Geothermal Resource Estimation of Ulubelu Area Based on Volcanostratigraphic Studies

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Abstract. The Ulubelu Geothermal Area is a Geothermal Working Area owned by PT. Pertamina Geothermal Energy (PGE), situated in Tanggamus Regency, Lampung Province. A scientific study is required to elucidate the correlation between volcanism in the Ulubelu area and the development of its geothermal system, in order to assess the geothermal potential of the region. Topographic maps at scales of 1:100,000 and 1:50,000. The study aims to ascertain the volcanic characteristic characteristics of Ulubelu, with volume as the primary data and geological structural patterns, volcanic age, and magma evolution as secondary data. The Randingan caldera in Ulubelu possesses a volcanic volume of 120 km³, signifying a sufficiently massive magma chamber serving as a heat source (Q=1.9x10^15 J). The most recent volcanism is 200,000 years old, which is within the optimal age range for the development of a mature geothermal system. The geological structure exhibits homogeneity, with a radial distribution of vents directed towards the summit of the Randingan dome. Considering these attributes, it is plausible to conclude that the Ulubelu Geothermal Area possesses significant geothermal potential for investigation and development.

Keywords: *geothermal system, randingan, ulubelu, volcanostratigraphy*

1 Introduction

The Ulubelu geothermal region is situated in Tanggamus Regency, Lampung Province. This site is 80 kilometers (2 hours by land) from Tanjungkarang. This area exhibits geothermal potential, indicated by hot springs, fumaroles, mud pools, and hydrothermal alteration zones. Magmatic activity facilitates the development of geothermal systems by heating water at depth, leading to the presence of hot fluids in the reservoir. High temperature geothermal systems can be found above subduction zones, along volcanic zones of mid-ocean ridges, and in areas with melting anomalies inside plates, according to Sumintadireja (2005) in [1]. Magma hydrothermal systems predominantly develop near the boundaries of tectonic plates in motion.

The volcanism in the region is defined by volcanic centers aligned in a northwest-southeast orientation along the southeastern extremity of the Sumatra Fault Zone.

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The volcanic rocks originate from a circumscribed array of volcanoes comprising Mt. Tanggamus, Mt. Kabawok, Mt. Kukusan, Mt. Sulah, Mt. Rendingan, and Mt. Kurupan, with Mt. Duduk positioned centrally. The area is situated amid challenging topography at elevations ranging from 300 to 1600 meters above sea level, while the peak of Mt. Rendingan approaches 1700 meters. The minimum elevation, approximately 300 to 400 meters, is located in the southern portion of the region, south of Mt. Kukusan. Mount Kabawok, Kurupan, Rendingan, Sulah, and Kukusan constitute the tallest volcanic terrains in the central region, with altitudes ranging from 700 to 800 meters above sea level.

The volcanism in the field manifests through volcanic foci arranged in a NW-SE orientation along the southeastern terminus of the Sumatra Fault Zone. The volcanic rocks originate from a circlet of volcanoes, including Mts. Tanggamus, Kabawok, Waypanas, Kukusan, Sulah, Rendingan, and Kurupan, with Mt. Duduk at the center. The area is situated in rugged terrain ranging from 300 m to 1600 m above sea level, with the peak of Mt. Rendingan nearing 1700 m. The lowest elevation, around 300 to 400 meters, is situated in the southern section of the area, south of Mt. Kukusan. The middle region features heights ranging from 700 to 800 meters above sea level, including the prominent volcanic terrains of Mts. Kabawok, Kurupan, Rendingan, Sula, and Kukusan.

To comprehend the correlation between volcanic activity in Ulubelu and the configuration of its geothermal system, it is essential to undertake a volcanostratigraphic study to elucidate the volcanic characteristics of the Ulubelu region, thereby providing technical data for geothermal development in the area. Davis (1973, in Wohletz & Heiken, 1992 [2]) states that there are several geological data that can be analyzed to determine the relationship between the volcanic characteristics of a volcano and the form of a geothermal system. This data encompasses the investigation of topography and distribution of volcanic stratigraphic units, geological structural patterns, relative rock ages, geothermal manifestation distribution, and geochemical data analysis.

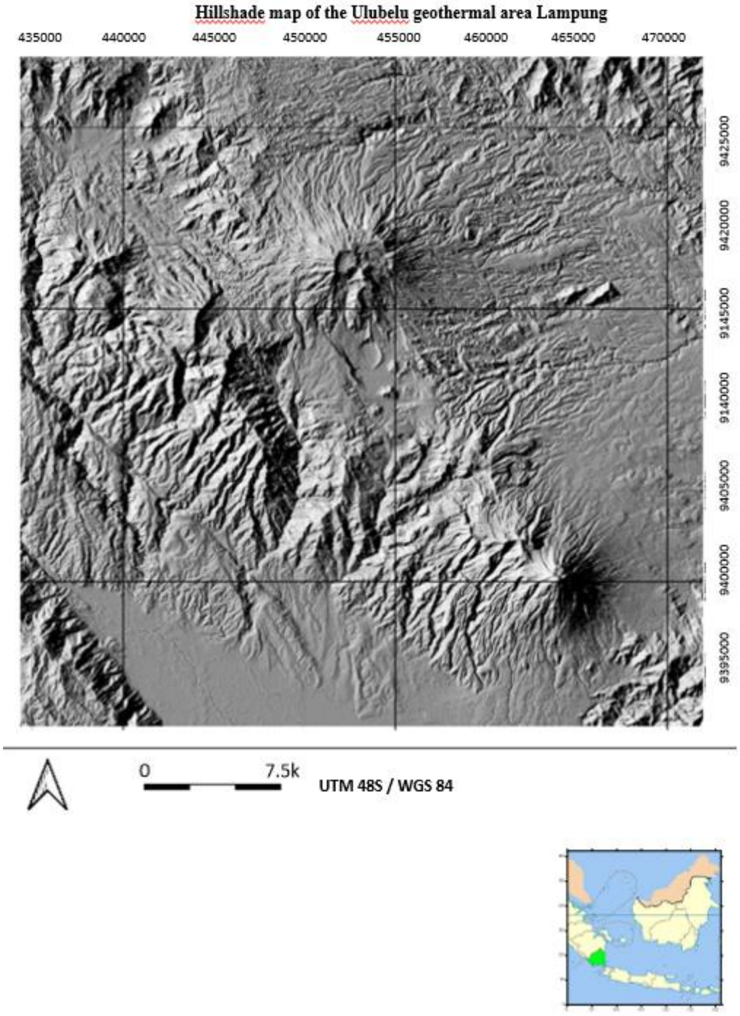


Figure 1 Location Map of the Ulubelu Geothermal Area

2 Methodology

The methodology used in this study includes a volcano stratigraphic study to determine the volcanic characteristics of the Ulubelu area, following the concept of geothermal exploration based on Wohletz & Heiken (1992) in [2] as presented in Figure 2.

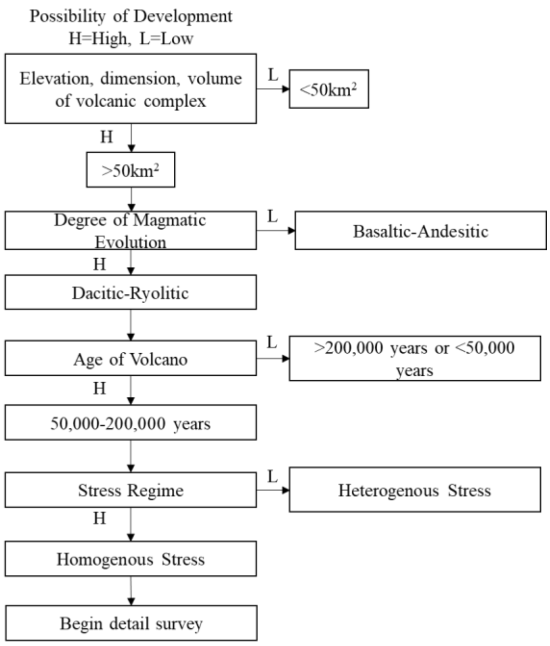


Figure 2 Geothermal potential exploration and evaluation concept flow (modification from Wohletz & Heiken, 1992 [2])

Figure 2 delineates the principal attributes of volcanoes, including the distribution of volcanic rocks according to eruption source, volcano dimensions, evolution of magma composition, age of volcanism, and geological structure construction. The study was undertaken via identifying the parameters of the Ulubelu's region volcanic features, which comprised the distribution of volcanic rocks, the volume and pattern of geological structures as primary data, and the age of volcanism and magma history as secondary data.

The distribution of volcanic rocks is established by recognizing stratigraphic units that correspond to formations, including crowns, and smaller units, such as hummocks (Alessandro et al., 2013 in [3]). As per the 1996 Indonesian Stratigraphic Code in [4]. A volcanic crown is an assemblage of rocks and sediments generated by one or more eruption sites that constitute a volcanic structure, while a volcanic hummock is a segment of the crown developed due to an eruption on the volcano's edifice, whether from central or lateral eruptions. The crown and hummock were delineated utilizing Indonesian Topographic maps (RBI) at scales of 1:100,000 and 1:50,000.

The initial stage in outlining a volcanic stratigraphic unit is to locate the tallest point, which is identified by a circular structure suggesting a crater, caldera, or crater depression, in order to pinpoint the site of the main and secondary eruptions. The eruption center must be identified to assess the dispersion of each eruption product. An analysis of the river flow pattern was conducted on the topographical features leading to the eruption core. This is conducted to obtain an overview of the structural patterns that arise in the studied area through morphological analysis. Following the analysis of the river's flow pattern, the ridge's lineament is assessed, as indicated by the topographical pattern radiating from the eruption center, to ascertain the morphology of the hills. This work identifies the crown by analyzing the contour patterns of large volcanic cones. The hummock unit is defined by the contour pattern of the little volcanic cone situated around the crown. The crown and hummock populations identified are delineated by volcanostratigraphic boundaries; especially, when the ridge and river flow populations exhibit a radial pattern, they are presumed to have a same origin (Van Zuidam, 1985 in [5]).

The evaluation of Ulubelu's geothermal resources and development potential was conducted utilizing the framework first suggested by Wohletz and Heiken (1992 in [2]). The methodology utilizes a flowchart, wherein several geological and physical parameters operate as decision-making constraints. In the case of Ulubelu, a simple assumption was made regarding its conical shape, allowing for a rough estimation of its volume as follows:

Vvol = 1/3 x A x h (1)

Table 1 Parameters of volcanic maturity level (modification from Wohletz & Heiken, 1992 in [2])

Parameter	Degree of Volcanic Maturity		
	Immature	Submature	Mature
Magma type	Mafic	Mafic-intermediate	Intermediate-Felsic
Vent Distribution	Along Fissures	Along fissures and/or a few central vents	Central and parasitic vents
Volcano Types	Cinder cone, tuff cone (monogenetic cones)	A group of cones within a volcanic complex, stratovolcanoes, lava domes	Stratovolcano, and cone complex, lava domes, caldera
Eruption Types	Strombolian, Vulcanian	Vulcanian, Pelean	Plinian, ultraplinian

The degree of magma evolution is assessed using geological maps of various rock types, whereas the degree of maturity (Table 1) is determined using magma evolution and volcanostratigraphic analysis. By assuming that the Ulubelu volcanic complex is entirely composed of layers of volcanic product in equal proportions (50% pyroclastics and 50% lava), and that the eruptive volume represents about 10% of the total magma chamber volume (Smith and Shaw, 1979 cited by Wohletz and Heiken in [2]), the resource base estimation of magmatic thermal energy contained within the magma chamber could be calculated using the following procedures:

Vdre Py = 0.6 x 0.5 x Vvol (2)

Vdre lava = 0.5 x Vvolc (3)

Q = rho x (Vdre py + Vdre lava) x 10 x H (4)

Where Q is the thermal energy (J), Vdre is the Dense Rock Equivalent, which is the equivalent rock volume if all the pore spaces within the rocks are replaced with the solid portion (Wilson dan Parfitt, 2008 in [6]), rho and H are the density (kg/m^3) and magmatic heat content (kJ/kg). Py is pyroclastics and lava is lava.

3 Geology of Ulubelu

The Ulubelu Geothermal Field represents a significant geothermal system linked to the Great Sumatran Fault's presence. The location (Fig. 3) is situated in the southern region of the Sumatra fault, encircled by various volcanoes including Sula Mountain to the west, Kurupan Mountain to the east, Rendingan Mountain to the north, Duduk Mountain centrally, and Kukusan Mountain to the south. Geological structures are characterized by prominent NW-SE normal faults, with a prevailing orientation of NW-SE, alongside some formations exhibiting a NESW direction. These structures create a NW-SE Graben that stretches in the NW-SE orientation. The NW-SE trending structure is also subparallel with the Great Sumatran Fault that is located in the southwestern part of the field. The circular structure located at the center of the depression zone developed as a component of the permeable zone in this field. The NWSE and NE-SW structures significantly influence the distribution of manifestations observed in the western and southern areas of the field.

The lithology of the Ulubelu geothermal field consists of Tertiary and Quaternary rocks. The Tertiary is composed of Miocene and Pliocene volcanic rocks, while the Quaternary includes Pleistocene and Holocene volcanic deposits. The Miocene succession includes the Hulusimpang Formations (Tomh) and granodiorite (Tmgr), which are extensively distributed beneath the Kabawok pyroclastics (Figure 3). The Hulusimpang Formation (Tomh) dates back approximately 19-20 Ma (Amin et al., 1994 in [7]) and is suggested to serve as a local basement in this region (refer to Figure 1). A granodiorite intrusion (Tmgr) dates back approximately 14.7 million years (Masdjuk, 1997 in [8]). The Pliocene succession includes the Mt. Sulah andesite lavas (Tpsv) dated at 4.5 Ma, the Mt. Kukusan basaltic andesite lavas (Tpkv) at 3.9 Ma, and the Mt. Duduk dacite lavas (Tpdv), also at 3.9 Ma. These are found in the western and central regions.

The Pleistocene succession is widespread within half of the study area and to the north and northwest. It consists of the Mt. Kabawok pyroclastics (Qhkbp), Mt. Tanggamus laharic breccia (Qhtb), Mt. Tanggamus andesite lavas (Qhrv), Mt. Randingan pyroclastics (Qhrp Andesitic lavas from Mt. Randingan (Qhrv), dacite tuff (Qhdt), and rhyolitic lavas from Mt. Kurupan (Qhkp). The pumiceous tuffs of the Ranau Formation (QTr) likely date back to the Pleistocene to Holocene period. The Holocene deposits are found in the southwestern region of the area, as evidenced by the extensive presence of alluvium (Qa).

Carbon dating of modified rocks suggests that certain alterations took place as recently as 2000-3000 years ago. An altered dike intersecting altered rocks in UBL-1 and UBL-2 has been dated between 0.23 and 0.56 million years ago, indicating that hydrothermal alteration has taken place over hundreds of thousands of years. Numerous formations in UBL-1 and UBL-2 exhibited signs of hydrothermal alteration. This suggests that a significant heat source is or has been located in the area.

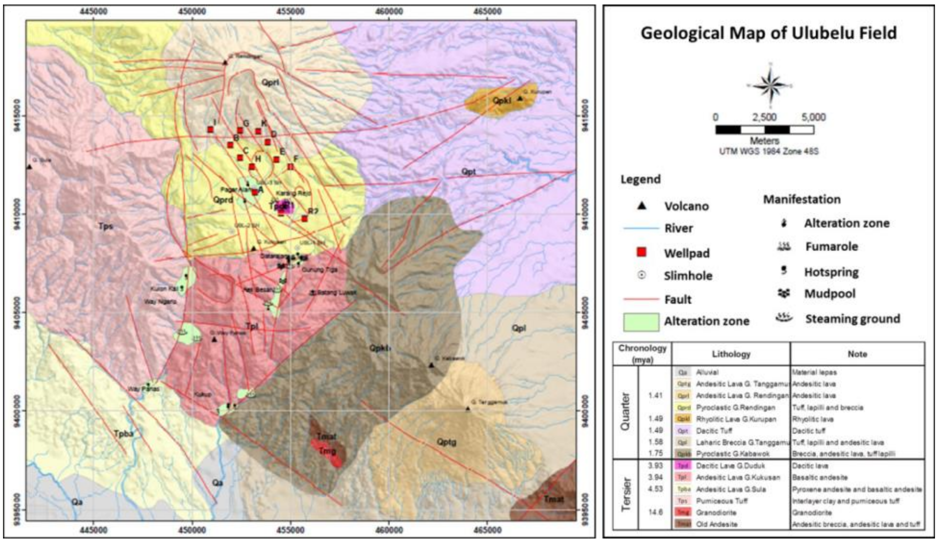


Figure 3 Geological Map of Ulubelu – Waypanas Geothermal Prospect (Mulyanto et all, 2015 in [9]).

4 Result and Discussion

The volcanostratigraphic analysis conducted on the sheet topographic map of Kota agung and its surroundings at a scale of 1:100,000 reveals that the Ulubelu geothermal area consists of seven distinct crowns: the Agas crown, the Gucung crown, the Kukusan crown, the Kabawok crown, the Pelangi Valley crown, the Randingan crown, and the Tanggamus crown. Additionally, there is one hummock located within the Randingan crown, referred to as hummock Kurupan (picture 4). The Ulubelu area features numerous crowns, each signifying the center of an eruption, indicating the presence of a sufficiently large magma chamber that serves as a heat source for the Ulubelu geothermal region.

The results of the interpretation were subsequently compared with the geological map of the Ulubelu region as published by Mulyanto et al. in 2015 [9]. The interpreted boundaries of the volcanostratigraphic units show a notable alignment with the distribution of volcanic lithological units. This suggests a relationship between the distribution of eruption products and the morphology of the Ulubelu geothermal field. The correlation results in the volcanostratigraphy map presented in Figure 5.

A comprehensive analysis was conducted on a topographic map of Kota agung and its surrounding areas, presented at a scale of 1:50,000. The analysis yielded a volcanostratigraphic map of the Ulubelu area and its surroundings, leading to the identification of several additional crowns, including Hotupan, Sardang, Waingingi, Way Panas, Tiga, Sulah, and Haraberak (Figure 6).

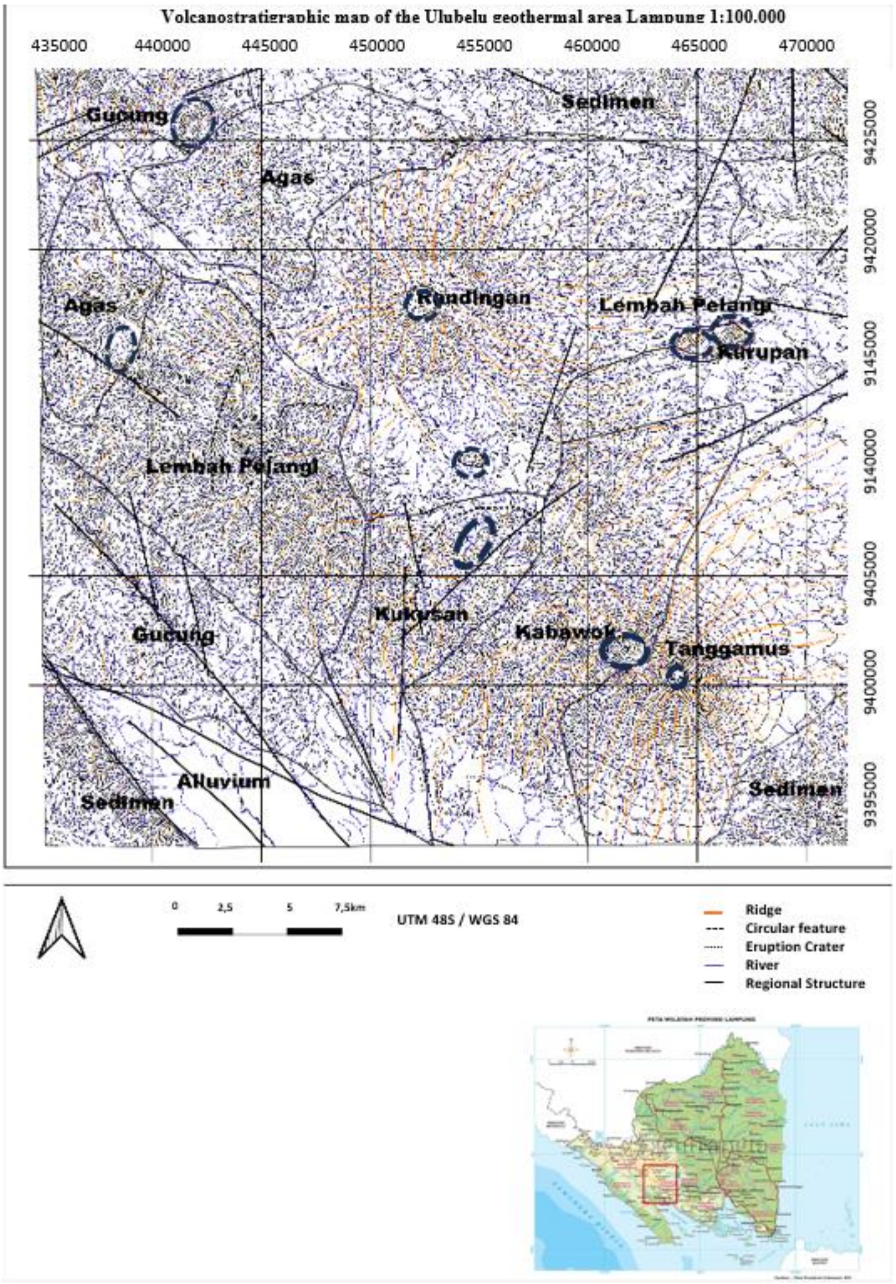


Figure 4 Distribution of volcanostratigraphic units and their boundaries based on morphological analysis using the scale 1:100000 topographic map of Kota Agung region.

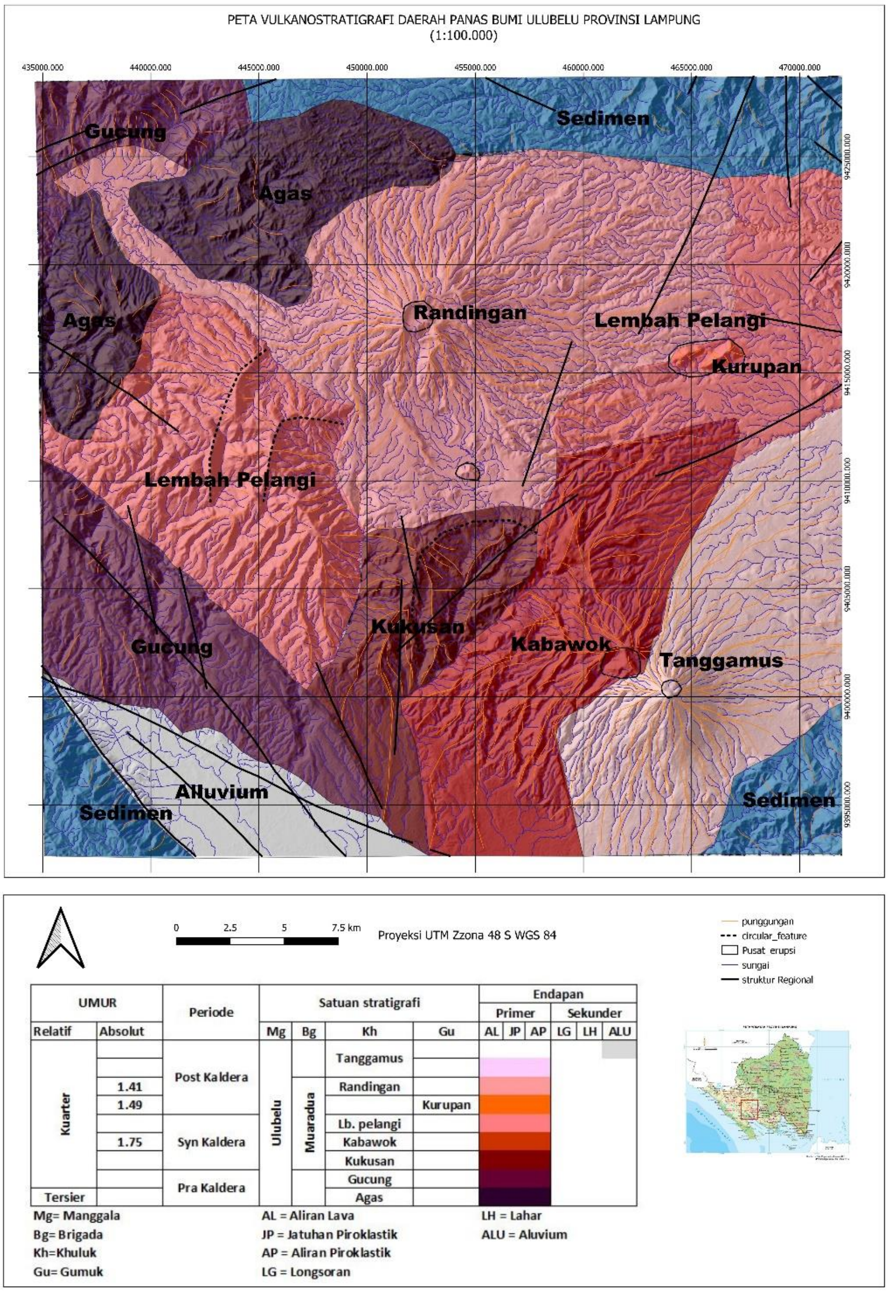
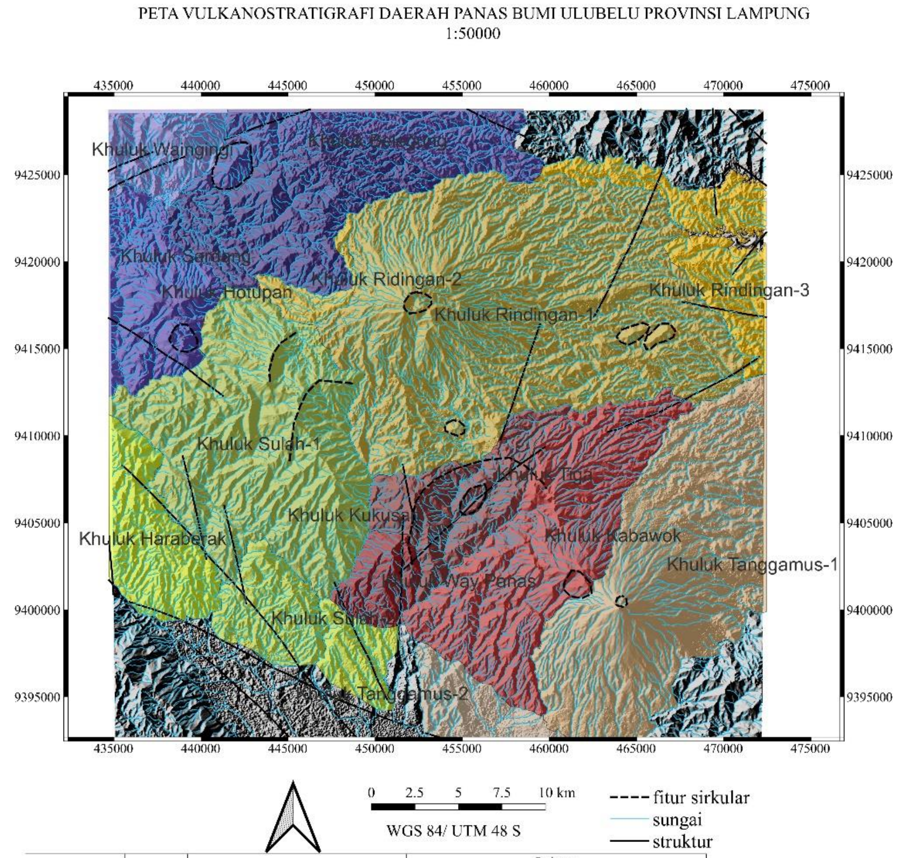


Figure 5 Volcanostratigraphic map of the 1:100,000 scale of the Ulubelu geothermal area



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							Primer			Sekunder		
Relatif	Absolut		Mg	Bg	Kh	Gu	AL	JP	AP	LG	LH	ALU
Kuarter		Post Kaldera	Ulubelu		Tanggamus 2							
					Tanggamus 1							
	1.41				Rindingan 3							
					Rindingan 2							
	1.49				Rindingan 1	Kurupan						
		Syn Kaldera			Haraberak							
					Sulah 3							
					Sulah 2							
					Sulah 1							
					Tiga							
	1.75				Kabawok							
					Way panas							
					Kukusan							
		Pra Kaldera			Waingingi							
					Sardang							
					Hotupan							
					Gucung							
Tersier					Agas							

Mg= Manggala
Bg= Brigada
Kh=Khuluk
Gu= Gumuk
AL = Aliran Lava
JP = Jatuhan Piroklastik
AP = Aliran Piroklastik

Figure 6 Volcanostratigraphic map of the 1:50,000 scale of the Ulubelu geothermal area

Through the examination of this map, combined with regional geological maps and supported by DEM SRTM imagery, it is evident that the volcanoes maintaining a relatively intact conical shape, characterized by a circular structure, are the Randingan crown and the Tanggamus crown. The smooth morphology indicates a level of erosion that has not been intensive, with the pattern of river flow still clearly visible radially towards the peak. A volcano exhibiting a well-defined conical shape, characterized by a circular structure that creates a crater or caldera at its summit, suggests the presence of a magma chamber beneath. This chamber may possess the necessary heat to establish a geothermal system (Nandhiwardhana, 2020 in [10]).

Mulyadi (2000) in [11] indicates that the heat source of the Ulubelu geothermal field could be attributed to intrusive bodies located beneath Mt. Rindingan in the northern region and/or Mt. Kukusan in the southern region of the area. Consequently, the subsequent analysis and discussion will focus exclusively on crown Randingan. The results of the Crown Randingan delineation show that the crown area is 275 km2, with the highest peak elevation of 1600 masl, and the lowest elevation of 300 masl. Using these parameters, the size or volume of the crown is calculated to be approximately 120 km3, as derived from equation (1).

Given that the eruption products of Randingan Crown are primarily of andesitic composition, a density value of 2400 kg/m3 was applied (Telford et al., 1990 in [12]), while the heat content for a relatively young magmatic body is 800 kJ/kg, as noted by Wohletz and Heiken (1992) in [2]. The calculation procedure utilizing equations (2) to (4) provides an estimate of the thermal energy contained within the Randingan Crown magma chamber, approximately 1.9 x 10^15 Joules. This is certainly overestimated, since all the parameters and assumptions used were derived only from the morphology of the volcano as well as the results obtained from previous studies. Furthermore, it is essential to recognize that the calculation model failed to incorporate the influence of magmatic recharge within the volcano’s magma chamber before previous eruption cycles. Nonetheless, the findings indicate a fairly strong alignment with the thermal energy estimates of basic magmatic structures, with volumes between 1 and 6 km3, as reported by Wohletz and Heiken (1992) in [2], which are approximately ~1018 Joule.

The dominant orientation of faults crossing the volcanic edifice NESW and NW-SE (Mulyanto et all, 2015) in [9]. The radial configuration of rivers and ridges converges towards the volcanic vents. The overall stress regime of the Randingan crown volcanic edifice is interpreted as homogeneous. Based on the information presented in Table 1, the volcano can be classified as being in a submature to mature stage. The andesitic volcanic rocks of Randingan crown indicate that the volcano has undergone a limited degree of magmatic evolution.

5 Conclusion

The analysis of topographic maps at scales of 1:100,000 and 1:50,000 reveals the existence of multiple volcanic units characterized by eruption centers that appear as crowns and hummocks. The arrangement of these volcanic units exhibits parallels with the volcanic rock distribution depicted on the geological map, indicating a strong correlation between the eruption products and the surrounding morphology of the Ulubelu geothermal area. The main eruption center of this area is around the crown of Randingan and crown of Tanggamus. Consequently, these two crowns may signify the existence of a magma chamber, which could serve as the primary heat source for the Ulubelu geothermal system. According to the flowchart presented in Figure 1, the crown Randingan exhibits dimensions exceeding 50 km3, dates back 200,000 years, and is characterized by a homogeneous stress regime. These factors indicate a strong potential for geothermal exploration and development in the Ulubelu area. Despite having a medium level of magma evolution (andesitic), the estimated heat energy stored in the magma is substantial (1.9 x10^15J). Additionally, the presence of significant geothermal manifestations in the area suggests that crown Randingan falls into the mature category.

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