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Research Paper

Volcanic Facies Architecture of Sedringo Volcano, Dieng Volcanic Complex

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Abstract

The Dieng Volcanic Complex (DVC) in Central Java, Indonesia, is situated within an active magmatic arc formed by the oblique subduction of the Indo-Australian Plate beneath Eurasia, with an additional influence from the Pacific Plate. Despite its importance as a major geothermal field, the eruptive history of Sedringo Volcano—a key but poorly studied edifice within the DVC remains undocumented. This study presents the first systematic reconstruction of Sedringo's volcanic evolution and introduces a novel, process-based volcanic facies model to link surface geology with subsurface reservoir architecture. We integrate field mapping, stratigraphic logging, and petrographic analysis of volcanic lithologies. Results reveal a bipartite facies architecture: (1) a central facies of coherent andesitic lava flows and caldera-related agglomerates, and (2) a proximal facies dominated by poorly sorted pyroclastic flow deposits. This pattern records a clear shift from effusive to explosive activity, culminating in caldera collapse and the formation of peripheral cones. The new facies model provides the first geologically constrained framework for interpreting geothermal reservoir geometry in the Sedringo sector. Moreover, the identification of hazardous pyroclastic units and caldera structures offers actionable guidance for geothermal well placement and volcanic hazard zonation. By directly connecting volcanic stratigraphy to energy exploration and risk mitigation, this work demonstrates how fundamental geological research enhances sustainable development in active volcanic systems.

Keywords: *Dieng, Facies, Sedringo, Volcanic*

INTRODUCTION

Volcanic facies analysis provides a critical foundation for reconstructing eruptive histories, assessing geohazards, and characterizing subsurface reservoir architecture in active volcanic terrains (Fontijn et al., 2024; Giordano et al., 2024). By decoding lithological, textural, and spatial patterns, facies models reveal the interplay between effusive construction and explosive disintegration processes that directly govern caprock integrity, fracture permeability, and slope stability.

The Dieng Volcanic Complex (DVC), Central Java, Indonesia, exemplifies a high-priority setting where such understanding is urgently needed. As one of Southeast Asia's most active geothermal provinces, the DVC hosts numerous high-enthalpy surface manifestations, including Sileri and Candradimuka craters, yet remains prone to phreatic explosions, lahars, and structural collapse (Harijoko et al., 2016; Miller et al., 1983). Despite decades of geothermal exploration, detailed facies-scale studies of individual volcanic centers within the DVC remain conspicuously absent. Existing geological maps offer only regional stratigraphic frameworks (Shalihin et al., 2022; Kencana et al., 2024), lacking the resolution to link surface lithofacies to subsurface fluid pathways or hazard-prone zones.

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This knowledge gap is particularly acute for Sedringo Volcano, a prominent edifice located south of the Dieng Plateau near active geothermal infrastructure. Although its topography suggests a complex eruptive history, no systematic facies model exists to constrain its eruptive transitions, caldera potential, or role in structuring local hydrothermal systems. Without this baseline, geothermal well siting remains speculative, and hazard zonation cannot account for concealed explosive deposits or unstable agglomerate slopes.

Therefore, this study is urgently motivated by both scientific and societal imperatives: to establish the first comprehensive volcanic facies architecture of Sedringo Volcano through integrated field mapping, petrography, and stratigraphy. The resulting model will not only fill a critical gap in the volcanic evolution of the southern DVC but also provide actionable geological constraints for safe geothermal development and evidence-based volcanic risk mitigation in a densely populated, energy-critical region.

LITERATURE REVIEW

Volcanic geology is a crucial aspect in understanding the dynamics of geological structure formation and development, as well as volcanic activity, which directly impacts the surrounding environment (Martí, 2024). Volcanic studies also encompass volcanic facies, which serve as lithological markers and indicate the relative position of volcanic rocks to the eruption center (Giordano et al., 2024).

In the context of the Dieng volcanic complex, particularly the Sedringo area, understanding volcanic facies is crucial. The Sedringo volcanic facies reflect the complexity of morphology and lithology that record volcanic processes from the past to the present. Through the study of these facies, the distribution of pyroclastic deposits, lava flows, and interactions between volcanic products can be identified, indicating the constructive and destructive phases of the volcano. The primary objective of research in the Sedringo area is to understand the characteristics of volcanic facies in detail, including lithological types, spatial distribution patterns, and morphological formations closely related to volcanic activity. By identifying the Sedringo volcanic facies, a clearer understanding of volcanic processes in the region can be gained, as well as their relationship to geothermal activity, which is a significant concern in the Dieng volcanic complex. Furthermore, this information is expected to make a significant contribution to the advancement of volcanic geology in the region. Understanding the Sedringo volcanic facies will support more accurate geological mapping, improve volcanic hazard prediction, and enable sustainable natural resource management.

Geological Framework

Sedringo Volcano is one of the Volcano in the Dieng Volcanic Complex, located in the south of Alang Volcano, Blado District, Batang Regency, Central Java (Figure 1). Physiographically, Sedringo Volcano is located to the north of the Dieng Plateau region. To the south of this location, the peak of Sikunir is clearly visible. This research location is also not far from several other important points in Dieng, such as Cebong Lake, Candradimuka Crater, and Sileri Crater (Van Bemmelen, 1949). The Sedringo Volcano area has a distinctive topography, characterized by hills and valleys formed by volcanic activity (Olivia et al., 2024). The road path can be seen circling the hilly area, connecting the surrounding villages such as Batur and Karangtengah.

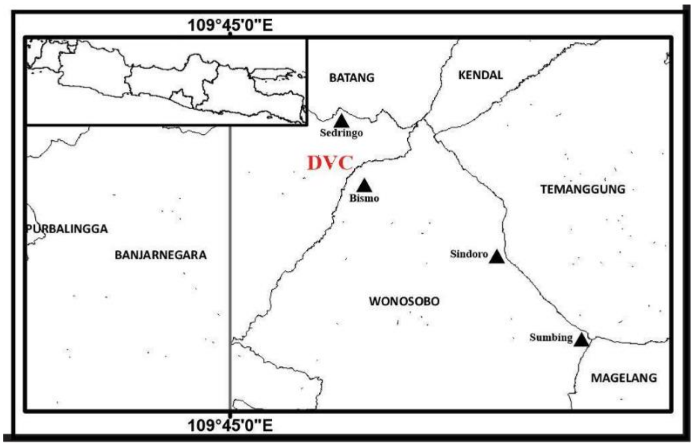

Figure 1. Research Area Location: Sedringo Volcano and its surrounding area are located within the Dieng Volcanic Complex (DVC).

According to Shalihin et al. (2022), the Dieng Plateau is a plateau comprising a Late Quaternary stratovolcano complex and recent volcanic rocks. The oldest known volcanic activity formed the rim of the Dieng Volcano (Miller et al., 1983). Smaller eruption centers subsequently emerged in the southwest part of the ancient caldera, followed by the formation of the Sedringo Volcano. Tectonic data indicate that the Sedringo Volcano formed within an active volcanic arc system due to the subduction of the Indo-Australian Plate beneath the Eurasian Plate (Verstappen, 2010). The formation phase of the Sedringo Volcano is estimated to have occurred during the Pleistocene (Kencana et al., 2024).

RESEARCH METHOD

This study adopts an integrated field- and laboratory-based methodology to reconstruct the volcanic facies architecture of Sedringo Volcano, following established protocols for facies analysis in andesitic arc volcanoes (Bogie, 1998; Giordano et al., 2024). The workflow is structured into four interdependent phases: (1) systematic geological mapping, (2) representative rock sampling and thin-section preparation, (3) petrographic characterization, and (4) stratigraphic correlation and facies synthesis.

Field campaigns were conducted across 15 strategically selected outcrop locations distributed throughout the Sedringo edifice (Figure 8), chosen to capture lithological diversity, facies transitions, and structural relationships. At each site, detailed geological mapping was performed at a scale of 1:4,000 using topographic base maps, a handheld GPS device (Garmin GPSMAP 64s, with a horizontal accuracy of ±3 m), a Brunton TruArc 10 compass clinometer, measuring tapes, and high-resolution digital photography. Key field observations included lithology, grain size, sorting, sedimentary and volcanic structures (e.g., grading, layering, jointing), stratigraphic contacts, dip and strike measurements, and spatial relationships between units. These data enabled the delineation of distinct facies domains, central, proximal, and caldera-associated, based on criteria defined by Bogie (1998), which link rock type, texture, and geometry to eruptive processes and vent proximity.

A total of 20 fresh, unweathered rock samples were collected from representative outcrops to minimize the effects of post-eruptive alteration. Samples encompass all primary lithologies: andesitic lava flows, pyroclastic flow deposits, pyroclastic fall breccias, and caldera-related agglomerates. In the laboratory, each sample was prepared as a standard 30-μm-thick thin section in accordance with ASTM D2797-15 guidelines for petrographic analysis of igneous rocks. Thin sections were examined using a Zeiss Axio Lab.A1 polarizing microscope equipped with a digital imaging system (AxioCam ERc 5s). Petrographic parameters systematically recorded included.

FINDINGS AND DISCUSSION

Based on pre-fieldwork studies and field observations, it is known that the volcanic type in the study area is a composite cone, with its crater located at Rogojembangan. Rogojembangan Volcano is classified as part of the pre-caldera episode (Harijoko et al., 2016). The pre-caldera stage indicates that the construction phase of Rogojembangan Volcano occurred prior to the collapse of the Prau caldera.

The rock units in the study area are divided based on the lithological genesis of the morphological formations in the study area. These lithologies consist of Pyroclastic Flow Deposits, Pyroclastic Fall Deposits, and Lava. The author divides these lithologies into several units based on their lithological characteristics and their presence in or near certain hills. The stratigraphic sequence of the study area from oldest to youngest is as follows.

Nagasari Volcano

Nagasari Volcano is one of the ancient volcanoes in the study area, located in the eastern part of the research area, especially around the foot of Nagasari Volcano to the west. The distribution of volcanic rock units from Nagasari Volcano is primarily composed of pyroclastic flow deposits. This area lies at a moderate elevation with steep slopes. The volcanic activity at Nagasari occurred during the Pleistocene and represents the initial phase of the volcanic complex formation in this region (Yudiantoro et al., 2022). Here are the lithological units that compose this volcano. Nagasari Pyroclastic Flow: The lithology composing this unit consists of lapilli-tuff pyroclastic flow deposits resulting from volcanic activity. The lithology found in this unit is generally weathered and not yet lithified. Its characteristics include angular grains, poor sorting, a fragment composition consisting of blocky andesite, oxidized lithics, with some pumice and scoria, a coarse tuff rock matrix, and a generally layered rock structure.

Pangamunamun Volcano

Pangamunamun Volcano is located at the east of the study area, encompassing volcanic slopes with steep to very steep slopes (55%-72%). The pyroclastic deposits of the study area, primarily consisting of flow lapilli-tuff deposits, have a lithology dominated by lava blocky fragments.

Alang Volcano

Alang Volcano is located in the northern part of the research area. This Volcano was formed through two main phases of volcanic activity (Hariyono & S, 2016): a destructive phase producing tuff, flow, and fall pyroclastic deposits, and a constructive phase characterized by andesitic lava emissions that built volcanic cones and hills. Field observations indicate that Alang Volcano is composed of the following lithologies: Alang Pyroclastic Fall, the lithology composing this unit is dominated by pyroclastic andesite blocks resulting from explosive eruption. Within this unit, pyroclastic fallout breccia deposits and andesite lava are also locally found. The pyroclastic avalanche breccias encountered range in grain size from very coarse sand (1 – 2 mm) to gravel (64 – 256 mm), well-sorted andesite, lithic, oxidized lithic, pumice, and scoria with a reverse gradation layering structure. Alang Pyroclastic Flows, the lithology of this unit generally consists of breccia deposits produced by volcanic activity and boulder-sized agglomerate fragments. The pyroclastic flow breccias typically range in grain size from pebbles to cobbles. Some contain pumice and scoria, a rock matrix made of coarse tuff, and the rock structure is generally massive. The tuff (vitric tuff) found in this unit has a well-layered sediment structure. Agglomerate is found as andesite boulder-sized fragments characterized by a hypocrystalline texture; aphanitic to moderately phaneritic granularity; porphyritic relationships; with the composition: groundmass 42%, plagioclase 36%, pyroxene 7%, hornblende 7%, and opaque 3%. The results of the petrographic analysis are presented in Table 1. Alang Andesite Lava: The lithology composing this unit is andesitic lava (sample A1), which is massively exposed. The lava in this unit is characterized by sheeting joint structures. Petrographically, it exhibits a hypocrystalline texture, characterized by aphanitic to moderately phaneritic granularity, porphyritic relationships, and the following composition: plagioclase (30%), pyroxene (8%), hornblende (7%), opaque minerals (5%), and a groundmass (50%) (Table 1).

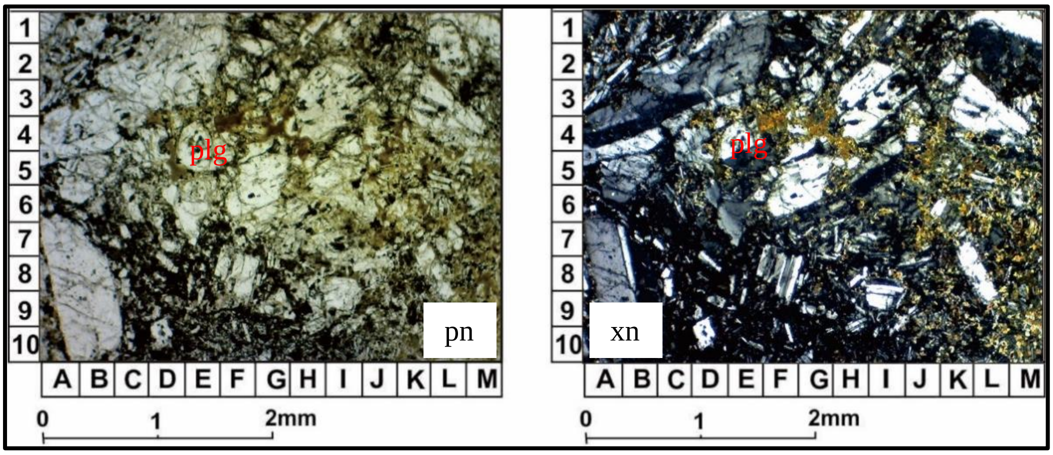

Figure 2. Shows a petrographic section of the andesite lava of Alang Volcano where plagioclase (plg) minerals are present in the volcanic glass goundmass. pn: parallel nicol; xn: cross nicol.

Sedringo Volcano

The stratigraphy at Sedringo Volcano consists of several volcanic rock units, primarily composed of pyroclastic flow deposits, andesitic lava, and agglomerate. The three central units that dominate this Volcano are pyroclastic flows, lava, and agglomerates. Sedringo Pyroclastic Flow, the lithology composing this unit is dominated by lapilli-tuff flow deposits resulting from volcanic activity (Figure 3). Locally, lapilli-tuff flow deposits and agglomerates are also found. The lithology in this unit is generally weathered and not yet lithified. The lapilli-tuff flow deposits are characterized by grain sizes ranging from very coarse sand (1 – 2 mm) to small pebbles (4 – 6 mm), fragment composition consisting of lithics, oxidized lithics, and some containing pumice.

Figure 3. The outcrop view of Sedringo pyroclastic flow (A and B) showing agglomerate fragments in a lapilli-tuff matrix.

Sedringo Lava, the lithology comprising this unit, is dominated by andesitic lava; pyroclastic fallout, including lapilli-tuff deposits, is also found. The pyroclastic flow breccia deposits are characterized by grain sizes ranging from coarse sand (0.5 – 1 mm) to small pebbles (4 – 6 mm), angular grains, and poor sorting. The fragment composition consists of lithics and pumice. The pyroxene andesite lava (S3) found in this unit can be described (Table 1) as follows: brown color with a 40% color index, hypocrystalline crystallinity degree; aphanitic to moderately crystal shapes ranging from anhedral to euhedral; porphyritic, consisting of a groundmass of glass 25% (see Figure 5). The phenocrysts consist of 63% plagioclase phenocrysts, 11% pyroxene, and 5% opaque minerals. The crystallite size ranges from 0.01 mm to 1.87 mm. The plagioclase composition is labradorite (An59). Sedringo Agglomerate, the Sedringo agglomerate unit (Figure 4) is a result of volcanic activity related to caldera formation, with rock fragments consisting of andesite and lithic fragments bound within a coarse tuff matrix. These rocks are generally fresh and partially weathered. The lithology composing this unit is dominated by agglomerates resulting from volcanic activity related to caldera formation. The lithology found in this unit is generally fresh, with some areas being partly weathered. The agglomerates encountered are characterized by a fresh gray color and a weathered brown color, grain sizes ranging from gravel (2 – 4 mm) to boulders (64 – 256 mm), rounded grains, poor sorting, fragment composition consisting of lithics and andesite, a coarse tuff rock matrix, and massive rock structure.

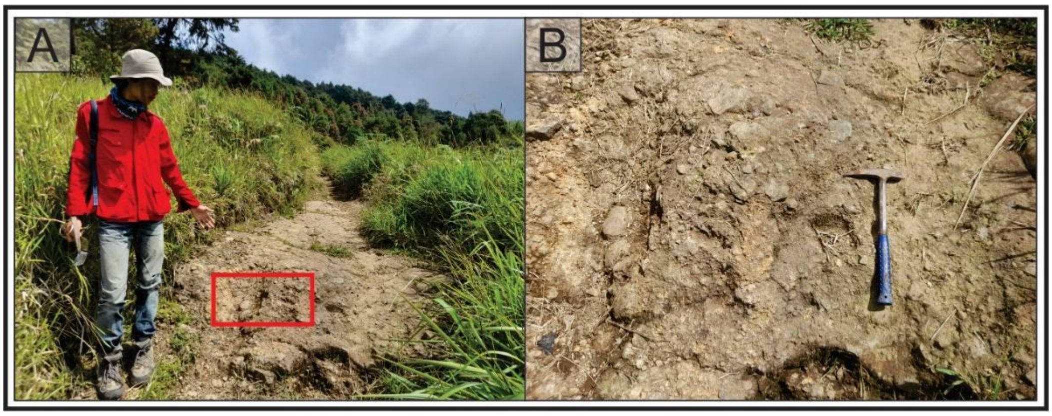

Figure 4. The outcrop view of the Sedringo agglomerate (A and B) with rock fragments consisting of andesite and lithic fragments.

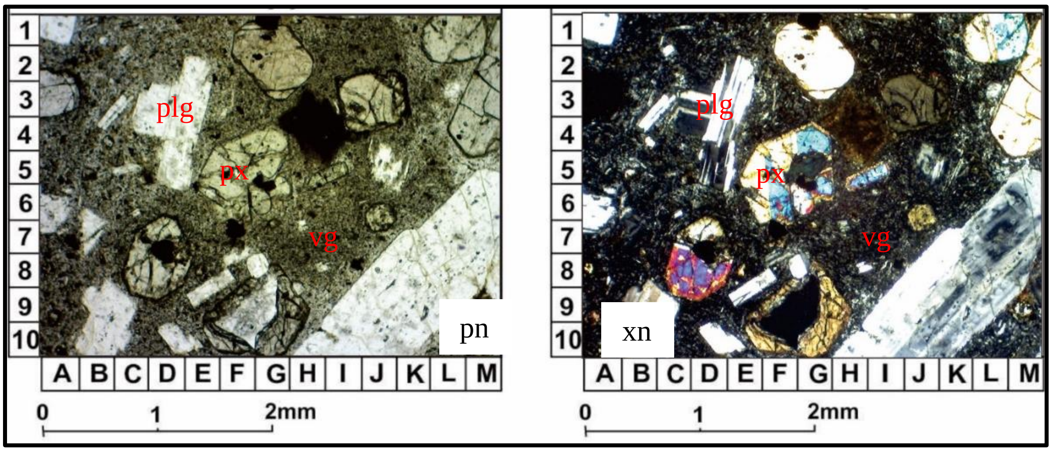

Figure 5. Shows a petrographic section of the pyroxene andesite lava of Sedringo Volcano where plagioclase (plg), pyroxene (px) minerals are present in the volcanic glass groundmass (vg). pn: parallel nicol; xn: cross nicol

Jimat Volcano

The constructive phase at Jimat Volcano is characterized by andesitic lava flows that form steep to very steep volcanic cones. The volcanic eruptions of this volcano have left important records as part of the volcanic evolution of the Dieng complex. Jimat Lava, the lithology commonly found in this unit is igneous rock in the form of andesitic lava that is massively exposed. The lithology found in this unit is generally fresh, with some portions showing weathering. The igneous rock in the Jimat Lava (J2) is characterized by sheeting joint structures and autobreccia structures. Based on petrography analysis (Table 1), the lava (Figure 6) in this unit can be described as follows: hypocristalline; aphanitic to moderately phaneritic; inequigranular, and glomeroporphyritic textures—Plagioclase 70%, pyroxene 10%, and opaque minerals 7% as phenocrysts. The plagioclase composition is Andesine (An49).

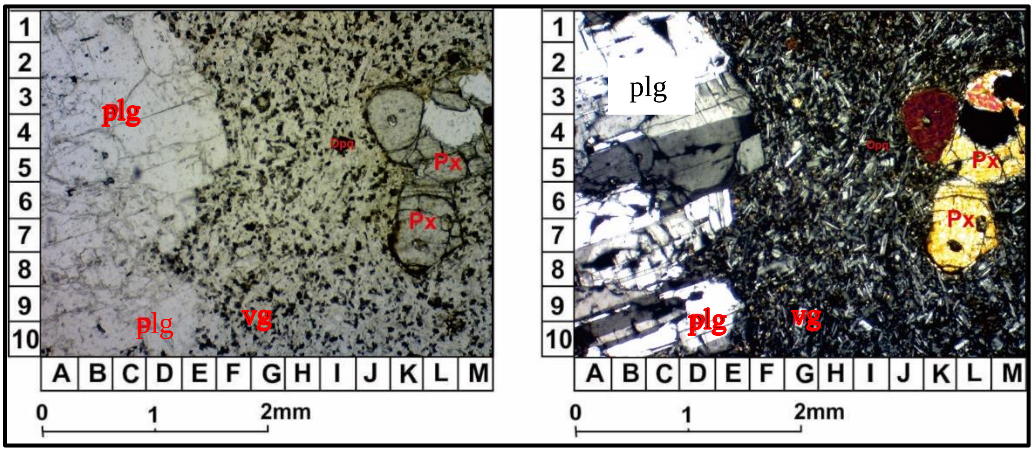

Figure 6. Shows a petrographic section of the andesite lava of Jimat Volcano where plagioclase (plg), pyroxene (px), opaque (opq) minerals are present in the volcanic glass groundmass (vg). pn: parallel nicol; xn: cross nicol

Butak Volcano

Butak Volcano occupies the central and western parts of the study area, characterized by an extensive distribution of volcanic rock units, primarily andesitic lava and pyroclastic flow units. The features of Butak Volcano are a half-caldera structure, reflecting explosive eruption activity and subsequent reintegration of the volcanic edifice in the past. The lithology of Butak Volcano is Butak Andesitic Lava, a unit composed of basaltic lava that is massively exposed. The lithology found in this unit is andesitic lava. Andesitic lava can be described (Table 1) as follows: hypocrystalline, aphanitic to moderately phaneritic, and inequigranular porphyritic, with xenoliths present. It is composed of a groundmass of 25% glass, 62% plagioclase, 8% pyroxene, and 5% opaque minerals. Labradorite-type plagioclase (An59) is a composition of plagioclase. Butak Pyroclastic Flow, the lithology of this unit is dominated by pyroclastic flow lapilli-tuff, with lava blocky fragments (Figure 7).

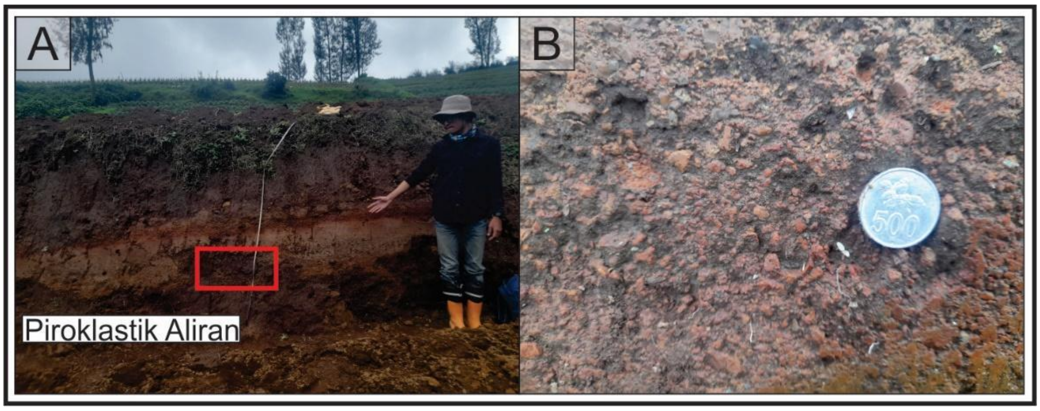

Figure 7. Outcrop view of the Butak Pyroclastic Flow with blocky fragment

Table 1. Petrographic analysis of lava samples and rock fragments of Sedringo Volcano

Sample Code	Rock Name	Rock Type	Lithology Unit	Mineralogy				
				plg	px	hb	opq	vg
A1	Andesite	Fragment	Agglomerate Alang	±	+	+	+	-
A2	Andesite	Lava	Alang Lava	±	+	+	+	-
S3	Pyroxene Andesite	Lava	Sedringo Lava	±	+		+	-
J2	Andesite	Lava	Jimat Lava	±	+		+	-
B3	Andesite	Lava	Butak Lava	±	+		+	-

Note: plg: plagioclase; px: pyroxene; hb: hornblende; opq: opaque; vg: volcanic glass

Evolution of Sedringo Volcano

The eruptive history of Sedringo Volcano is reconstructed as a three-stage cyclical evolution, reflecting the dynamic interplay between magmatic supply, volatile exsolution, and structural instability in an active arc setting. This sequence is discernible through the spatial and stratigraphic relationships among its dominant lithofacies.

1. Early Destructive Phase

The initial activity of Sedringo was characterized by highly explosive eruptions that generated widespread pyroclastic density currents. These deposits, classified as the Sedringo Pyroclastic Flow Unit, consist of poorly sorted lapilli-tuff (grain size: 1–6 mm) with angular andesitic lithics, oxidized clasts, and minor pumice fragments embedded in a coarse vitric tuff matrix. The absence of welding and the presence of massive bedding suggest rapid emplacement under high-energy, gas-rich conditions, typical of Vulcanian to sub-Plinian eruptions (Maeno et al., 2019). This phase likely reflects magma fragmentation driven by high volatile content during early ascent through a fractured conduit system (Lo et al., 2021).

2. Constructive Phase

Following the initial explosive episode, eruptive behavior shifted toward effusive activity, marked by the extrusion of viscous pyroxene andesitic lava (plagioclase An_{59}; 63% phenocrysts). The Sedringo Lava Unit forms a coherent central facies characterized by well-developed sheeting joints and a hypocrystalline groundmass, indicative of slow cooling near the vent. The lava accumulated to build a steep-sided dome or spine complex, acting as both a structural core and a temporary caprock. The transition from explosive to effusive activity suggests a reduction in magma ascent rate or volatile content, allowing degassing and lava extrusion rather than fragmentation (Wadsworth et al., 2022).

3. Late Destructive Phase

The final stage involved renewed explosive activity, culminating in caldera-forming collapse. This phase produced the Sedringo Agglomerate Unit, a coarse, matrix-supported deposit comprising fresh andesitic blocks (2–256 mm) in a tuffaceous matrix. The angularity of clasts, lack of rounding, and minimal sorting indicate proximal, high-energy fragmentation during a violent magmatic or phreatomagmatic explosion (Hencz et al., 2024). The spatial association of these agglomerates with the central lava dome suggests that overpressurization of the conduit, possibly due to renewed magma injection or hydrothermal pressurization, triggered catastrophic failure of the edifice, leading to partial caldera collapse (Gooday et al., 2018).

This tripartite evolution, from explosive onset through effusive construction to terminal collapse, mirrors the cyclic behavior observed in other andesitic stratovolcanoes of the Sunda Arc (e.g., Merapi, Dieng's Butak Volcano) (Pacey et al., 2013). Critically, the juxtaposition of impermeable lava and fractured agglomerate units creates a complex permeability architecture that directly influences hydrothermal fluid circulation (Lamur et al., 2017), making Sedringo not only a record of past volcanism but also a key control on present-day geothermal reservoir geometry.

Volcanic Facies of Sedringo Volcano

Facies refers to the physical, chemical, or biological features of sediments that formed simultaneously. The concept of facies is widely applied in the study of sedimentary rocks and can also be a valuable tool for examining volcanic products (Lee et al., 2021). Facies volcanic (Figure 9) can also be defined as a body of rock adjacent to another body of rock with distinctive and clearly identifiable unifying characteristics (Bogie, 1998). Based on this, the eruption facies of Sedringo Volcano can be divided into two facies: central facies and proximal facies. The explanation of each facies can be explained as follows: Central Facies, characterized by igneous rock associations such as lava domes and various types of subvolcanic intrusions, including volcanic necks, sills, dikes, and cryptodomes (Bogie, 1998). The central facies is dominated by fresh andesitic lava, exhibiting a layered and jointed structure. It is composed primarily of plagioclase and pyroxene minerals. The central facies is formed by the accumulation of effusive magma, resulting in a volcanic edifice dominated by coherent lava that serves as the foundation for the lava dome and the main magma conduit. Agglomerates are also present among the lava. Agglomerates, large andesite fragments that comprise these formations, indicate intense destructive volcanic activity, marking the stage of reconstruction and restructuring that follows a major volcanic eruption (Quah et al., 2023).

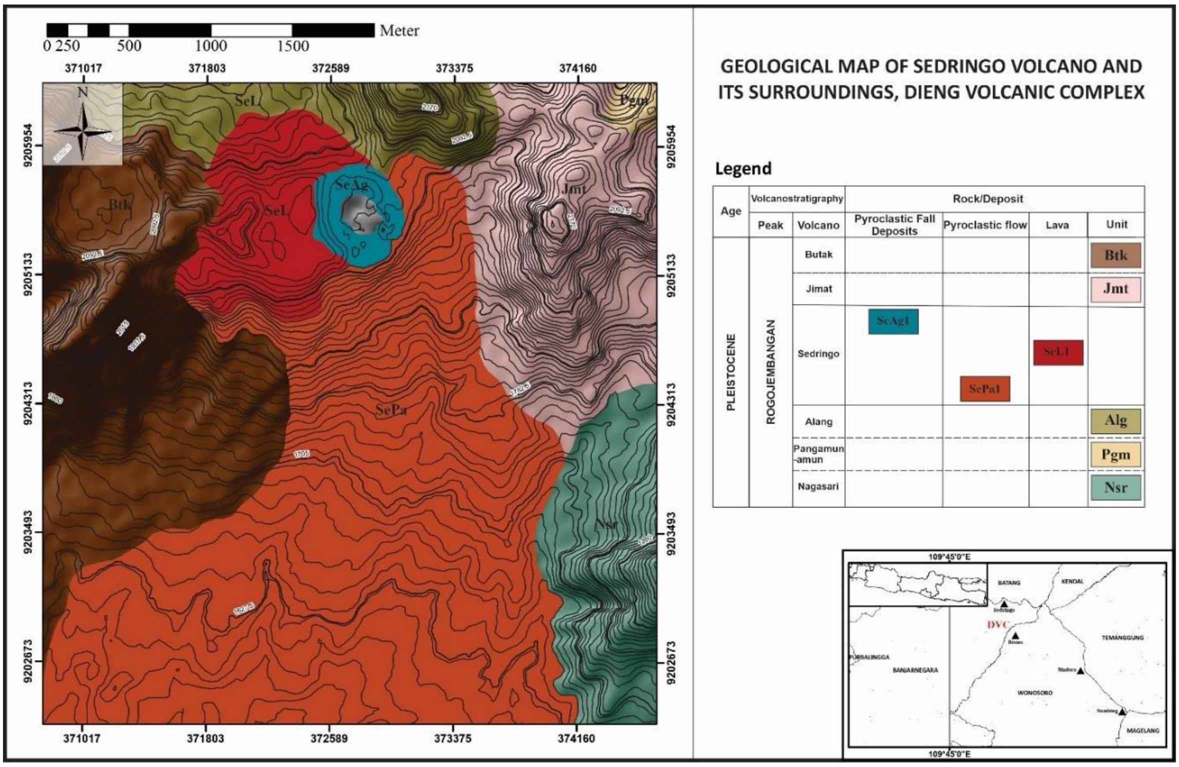

Figure 8. Geological map of Sedringo Volcano and its surrounding

The proximal facies is the facies closest to the central facies. Rocks in the facies share many of the following characteristics: dominated by extensive lava flows, some of which are autobreccia-bedded, interbedded with coarse-grained pyroclastic, and containing poorly sorted pyroclastic breccia; dikes may cut these breccias and typically have moderate to steep initial slopes (Bogie, 1998). The proximal facies is a constructive phase, characterized by pyroclastic material derived from explosive eruptions (Andrade et al., 2023), which dispersed large fragments of andesite and other volcanic rocks on the volcano's slopes. The lithology includes andesite and oxidized lithic fragments dispersed within a coarse tuff matrix, reflecting the intense distribution of eruptive material and marking a destructive phase in the volcanic cycle. These deposits exhibit pyroclastic dispersal patterns that indicate distribution and deposition during explosive eruptions (Paine & Wadsworth, 2025).

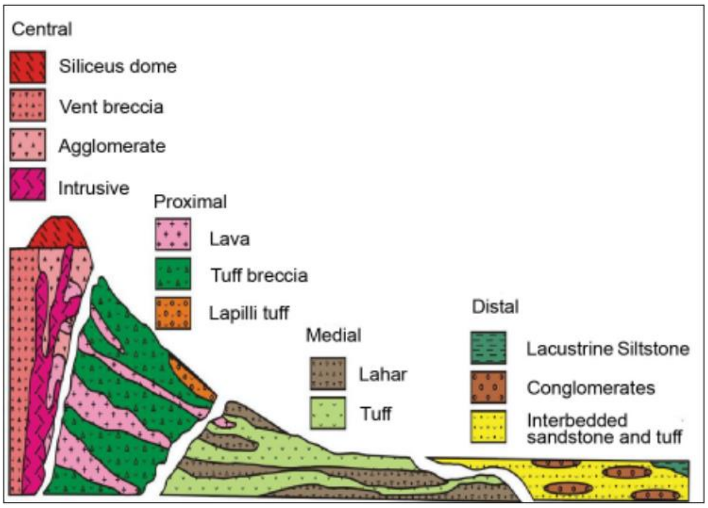

Figure 9. The division of volcanic facies into central facies, proximal facies, medial facies, and distal facies along with the composition of their constituent rocks (Bogie, 1998)

CONCLUSIONS

This study set out to delineate the volcanic facies architecture of Sedringo Volcano within the Dieng Volcanic Complex through integrated geological mapping, petrographic analysis, and stratigraphic correlation. The results confirm a three-stage eruptive evolution: (1) an early destructive phase dominated by poorly sorted lapilli-tuff pyroclastic flow deposits; (2) a constructive phase marked by the emplacement of massive, plagioclase-rich (An_{59}) andesitic lava forming a central facies with sheeting joints; and (3) a late destructive phase characterized by coarse agglomerates (2–256 mm) embedded in a tuff matrix diagnostic of caldera-forming collapse. This cyclical transition from effusive to explosive activity underscores the dynamic interplay between magma viscosity, volatile content, and structural instability in shaping the edifice.

The spatial juxtaposition of coherent lava and unconsolidated pyroclastic units has direct implications for geothermal exploration in the Dieng region. The central facies provides a potential caprock for high-enthalpy reservoirs, while the fractured agglomerate zones may serve as permeable conduits for hydrothermal fluid circulation. Conversely, the presence of fresh, unaltered agglomerates and steep slopes indicates ongoing volcanic instability, necessitating an update to hazard zonation, particularly given the proximity to active geothermal infrastructure, such as *Sileri* and *Candradimuka*.

In sum, this work not only establishes the first comprehensive facies model for Sedringo Volcano but also provides a geologically grounded framework to guide sustainable geothermal development and volcanic risk mitigation in one of Indonesia's most active geothermal provinces.

LIMITATIONS & FURTHER RESEARCH

Despite its contributions, this study is limited to surface-based facies mapping and lacks subsurface validation (e.g., borehole data, geophysical imaging). Future research should integrate remote sensing (e.g., InSAR for ground deformation monitoring), geochemical modeling of hydrothermal alteration minerals, and 3D geological modeling to link surface facies with reservoir architecture. Additionally, dating of key units (e.g., via Ar-Ar or U-series) would refine the eruptive chronology and improve probabilistic hazard forecasting.

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