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Pieces of Evidence of Tectonically Dissected Caldera Setting that control the Ulubelu-Waypanas Geothermal System

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ABSTRACT

Ulubelu-Waypanas geothermal prospect is located in the southernmost Province of Sumatera Island, Lampung Province. It consists of a tertiary to quaternary volcanic complex and a prominent depression structure along an NW-SE trend axis. Several authors have described the field-geologic situation as volcano-tectonic depression (Trianggo et al., 2015), strongly influenced by overlapping NW-SE parallel to Sumatera Fault System (Husein et al., 2015). Siahaan et al. (2015) identified that the geological framework of Ulubelu lies in lineament patterns, fault segments, collapse structure, and circular features from Radar and Imagery Landsat study.

This paper describes the geothermal field setting based on recent findings from geological field mapping, borehole data of wells inside Ulubelu-Waypanas, and gravity data. A recent study found strong evidence of the Caldera environment in the vicinity of the Ulubelu-Waypanas Geothermal System. An advanced remote sensing map initially identified the field's semi-circular collapse structure from the west to the south. Clarification was made by visiting the caldera wall to find evidence of such volcanic structure existence, and subsurface data from wells inside the Ulubelu depression was also evaluated to support the study. Furthermore, The Geophysical survey was deployed to investigate the caldera structure using the gravity method.

The result of the joint study reveals that there is strong evidence of caldera structure in the area. It also displays strong post-caldera tectonic activity. Major faults and systematic joints inside the caldera are well recorded in the morphology and the surface outcrops, respectively. The caldera itself is named in the volcano-stratigraphical Units as Sula Volcanic. It is described in a geological map by Masdjuk (1997) composed of andesitic composition and Tertiary age (4.5 mya). The gravity residual anomaly map depicts the caldera wall as a circular higher anomaly, enclosing the graben's lower residual anomaly inside. The volcanism that follows later may initially be controlled by the formation of the caldera structure and recurring tectonic events. The Pagar Alam normal fault is the most prominent structure that formed inside the caldera. It is the main feature of the graben structure inside the Sula Caldera that acts as a conduit for the geothermal system of Ulubelu. The combination of the Sula Caldera product and volcanism after that, together with faulting and fracturing that occur post-Sula Caldera due to tectonic activity, is a perfect recipe for establishment of Ulubelu-Waypanas geothermal system.

1. INTRODUCTION

Ulubelu-Waypanas geothermal prospect is located in the southernmost Province of Sumatera Island, Lampung Province. It consists of a tertiary to quaternary volcanic complex and a prominent depression structure along an NW-SE trend axis. Several authors have described the field geologic situation as volcano-tectonic depression (Trianggo et al., 2015), strongly influenced by overlapping NW-SE parallel to Sumatera Fault System (Husein et al., 2015). Siahaan et al. (2015) identified that the geological framework of Ulubelu lies in lineament patterns, fault segments, collapse structure, and circular features from Radar and Imagery Landsat study.

2. REGIONAL GEOLOGY OF ULUBELU-WAYPANAS GEOTHERMAL FIELD

Ulubelu Geothermal Field lies on the southern tip of the Sumatera Fault System with an NW-SE trend. It is Physiographically located within the Bukit Barisan Mountain Range (Figure 2.1. Location of Ulubelu-Waypanas Geothermal Prospect near the Semangko Segment (the south end of Sumatera Fault System). The Ulubelu-Waypanas prospect has a slightly different trend (NNW-SSE) than the Semangko segment (NW-SE). The Sumatera Fault System is believed to have a close relationship with the volcanism along Bukit Barisan Mountain Range. The segmented Sumatera Fault limits the southern part of Sumatera Island by the Semangko Segment. It corresponds to the dextral slip movement of oblique convergence plates beneath Sumatera Island that terminates at Teluk Semangko. It also exhibits several fault splays and prominent pull-apart basins (Suoh Sekincau). The field is located around 15-20 km from Semangko Fault and has a slightly different trend from Semangko Fault (NNW- SSE).

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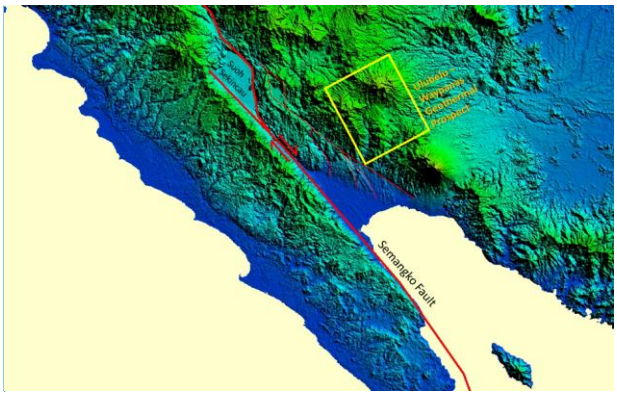

Figure 1. Location of Ulubelu-Waypanas Geothermal Prospect near the Semangko Segment (the south end of Sumatera Fault System). The Ulubelu-Waypanas prospect has a slightly different trend (NNW-SSE) than the Semangko segment (NW-SE).

3. VOLCANO-TECTONIC CALDERA

3.1. Rindengan-Tanggamus Volcanic Complex

Ulubelu depression is roughly bounded north and southeast by Mt. Rindengan and Mt. Tanggamus andesite stratovolcanoes, respectively. It is a volcanic complex that trends NW-SE and NNW-SSE to the north (Figure 2.2). Numerous circular and semi-circular bodies represent the volcanic edifice along Rindengan-Tanggamus, the latter being the youngest volcano. The remnant of the semi-circular body of G. Sula on the eastern part of the area suggests that a major volcanic event initiated a catastrophic collapse on the western body of Mt. Sula. This implies the formation of the caldera structure of post-Mt. Sula volcanism. Tectonism and volcanism followed later within and on the perimeter of Mt. Sula's damaged body.

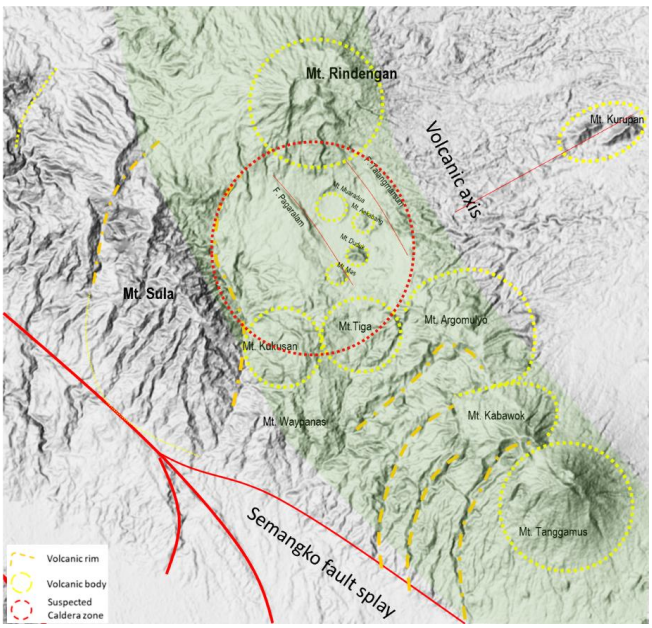

Figure 2. Rindengan-Tanggamus volcanic complex is marked by the NNW-SSE and NW-SE trending volcanic axes. A recent study shows evidence of caldera product followed by an intensive tectonic event that created a prominent geological structure (e.g., Pagar Alam Fault).

3.2. Field Geological Evidences

The semi-circular body of the Sula volcano is evidenced in the west part of the field. Outcrops of ignimbrite and co-ignimbrite breccia deposits were found during the field survey in the river stream south of the Sula Volcanic Rim. The ignimbrite consists of lapilli-size pumiceous fragments in a massive tuff-dominated matrix. Alongside the lapilli tuff, co-ignimbrite breccia deposited on top of the lapilli tuff. The polymictic breccia represents mixed fragments from the reworked older volcanic body and metasediment basement. Those outcrops exhibit systematically fractured and filled with secondary minerals such as silica and calcite. It suggests that the area is tectonically active prior to the eruption of the Sula Volcano.

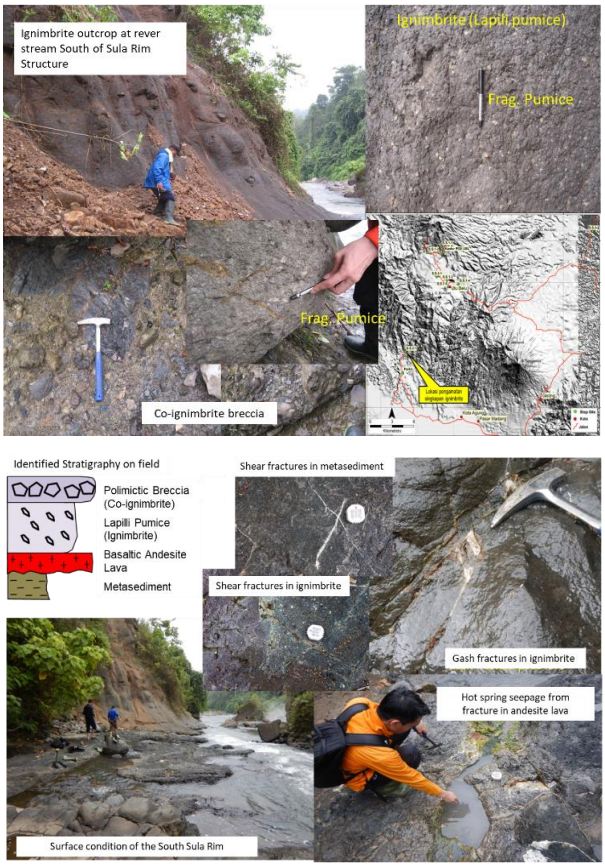

Figure 3. Rindengan-Tanggamus volcanic complex is marked by the NNW-SSE and NW-SE trending volcanic axes. A recent study shows evidence of caldera product followed by an intensive tectonic event that created a prominent geological structure (e.g., Pagar Alam Fault).

Other evidence of the post-caldera tectonic event is the development of tensional faulting, followed by Pagaralam and Talang Marsum Faults establishment inside the Mt. Sula caldera. The faulting and fracturing inside the caldera allowed for later volcanic events to emerge, as shown by the number of highly weathered monogenic volcanoes (Muaradua Rim, Mt. Aekabang, Mt. Duduk, Mt Mas) inside of the Ulubelu graben. Volcanoes are also developed at the periphery of the suggested Mt. Sula caldera. Mt. Rindengan, Mt. Tiga, Mt. Argomulyo, and Mt. Kukusan possibly developed later after the monogenics due to their lower weathering intensity compared to the monogenics. The volcanic events shifted to the southeast and emerged as Mt. Kabawok and the youngest Mt. Tanggamus that still has perfect cone-shaped strato-volcano morphology. The shifting of the volcanism toward the southeast is visible by the crescents morphology on Mt. Argomulyo, Mt. Kabawok, and Mt. Tanggamus, respectively.

Table 1. The summary of volcano-stratigraphy in Rindengan-Taggamus Volcanics

Age (Mya)			Formation	Lithology	Note
Quaternary	Holocene	0.023	Alluvium Deposit	Alluvium and hydrothermal spring deposits including fluviatile deposit, bouldersm sand, clay, gravel, and epiclast	
		0.060	Altered Rocks		
			Tanggamus	Andesite lava & pyroclastic, Gray, vesicular, porphyritic pyroxene andesite in glassy matrix	It needs confirmation of relative age compare to Rendingan
			Young Rendingan	Andesite lava, columnar jointed, Grey, aphanitic, microcrystaline plagioclase and pyroxene in glassy groundmass	
	Pleistocene	1,7 ?	Kabawok	andesite lava & Pyroclastic,	It needs confirmation of relative age compare to young Rendingan
		1,4	Old Rendingan	Andesite lava, sheeting jointed, weathered, Grey, porphyritic, microcrystaline plagioclase and pyroxene in glassy groundmass	
			Argomulyo	andesite lava & Pyroclastic,	
			Tiga	Highly altered and weathered volcanic breccia, associated with steam heated geothermal manifestation	
		3,9?	Kukusan	Basaltic andesite lava, dark grey, porpyritic to aphanitic, microcrystaline plagioclase and pyroxene in glassy groundmass	It needs confirmation of relative age
Tertiary	Pliocene		Mas	Altered Rocks, fragmented, strongly altered and weathered, light grey to brown, clay altered matrix	
		3,9?	Duduk	Altered Rocks possibly andesite, massive to fragmented, strongly altered and weathered, light grey to brown, porphyritic, altered plagioclase phenocryst in clay altered groundmass	Strongly altered and didn't found suitable sample for rock age dating
			Aekabang		
			Waypanas	Volcanic breccia, weathered and altered, fragmented	
		4,5	Sula Muda	Andesite lava, Pumice, tuff, massive, columnar jointed, polymictic breccia, Porphyritic andesite lava, dark-light brown lapilli pumice tuff, matrix supported polymictic breccia	
		1,4?	Kurupan	Breccia, tuff, pumice, highly weathered and dissected, clay yellowish gray, quartz, limonite, glass & pumice	based on weathering intensity and highly eroded and disected morphology, Kurupan is considered old monogenic volcano post Old Sula
		>4,5	Old Sula	Andesite lava and andesite breccia, weathered, grey, aphanitic,	

3.2. Gravity Data

The gravity residual anomaly map (Figure 4) shows the variation of the residual anomaly over the study area. The residual Anomaly in Ulubelu ranges from -12 mGal to 12 mGal, with a reduced density of 2.2 gr/cm^3. According to the residual map, it can be seen that Mount Rindengan, where the heat source is situated, has a slightly higher anomaly (+2 mGal) than its surrounding rock. Ulubelu's depression is shown as a lower residual anomaly of -8 mGal to -5 mGal (bluish color), which corresponds to the pyroclastic rock and graben-filled formation. In contrast, the highest anomaly is observed in the South of Ulubelu in the vicinity of Mount Argomulyo, Mt. Tiga, Mt. Waypanas, and Mt. Kukusan, where the residual anomaly reaches its maximum value of 8 mGal to 12 mGal mGal. Moreover, the semi-circular shape of the low to high residual anomaly interface is interpreted as the caldera structure of the Old Sula Volcano.

4. CONCLUSIONS

The result of the joint study reveals that there is strong evidence of caldera structure in the area. It also displays strong post-caldera tectonic activity. Major faults and systematic joints inside the caldera are well recorded in the morphology and the surface outcrops, respectively. The caldera itself is named in the volcano-stratigraphical Units as Sula Volcanic. It is described in a geological map by Masdjuk (1997) composed of andesitic composition and Tertiary age (4.5 mya). The gravity residual anomaly map depicts the caldera wall as a semi-circular higher anomaly, enclosing the graben's lower residual anomaly inside. The volcanism that follows later may initially be controlled by the formation of the caldera structure and recurring tectonic events. The Pagar Alam normal fault is the most prominent structure that formed inside the caldera. It is the main feature of the graben structure inside the Sula Caldera that acts as a conduit for the geothermal system of Ulubelu. The combination of the Sula Caldera product and volcanism after that, together with faulting and fracturing that occur post-Sula Caldera due to tectonic activity, is a perfect recipe for establishment of Ulubelu-Waypanas geothermal system.

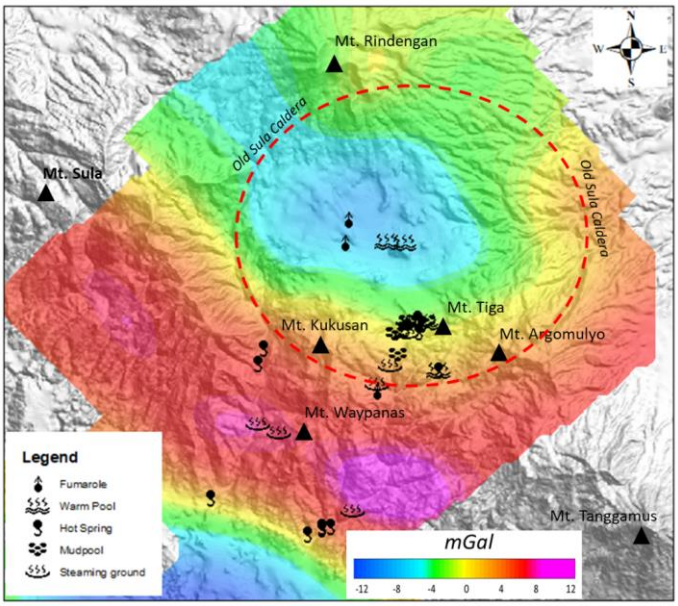

Figure 4. Complete Bouguer Anomaly Map of Ulubelu; the Old Sula Caldera is shown as a red semi-circular dashed line (Pertamina Geothermal Energy, 2021).

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