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Characteristics of subvolcanic intrusion: a case study at Tempel Hill, Kalisonggo, Girimulyo, Kulonprogo, Yogyakarta

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Abstract. The genesis of Mount Tempel which is part of Mount Mujil is still being debated by some geologists discussing the Kulon Progo Mountains. The surface and subsurface measurements must be done to know a geological aspect that building the area around Mt. Mujil, precisely in Tempel Hill on the northeast side of Mt. Mujil, Girimulyo, Kulonprogo, Yogyakarta. The geology of this location is still a mystery and has always been a hot topic regarding origins, geotourism, and disasters. The general problem in this study is related to the occurrence of the northeast side of Mt. Mujil which is still not final and much debated, so it is necessary to approach the concept of volcanic geology to help answer these problems. The purpose of this study was to identify the physical characteristics of igneous rocks in Tempel Hill based on surface and subsurface data. The approach method is carried out through geological mapping, geophysical resistivity measurements, and petrological, petrographic and geochemical analysis. The results of the petrological analysis show that the igneous rock has a porphyroafanite – microcrystalline texture without a flow texture, some scoria – massive structures, geochemically it shows that calc – alkali refers to subduction products. On the other hand, resistivity analysis shows the presence of volcanic rocks with density values and resistivity values of intrusive rocks and volcanic breccia in the vicinity. Indications of the presence of volcanic rocks with an area the size of Tempel Hill are defined as magma fossils or subvolcanic intrusion rock bodies. Tempel Hill has potentially for tourist attractions that can improve the welfare of local residents.

Keywords: resistivity, petrogenesis, subvolcanic intrusion, tempel hill

1. Introduction

Tempel Hill is a part of Mt. Mujil which is located on the northeast side, approximately 25 km to the west of the city of Yogyakarta (Figure 1). Tempel Hill (+187.5 m) has a relatively irregular oval shape that appears attached and elongated on the northeast side of Mt. Mujil with a weak wavy topography, steep slopes on both the northwest and southeast sides (Figure 2). The presence of Tempel Hill in the research area is quite interesting because it occupies the eastern part of Mount Gajah and occupies an open arch morphology to the east. This location occupies a low landscape on the east side of the foot of Mt. Gajah.

The existence of Tempel Hill needs to be discussed further with regard to its characteristics because some experts have different views. On the other hand, the high morphology of Tempel Hill which extends between the low morphology in the surrounding area indicates that Tempel Hill is composed of rocks that are more resistant than the Nanggulan Formation. Initial indications in the study area refer to the presence of subvolcanic intrusions, both sills and dikes. There is a need for geological research using surface and subsurface data to answer the genesis of Tempel Hill section of Mt. Mujil as an avalanche of the Mt. Gajah rock group or as a subvolcanic intrusion in the area.

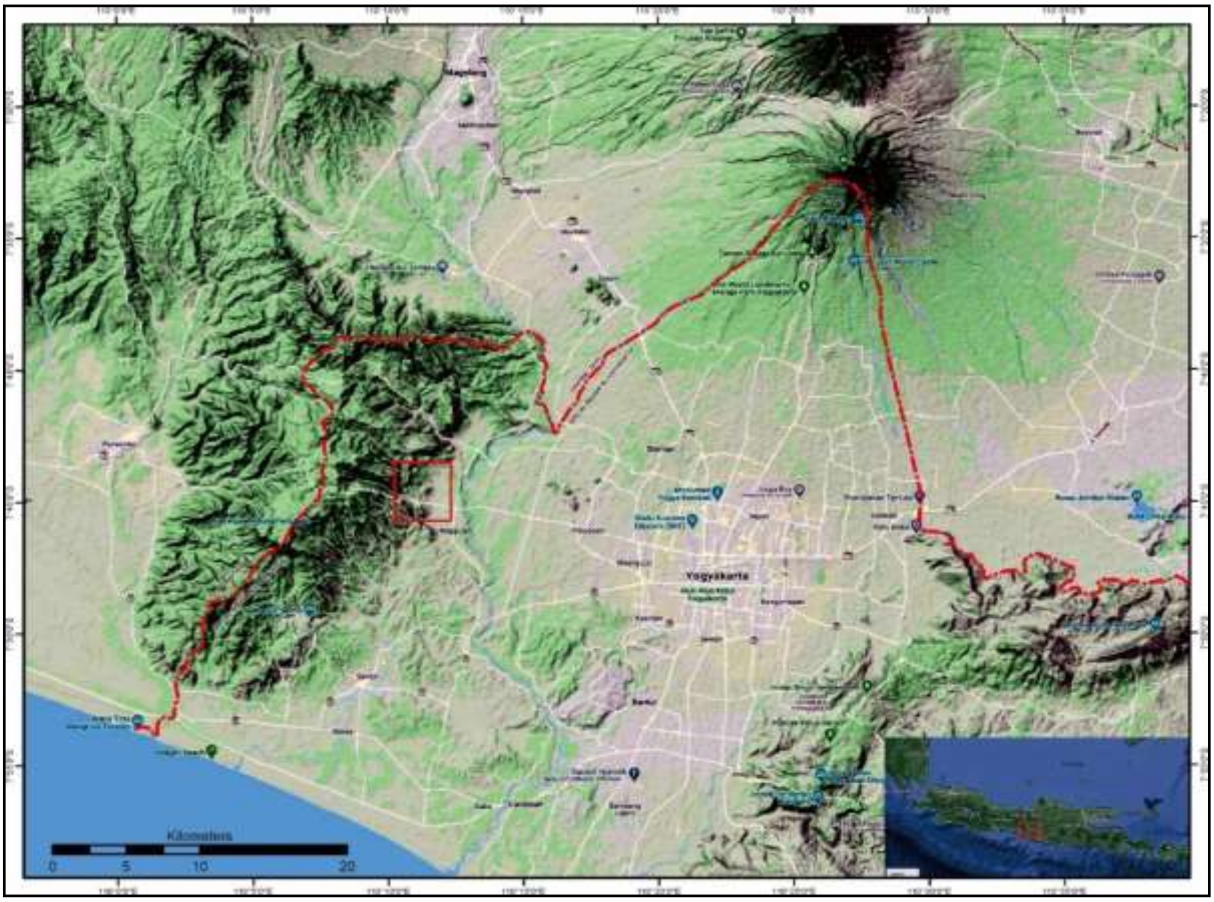

Figure 1. The location of the research area, Bukit Tempel juts to the northeast of G. Mujil

According to [1] the research area is composed of the Old Andesite Bemmelen Formation (Tmoa) which is generally composed of andesite breccia, tuff, lapilli tuff, agglomerate and andesite lava flows. In particular, [2] stated that the research area is the result of a process resulting from the squeezing of marine plastic layers under the load of andesite breccia in the Kulonprogo Dome Mountains, so that this side part has been converted into a local bulge, isolated and caused the Nanggulan plastic layer to open. Furthermore, based on the measurement of the force around Mt. Mujil [3] proved that there is a contrasting value between the nanggulan formation (2.5 gr/cm^3) and the Tua Andesite (2.7 gr/cm^3) which is defined as vertical stratigraphic contact, namely breccia andesite which is brittle and heavy, colored by layers of plastic marine sediments. On the other hand, the origin of the nanggulan formation is very limited to a closed shallow basin, so the position of the Nanggulan Formation as a basement in the Kulonprogo area is questioned [4] In addition, [5] state that Mt. Mujil is the remains of an ancient volcano consisting of basalt andesite, while [6] state that Mt. Mujil is a monogenetic ancient volcano consisting of basalt andesite – andesite with a short life.

In the initial study, in the Tempel Hill area, especially in the highest morphology, there is a large collection of igneous rocks (larger than the rocks in the Mt. Mujil area) with a diameter of 3-5 meters with a porphyritic to faneric texture. This indicates that Tempel Hill has a slightly different character from Mt. Mujil. The initial suggestion was that the formation of sills or dikes from the central eruption of Mt. Mujil as a unit of brief volcanic activity. To answer this, it is necessary to conduct comprehensive research using surface and subsurface geological methods so that relevant conclusions relate to the characteristics and genesis of Tempel Hill. The purpose of this study was to determine the physical character and shape of the subsurface conditions of the igneous rocks that compose Tempel Hill.

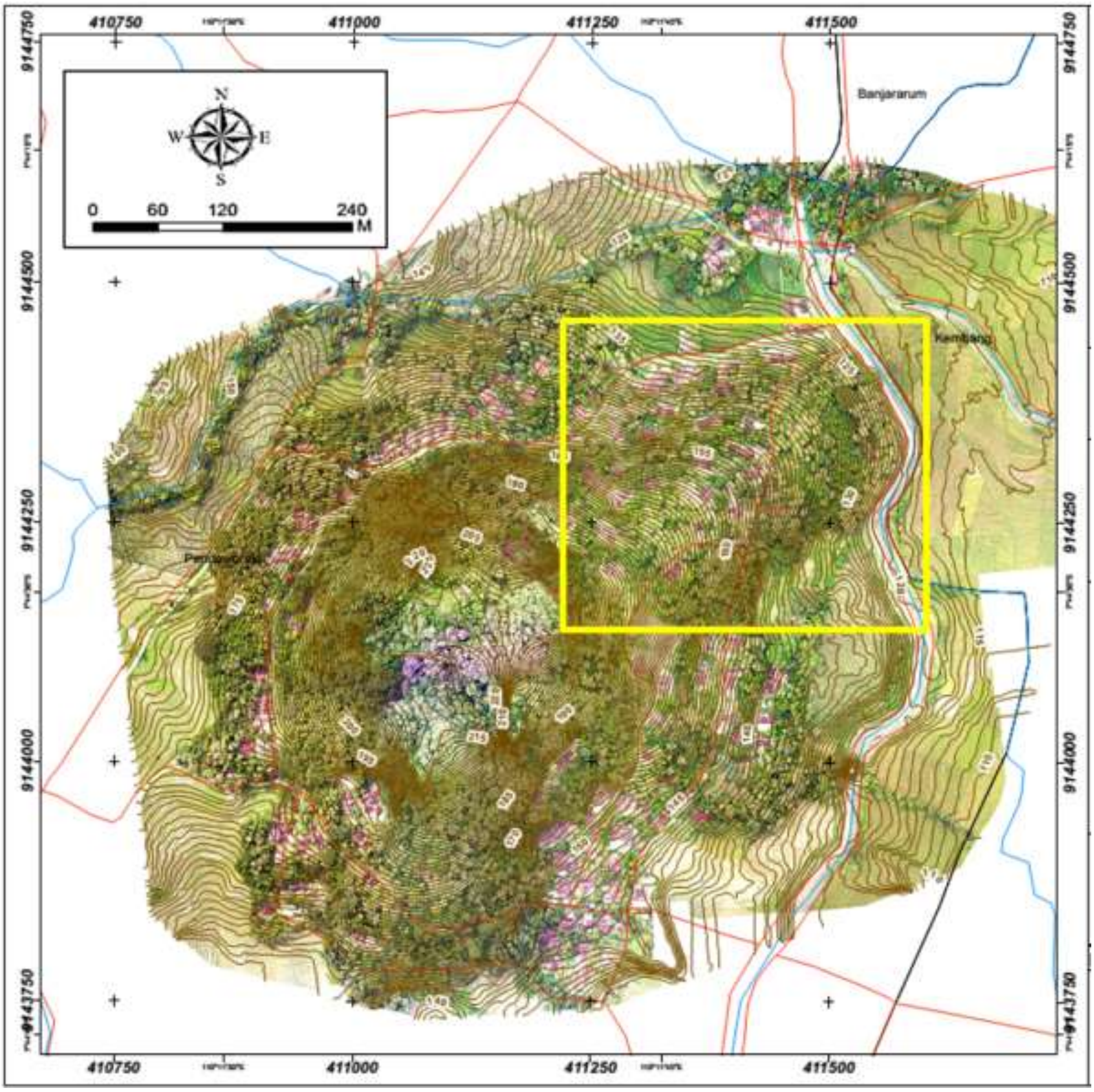

Figure 2. Overlay topographic map with images of the Tempel Hill area and its surroundings (Tempel Hill is shown in yellow box)

2. Geology of Tempel Hill and its Surroundings

The Kulonprogo Mountains are an elongated dome-shaped mountain complex consisting of Mt. Ijo, Mt. Gajah, and Mt. Menoreh which stretches relatively north-south. The morphology of the study area occupies the eastern foothills and is Oligo-Miocene in age. On the other hand, [7] mentioned the Kulonprogo Dome Mountains as part of the Southern Mountains of East Java. This refers to its geographical and stratigraphic position which is more related to the Southern Mountains of East Java, both of which are only separated by lowlands which are covered by the flow of Mt. Merapi material.

The stratigraphy of the Kulonprogo Dome Mountains is composed of Tertiary-aged rocks such as the Nanggulan Formation, Old Andesite Bemmelen (including Tempel Hill), Jonggrangan Formation, and Sentolo Formation [1]. In particular, the Old Bemmelen Andesite Formation is divided into the Kulonprogo Formation with Ijo Members and the Giripurwo Formation [8], the stratigraphy of the two formations is unconformity, while Pringgoprawiro and Riyanto (1988) divide into the Dukuh Formation and the Progo Volcanic Complex, both of which are cconformity.

The Old Andesite Bemmelen Formation is composed by volcanic rock dominance (Figure 3). The Old Andesite Bemmelen Formation is the result of volcanic activity in Late Oligocene – Early Miocene from the oldest Mt. Gajah, Mt. Ijo, and Mt. Menoreh [2]; [1]. The K-Ar radiometric age assessment conducted by [9] stated that the age of the rocks exposed in the Kalisonggo River, exactly 150 m to the east of the study site, was 42.73 ± 9.78 to 15.30 ± 0.88 million years ago (Late Eocene – Early Miocene). On the other hand, [10] date based on the limestone Nanggulan Formation showing an age range of 42.67 – 40.36 million years ago (Middle Eocene – early Eocene End), while [11] and [12] mention the Nanggulan Formation which was deposited in estuary, shallow sea, and tidal environments. The Jonggrangan Formation consists of coral reef limestone, while the Sentolo Formation consists of layered limestone aged Upper Miocene - Pliocene followed by sedimentation in the form of colluvial flow deposits, Mt. Merapi, and Quaternary alluvial.

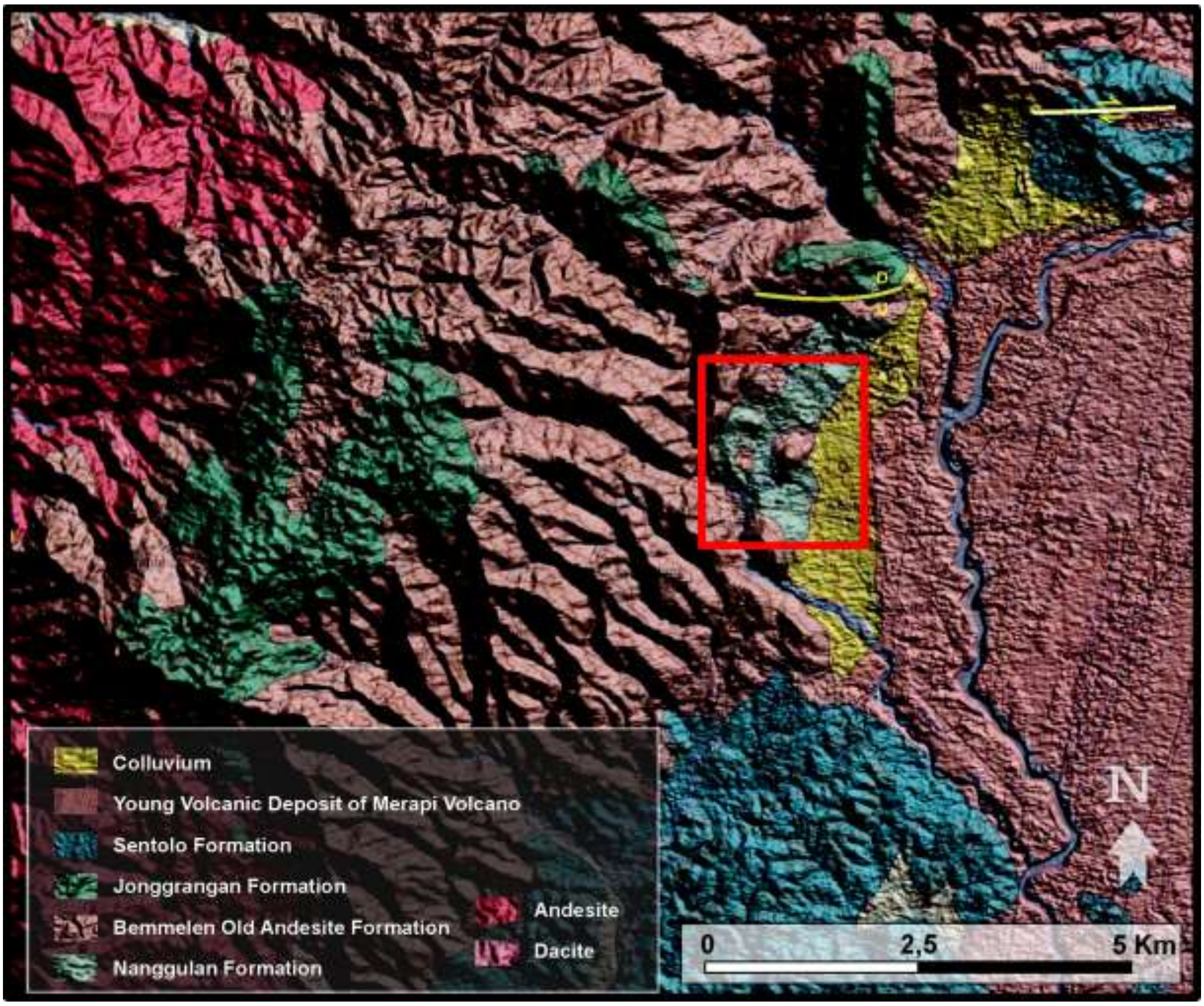

Figure 3. Geological map of Tempel Hill and its surroundings (Rahardjo et al. [1]), the red box is the research area.

3. Methods

The research uses surface and subsurface mapping methods. Measurement of surface and subsurface data is then analyzed comprehensively, relevant modeling and concluded. Surface research begins with geological mapping, description, rock sampling for petrography and geochemical analysis, large-scale contour data collection using the Mavic 2 pro drone and data processing using agisoft metashape pro and PIX4d pro. Subsurface research is carried out by measuring rock resistivity through 7 paths. Studio work such as contour drawing, map making, rock resistivity models, while laboratory work for modal mineralogy analysis uses a polarizing microscope by taking a total of 4 rock samples. Geochemical analysis of the main oxides and trace elements was carried out on 2 rock samples using the XRF method at BATAN, Jakarta. For more details in this study, the research flow is shown as Figure 4.

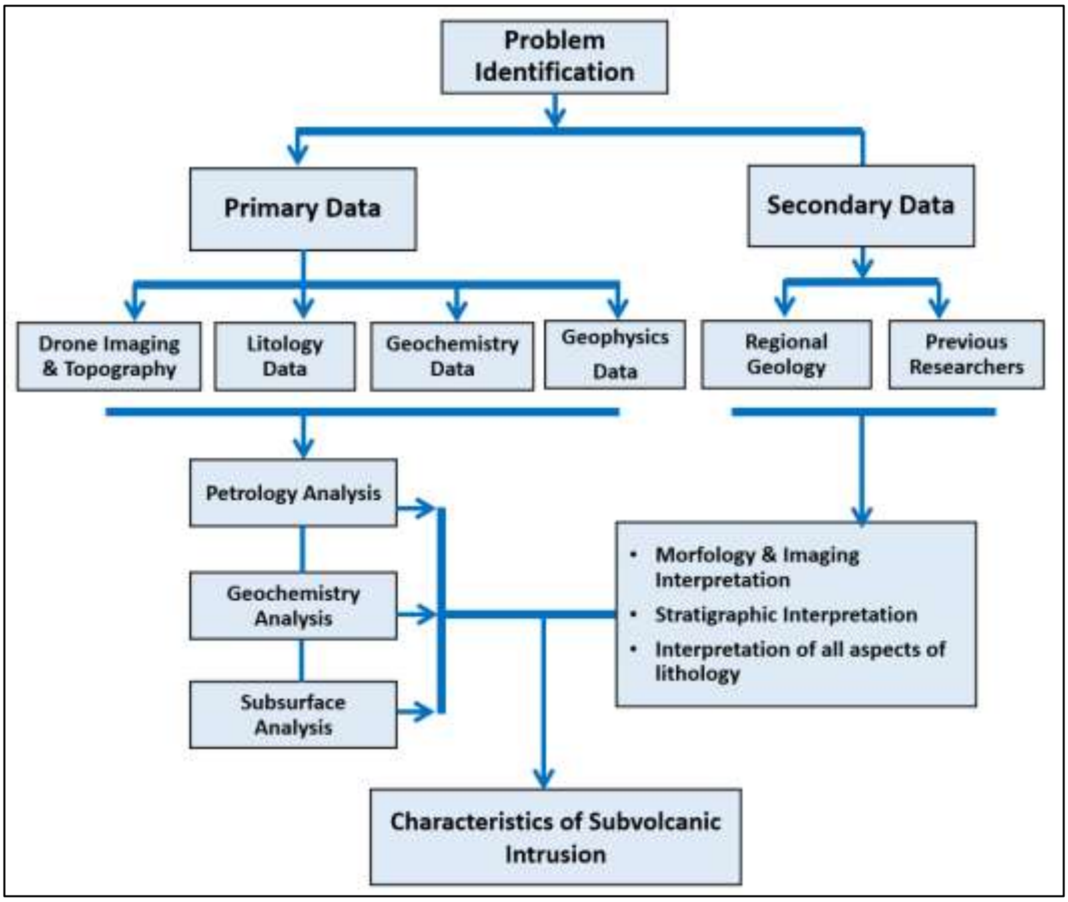

Figure 4. Flowchart flow chart in this research

4. Results and Discussion

Surface image data was collected using drones and then processed to obtain detailed contour patterns with contour intervals of 1 meter. From the detailed topographic map, it appears that Tempel Hill extends to the northeast and is part of Mt. Mujil (Figure 5). This indicates that there is a unity with the rocks that make up Mt. Mujil and its distribution to the northeast (Tempel Hill). Mount Mujil is interpreted as a monogenetic volcano [6] and once erupted weakly and formed a crater opening to the east. The weak eruption correlates with the composition of the rock that composes the crack and fragments of andesite breccia to andesite basalt, and the distance of the ejected material is less than a radius of 5 km. The morphology of the hill that extends to the northeast (Tempel Hill) indicates the presence of resistant lithology as a shallow intrusion, but it is not certain whether the intrusion is a sill or dike.

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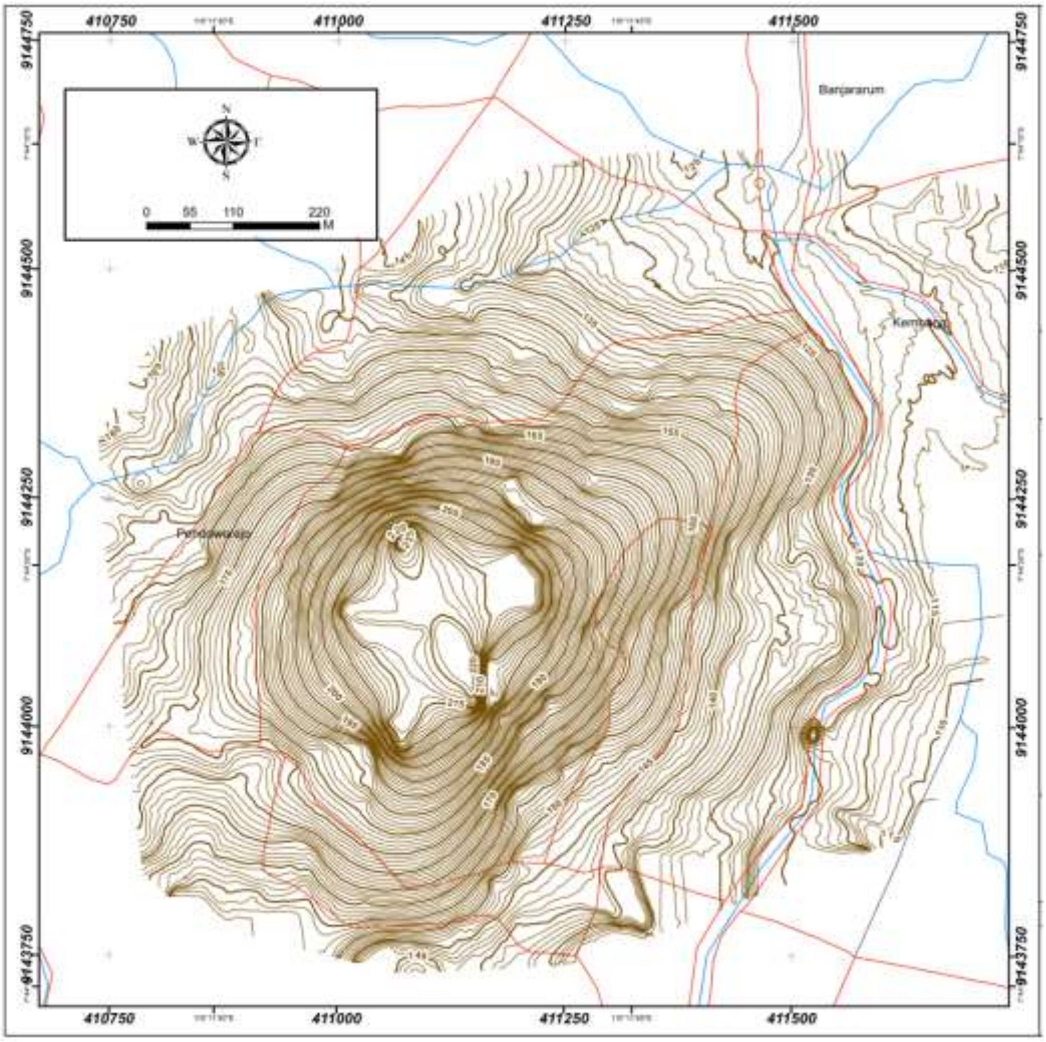

Figure 5. Topographic map of Tempel Hill and its surroundings with contour intervals of 1 meter

Petrological field observations show the distribution of igneous rock, both external igneous rock, igneous rock chunks and indications as shallow intrusion, slightly light gray to dark gray color, fine aphanitic - porphyritic texture, vesicular structure (cracked hole structure). and its distribution surrounds Mt. Mujil and is exposed in an arch that opens to the northeast. In several locations, volcanic bombs were found, with andesite composition, relatively rounded and rough surface shape, developing radial, vesicular and amygdaloidal cooling structures. In particular, the development of vesicular structures indicates the presence of these rocks just below the volcanic crater from which magma erupted. The interesting thing that was discussed at Tempel Hill was that a large collection of igneous rocks was found in situ (Figure 6).

Many igneous rocks are found, mostly in the form of lumps (< 5m). At locations MJ_2 and MJ_3 was dominated by large lumps collected at a hill height and quite coarse textured (fanero porphyritic) with little and or no vesicular. This indicates a shallow intrusive igneous rock (subvolcanic intrusion). At other observation locations (besides MJ_2 and MJ_3), only small lumps were found with textures ranging from porphyry to aphanite, but dominated by aphanite texture, some of which showed the presence of quite a lot of vesicular which indicated it was formed on the surface. The boulders are mostly concentrated or collected in the highest area of Tempel Hill, this indicates that in the sampling area MJ_2 and MJ_3 are intrusive bodies as part of the shallow intrusion of the ancient Mt. Mujil which extends to the Tempel Hill area.

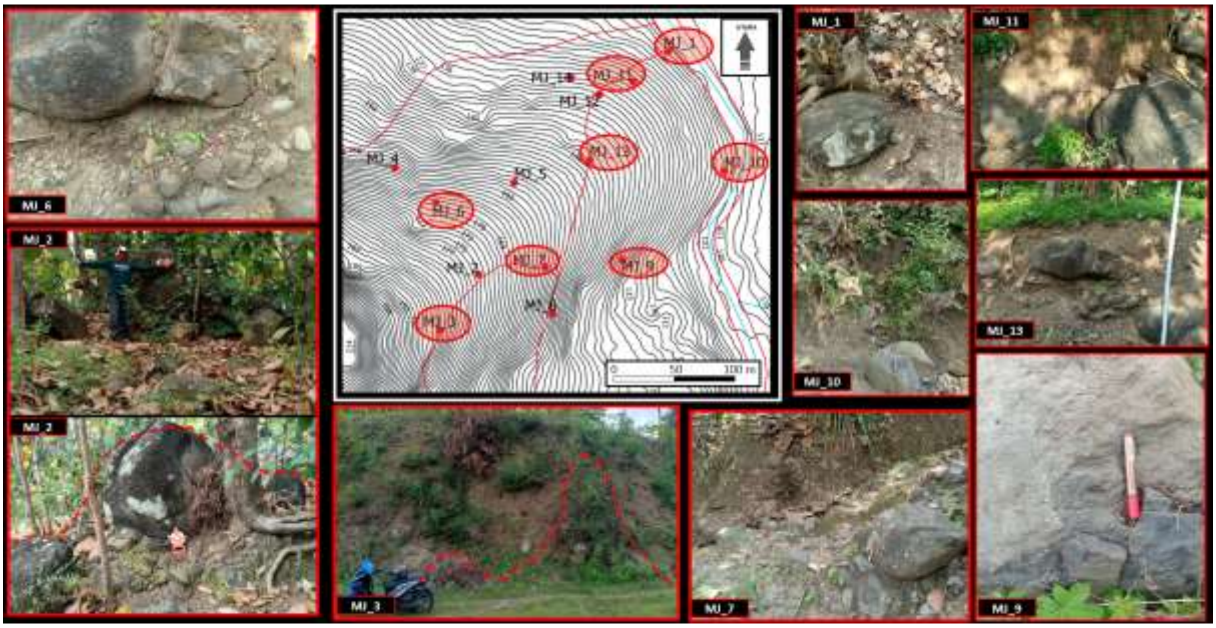

Figure 6. Lithological appearance and condition of the boulders found in the Tempel Hill area.

Petrographic data taken a number of 4 samples of igneous rocks that compose in the study area. At the observation location MJ_2 is the peak area of Tempel Hill which indicates the intrusion body, 2 samples were taken for petrography (Figure 7). Porphyry texture which tends to be holocrystalline indicates intrusive body rock, this is supported by the absence of significant glass and less or no flow effect (trachytic) as a characteristic of lava.

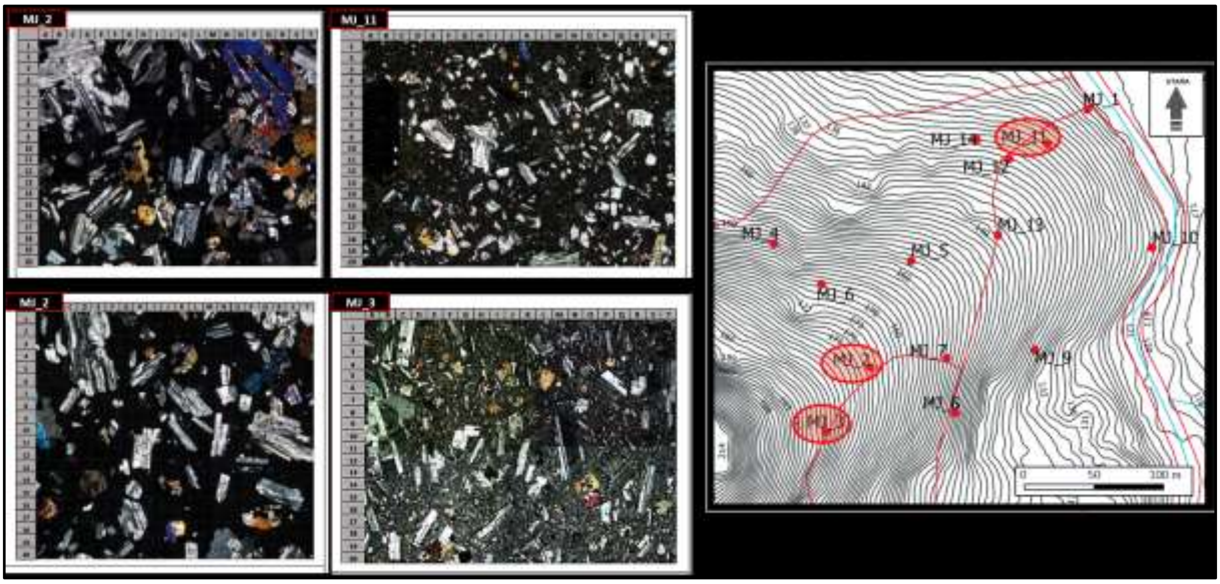

Figure 7. Petrographic results of 4 rock samples show a porphyry texture in the intrusion indication area (MJ_2 & MJ_3) and a fine texture (aphanitic) indicating lava (MJ_11).

Two other petrographic samples were taken at locations MJ_3 and MJ_11. The petrographic appearance shows that the rock types are relatively the same as andesite rocks. An interesting difference is in the texture where the MJ_11 sample which is located far from the indication of the intrusion center has a smoother texture (aphanitic) showing a lot of glass content. In addition, this sample found vesicular either megascopically or microscopically, the vesicular structure indicates the traces of gas expulsion from the lava. This indicates that the igneous rocks in MJ_11 tend to be extrusive igneous rocks found in the form of chunks or lava fragments.

Sampling for geochemical analysis of major oxide elements and trace elements was taken at MJ_2 and MJ_3, sample analysis was carried out at the BATAN Laboratory using the XRF method. The results of the geochemical analysis (Table 1) show that of the 11 major oxide elements analyzed there are LoI (Loss on Ignition) of 0.34 % (MJ_2) and 0.40% (MJ11). In general, the two samples show relatively similar chemical content and refer to intermediate igneous rocks, especially andesite. Based on these geochemical data, it can be used to determine the genesis of igneous rocks concerning tectonic settings and magma origin.

Table 1. Results of geochemical analysis of major oxide elements

Element/ Major Oxide	**Sample**	
	MJ 02 (%)	**MJ 11 (%)**
Fe	6,11	6,19
Fe_2O_3	8,73	8,85
Al_2O_3	20,55	17,99
CaO	8,59	7,20
MgO	3,17	3,74
MnO	0,15	0,17
Cr_2O_3	<0.01	<0.01
Na_2O	1,30	1,65
K_2O	1,17	1,47
TiO_2	0,81	0,68
SiO_2	55,11	57,74
LOI	0,34	0,40
P	0,107	0,115
S	<0.01	<0.01
Ni	<0.01	<0.01
Co	<0.01	<0.01
Total Oxide	100,17	100,15

Based on the results of plotting the analysis of the major oxide elements by comparing the values of SiO_2 with (Na_2O+K_2O) on the TAS (Total Alkali-Silica) diagram [13] (Figure 8) shows that the geochemical analysis of igneous rocks has a columnar joint structure at the research area is andesite type, so from the results of megascopic descriptions and geochemical analysis, the rocks in the research area are andesite porphyry. Based on the composition of SiO_2 magma according to [13], igneous rocks in the research area have intermediate (intermediate) types or properties of magma because the SiO_2 element analyzed is worth 55-57% or can be called andesite. Magma affinity can be known from the results of geochemical data analyzed on igneous rock samples and the type of magma affinity is determined based on the content of the main oxide elements in the rock. Based on the results of the plotting on the SiO_2 vs K_2O diagram [14] (Figure 9) shows that andesite igneous rocks in the research area have a magma affinity that is calc-alkaline series. Magma with an alkali calc affinity interpreted in the table shows that magma in the research area is produced from plate boundaries with destructive type (convergent), which produces volcanic feature island arc or continental margin, with SiO_2 range andesite.

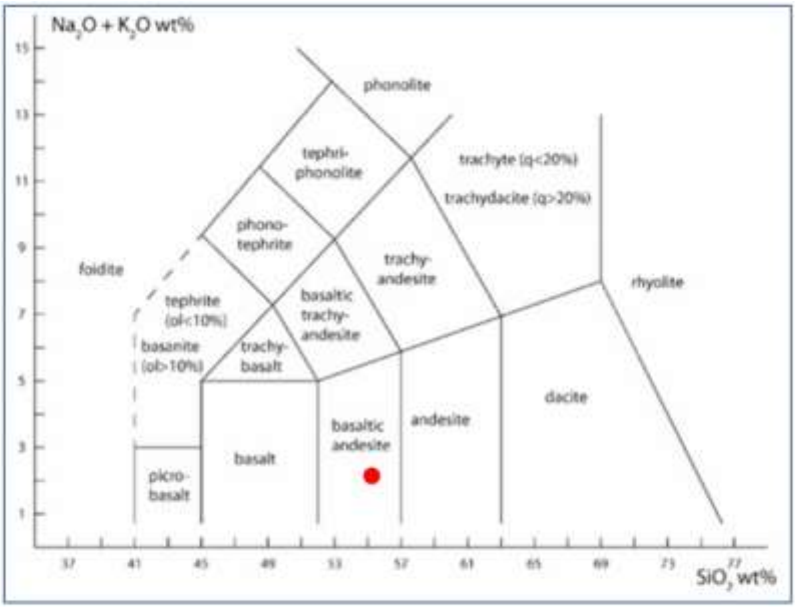

Figure 8. Classification of naming volcanic rocks based on SiO_2 vs. (Na_2O+K_2O) content (Le Bas et al. [13]) shown a red dot.

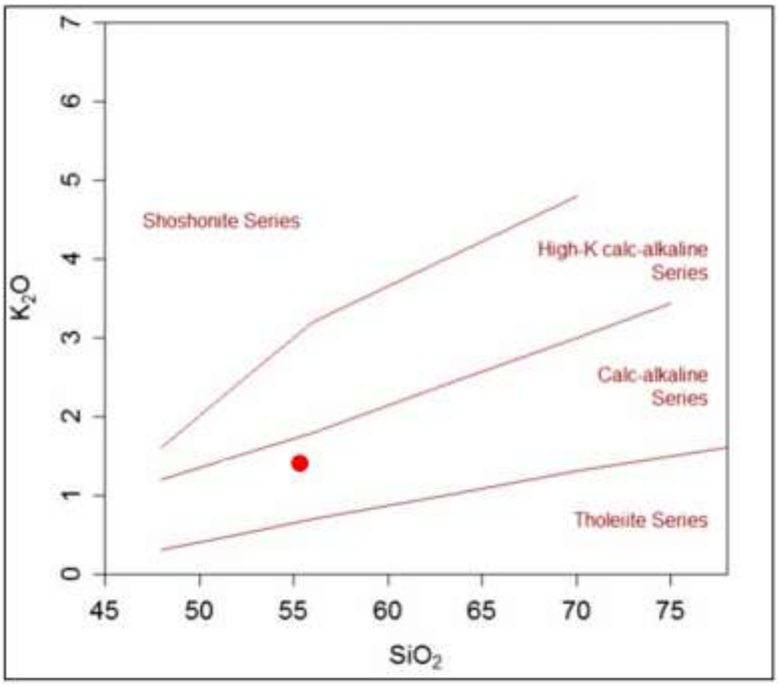

Figure 9. Magma affinity diagram based on SiO_2 vs K_2O (Peccerillo and Taylor [14]) with a sample of MJ_2 shown a red dot.

Geoelectric measurements with a dipole-dipole configuration with a stretch of 200 m, spaced 10 m were carried out on Tempel Hill with an elongated direction to the northeast (Figure 10-15). The B-B' path shows the results of subsurface modeling with a resistivity of around 1 m -100 m which is indicated by dark blue to purple colors. The interpretation of the modeling results on this path is shown in red – purple with a resistivity range of 60 – 100 m, this value is probably colluvium deposits from the Old Andesite Formation. In the area approaching the peak (direction B) shows a weathered rock unit which is possible to still have downward continuity (intrusion).

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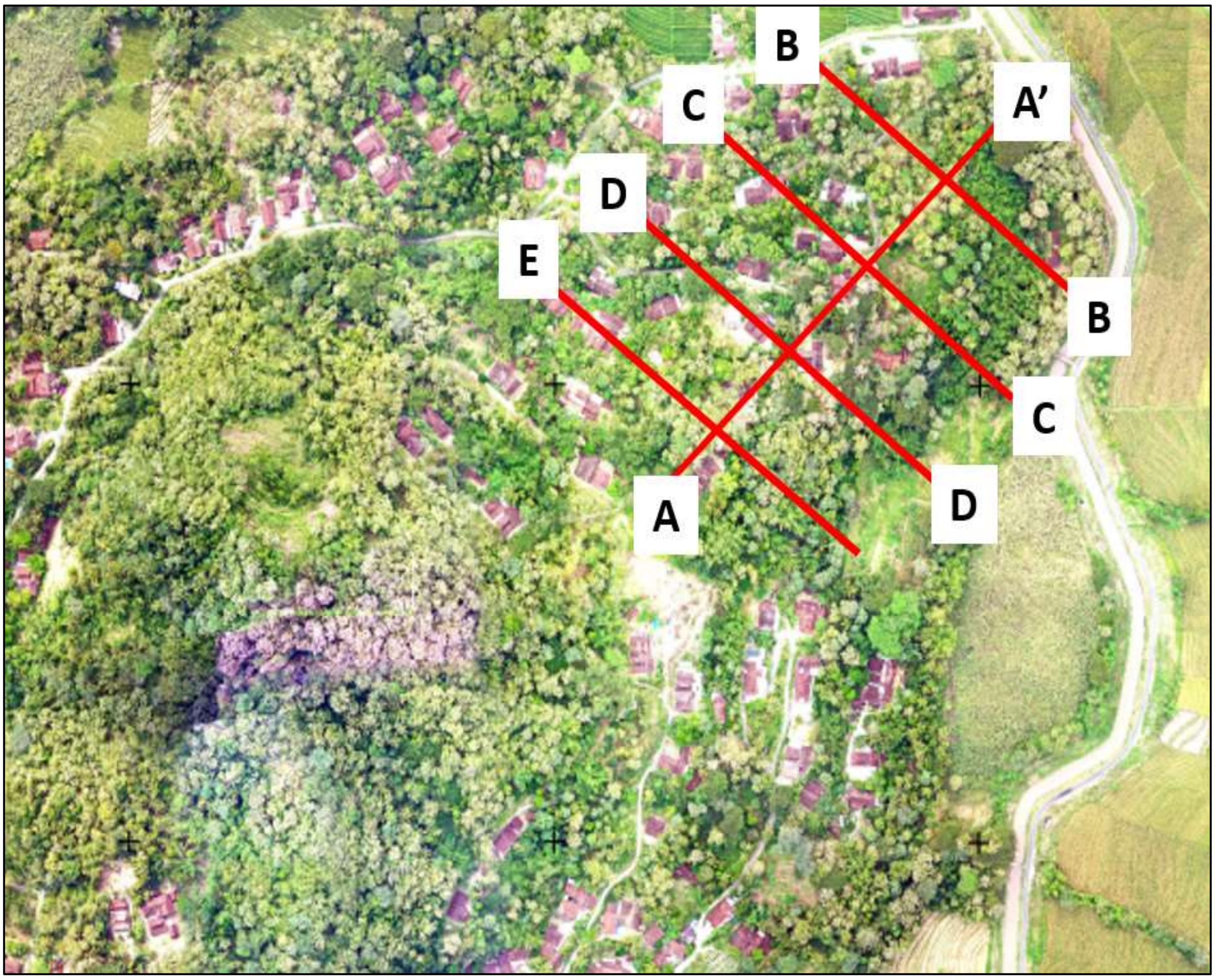

Figure 10. Line resistivity measurement.

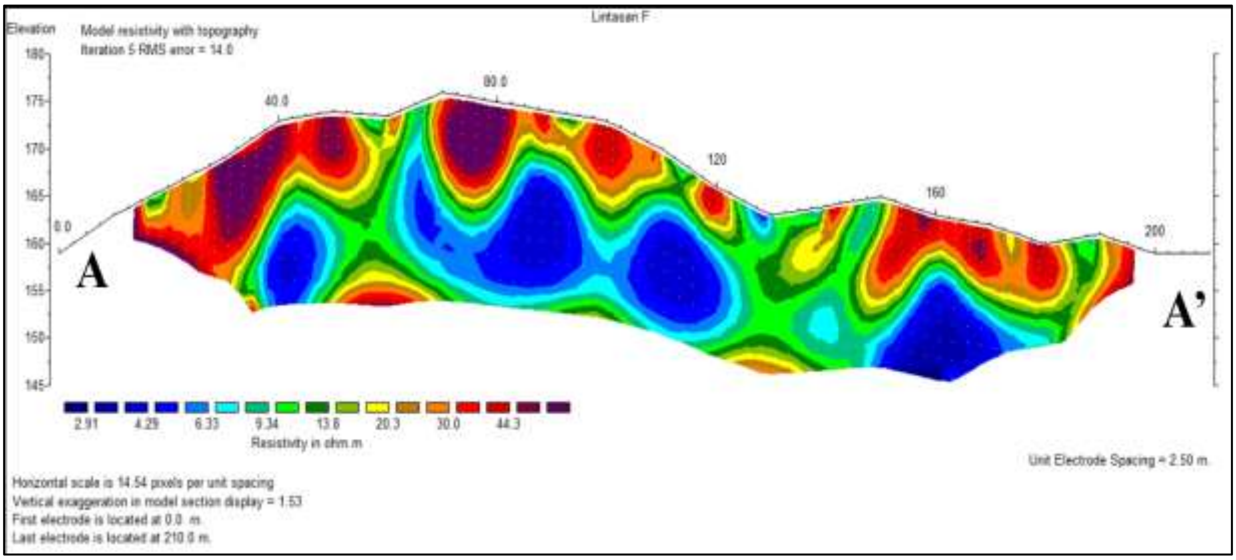

Figure 11. Line measurment A-A’

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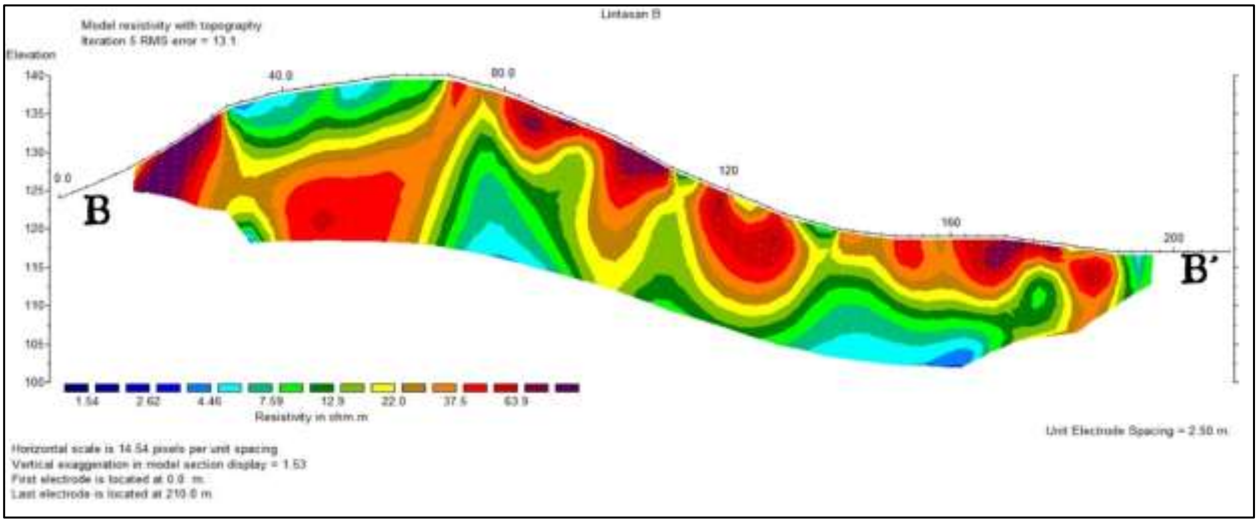

Figure 12. Line measurment B-B’

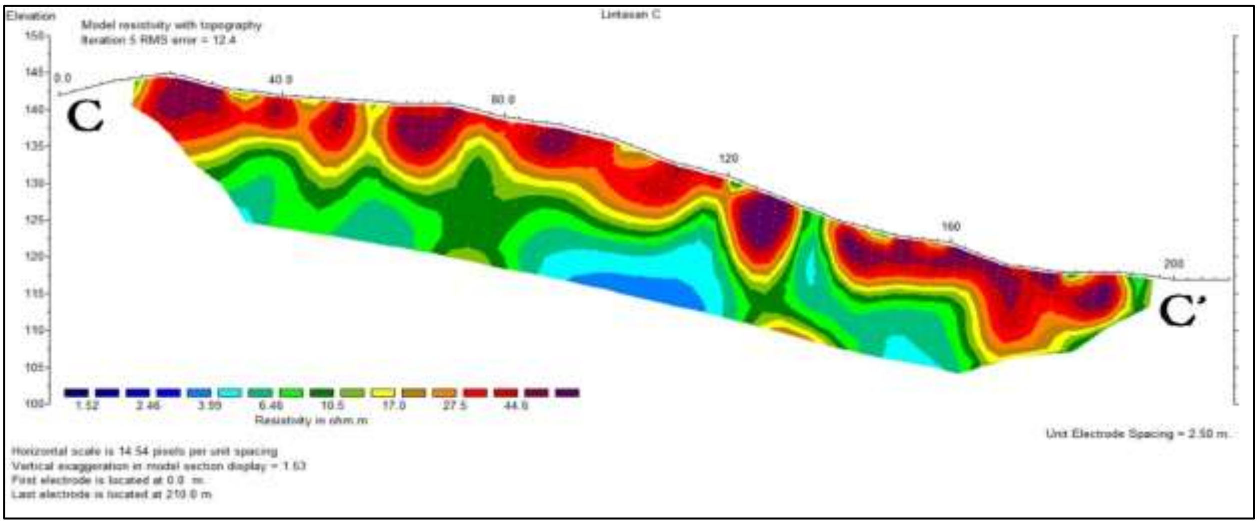

Figure 13. Line measurment C-C’

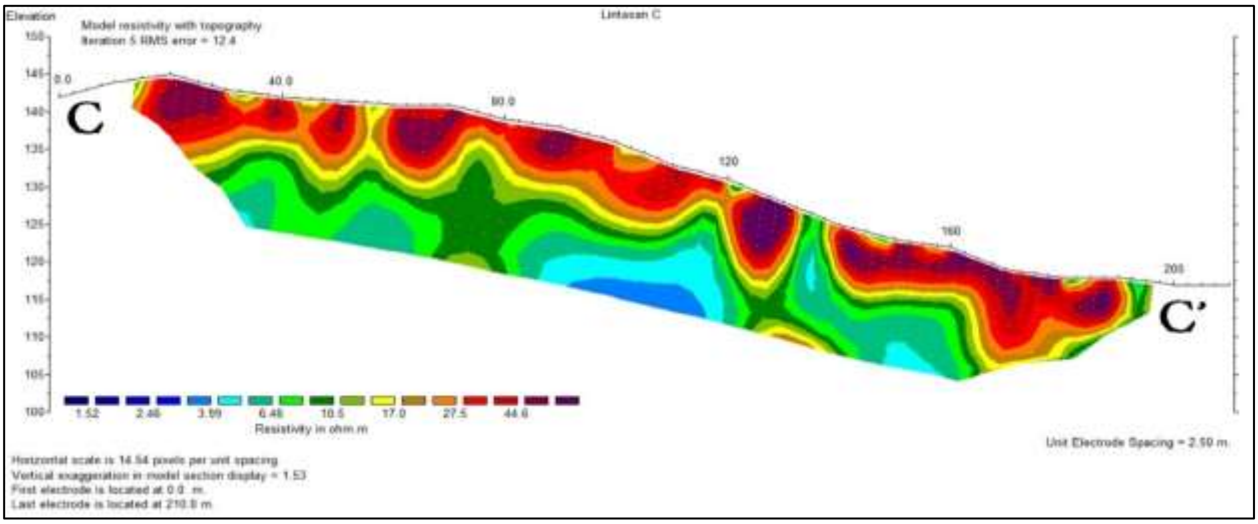

Figure 14. Line measurment D-D’

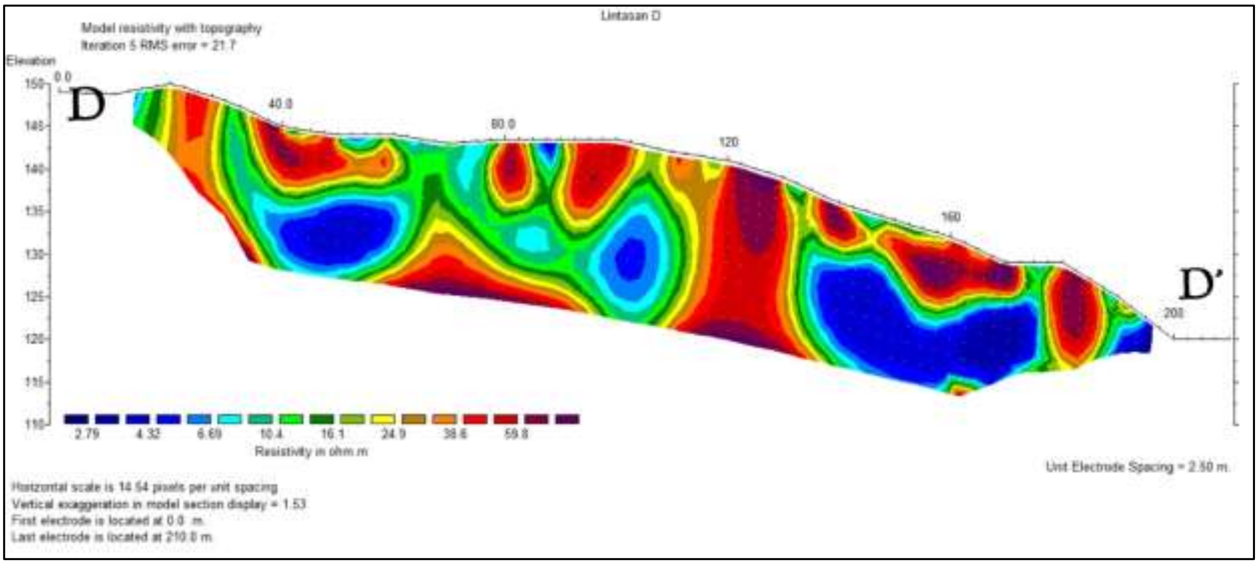

Figure 15. Line measurment E-E’

The C-C' path shows the results of subsurface modeling with resistivity values between 1 m - 70 m which are indicated by dark blue to purple colors. The interpretation of the modeling results in the red – purple trajectory with a resistivity range of 44.6 – 70 m may be the product of weathering of andesite breccia from the Old Andesite Formation. The D-D' path shows subsurface modeling results similar to the B-B' path with resistivity between 1 m - 100 m and is indicated by dark blue to purple colors. The interpretation results of the modeling with a resistivity range of 59.8 – 100 m may be colluvium deposits from the Old Andesite Formation. The red color in the middle of the track indicates the mass of weathered rock units that are likely to continue downwards which indicates an intrusion.

The path E-E' shows subsurface modeling results that are similar to paths B-B' and D-D' with a resistivity of around 1 m - 100 m and is shown in dark blue to purple. The interpretation of the modeling results on this path in red – purple color with a resistivity range of 65 – 100 m may be colluvium deposits from the Old Andesite Formation. Path F-F' is a path that intersects all paths that show results similar to paths C-C'. Resistivity measurements show the results of subsurface modeling with a resistivity of around 1 m - 70 m displayed in dark blue to purple. The interpretation of the modeling results on this trajectory, the red – purple color with a resistivity range of 44.6 – 70 m may be the product of weathering of andesite breccia from the Old Andesite Formation. The red color (near F) that continues from top to bottom indicates a weathered intrusion and may continue downwards.

On the other opinion, the existence of Mount Tempel, which represents part of Mount Mujil, is part of Kulon Progo's tourism power. The existence of YIA airport is a support for the rapid development of Kulonprogo tourism, the better and more access to the research area at this time makes residents start to build several shops around the research area. The view of Mount Tempel which looks like an isolated hill is quite attractive for tourists, both in terms of tourism and geological education. With this research, it is hoped that there will be educational tours in the Kulonprogo area specifically for Mount Tempel which is part of Mount Mujil.

5. Conclusion

Tempel Hill is composed by volcanic rocks in the form of volcanic breccia andesite intrusion. Magmatism activity 42.73 ± 9.78 to 15.30 ± 0.88 million years ago (Late Eocene – Early Myocene) produced the shallow intrusion rocks of Tempel Hill. Based on field and laboratory research, in the research area found indications of an intrusion on Bukit Tempel which is part of Mount Mujil.The existence of indications of intrusion is supported by andesite chunk data collected and concentrated at the highest point of Bukit Tempel. Other data that supports petrography data that shows the texture of porphyry that tends to be holocrystalline. This indicates in the form of an intrusive body that is strengthened by the absence of glass with a significant amount. The absence of flow texture (trachytic) increasingly indicates that the igneous rocks found are intrusions, not lava. Geochemical data show rocks in andesite-type research areas with an affinity for alkaline calk associated with plate subduction products forming island arcs. Based on the results of geoelectric interpretations of the polished-polished configuration, it is possible that the uppermost Tempel Hill is the result of intrusion. The view of Mount Tempel is an additional attraction for Kulonprogo tourism and can support the improvement of the local economy.

Acknowledgements
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