocks from side eruptions scattered in the Lamongan Volcano Complex. These rocks indicate the presence of cinder cones and maars around Mount Lamongan, estimated at 61 cinder cones and 29 maars (Carn & Pyle, 2001). These monogenesis volcanoes are the result of a single eruption period, which can produce pyroclastic cones or maars if the eruption intersects the nearby groundwater table (Bronto, 2013). Carnet al. (1999) found that the distribution of cones and maars around Lamongan Volcano has the same orientation as the geological structure in the area, which is in a northwest–southeast direction. Regional structure due to tectonic activity in conjunction with magmatic pressure has probably been the major influence on the distribution of volcanic activity in the Lamongan Volcano

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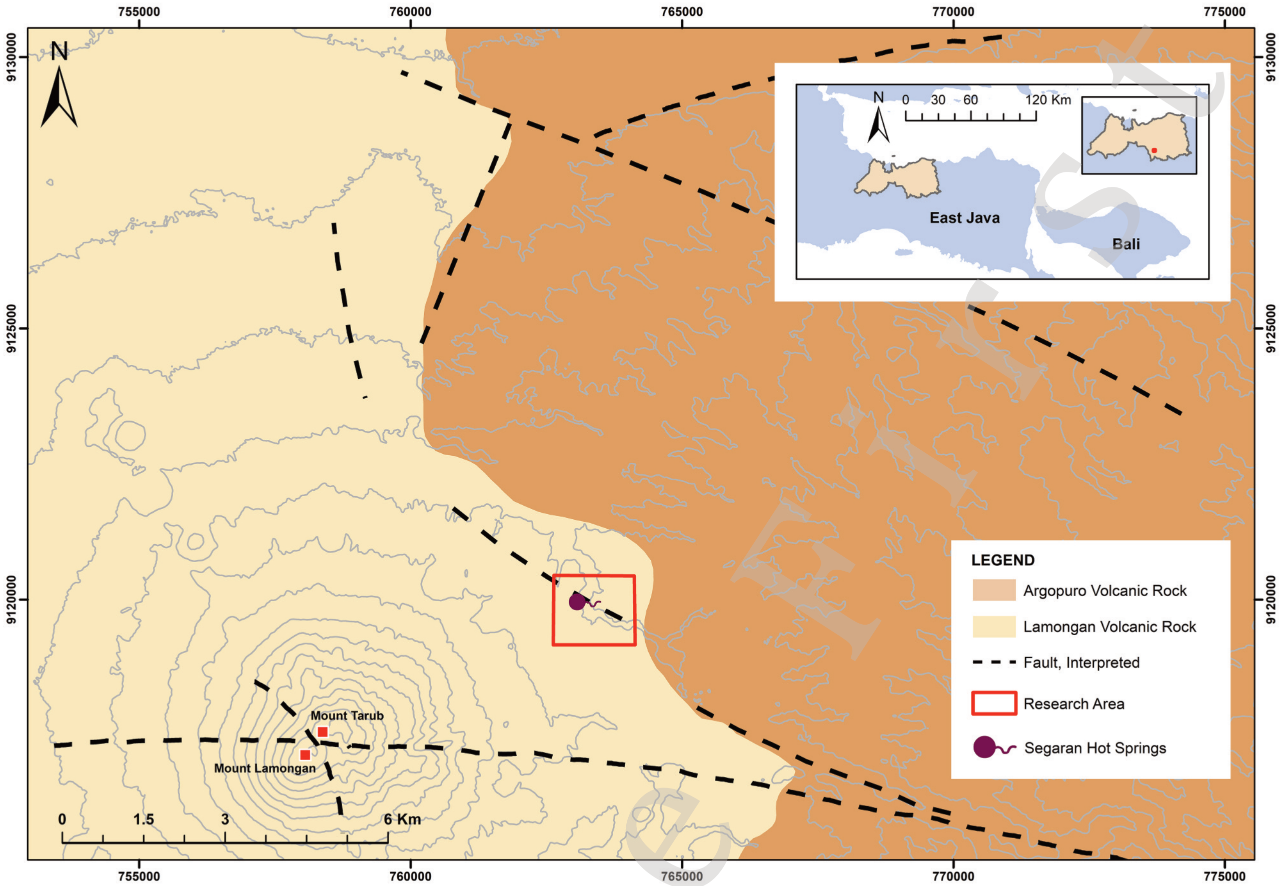

Fig. 1. *Geological map of the research area, adopted from Geological Map of Probolinggo Quadrangle (Suharsono & Suwarti, 1992 modified). One of the faults is interpreted to be near Segaran hot springs in a northwest-southeast direction.*

Complex (Carn et al., 1999; Puswanto et al., 2022). Likewise, the distribution of several hot springs is associated with Tancak river, which is controlled by geological structures (Wiyono et al., 2022). According to data from the Ministry of Energy and Mineral Resources, several regional structures exist in the Lamongan Volcano Complex, one of them passes through near Segaran hot springs with a northwest-southeast orientationand is indicated to control the Tiris Geothermal Area (TGA) (Suharsono & Suwarti, 1992; Siombone et al., 2022).

Segaran hot springs are composed of Lamongan volcanic rocks and are close enough to Argopuro volcanic rocks. This might lead to the possibility of Argopuro volcanic rocks being found in the subsurface of the research area. Based on the Geological Map of Probolinggo Quadrangle from Ministry of Energy and Mineral Resources, Argopuro Volcanic Rocks (Qva) are composed of andesitic to basaltic lava, volcanic breccia, and tuff (Suharsono & Suwarti, 1992). Siombone et al. (2021) described subsurface conditions using field gravity data by performing inversion on residual gravity anomaly data. There are four rock layers that have variations in density values and structures in the form of faults near hot springs. Layer 1 is interpreted as a layer of lapilli tuff, layer 2 is interpreted as a layer of tuffaceous breccia, layer 3 is interpreted as a layer of volcanic breccia, and layer 4 is interpreted as an intrusion of basalt. A fault structure was found beneath Segaran hot springs, passing through three layers over an intrusion of basalt up to around 150 m depth. Lapilli tuff layers are generally aquifers in volcanic settings (Fajar et al., 2021). The location of this hot spring is close to one of the maars in the Lamongan Volcano Complex, Ranu Segaran, which is composed of grayish-orange fine ash to lapilli deposits and has a cross-bedding structure (Gurusinga et al., 2023).

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Data and Method

The research was conducted around the Segaran hot spring, Lamongan Volcano Complex, Probolinggo, covering an area of 1×1.2 km^2 as indicated by a red box in Figure 2. There are several hot spring spots along the Tancak riverbank in the Segaran hot spring area. The river passes through the research area from the southeast to the north side of the research area and the surrounding area consists of hills with a moderately steep slope towards the river. Magnetic data collection was carried out using a Geotron G5 Proton Magnetometer with the rover-rover or looping method. Measurement at the base station was carried out at the beginning and the end of each day's measurement. A total of 117 data points were collected at various intervals, following the contours of the research area because there are local houses and steep slopes.

Magnetic methods are based on variations in magnetic field intensity at the Earth's surface in response to differences in the magnetization properties of subsurface rocks. These differences in magnetization cause the Earth's total magnetic field measured at the surface to be inhomogeneous, leading to what are known as magnetic anomalies (Clark, 2014; Sehah et al., 2020). To obtain the magnetic anomaly value, the measured magnetic field value needs to be corrected using daily variation correction and International Geomagnetic Reference Field (IGRF) correction. A significant contrast in magnetic anomaly values reveal how magnetic fields react around geological structures and lithological boundaries (Ariyo et al., 2020; Atta, 2023). Several research using magnetic methods in geothermal areas have been conducted before. Mekkawi et al. (2022) combined aeromagnetic and magnetotelluric data to evaluate geothermal potential by

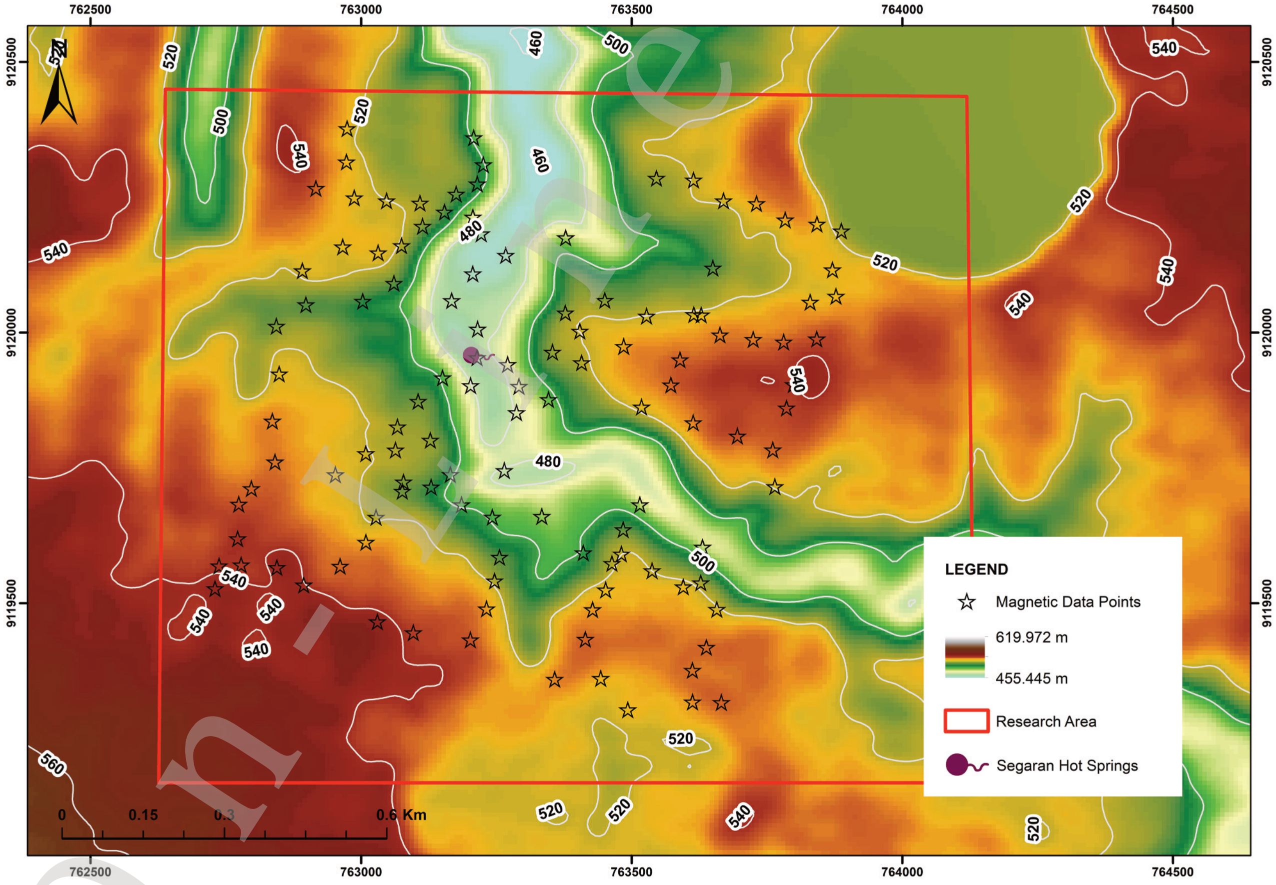

***Fig. 2**. Elevation map of research area with distribution of measurements magnetic data. Segaran hot springs is located in Tancak riverbank at low elevation between several hills.*

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identifying the subsurface geological structure. Basantaray & Mandal (2022) used magnetic and gravity methods in a non-volcanic hot spring area to identify the subsurface structure and its influence on geothermal activity. Low (2020) also employed magnetic and gravity methods in a hot springs area to describe the subsurface structure and its influence on geothermal activity.

Gridding of the data was performed using the Kriging method because this method provides a good estimation of values for unsampled areas (Bergbauer et al., 2003). Before separating the residual and regional anomalies, a reduction was performed using the reduce to equator (RTE) filter to ensure that the magnetic field direction would be uniform at each measurement point. This filter is used because the sampling location is closer to the equator and the results are not significantly different from the total anomaly (Ekwok et al., 2022; Rusman et al., 2023). The separation of residual and regional anomalies was performed using a combination of radially averaged power spectrum and upward continuation to obtain a reduced regional anomaly distribution in the research area. According to Toviatun & Suprianto (2020), applying these two procedures is quite effective because the depth estimate from radially averaged power spectrum can be used as a reference in performing upward continuation.

The transformations using First Vertical Derivative (FHD) and Second Vertical Derivative (SVD) on magnetic data aim to identify subsurface structures (Verduzco et al., 2004; Azkia & Daud, 2021). These transformations delineate the boundaries of the magnetic anomaly values. FHD describes the boundary of the difference in magnetic anomaly values horizontally. while SVD describes the boundary of the difference in magnetic anomaly values vertically, confirming the FHD results. The combination of these two transformations can indicate the position and direction of lineaments in the research area that are suspected to be subsurface structures. Anomaly values at 0 on the SVD anomaly distribution map, associated with the maximum value of the FHD anomaly map, can indicate the presence of subsurface structures (Azkia & Daud, 2021; Balogun, 2022). To determine the estimated depth of the structure, located Euler deconvolution was applied. The standard Euler deconvolution which uses a guided window size, can lead to errors in characterizing the depth of the anomaly (Castro et al., 2020). Determining the window width at the beginning of the process is difficult because the window size must cover the anomaly without being too large, as overlap can occur. The integration of the three transformations on the magnetic data is sufficient to interpret the position, direction and depth of subsurface structures in the research area (Balogun, 2022).

The results of the magnetic data were correlated with the results of the density lineament analysis that had been obtained before collecting the magnetic data. This analysis is preliminary research to determine the distribution of lineaments in the research area regionally. The lineaments are generated from the Digital Elevation Model Nasional (DEMNAS) data with some shadow reliefs that are interpreted manually. According to Fossi et al. (2021), a high value of density lineaments indicates the presence of geological structures at that location. The correlation of magnetic data and density lineament analysis will support each other to identifying the location, direction, and depth of geological structures in this research.

Results and Discussion

Density lineaments analysis was performed based on Digital Elevation Model Nasional (DEMNAS) with azimuths of 315°, 200°, 100°, and 50°. The dominant direction of the lineaments formed in the research area is northwest-southeast, as shown by plotting on the rosette diagram in Figure 3 (Nabhan et al., 2024). Figure 4 show the density lineament map of research area, which was generated from the ratio of lineament length per unit area.

This result aligns with the analysis of Siombone et al. (2022), which shows that the lineaments around the Lamongan Volcano Complex have a dominant northwest–southeast direction based on rosette diagram analysis. The resulting density lineaments have a value range of 0–8.09 km/km^2, with high values represented in red on the map while low values are represented in blue. This map shows that

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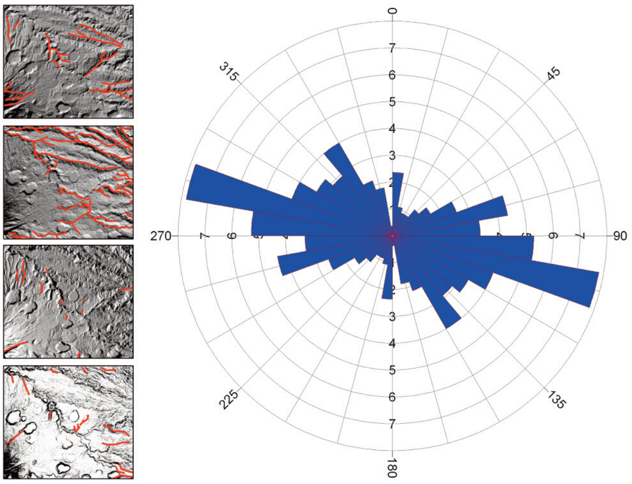

***Fig. 3**. Lineaments extracted from each azimuth, 315°, 200°, 100°, and 50° (top to bottom). Plotting on the diagram rosette shows dominant lineaments of research area in northwest-southeast direction.*

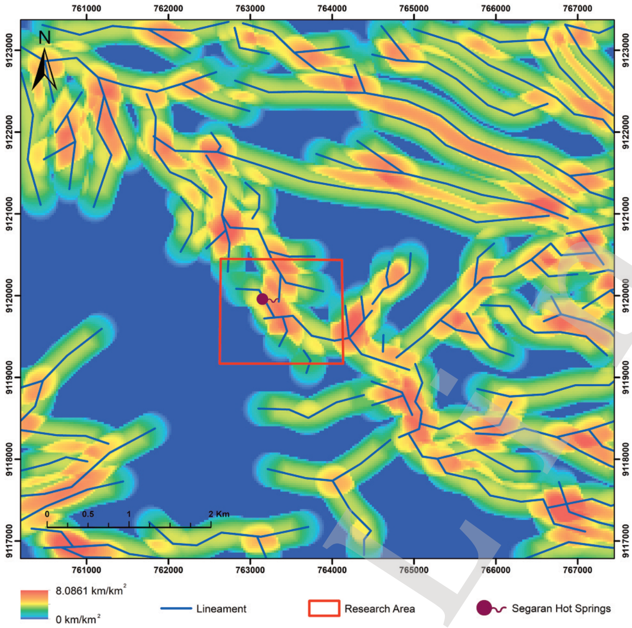

***Fig. 4.** Density lineament map indicates that the research area located in red zone with high density lineament value.*

the research area, symbolized by the red box, is included in an area with a high value of density lineaments, especially in the central part of the research area near the Segaran hot springs (Fig. 4). The main fault in the research area will increase the density of lineaments so that it has a high value of density lineaments (Al Brouki et al., 2023). The high value is interpreted to be the presence of a geological structure in the area which indicates that it may control the formation of hot springs in this location.

Total magnetic anomalies resulting from diurnal and International Geomagnetic Reference Field (IGRF) corrections are presented in contour maps using the Kriging gridding method. Refer to Jain (1998) in Basantaray & Mandal (2022), reduce to equator (RTE) transformation is preferred over reduce to pole (RTP) in the mid latitude areas. RTE transformation applied with average inclination dan declination values of the research area are as -32.4254° and 0.7053168°. The result from the transformation is shown in Figure 5.

The result of RTE transformation shows an anomaly value range of -594.480–195.123 nT. Low anomalies of magnetic intensity dominate the north and east sides of the research area with a value range of -594.48 – -205.976 nT in a diagonal direction so that it forms a northwest–southeast orientation. However, there is a low anomaly among the high anomaly, precisely on the southwest side of the research area. The high anomaly dominates the south and west sides of the research area with a value range of -193.382 – 195.123 nT. The hot spring that is the object of research is located near a significant contrast of magnetic field variations.

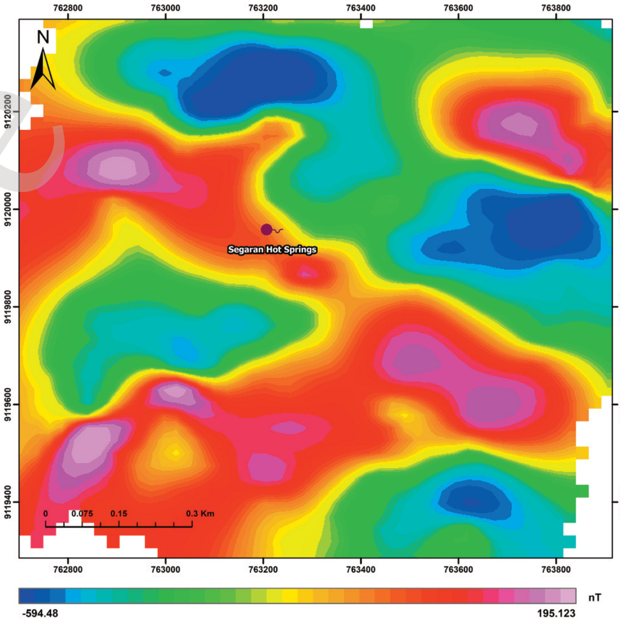

***Fig. 5.** Map of total reduced magnetic anomaly using reduce to equator (RTE) transformation.*

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These results will be transformed using first horizontal derivative (FHD), second vertical derivative (SVD), and located Euler deconvolution.

Radially averaged power spectrum was performed to estimate the depth of the regional and residual magnetic anomalies. The natural logarithm of power of anomaly data was calculated using Fast Fourier Transform (FFT) and plotted against the wavenumber, as shown in Figure 6. The first trend line with a gradient of 1118.5 represents the deeper source of the anomaly or known as the regional anomaly (Abdelrahman et al., 2002; Kebede et al., 2022; Kosaroglu et al., 2016). While, the second trend line with a gradient of 493.61 represents a shallow anomaly source or residual anomaly. Depth estimation can be calculated by dividing the gradient value by 4π, which is about 40 m for residual anomalies and 89 m for regional anomalies.

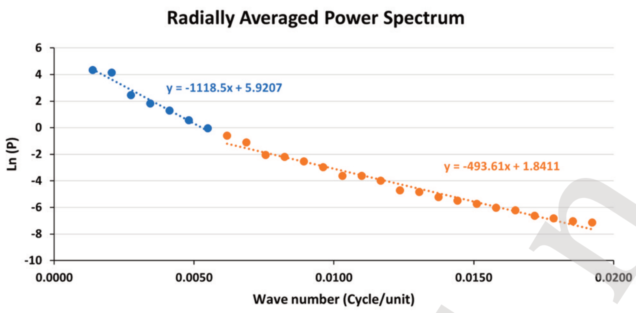

Fig. 6. *Radially averaged power spectrum of total reduced magnetic anomaly. The first trendline represents the deeper source (89 m) and second trendline represents the shallower source (40 m).*

To separate the regional and residual anomalies into contour maps, an upward continuation filter is used. The estimated depth of the regional anomaly is the input to transform the regional anomaly from its actual depth to the surface level, shown as Figure 7(A). Whereas, the residual anomaly map in Figure 7 (B) was performed by subtracting the total reduced anomaly to the regional anomaly.

The distribution of low anomalies in the regional anomaly map dominates the north and east sides of the research area with a value range of -382.244 – -286.30 nT in a diagonal direction, forming a northwest-southeast orientation (Fig. 7A).

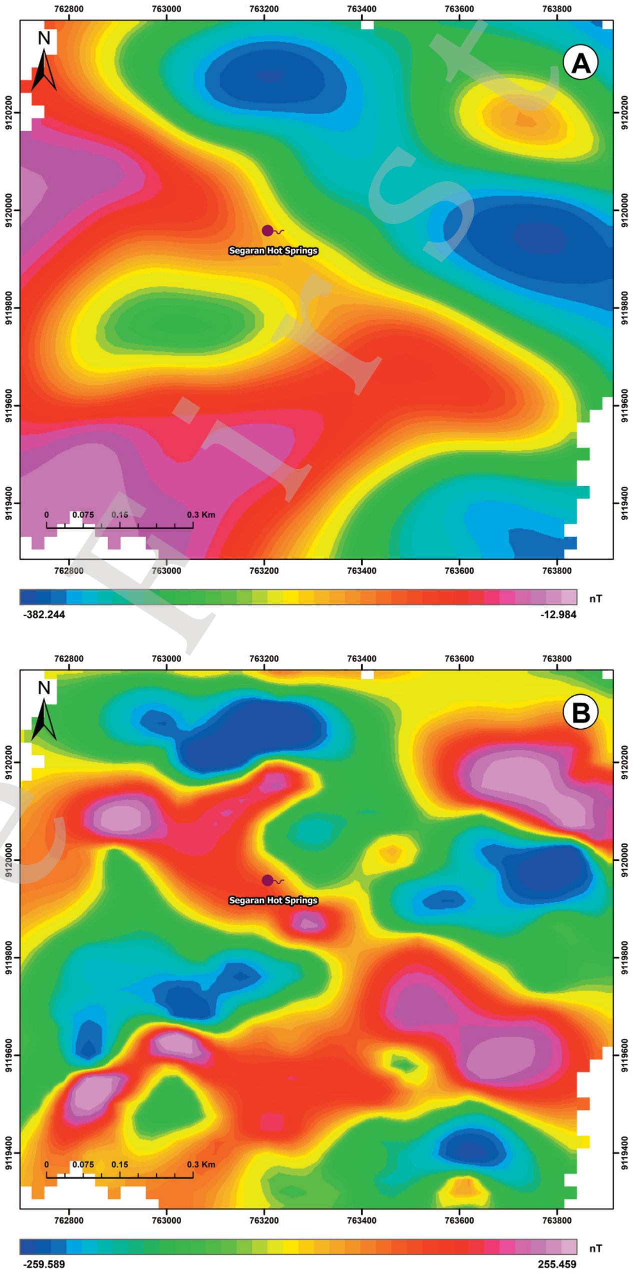

Fig. 7. *Regional anomaly map (A) and residual anomaly map (B) resulted from upward continuation. Similar results for each anomaly indicate the shallower anomaly continues up to deeper anomaly.*

However, there is a low anomaly among the high anomaly, precisely on the southwest side of the research area. While the high anomaly dominates the south and west sides of the research area with a value range of -109.41 – -12.984 nT. The hot spring that is the object of research is located near a significant contrast of magnetic field variations. A significant

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contrast reveals how magnetic fields react around geological structures and lithological boundaries.

Similarly, on the right side of the hot spring or northeast side of residual anomaly map, there is a low anomaly with a value range of -259.589 – -28.36 nT, while on the left side of the hot springs, or southwest side, there is a high anomaly with a value range of 50.84–255.459 nT (Fig. 7B). The significant contrast in magnetic field variations in the hot spring area is clearly illustrated. Results from Balogun (2022), Basantaray & Mandal (2022) and Mekkawi et al. (2022) show significant anomalous contrasts correlated with the geological structures in the area.

The first horizontal derivative (FHD) and the second vertical derivative (SVD) were subjected to the total reduced magnetic anomaly. The results of FHD are shown in Figure 8 with anomaly value is range of -1.789 – 5.694 nT/m, the maximum value shown in pink and the minimum value shown in dark blue. High anomalies are scattered in northwest-southeast and southwest-northeast parts of research area. Low anomalies are also scattered in several locations in the research area. Segaran hot springs is located at a high anomaly, which is the maximum value of the first horizontal derivative. The results of SVD in Figure 9 can confirm the FHD results. The value of SVD anomaly is range of -0.239 – 0.238 nT/m^2. High and low anomalies are scattered in several locations of the research area, with the distribution pattern having a northwest-southeast and southwest-northeast orientation, like the FHD anomaly map.

The maximum values of FHD anomaly correspond to contacts between total reduced anomaly boundary, which can be interpreted as lineaments. The black line on the FHD map shows the lineaments from maximum anomaly value which have a dominant direction northwest-southeast and southwest-northeast (Fig. 8). The SVD anomaly value at point 0 is marked with a black line and having a northwest-southeast and southwest-northeast direction (Fig. 9). The lineaments resulting from the FHD map is then overlaid with the lineaments resulting from the SVD map, as shown in Figure 10. The lineaments that coincide can indicate the presence of subsurface structures (Azkia & Daud, 2021; Balogun, 2022).

From the total reduced magnetic anomaly map, the located Euler deconvolution can be used to estimate depth of anomaly sources. An important parameter in located Euler deconvolution transformation is the Structural Index (SI). According to Ariyo et al. (2020), an SI value of 1.0 is the most useful Euler so-

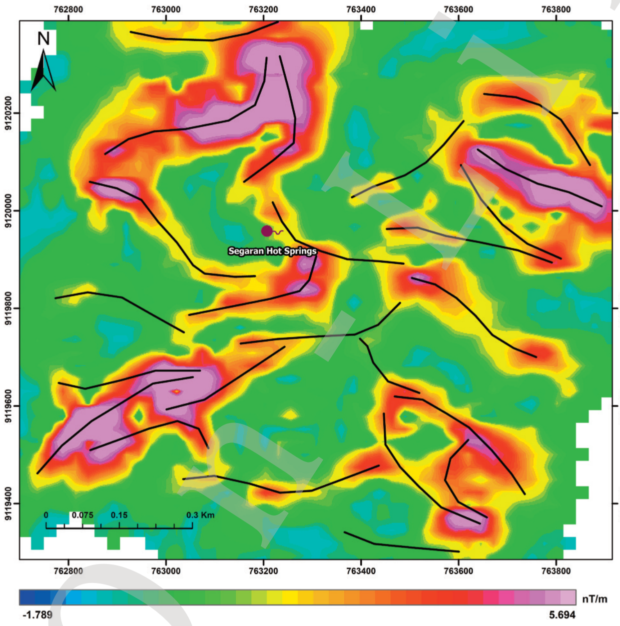

Fig. 8. Map of the first horizontal derivative (FHD) anomaly with the black line shows the maximum value of the FHD.

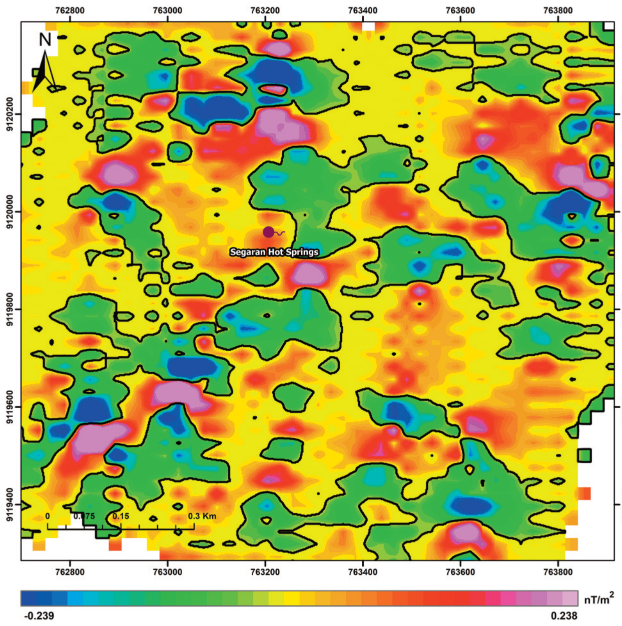

Fig. 9. Map of the second vertical derivative (SVD) anomaly with the black line shows the value at 0 of the SVD.

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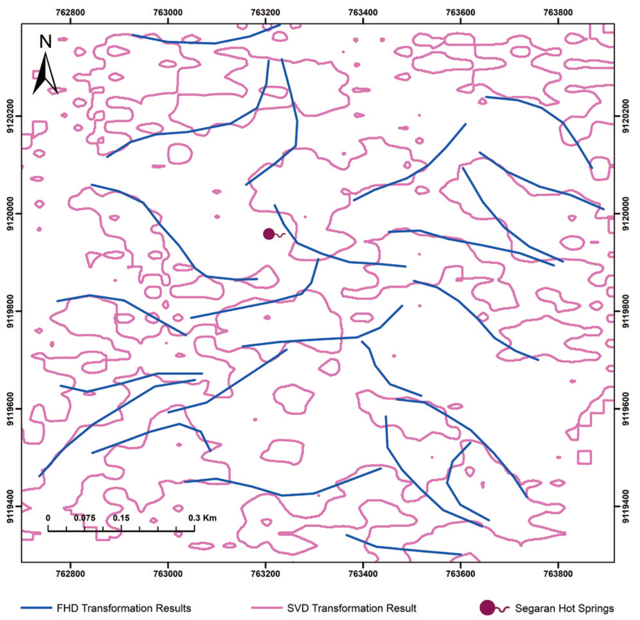

Fig. 10. *Map of the interpreted lineament of first horizontal derivative (FHD) and second vertical derivative (SVD) transformation.*

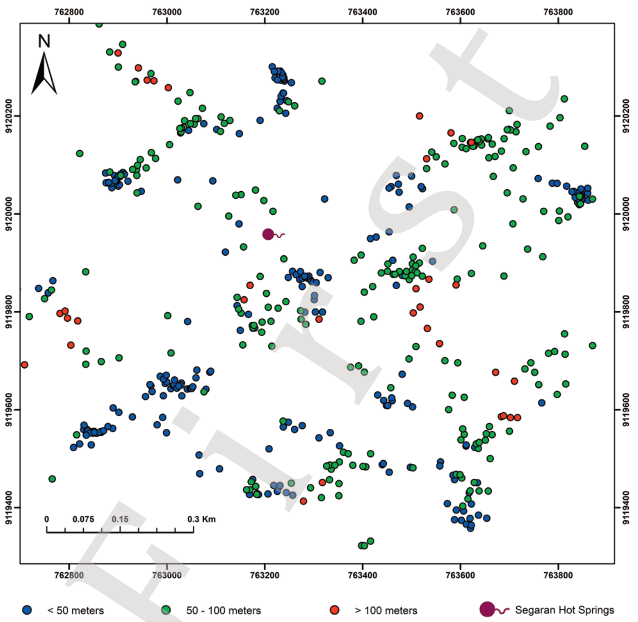

Fig. 11. *The anomaly distribution of located Euler deconvolution is given with three classification depth.*

lution for characterizing the depth of magnetic anomaly sources because the geometric assumptions can be linear or oblique. The results of this deconvolution are shown in Figure 11.

The depths of anomaly sources from the located Euler deconvolution transformation are grouped into three categories: <50 m (blue dots), 50–100 m (green dots), and >100 m (red dots). Anomalies with depths <50 m are dominantly located in the southwest of the research area and have a southwest-northeast orientation near Segaran hot springs. Anomalies with depths of 50–100 m and >100 m have a northwest–southeast orientation. The anomalies corresponding to the results of the FHD and SVD transformations indicate subsurface geological structures. The overlaid results of FHD, SVD, and located Euler deconvolution are shown in Figure 12.

The lineaments from magnetic data have northwest–southeast, north–south, and southwest–northeast directions, marked by a dashed red line. These results are agreed with the preliminary research using density lineament analysis based on Digital Elevation Model Nasional (DEMNAS), marked by a dashed blue line. Overlaid of both data shows the dominant direction of the lineament of the study area is northwest–southeast. The Geological Map of the Probolinggo Quadrangle from the Ministry of Energy and Mineral Resources shows the presence

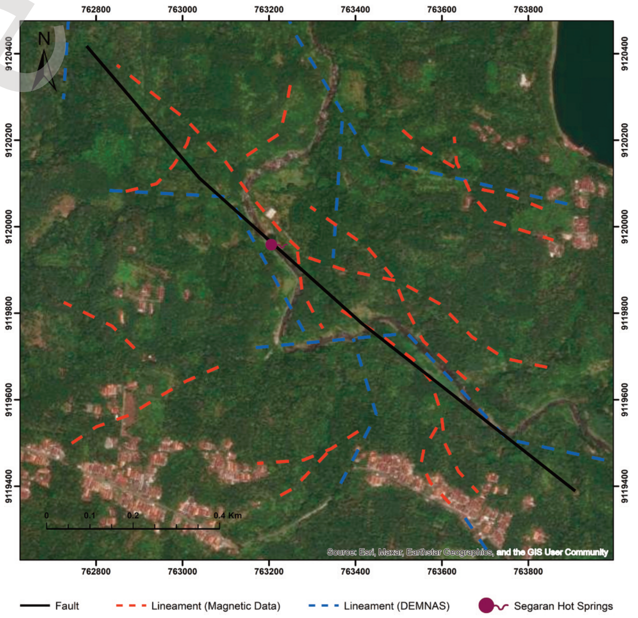

Fig. 12*. The position of the fault structure near the Segaran hot springs is oriented in a northwest-southeast direction. This result is derived from the overlay of lineaments identified through the integration of FHD, SVD, and located Euler deconvolution transformation with the lineament obtained from DEMNAS.*

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of fault structures near the Segaran hot springs in a northwest-southeast direction. This research confirms the results of previous research using different methods. Analysis by Siombone et al. (2022) using satellite gravity data successfully figured out the direction of a discontinuity fault structure around Tiris Geothermal Area (TGA) in a northwest-southeast direction. These results are supported by lineament analysis on Digital Elevation Model Shuttle Radar Topography Mission (DEM SRTM) data in the same research.

The presence of a depth anomaly of >100 m near the Segaran hot springs indicates that geological structure for the hot water flows reaches a depth of more than 100 m. The depth of over 100 m is supported by the consistent distribution of regional and residual anomalies that have depths of 89 m and 40 m, respectively. The location of the Segaran hot springs is always near significant anomaly changes that may indicate a discontinuity in the geological structure at representative depth. Siombone et al. (2021) shows 3D subsurface model performed by inversion on the residual anomaly data with 1000 m depth. A fault structure was found beneath Segaran hot springs, passing through three layers over an intrusion of basalt up to around 150 m depth. Consistent with these findings, fault structures near the Segaran hot springs in a northwest-southeast direction are marked by solid black lines (Fig. 12).

Conclusion

The results of first horizontal derivative, second vertical derivative and located Euler deconvolution transformation on magnetic data successfully identified the location, direction, and depth of lineaments. The dominant direction of lineament around Segaran hot spring is a northwest-southeast. These results are consistent with the density lineaments analysis that shows the presence of geological structures in the same direction. Then, the similarity of the regional and residual anomaly distributions supports the results of the located Euler deconvolution, that there is a structure beneath the Segaran hot spring for hot water flow up to 100 m depth. According to some previous research, fault structures were found near the Segaran hot springs with the same orientation as the analysis results of this research. The existence of fault structures correlated with Segaran hot springs can lead the indication of geothermal potential in Lamongan Volcano Complex, especially in Tiris area.

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Резиме

Идентификација геолошких структура у геотермалном комплексу вулкана Ламонган на основу анализе геомагнетних података

Област Тирис у комплексу вулкана Ламонган (Проболинго, Источна Јава) представља подручје са значајним геотермалним потенцијалом у Индонезији. Уз реку Танцак постоји неколико топлих извора који су контролисани геолошким структурама и поређани су у низу са растојањем од око 20–50 m између сваког извора. Једна од хидротермалних манифестација која указује на геотермални потенцијал овог подручја су топли извори Сегаран. Претходна истраживања су указала на постојање геолошких структура око топлих извора Сегеран са правцем пружања северозапад–југоисток. Прикупљање магнетних података обављено је праћењем контура истраживаног подручја, што је резултирало различитим интервалима између тачака, са укупно 117 тачака. Неколико филтера је примењено на податке о укупном интензитету магнетног поља, укључујући редукцију екватора (RTE) да би се стандардизовао смер магнетног поља у свакој тачки мерења, спектралну анализу да би се проценила дубина регионалних аномалија и откривање аномалија дубљих извора. Ови филтери су омогућили израду регионалне мапе магнетних аномалија и мапе резидуалних магнетних аномалија. Обе карте су показале аномалије са правцем пружања северозапад-југоисток у близини топлих извора Сегаран и правцем пружања југозапад-североисток на југозападу истраживачког подручја. Трансформације прве хоризонталне и друге вертикалне деривације су спроведене да би се извукле границе извора магнетних аномалија. Ојлерова деконволуција је извршена да би се одредила дубина извора магнетне аномалије и преклопљена је са деривационом анализом. Применом ових трансформација на магнетне податке може се дефинисати локација, правац и дубина подземних структура у области истраживања. Резултати показују доминантну раседну стрктуру у комплексу вулкана Ламонган у близини топлих извора Сегаран са оријентацијом северозапад-југоисток. Ови резултати су у сагласности са доминантном оријентацијом анализе густине структура изведене на основу Digital Elevation Model Nasional (DEMNAS). Постојање раседних структура у корелацији са топлим изворима Сегаран повећава индикацију геотермалног потенцијала у комплексу вулкана Ламонган, посебно у области Тириса.

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