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Characteristics and Genesis of Mount Pengki: A Scoria Cone of Dago Volcano, West Java, Indonesia

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ABSTRACT

Scoria cones are a typical product of volcanic activity constructed by the bomb and lapilli-sized pyroclasts formed by Strombolian eruption. Mount Pengki is a scoria cone found in Miocene Dago Volcano, West Java. Mount Pengki was a remnant of a Miocene volcano that was exceptionally well preserved and exposed. This scoria cone contains layers of scoria beds and a lava flow unit. The study aims to characterize the exposed scoria bed deposits and investigate the eruptive history and degradation process of Mount Pengki. Field observation, including measured sections and detailed characterizations of the Mount Pengki quarry, allows us to observe its volcanic sequence from its internal structure toward the surface. Morphometric analysis of Mount Pengki can describe the degradation process undergone by the scoria cone. The early phase deposits were characterized by massive to weakly bedded, poorly sorted, clast-supported beds mainly composed of coarse lapilli to bombs/blocks scoria grain. The middle phase deposit typically shows well-stratified, well-sorted, clast-supported scoria beds with coarse ash to coarse lapilli grain size. The late phase deposit is similar to the middle phase deposit, with additional features of coarser-grain, reverse grading, and clast-supported lenticular beds. Eruptive mechanisms involved in the formation of Mount Pengki include ballistic transport of clasts, fallout deposition, and grain avalanching process. The degradation process was likely influenced by prolonged exposure to weathering, cone rim collapse, and regional deformation processes.

Keywords: Mount Pengki, Dago Volcano, basalt, monogenetic eruption, scoria cone

INTRODUCTION

Scoria cones represent the most common product of volcanic landforms characterized by their conical morphology [1], [2]. Scoria cones are typically produced by Strombolian or Hawaiian-style eruptions, characterized by intermittent, weak-intensity explosive events driven by the bursting of gas bubbles [3]. These cones have a typical height of up to 200 m and a basal diameter of 0.3 to 2.5 km [4]. Scoria cones are dominantly composed of bomb and lapilli–sized pyroclast from low to medium silica magma [5], [6]. The bombs will be fluidal in shape, and the lapilli-sized pyroclast will be fluidal to angular. The early phase of cone building will commonly be weakly bedded. The bedding structure will be dominated in the late phase of the scoria cone.

The late phase deposit will commonly be attributed to grain avalanching features such as irregular bedding contacts and lenses of coarse inversely graded clasts [7], [8].

The abundance of scoria cone occurrence makes these cones critical volcanic edifices in monogenetic volcanic fields [2]. The observed diversity in the morphological characteristics of scoria cones, such as their size, shape, and internal structure, provides essential insights into the complex interplay of magmatic processes and eruption dynamics that govern their formation [8], [9]. Several studies in Indonesia help us to understand the diverse eruption style, water-magma interaction, structural control, and magma homogeneity of scoria cones [10]–[12]. Mount Pengki is a scoria cone deposit of Dago Volcano [13]–[15] located in Bogor Regency, West Java (Figure 1).

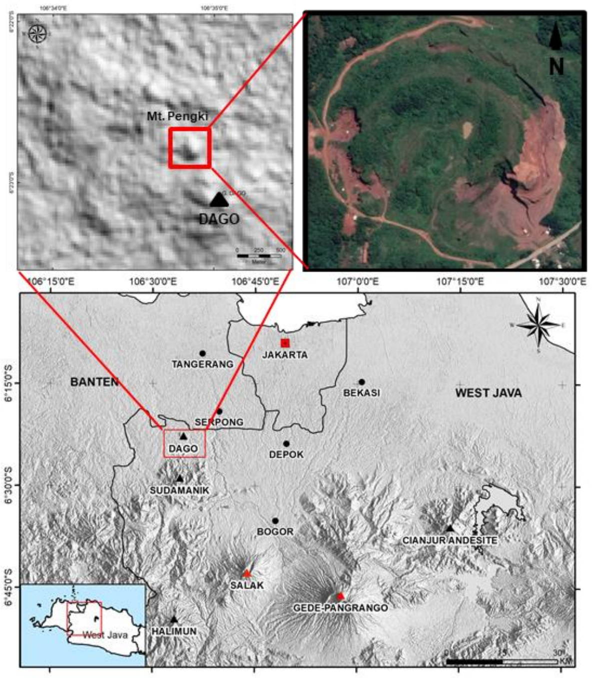


Figure 1. Mount Pengki Scoria is located in Bogor Regency, West Java, Indonesia

Compared to most scoria cones in Indonesia, Mount Pengki is relatively older but still exhibits well-identified cone morphology. Quarrying activities in Mount Pengki allow us to observe its volcanic sequence from its internal structure toward the surface. This paper presents a study of the characteristics and genesis of the Mount Pengki scoria cone, which is a product of the Dago Volcano in West Java, Indonesia. The study aims to characterize the exposed scoria bed deposits and investigate the volcanic feature's eruptive history and degradation process. This research provides insights into the complex interplay of magmatic processes and eruption dynamics that govern the formation and diversity of scoria cones.

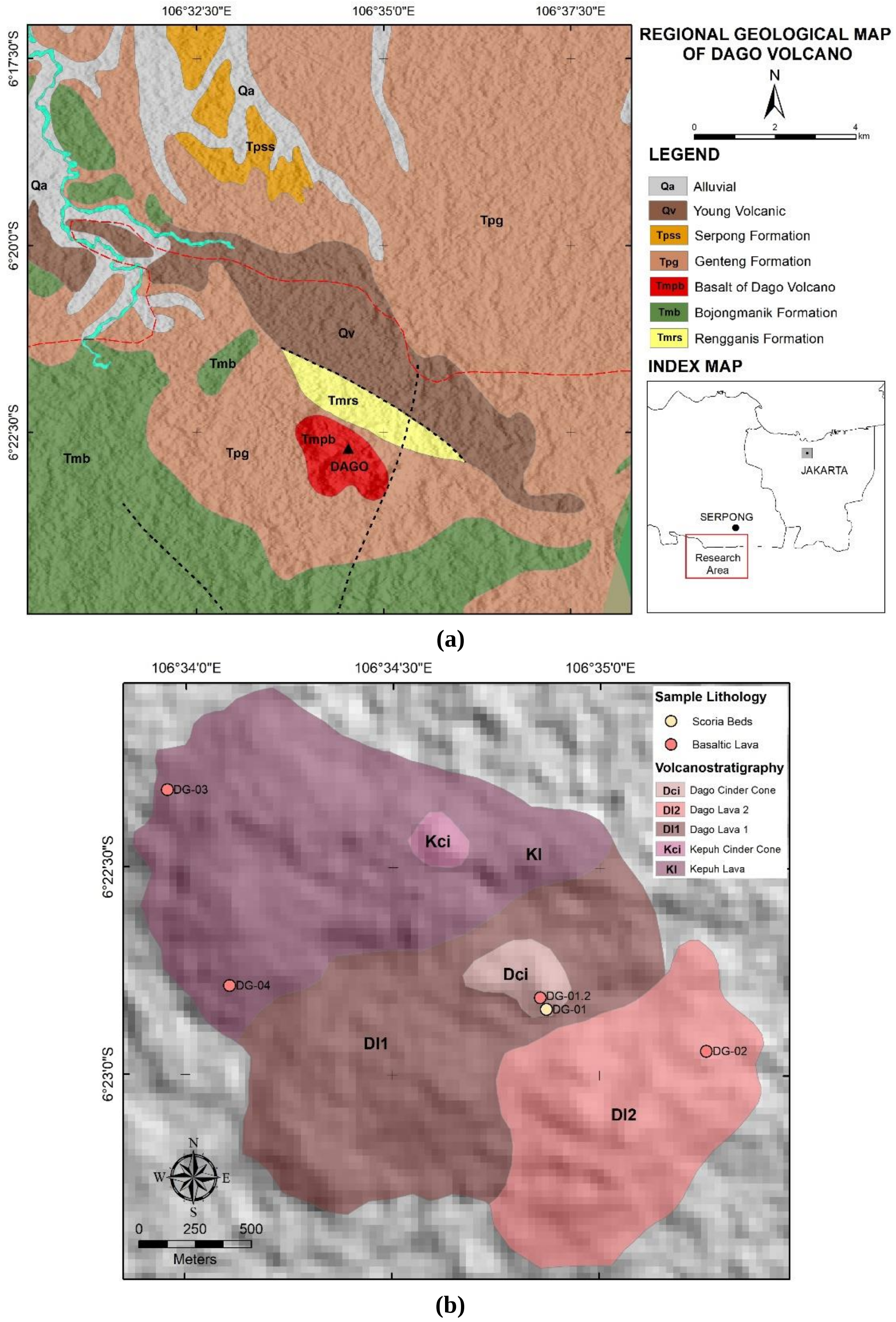
GEOLOGICAL SETTING

The basement beneath Dago Volcano consists of the Miocene sedimentary rock of Rengganis and Bojongmanik Formation. The Rengganis Formation consists of fine to coarse-grained sandstone, conglomerate, and claystone [13]. The Bojongmanik Formation comprises sandstone, pumice tuff, marl, limestone, and claystone with bituminous clay intercalation [13]. These sedimentary rocks were deposited in the outer to middle neritic environment and formed in the Middle Miocene [16]. Overlaying Dago volcanic products were the Pliocene Genteng Formation consisting of volcano-sedimentary products deposited in the fluviatile environment [13], [16] (Figure 2a).

Dago volcano was an Upper Miocene volcano located in West Java [13]. Dago Volcano products erupted from 2 eruption centers, the Kepuh and Dago. The Kepuh eruption center, formed earlier, erupted basaltic trachyandesite lava and cinder cone product. Later, the Dago eruption center produced trachyandesite lava flows and scoria cone products [15].

Mount Pengki is a scoria cone product of Dago eruption center, which is referred to as

Dago Cinder Cone (Figure 2b). Mount Pengki consisted of scoria layers and andesitic lava flows. The scoria cone product was classified as basaltic andesite rocks with low-K calc-alkaline magma affinity [15]. Mineralogically, the scoria clast of Mount Pengki was comprised of plagioclase and olivine phenocrysts in vitrophyric groundmass [15]. Mount Pengki was the youngest product of Dago Volcano and is interpreted as a flank eruption product that overlaid the andesitic lava of Dago Volcano [15].



(a)

(b)

Figure 2. (a) Regional geological map of Dago Volcano after Turkandi et al; [13]. (b) Detailed geological map of Dago Volcano after Adimedha et al. [15]

METHODOLOGY

Field observation was conducted at four observation points: A, B, C, and D to understand the characteristics and genesis of the Mount Pengki scoria cone. At each observation point, measured stratigraphy was conducted to determine stratigraphy position, sedimentary and pyroclastic features and the structure of scoria beds. Several features described in each outcrop were bed thickness, grain size, sedimentary structure, etc. From the morphometric analysis, the cone degradation level of Mount Pengki was conceived [19]. This analysis was conducted using an aerial photograph [17] and digital elevation model (DEMNAS) [18] to determine basal cone diameter (Wco), crater rim diameter (Wcr) and cone height (Hco) (Figure 3). The Hco/Wco ratio expresses the degradation level.

(a) **(b)**

Figure 3. Illustration of morphometric analysis using aerial photograph [17] to determine basal cone diameter, crater rim diameter, and cone height of Mount Pengki; Overhead aerial view analysis (a) to determine Wco and Wcr; tilted aerial view analysis to determine Hco

RESULTS

Morphometric analysis

Mount Pengki's morphology shows a horseshoe-shaped cone [4], [20], [21] with a crater breached to the south. Aerial photographs and digital elevation models reveal that the basal diameter of Mount Pengki (Wco) is approximately 350.7 meters, while the crater rim diameter (Wcr) is around 160.2 meters. Measurements from the digital elevation model indicate that the maximum height of the scoria cone is 27.9 meters. The Hco/Wco ratio of Mount Pengki is 0.079, a lower number compared to Mt Slamet Cinder Cone [11] and the Hco/Wco ratio of fresh cinder cone [22] (Figure 4).

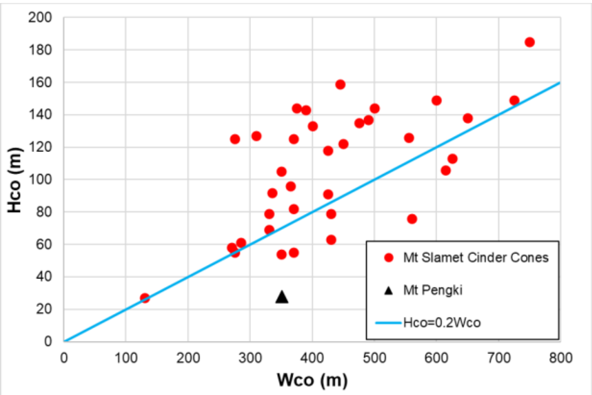


Figure 4. Basal diameter (Wco) vs. Cone Height (Hco) diagram of Mount Pengki compared to Slamet cinder cone [10] and fresh cone [21]

Deposit Characteristics

Mount Pengki's scoria beds can be divided into three phases based on grain size and pyroclastic edifice structure. The stratigraphic

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measurement on Mount Pengki describes sedimentary properties for early, middle, and late phases facies. The early phase facies were exposed in the northwest flank non-active quarry site. It is massive to weakly bedded, dipping southward at ~25º. The beds show a reverse grading structure, with grain size including minor coarse ash, but are dominated by coarse lapilli to bombs and blocks that reach 10 cm in diameter. Minor large blocks of 30 cm size were found in coarse lapilli-size scoria beds. This deposit is partly welded, poorly sorted, and mainly clast-supported. Reddish and yellowish color clasts were found in these facies (Figure 5a).

The middle phase facies were exposed dominantly at the southeast flank of Mount Pengki's body. This outcrop was exposed due to active quarrying activities and generally showed a reddish-brown color. The middle phase facies show well-stratified scoria beds, which dipped southward at 20-25º. Those beds, generally, show reverse-graded beds with the grain size of coarse ash to coarse lapilli scoria. The beds are typically 10 cm to 1 m thick, showing well-sorted and clast-supported textures. Several scoria blocks ranging from 7–15 cm in size were found in lapilli-dominated beds (Figure 5b).

The late phase facies of Mount Pengki show well-stratified beds dipping southward at 30-35º. Typically, the beds consist of a well-stratified scoria layer composed of coarse ash to coarse lapilli-sized scoria. The beds show reverse-graded bedding, clast supported, and well-sorted texture with a typical thickness of 30 cm to 1 m. Some beds have additional features of lenticular beds with coarser grain, reverse grading, and clast-supported textures (Figure 5b and Figure 6). Andesitic lava flows effused from the southeast flank of the cone body and were observed in observation point A or the middle phase facies (Figure 7). The outer part of lava shows a vesicular structure up to 10 cm zone along the contact with scoria layers; the core part is massive.

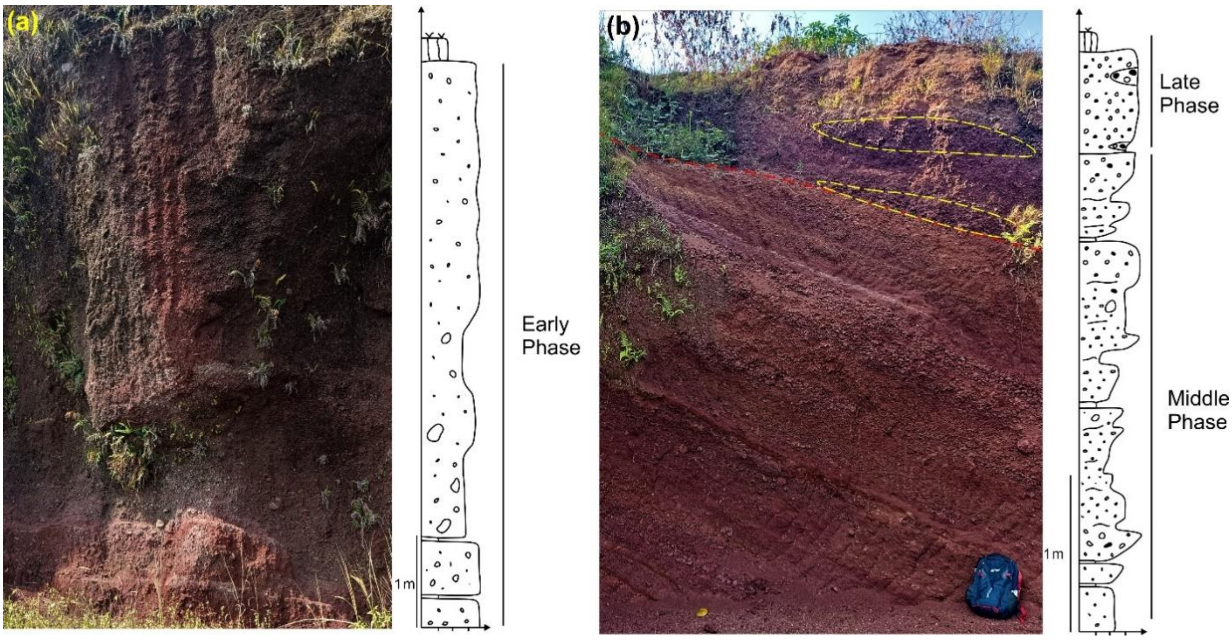

Figure 5. Photograph and stratigraphic column of pyroclastic sequence in Mount Pengki that consist of (a) early phase deposit, (b) middle phase deposit, and late phase deposit

Figure 6. Late phase deposit of Mount Pengki scoria beds show additional features of lenticular beds with coarser grain, reverse grading, and clast-supported textures

Figure 7. Andesitic lava body from middle phase eruption, which effused in the southeast flank of Mount Pengki

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DISCUSSION

Facies Model and Eruptive Mechanism

The exposed outcrop in the Mount Pengki scoria cone shows distinguish characteristics in each facies. The facies classification of Mount Pengki was based on the published scoria cone facies model from [7], [8], [12] (Figure 8a). The early phase facies exhibit relatively consistent characteristics with McGetchin et al. [7] and Valentine et al. [8] models. It is massive, coarse-grained beds (coarse lapilli to 10 cm bombs/blocks) and contains abundant block fragments up to 30 cm in size. The coarse clasts were transported ballistically from low and erratic eruption columns [2] (Figure 8b) and then deposited near the eruption center. The proximal location of the clast deposition makes it hot enough to weld upon deposition [8].

The middle phase facies were correlated to Harijoko et al. model [12], characterized by well-stratified scoria beds. The middle phase facies comprise un-welded, clast-supported scoria layers with coarse ash to coarse lapilli grain size and contain smaller bombs or blocks ranging from 7–25 cm. The beds were produced by high eruption intensity, forming sustained and well-fragmented eruption columns [7], [8], [12] (Figure 8b). The deposit covered the cone slopes because the fallout process dominated these facies. From time to time, the slopes become over-steeped, and minor grain avalanching occurs to maintain the angle of repose [2], [8] (Figure 8b). The grain avalanching process would create lenticular beds with a coarser grain and reverse grading structure. Those features characterize the late-phase deposit facies [8]. In observation point A, the lava flow shows disconformity contact with the middle phase deposit. Mineralogically and geochemically, this lava flow shows characteristics similar to those of the scoria grain of the middle phase deposit [15]. Thus, it is interpreted that the lava erupted during the middle phase eruption (Figure 8b).

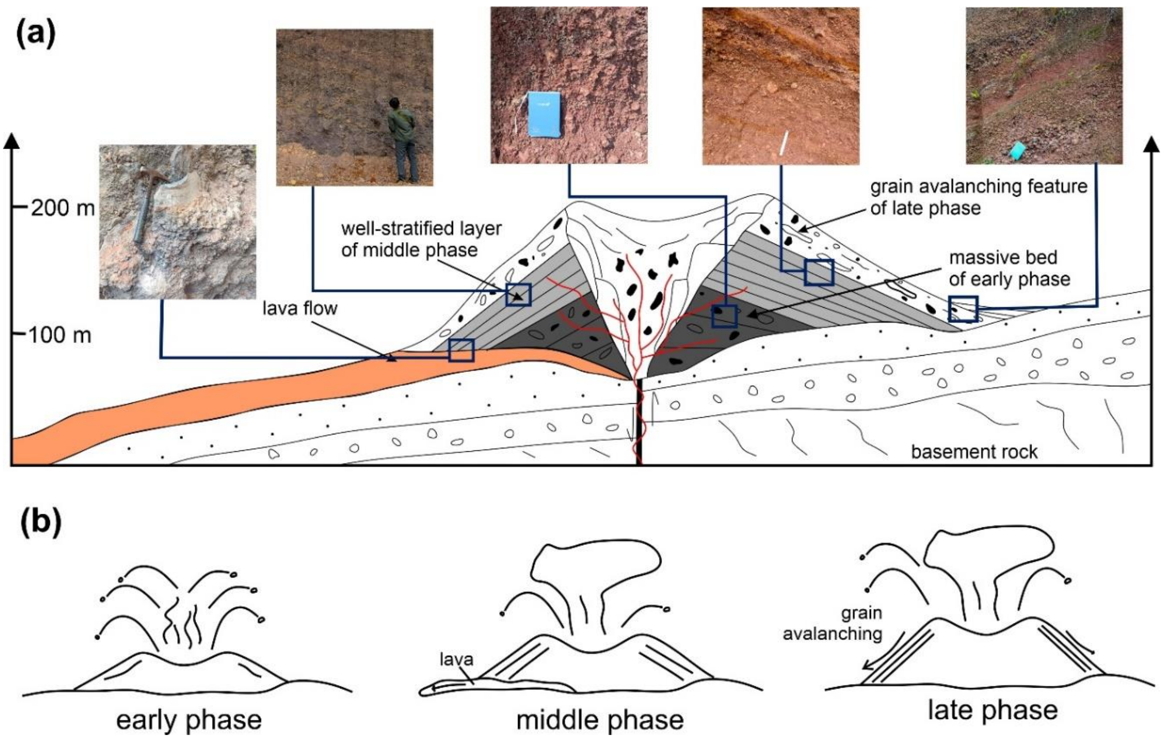

Figure 8. (a) Mount Pengki facies model (modified after Kerezturi & Nemeth); (b) Eruptive mechanism model of Mount Pengki

Comprehensive facies analysis and integration with published models suggest a complex multi-phase eruptive history for the Mount Pengki scoria cone. The early phase was characterized by energetic but relatively short-lived eruption, producing a massive and welded basal layer [23], [24]. This early phase followed a more sustained eruption during the middle phase, depositing well-stratified scoria layers that mantled the cone slopes. Towards the end of the eruption, the intensity declined, allowing for grain avalanching and lava effusion [25], [26]. Interestingly, forming a scoria cone appears to be a multifaceted process, with the volcano undergoing various eruption phases, each with its distinct eruptive mechanisms and depositional patterns.

Degradation Process

Morphometric analysis of the scoria cone would describe its degradation level. The Hco/Wco ratio of the Quaternary Slamet cinder cone is 0.25 [11], and the Hco/Wco ratio of the fresh cinder cone proposed by Bloomfield et al. is 0.2 [22]. The Hco/Wco ratio of Mount Pengki is 0.079, lower than Mt Slamet and fresh cinder cone (Figure 4). The ratio implies that Mount Pengki was a degraded cone. Several possibilities that control the degradation process are prolonged exposure to the weathering process, cone rim collapse, and regional deformation process [27], [28]. Since Mount Pengki was formed in the Upper Miocene [13] and was exposed until today, the weathering process might be the main factor controlling the degradation in Mount Pengki. Aerial images from Google Earth [17] show southward-facing breached cone morphology (Figure 3). This morphology could be another factor controlling the cone's degradation process.

The dip direction of the scoria beds indicated Mount Pengki's regional deformation process. Typically, a scoria bed would have a dip direction outward from the rim. However, in Mount Pengki's case, all the beds have a southward dip direction, even located on the north flank of the cone. This fact explains that Mount Pengki undergoes some regional deformation processes. Regional structures that might correlate to the deformation were active faulting of West Java in the Rerata and Salak segment [29].

CONCLUSION

Characteristic facies analysis of Mount Pengki scoria cone suggests a multi-phase eruptive history. The sequence could be divided into an early phase, middle phase, and late phase facies based on the observed variations in bed characteristics such as grain size, grading, and bedding features and the inferred emplacement mechanisms such as ballistic fallout, sustained fallout, and grain avalanching. The early phase was characterized by an energetic but relatively short-lived eruption, producing a massive and welded basal layer. The middle phase was characterized by a more sustained eruption, forming well-stratified scoria layers that mantled the cone slopes. Toward the end of the eruption, the intensity declined, allowing for grain avalanching and lava effusion. Furthermore, the Hco/Wco ratio of Mount Pengki indicates that Mount Pengki was a degraded cone. Extended exposure to weathering, cone rim collapse, and regional deformation processes likely influenced the degradation process.

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