Volcanostratigraphy Study of the Kepahiang Geothermal Field

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Abstract. The island of Sumatra has high geothermal potential as a result of tectonic activity from the Great Sumatran Fault running along the island. This tectonic activity has formed volcanoes and surface thermal activity in various regions, including Kepahiang. This study aims to analyze the geological conditions, geomorphology, and volcanic products in the area, and then classify them according to the Indonesian Stratigraphy Code (1996). The analysis focuses on volcano stratigraphy using satellite imagery, topographic maps, and ridge delineation from Digital Elevation Model (DEM) data. The study will be presented as volcano stratigraphy maps at scales of 1:50,000 and 1:100,000, which can serve as a guide for geothermal resource exploration and utilization in Kepahiang.

Keywords: *Geothermal, volcanoes, volcano stratigraphy, Digital Elevation Model.*

1 Introduction

Sumatra is one of the islands with the largest geothermal potential in Indonesia. PT Perusahaan Listrik Negara (PLN) has been assigned to manage the Kepahiang Geothermal Working Area (Wilayah Kerja Panas Bumi or WKP for short) to accelerate the energy transition towards increasing renewable energy. The Kepahiang WKP is currently still in the exploration phase. A pre-feasibility study has been completed for this WKP. The volcano stratigraphy study is expected to enhance confidence in determining the boundaries of the geothermal system for resource estimation.

The location of the Kepahiang WKP is shown in Figure 1, situated within two administrative regions: Kepahiang Regency and Rejang Lebong Regency, in Bengkulu Province. The Kepahiang WKP is located 40 km northeast of downtown Bengkulu, which falls under the administrative area of Central Bengkulu Regency. The geothermal system in this area is linked to the volcanic activity of Mount Kaba, located within the Kepahiang WKP.

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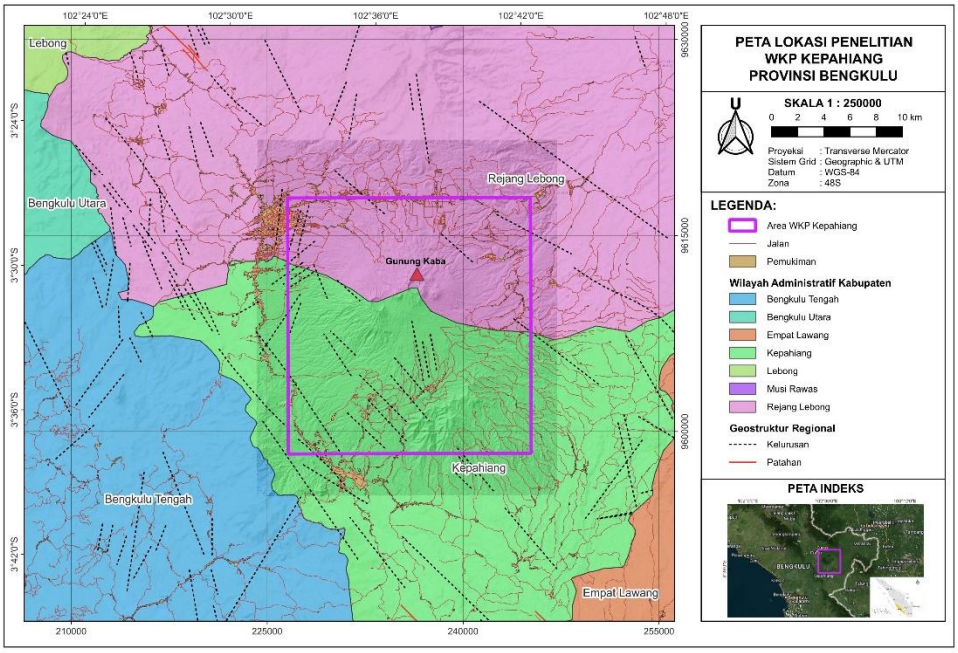

Figure 1. The Research Location

The purpose of this study is to identify the volcano stratigraphy units of the Kepahiang geothermal field, which are expected to be used in determining the boundaries of the geothermal system in the Kepahiang WKP.

2 Materials and Methods

In this study, the research methods are divided into several stages, starting with a literature review, followed by data processing, data interpretation and analysis. Geological data obtained from various sources, such as DEMNAS data and Rupa Bumi Indonesia Map (RBI), is processed to determine slope gradients and river flow patterns. The processed data is interpreted to define the boundaries of volcano stratigraphy units according to the Indonesian Stratigraphy Code (SSI) 1996. The discussion includes a review of the interpretation and analysis results, presented in the form of conclusions and recommendations.

3 Geological Review

Bengkulu Province features a varied topography, ranging from plains to high mountains. According to the regional geological map of the Bengkulu sheet, the area is home to several young volcanoes, including Bukit Dingin, which reaches an elevation of 2,020 meters above sea level, Bukit Balai (1,683 m), Bukit Condong (2,079 m), Bukit Daun (2,467 m), Mount Hulupalik (2,493 m), and Bukit Gendahululai (2,130 m). These mountains form a chain of stratovolcanoes as part of the Bukit Barisan Range, generally stretching in a northwest-southeast direction. The region is bordered by rolling hills to the west and east, with sharp ridges found in the northern and southern parts. A narrow plain lies along the southwest coastal area.

The Great Sumatran Fault, trending NW-SE, cuts through rocks ranging in age from the Oligocene to the Quaternary, such as the Semangko Fault, which runs roughly parallel to the island of Sumatra, causing earthquakes along the fault zone. In certain locations, the Sumatra Fault forms a contact between Quaternary volcanic lithology and older consolidated rocks.

The Kepahiang Geothermal Working Area (WKP) is located in a volcanic region on the western part of Sumatra. The increased magmatic activity at Mount Kaba is believed to be the geothermal heat source, as evidenced by several volcanic arcs within the Kepahiang WKP (Figure 2). According to the regional geological map of the Bengkulu sheet (Gafoer et al., 2007) [2], the Kepahiang WKP is situated in the Breccia Volcanic Unit (Qhvk), which consists of volcanic breccia, lava, and tuff composed of andesite-basalt.

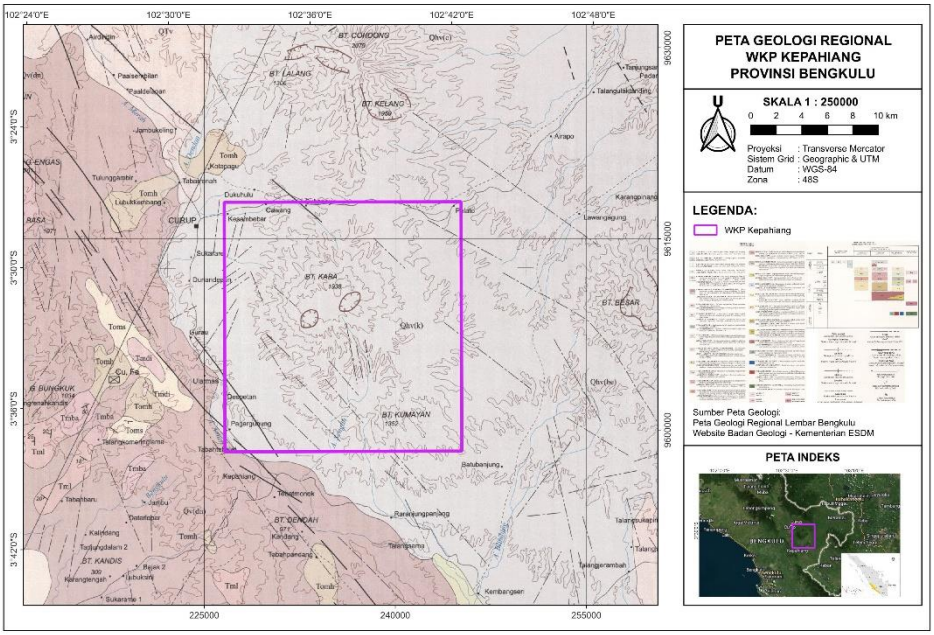

Figure 2. Regional Geological Map of the Bengkulu Sheet (modified from Gafoer et al., 2007) [2]

4 Geomorphology

The geomorphological analysis aims to provide a general overview of the morphology, identify eruption centers, and map the distribution of volcanic products' lithology. The geomorphological studies conducted include the analysis of river flow patterns and slope gradients.

4.1 River Flow Patterns

The identification of river flow patterns aims to understand the general lithological characteristics based on the flow patterns formed. The river flow patterns refer to Howard's Classification (1967). River flow data was obtained from the Indonesian Topographic Map (RBI) by the Geospatial Information Agency (BIG), downloadable from https://tanahair.indonesia.go.id/unduh-rbi/.

The analysis results in Figure 3 show that the Kepahiang WKP consists of four river flow patterns as follows:

- Parallel: A flow pattern with relatively parallel directions, occurring in areas with moderate to steep slope gradients, and also in regions with elongated and parallel morphology. This pattern tends to develop into dendritic or trellis patterns.
- Sub-Parallel: Similar to the parallel pattern, but small rivers show slight variations in direction, making them not entirely parallel. While generally following the same direction, there are slight deviations or curves in the flow paths, resulting in a "sub-parallel" pattern. This pattern often occurs in areas with more complex topography or uneven sedimentation.
- Radial: This flow pattern is characterized by a network radiating outward from a central point, typically indicating a dome or volcanic area.
- Dendritic: A tree-like pattern where river branches connect to the main river at sharp angles. This pattern generally forms in homogeneous rock formations with little or no structural control.

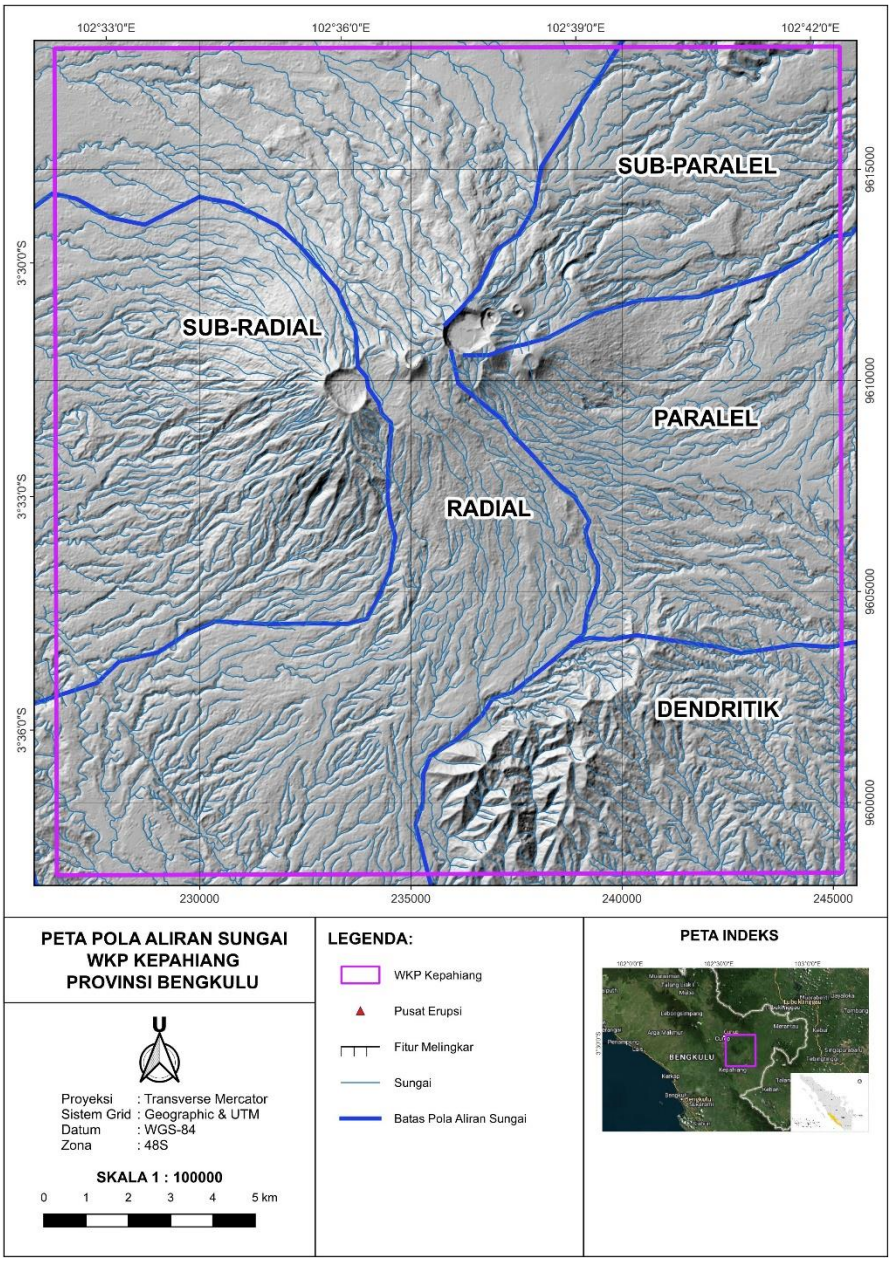

Figure 3. River Flow Pattern Map of Kepahiang WKP

4.2 Slope Gradients

Slope gradient analysis uses Digital Elevation Model (DEM) data to help illustrate the morphological characteristics of the study area. The slope

classification is based on Bermana (2006) [1]. In the central part of the study area, several zones with very steep slopes (56-140%) and steep slopes (21-55%) are present, as shown in Figure 4. The hilly areas are indicated by circular features on the surface that appear in the zones with very steep slopes

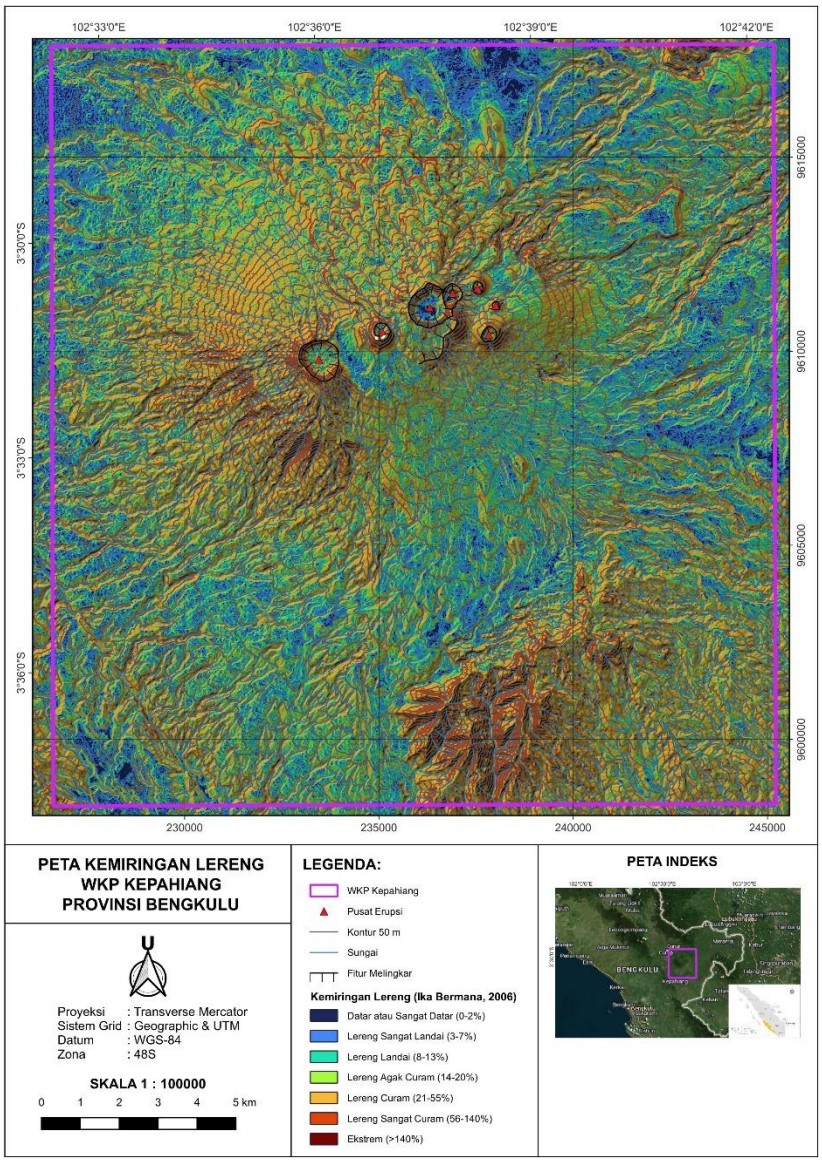

Figure 4. Slope Gradient Map of Kepahiang WKP

5 RESULT AND DISCUSSION

Previous literature, such as the study by Kusnadi et al. (2010) [3], outlines the chronology of Mount Kaba's formation, which began in the Early Quaternary with explosive eruptions that produced lava from Kaba Tua I to III and pyroclastic flow deposits. The development of the complex tectonic activity of Mount Kaba is marked by a massive eruption that formed caldera rims on the western and eastern parts of the Kaba complex, as evidenced by the discovery of pumice and scoria in bomb to lapilli sizes. After this large eruption, intense voids and fractures facilitated magmatic eruptions that produced features such as Bukit Itam, Bukit 1960, Biring, Salojuang, and Mount Kaba. Another study by Wijaya and Setijadji (2022) [5], focused on the northern part of the research area, indicated that the valley morphology is predominantly V-U shaped, with elevations ranging from 975 to 1,825 meters above sea level.

In this study, the volcano stratigraphy analysis was carried out based on the Indonesian Stratigraphic Indonesia (Sandi Stratigrafi Indonesia) (SSI) of 1996. The volcanostratigraphy units are categorized into bregada, khuluk, and gumuk (Martodjojo and Djuhaeni, 1996) [4].

The volcano stratigraphy analysis aimed to determine the distribution of volcanic deposits and their formation sequence. It began with identifying volcanic cones or circular features, followed by tracing ridgelines and rivers (valleys) on topographic maps at scales of 1:100,000 and 1:50,000. The delineation of the volcano stratigraphy units was based on literature reviews and the traced ridgelines and rivers. This analysis successfully classified the volcanostratigraphy units into bregada, khuluk, and gumuk.

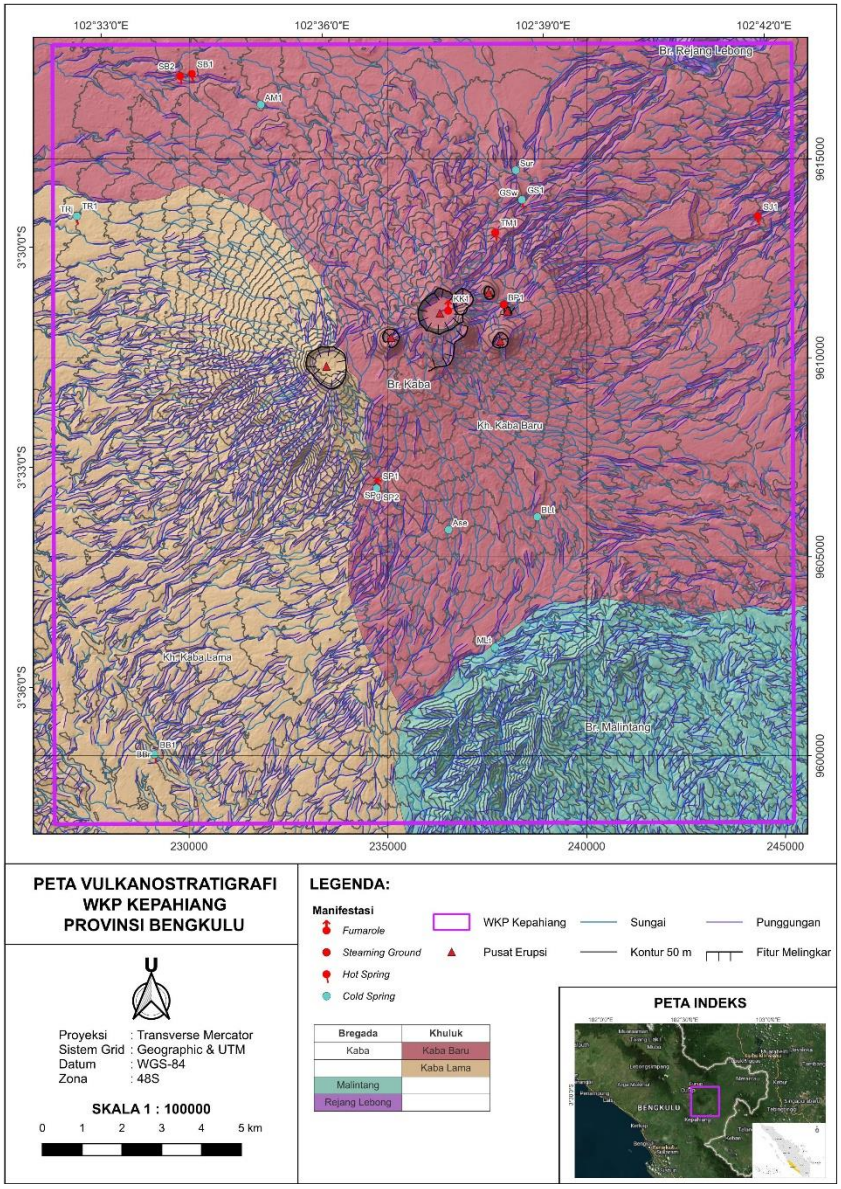

Figure 5. Volcanostratigraphy Map at a 1:100,000 Scale

The delineation of volcano stratigraphy units on the 1:100,000 scale volcanostratigraphy map, shown in Figure 5, places the research area within Bregada Kaba, Bregada Malintang, and Bregada Rejang Lebong. The majority of the research area lies within Bregada Kaba, which will be

the primary focus for further stratigraphic delineation into several Khuluk and Gumuk units. The research area is divided into two Khuluk units: Khuluk Kaba Lama and Khuluk Kaba Baru.

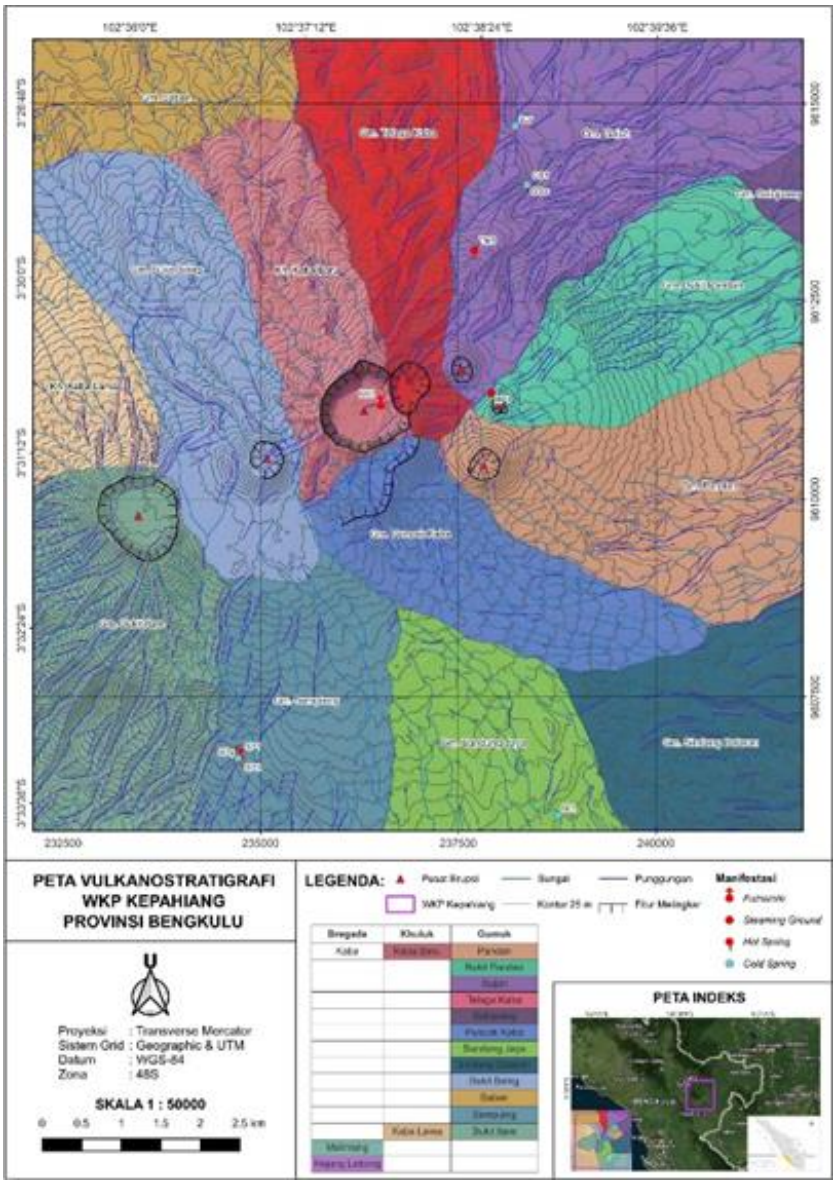

Figure 6. Volcanostratigraphy at a 1:100,000 Scale

The 1:50,000 scale volcano stratigraphy map shown in Figure 6 displays the division of gumuk units based on the khuluk identified on the

1:100,000 scale map. Khuluk Kaba Lama consists of one gumuk, named Gumuk Kaba Lama. Khuluk Kaba Baru is composed of 11 gumuk units. Table 1 presents the volcano stratigraphy units based on the 1:100,000 and 1:50,000 scale volcano stratigraphy maps.

Volcanostratigraphy Unit

- **Bregada Rejang Lebong**
  Bregada Rejang Lebong is estimated to have the oldest volcanostratigraphic chronology. This formation is located in the northern part of the Kepahiang WKP. According to the regional geological map of the Bengkulu sheet, the deposits in the Bregada Rejang Lebong area consist of volcanic breccia lava.

- **Bregada Malintang**
  Bregada Malintang has a younger volcanostratigraphic chronology than Bregada Rejang Lebong but is older than Bregada Kaba. This formation is situated in the southeastern part of the Kepahiang WKP. Based on the regional geological map of the Bengkulu sheet, the deposits in the Bregada Malintang area are also volcanic breccia lava, similar to those in Bregada Rejang Lebong.

- **Bregada Kaba**
  Bregada Kaba is considered younger than both Bregada Rejang Lebong and Bregada Malintang, and is located around the Kepahiang WKP. Bregada Kaba has a diameter of over 10 km and displays a circular feature forming a crater with several eruption centers.

Table 1 Volcanostratigraphy Unit based on scale 1: 100.000 and 1: 50.000

Relative Age	Stratigraphic Unit Gafoer dkk. (2007)	Bregada	Khuluk	Hummock	Eruption Activity
Quarter	**Volcanic Breccia Unit (Qhvk) :** volcanic breccia, lava, and tuff with an andesite-basalt composition.	Kaba	Kaba Baru	Pandan	*Flank*
				Bukit Pandan	*Flank*
				Gajah	*Flank*
				Telaga Kaba	*Central*
				Salojuang	*Flank*
				Puncak Kaba	*Central*
				Bandung Jaya	*Flank*
				Sindang Dataran	*Flank*
				Bukit Biring	*Flank*
				Saban	*Flank*
				Sempiang	*Flank*
			Kaba Lama	Bukit Itam	*Central*
		Malintang			
		Rejang Lebong			

The stratigraphic units of Bregada Kaba are divided into Khuluk Kaba Lama and Khuluk Kaba Baru (from older to younger).

Khuluk Kaba Lama

This khuluk consists of a single gumuk, Gumuk Kaba Lama. It borders Khuluk Kaba Baru and contains an eruption center within its circular feature, indicating that its eruptive activity is classified as central.

Khuluk Kaba Baru

This khuluk is composed of 11 gumuk, listed from youngest to oldest: Gumuk Pandan, Gumuk Bukit Pandan, Gumuk Gajah, Gumuk Telaga Kaba, Gumuk Salojuang, Gumuk Puncak Kaba, Gumuk Bandung Jaya, Gumuk Sindang Dataran, Gumuk Bukit Biring, Gumuk Saban, and Gumuk Sempiang.

Thermal manifestations such as fumaroles, steaming grounds, and hot springs are found on Gumuk Sempiang, Gumuk Gajah, and Gumuk Bukit Pandan. Gumuk Sempiang, the oldest according to its chronology, is a product of a flank eruption located southwest of Mount Kaba, while Gumuk Gajah and Bukit Pandan are products of flank eruptions located east of the Khuluk Kaba Baru eruption center.

Based on the volcanostratigraphic analysis correlated with surface manifestations (as shown in Figure 6), there are two geothermal systems: the Sempiang System (associated with Gumuk Sempiang) and the Kaba System (associated with Gumuk Gajah and Bukit Pandan).

Conclusion

6

The Kaba volcanic complex is situated within Bregada Kaba, which is composed of Khuluk Kaba Lama and Khuluk Kaba Baru. Khuluk Kaba Lama consists of one gumuk, while Khuluk Kaba Baru comprises 11 gumuk.

There are two geothermal systems identified: the Sempiang System (associated with Gumuk Bukit Biring) and the Kaba System (associated with Gumuk Gajah and Bukit Pandan), based on the correlation between the volcanostratigraphic units and surface manifestations.
The definition of volcano stratigraphy units in this study provides new insights into determining the boundaries of geothermal systems. A more detailed definition is needed through integration with field geological observations and rock sampling, which will lead to the development of a detailed geological map.

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