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FLOW DYNAMICS OF UNSTEADY PYROCLASTIC DENSITY CURRENTS (PDC) FROM SUNDA IGNIMBRITE, WEST JAVA, INDONESIA

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ABSTRACT

Sunda Volcano is the one of several volcanoes in Indonesia which produced ignimbrite deposit from caldera forming eruption. Depending on the volume and considerable thickness of the deposits, Sunda ignimbrite might has been deposited with a variety of flow mechanisms. Heterogeneous deposition mechanism will heavily controlled by numerous parameters such as velocity, rheology, types of flow-boundary zone, or pre-existing topographic influence. According to the deposition parameters, Pleistocene Sunda ignimbrite transportation and deposition mechanisms are still unclear. Here we show detailed observations of each facies and the Unconformity Bounded Stratigraphic Units (UBSU) approach to determine the flow sub-units and flow mechanism of the Sunda ignimbrite. Overall, we found that Sunda ignimbrite consists of five different facies. Forestepping stacking pattern from Sunda ignimbrites also observed from stratigraphic correlation indicates that energy instability occurred during transport and deposition in the PDC. Waxing energy of PDC which occured is caused by the development of granular-flow and fluid-escape dominated flow-boundary zone at the base and body of emplaced PDC. Our results demonstrate how Sunda ignimbrite emplacement mechanism can be affects by pre-existing topography which developed during the effusive eruption of Sunda Volcano. Furthermore, we also found that Sunda ignimbrite deposition has been changed the topography into the gentler relief due to this forestepping pattern of each ignimbrite units. The study of Sunda ignimbrite facies can reveal suitable hazard mitigation and also use to characterize heterogenity in groundwater aquifers and geothermal reservoirs. Moreover, detailed facies analysis and UBSU could give us informations on how explosive eruption at 0.205 M.a take places on the southern flank of Sunda Volcano.
***Keywords** : Ignimbrite, Sunda Volcano, Pyroclastic Flow*

ABSTRAK

Gunungapi Sunda adalah salahsatu daari banyak gunungapi di Indonesia yang menghasilkan ignimbrit dari erupsi pembentukan kaldera. Berdasarkan besar volume dan ketebalan dari endapannya, ignimbrit Sunda kemungkinan terdeposisi dalam mekanisme aliran yang bervariasi. Mekanisme deposisi heterogen ini akan sangat dikontrol oleh beberapa parameter seperti kecepatan, rheologi, tipe *flow-boundary zone*, atau pengaruh topografi sebelum pengendapan terjadi. Merujuk pada parameter-parameter tersebut, mekanisme transportasi dan deposisi dari ignimbrit Sunda pada Pleistosen belum dipahami dengan baik. Pada artikel ini, observasi detil dari setiap fasies ignimbrit Sunda serta pendekatan *Unconformity Bounded Stratigraphic Units* (UBSU) disajikan untuk menentukan sub-unit dan mekanisme aliran yang terjadi pada deposisi ignimbrit Sunda. Secara keseluruhan, kami menemukan bahwa ignimbrit Sunda tersusun atas 5 fasies yang berbeda. Pola penumpukan *forestepping* juga teramati sebagai indikasi adanya ketidakstabilan energi saat transportasi dan deposisi PDC. Peningkatan energi yang terjadi pada PDC disebabkan oleh berkembangnya *flow-boundary zone* berjenis *granular* dan *fluid-escape* di bagian dasar serta tubuh aliran PDC. Hasil yang kami temukan menunjukkan bagaimana mekanisme transportasi dan deposisi ignimbrit Sunda dapat dipengaruhi oleh topografi yang berkembang akibat erupsi efusif yang telah terjadi sebelumnya. Selain itu, kami juga menemukan adanya perubahan topografi menjadi lebih landai setelah adanya deposisi ignimbrit Sunda yang disebabkan oleh pola penumpukan *forestepping* dari setiap unit ignimbrit. Penelitian dari setiap fasies ignimbrit Sunda dapat mengungkap metode mitigasi bencana yang cocok serta dapat juga digunakan untuk mengetahui heterogenitas dari batuan yang menjadi akuifer airtanah dan reservoir geotermal. Selebihnya, analisis fasies dan pendekatan UBSU dapat memberikan informasi bagaimana

erupsi eksplosif pada 0.205 juta tahun lalu terjadi pada lereng bagian selatan Gunungapi Sunda.
Kata Kunci : Ignimbrit, Gunungapi Sunda, Aliran Piroklastik

Introduction

Ignimbrite is one of several explosive eruption products produced by a volcano. This volcanic product is formed by a pyroclastic density current caused by the collapse of an eruption column, lava dome collapse, or a horizontal blast (Branney & Kokelaar, 2002). The pyroclastic density current has a heterogeneous forming mechanism that is controlled by flow parameters (i.e., velocity and rheology), segregation of rock fragments, differences in flow habit at the flow-boundary zone, flow instability, topographic influence, and the current's deposition-erosion mechanism. All of these mechanisms were observable in the present structures of each ignimbrite facies (Branney & Kokelaar, 2002).
Numerous volcanoes in Indonesia has produced ignimbrite as a result of a large-scale eruption. Sunda Volcano in West Java is one of them. This volcano's catastrophic eruption leaves a caldera morphology on the western side of Tangkuban Parahu Volcano. Furthermore, the ignimbrite was produced in large quantities and with a significant thickness of about 80-180 meters during this eruption (Nasution et al., 2004). Sunda ignimbrite may have been deposited by a variety of flow mechanisms, depending on the volume and significant thickness of the deposits. Each vertical and horizontal facies succession change must be recorded to comprehend this situation. Facies succession of Sunda Ignimbrite could give information on how the palaeo-topography can modify the PDC emplacement.
In this study, detailed observation of the PDC deposition mechanism is not only used for understanding the past eruptions, but disaster mitigation is heavily reliant on the availability of knowledge on the dynamics of complex PDC transportation and depositions. This paper will present detailed observations on the facies analysis as well as the reconstruction of the internal architecture of Sunda ignimbrite through the unconformity bounded stratigraphy unit (UBSU) approach, implying to define the stratigraphic position and lateral distribution of Sunda ignimbrite regionally. In addition, an understanding of flow behavior generated from the explosive eruption of Sunda Volcano at 0.205 M.a will be revealed to understand the distribution of PDC, which has an implication to the groundwater reservoir within the Bandung Area.

Geological Setting

Sunda Volcano is the result of a subduction process that occurred in the southern side of Java Island (Hamilton, 1979)(Figure 1a). This subduction results in the formation of Sunda Arc volcanism, which extends from the western side of Sumatra to the island of Flores(Sendjaja et al., 2009). According to seismic data, the volcanic arc is evidence of subduction between the Indo-Australian Plate and the Eurasian Plate at a depth of up to 600 km (Ghose et al., 1990; Puspito & Shimazaki, 1995; Sendjaja et al., 2009; Widiyantoro & Van Der Hilst, 1997). Sunda Volcano erupted products are deposited above tuffaceous marl from the Neogene Citalang Formation in the region (Silitonga, 1973).
Previously, basalt lava flows were produced during the Pre-Sunda volcanism period (Figure 1b). Based on the measurements, the age of this lava flow is 1.105 million years ago (Sunardi & Kimura, 1998). Following the effusive eruption, the caldera formation occurred, resulting in a pyroclastic flow deposit of scoria fragments known as Cisarua ignimbrite (Kartadinata, 2005).
The Sunda period's volcanism began 0.560-0.205 million years ago (Sunardi & Kimura, 1998). The Sunda Volcano had three primary bodies during this period of volcanism: Sunda, Burangrang, and Tangkuban Parahu (Nasution et al., 2004). Initially, the Sunda volcanism period began with an effusive eruption producing basalt lava (Figure 1b). Then, at the age of 0.205-0.18 million years ago, an eruption related to caldera formation occurred (Nasution et al., 2004). The explosive eruption caused Manglayang ignimbrite deposition to spread widely to the northeast and south of the caldera wall (Angkasa et al., 2019)(Figure 1c).
Furthermore, Tangkuban Parahu volcanism began 0.09 million years ago (Kartadinata et al., 2002). This eruption period is characterized by magmatic, phreatomagmatic, and phreatic eruptions as well as effusive eruptions in the form of basalt lava flows aged 0.04 million years ago (Angkasa et al., 2019; Sunardi & Kimura, 1998)(Figure 1b). This period of volcanism continues to the present day, as evidenced by the hydrothermal activities at the crater's rim (Angkasa et al., 2019).

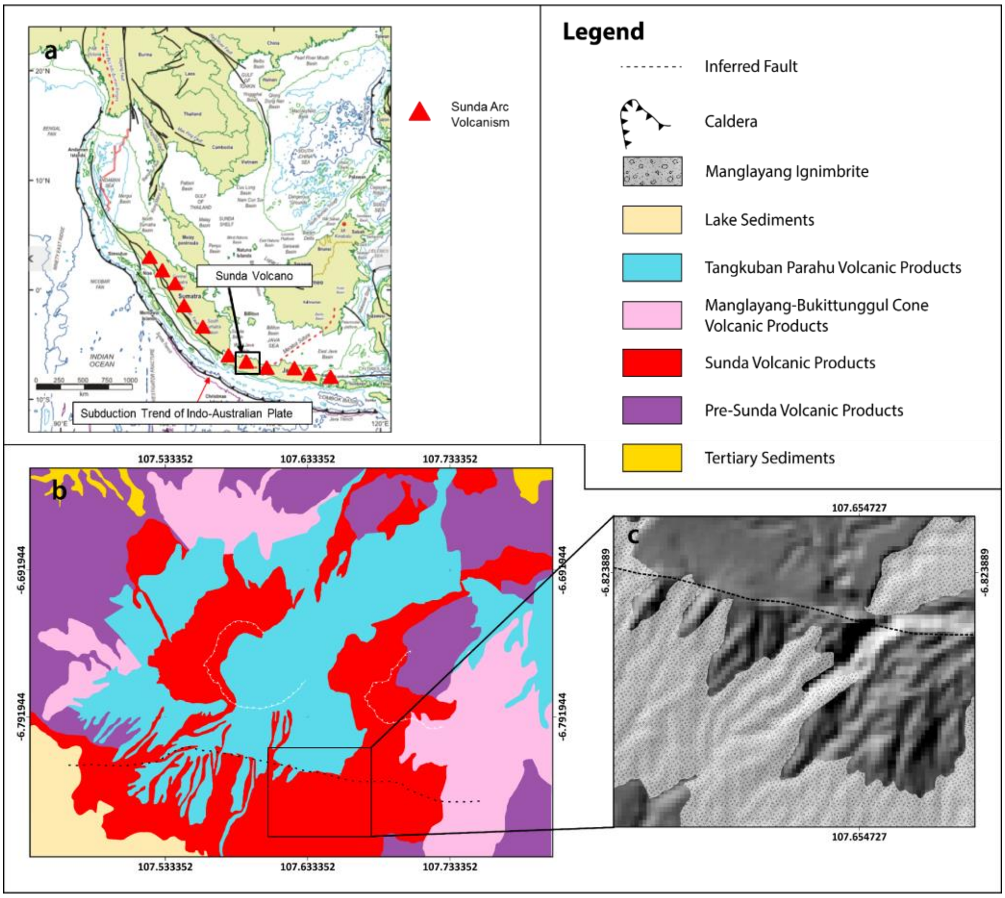

Fig. 1 Map showing the location of Sunda Volcano (modified from Hall, 2012) along with a simplified geological map (modified from Soetoyo & Hadisantono, 1992) on the studied area at Northern Bandung, West Java.

Fieldwork Method

Fieldwork was conducted within the area of 40 km^2 at Cimenyan, Bandung, where we identified most of the distribution of Sunda pyroclastic deposits based on (Soetoyo & Hadisantono, 1992). We observed volcanic succession on a single ignimbrite lobe (107.605491 to 107.625145, -6.839016 to -6.868024) from 801 masl to 1082 masl to understand the depositional system on a detailed vertical succession. Outcrops were observed based on their physical characteristics of volcanic deposits in (Cas & Wright, 1987) such as type of deposits, size and shape of fragments, sortation, and fabric. Moreover, we utilized those characteristics to understand the emplacement of volcanic products by the eruption (McPhie et al., 1993). The stratigraphic correlation was defined by our finding on lithological and emplacement structures on each volcanic facies (e.g. Báez et al., 2020; Giordano, 2005; Rita et al., 1998). Furthermore, fluid dynamics on the emplacement of pyroclastic rocks were interpreted based on our understanding of this similar study elsewhere in (Branney & Kokelaar, 2002).

Pre and Post-Depositional Topography

This region was covered by effusive eruption products in the form of lava flow before the Sunda ignimbrite was deposited on the southern flank of the Sunda Volcanic body. Hills created by lava flow products have slopes ranging from 16° to 35°. The topography of the southern flank region is quite elevated at 1000-1500 meters above sea level (masl) and has rough topographical relief. The stream pattern that emerged in this location is characterized by a parallel pattern that is co-vertical erosion controls valleys, causing them to become deeper and more constrained by lava flow walls.

Topographical rises formed during Sunda ignimbrite deposition have a slope of 0°-4°. The topography of these hills is gentler than that of the lava flow product. Sunda ignimbrite deposition has transformed the stream pattern into a sub-parallel pattern in which the valleys have not been extensively degraded.

Facies Analysis and Interpretation

Sunda ignimbrite consists of five main major facies, which crop out at lower topographic regions. We observed many pyroclastic density currents at eight sections within the 1.68 km traverse section at 908 to 1028 meter-above-sea-level (masl). The observed section mainly consists of pyroclastic breccia deposits. Cross stratified lapilli tuff is commonly observed on the lower section of pyroclastic breccia. On several observed sections, laminated ash deposit mostly found along with accretionary lapilli, which is situated below the pyroclastic breccia. Here, we provide a qualitative description and interpretation of the pyroclastic density currents within the observed section.

Massive Lapilli Tuff (mLTacc)

mLTacc displays a massive structure and is mainly observed at location IL-15-2. mLTacc mainly consists of lapilli and tuff deposits. Accretionary lapilli and pumice were commonly observed in the mLTacc and occurred with coarsening upward with a thickness of 1-2 centimeters (cm) (Fig. 2a). The first facies mainly consist of lapilli and tuff deposits, indicating poor fragment sortation. Accretionary lapilli and pumice fragments are commonly found in volcanic products with a thickness of <2 cm.

Interpretation

The lack of stratification and poor sorting of the mLTacc facies indicate that deposition occurs at a transitional state from granular-flow dominated flow-boundary zone to fluid-escape dominated flow-boundary zone where fragment segregation will not occur due to fragment reorientation by the flow body (Branney & Kokelaar, 2002). The absence of gas elutriation pipe on the mLT facies is associated with the presence of pumice fragments (Báez et al., 2020). Poor sorting of pumice particles restricts flow movement of mass and causes gas and ash material to disappear through flow-boundary zones (Báez et al., 2020).

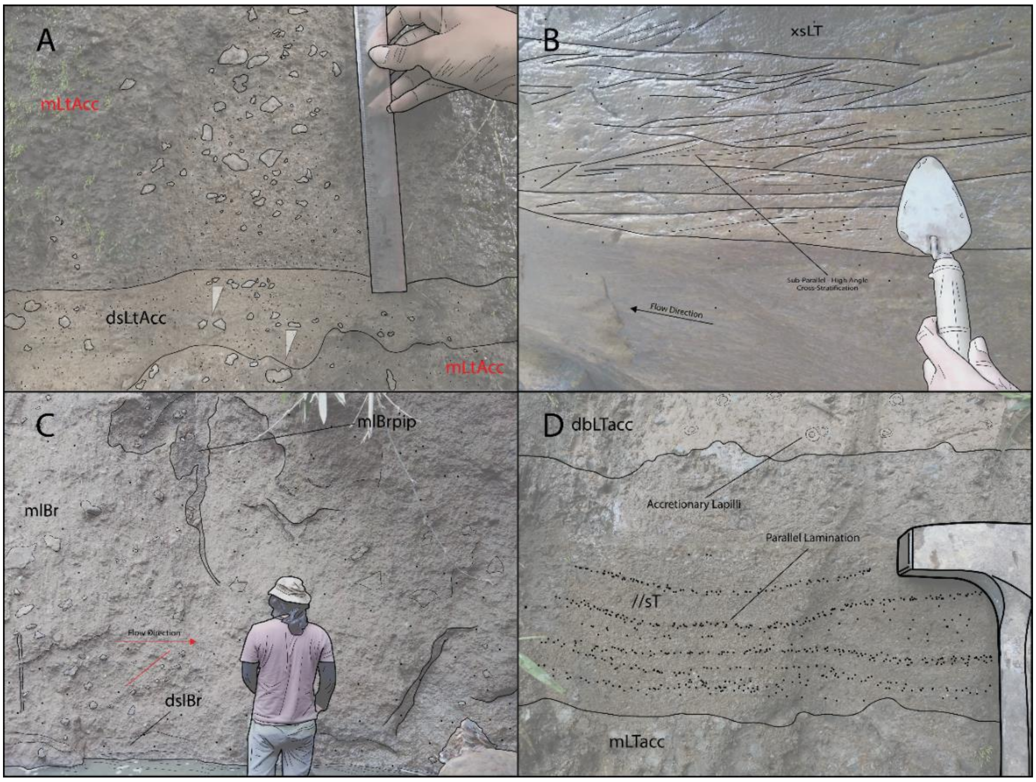

Fig. 2 Lithofacies of Sunda ignimbrite, **(a)** diffused-stratified Lapilli Tuff (dsLTacc) showed multiple reverse gradded bedding between massive Lapilli Tuff(mLTacc) layers which consists of grey pumice, lithic, and accretionary lapilli fragments, **(b)** sub-parallel to high-angle cross-stratification within xsLT facies, **(c)** 3 different types of breccia: diffused stratified (dslBr), massive (mlBr), and elutriation gas pipe (mlBrpip), **(d)** parallel stratified Tuff (//sT) layer between mLTacc and dbLTacc facies.

Diffuse Stratified dan Bedded (dsLT, dbLTacc)

Diffuse Stratified and Bedded (dsLT, dbLTacc) at IL-15-2 is typically distinguished by the presence of repetitive reverse grading structure (multiple grading) with a thickness of 5-10 centimeters (Fig. 2a). Lapilli to ash-sized grey pumice fragments makes up the dsLT facies. Pumice fragments sort well, and their forms range from sub-rounded to sub-angular.

Intergradational fabric with mLT facies was identified in the diffuse stratified and bedding facies, with sharp or subtle contacts on the top and bottom of the bedding. The predominant composition of these facies is accretionary and armored lapilli seen in dbLTacc. Accretionary lapilli in dbLTacc has a parallel orientation in the center of beds.
Interpretation
The reverse grading structure in the dsLT facies indicates that waxing energy occurs during transportation. Waxing energy can increase the velocity or concentration of materials. Fluctuating velocity and material concentration values cause the flow-boundary zone to shift from granular flow to fluid-escape dominance. Another possibility is that turbulence flow occurs in the flow-boundary zone, causing unsteadiness in PDC transportation (Branney & Kokelaar, 2002).

Cross Stratified (xsLT)
Stratified tuff facies (xsLT) represented centimeters-scale sub-parallel stratification of about 15°-30° with direction to the south (Fig. 2b). xsLT at location IL-19-1, IL-19-3, IL-19-4, IL-19-6, and IL-19-7 primarily consist of ash to lapilli fragment which has good sorting with sub-rounded to sub-angular fragment shape. The xsLT facies show a significant thickness of about 1-1.5 meters (m) with irregular contact at the base and top of the deposit.
Interpretation
These facies may have been deposited under a traction-dominated flow barrier with a high slope angle, based on cross-stratification. The presence of accretionary lapilli shows that the facies was emplaced in a moist environment with a water content temperature of 100˚C (Branney & Kokelaar, 2002).

Massive to Stratified Lithic Breccia (mlBr, mlBrpip, dslBr)
Massive to Stratified Litchic Breccia facies composed of cognate lithic and scoria fragments with 5-10 cm in diameter. These facies consist of mlBr, mlBrpip, and dslBr which have different characteristics of their texture and internal structure. Three different types of breccia have been observed at location IL-19-6. In general, massive to stratified lithic breccia has poor sorting of fragments and is clast-supported with less matrix composition.
At the base of the deposit, we observed that dslBr occurs within the outcrop. dslBr facies in this outcrop shows reverse grading structure of cognate lithic fragment. Reverse grading structure for dslBr deposit gradually becomes pinched and disappears. The vertical section shows the deposit of dslBr changing into massive lithic breccia (mlBr) that displays fragment segregation of about ±45° to the south (Fig. 2c). mlBr deposits mainly consist of lithic blocks with subangular-angular in shape. Elutriation gas pipe structure that is found at the top of the deposit has an irregular shape 5-10 centimeters (cm) of spacing and is filled with lithic fragments (Fig. 2c).
Interpretation
Volcanic fragments consist of bombs and blocks, which possibly emplaced from volcanic debris during an eruption, caldera collapse, and erosion of the previously deposited PDC (Branney & Kokelaar, 1994; Moore & Kokelaar, 1998). Parallel stratification at the lower section of facies may indicate PDC bodies flowing within the transition between granular flow-dominated flow-boundary zone to fluid escape-dominated flow-boundary zone. Gas releasing process which occurs from mLT facies which lied below mlBr causing elutriation pipe gas formed. The absence of fine-grained matrix inside the elutriation pipe gas reflected this gas releasing process which suppresses the matrix out from the pipes.

Parallel Stratified (//sT)
At IL-15-2 and IL-19-1, parallel stratified tuff (sT) is frequently encountered intermittently between massive lapilli tuff (mLT) and diffuse stratified lapilli tuff (dsLT). //sT facies is primarily formed of coarse to fine ash fragments. This facies features a parallel lamination structure within a bed thickness of 5-10 centimeters and a horizontal sharp contact in the top and lower parts of the deposit (Fig. 2d).

Interpretation
Facies were deposited by direct fallout-dominated processes within the flow-boundary zone of fully diluted Pyroclastic Density Current (PDC) (Branney & Kokelaar, 2002), where the velocity of PDC is very high and without any traction flows on the system. This type of flow-boundary zone can be generated when the flow velocity is very high where the deposition rate is strong enough to suppress the formation of the traction mechanism (Arnott & Hand, 1989).

Stratigraphic Correlation
The stratigraphic cross-section correlation performed at 8 observation outcrops reveals the presence of three pyroclastic flow units that comprise the Sunda ignimbrite. The stacking pattern of forestepping was observed in all three flow units. The three flow units are constrained by a second-order unconformity between the dsLT or mLTacc facies and the xsLT facies. Each flow unit is

made up of three flow sub-units: the base, the body, and the top of the flow (Fig. 1a-1c).

Discussion

Internal Architecture of Sunda Ignimbrite

Stratigraphic correlation shows inferred geometry of Sunda ignimbrite at the southern flank of its eruption center which has a steep to the very steep slope. The valley gradually sloped gently during the deposition of Sunda ignimbrite. Second-order unconformity displays forestepping stacking pattern from each flow sub-unit of Sunda ignimbrite (Fig. 2a). This forestepping pattern is generated from an enhancement of supply rate (Rs). The increase in the supply rate (Rs) in the Sunda ignimbrite sedimentation is always in contrast to the deposition rate (Rd), where the deposition rate (Rd) is less than the supply rate (Rs), as shown by a decrease in the thickness from each base layer of sub-unit flow (Branney & Kokelaar, 2002).

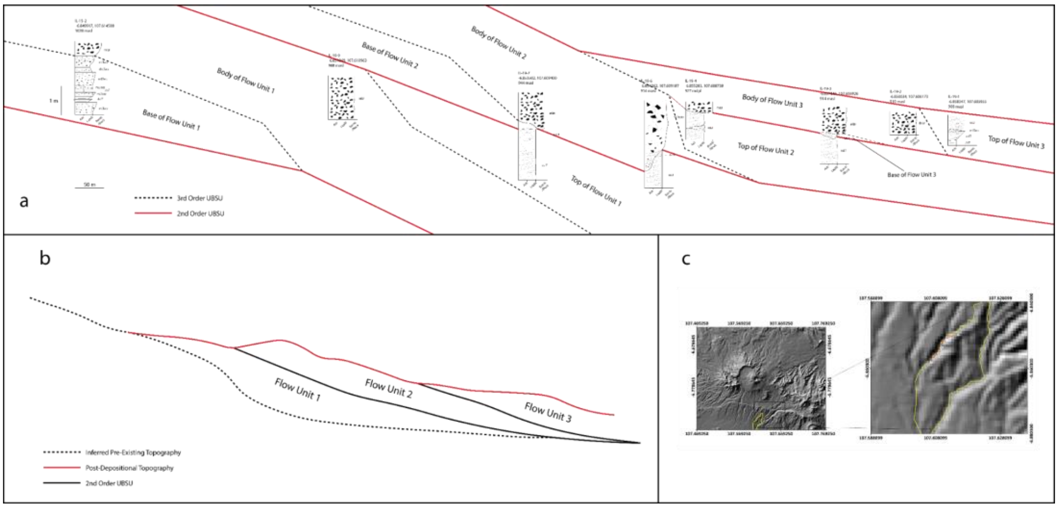

Fig. 3 Stratigraphy correlation of 8 outcrops from Sunda ignimbrite that shows 3 sub-unit flows **(a)** interpretation of topographical changes caused by the deposition of each sub-unit flows **(b)**, section map of each observed outcrops **(c)**.

The clinoform geometry formed during Sunda ignimbrite deposition is the result of a forestepping accumulation pattern of flow material controlled by topography (Fig. 3b). PDC material will continue to be sedimented and suspended indefinitely, depending on the slope where the PDC was deposited (Bagnold, 1962; Pantin, 1979; Parker et al., 1986; Gerber et al., 2008;).

Each sub-unit of the Sunda ignimbrite flow moves valleyward only if the foreset of the clinoform has a steep enough slope to increase mass and flow velocity while passing and eroding the foreset continuously (Gerber et al., 2008). The vertical succession displaying the forestepping stacking pattern as well as the clinoform geometry in each Sunda ignimbrite flow unit is interpreted as the result of waxing energy during PDC deposition. The second-order unconformity that limits each flow unit reveals this stacking pattern. This unconformity can be directly linked to energy instability within the same. eruption pulse (Giordano, 1998; Rita et al., 1998)

Flow Dynamics

Flow instability which occurs at the base of sub-unit flow 1 was marked by the presence of dsLT facies. The presence of dsLT noted that the initial flow of PDC was in a granular-flow dominated flow-boundary zone condition (Branney & Kokelaar, 2002). mLTacc facies which occur intermittently with dsLT facies proves that flow-boundary zone fluctuates to fluid-escape dominated flow-boundary zone along with deposition of PDC materials (Fig. 4). The thin sheet of //sT (Parallel stratified Tuff) facies between dsLT and mLTacc interpreted as a result from stable energy of material transportation where velocity and particle density has a constant value causing laminar flow condition formed within high velocity. The base of each sub-unit flow is interpreted as a 'ground surge' deposit where the PDC is still transported in chaotic nature. Fluctuating condition of the flow-boundary zone may be caused by collapsing of eruption columns that generate high gas pressure which penetrates forward movement of PDC material to the head of initial flow (Sparks et al., 1973; Wilson, 1980; Wright et al., 1980; Valentine et al., 1989; Fisher et al., 1993; Dellino & La Volpe, 2000; Rowley et al., 2014).

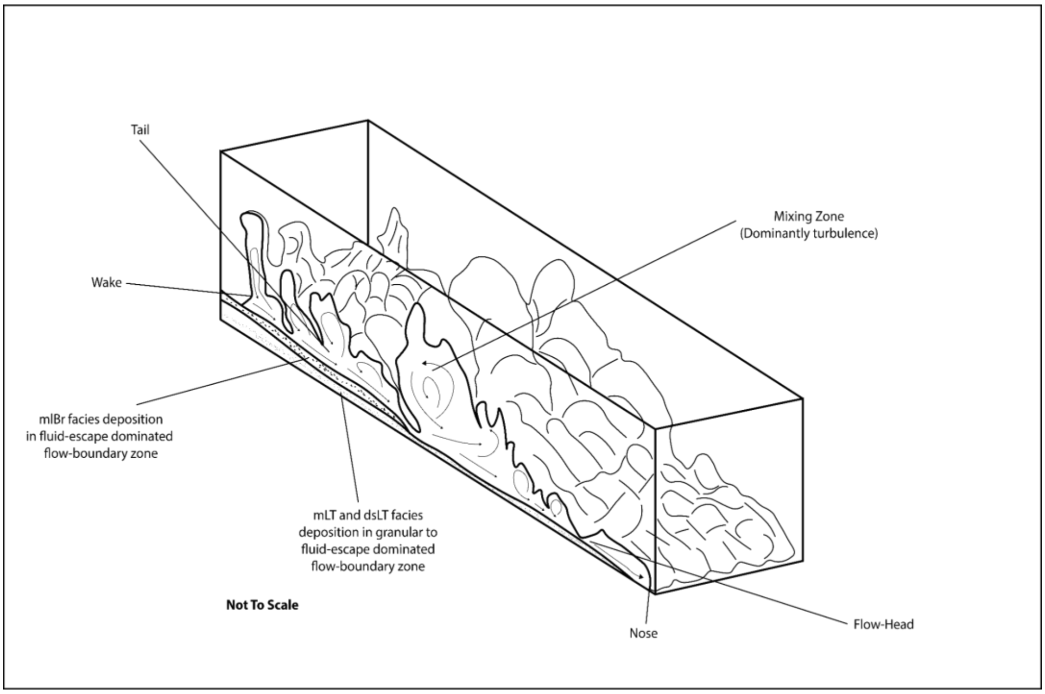

Fig. 4 Block model of Sunda PDC transportation which shows 3 different types of flow-boundary zone and emplacement mechanism.

In sub-unit flow 2, we do not observe the presence of mLTacc facies at the bottom of the unit. The absence of mLT facies may be related to a rapid change of flow-boundary zone from granular-flow dominated FBZ to fluid-escape dominated FBZ without transition. This rapid change of FBZ was recorded in dslBr facies at the base of the flow body of sub-unit flow 2.

mlBr facies deposition within the body of PDC sub-unit low indicates the fluid condition is fully changed into fluid-escape dominated flow-boundary zone which supports fragments segregation at the distance of about ±6 kilometers (km) from the eruption center (Báez et al., 2020). Sedimentation occurs at the proximal area primarily controlled by fluid-escape dominated flow-boundary zone where the energy becomes increased along with fragments accumulation inside the PDC body (Fig. 4). High fluidization in this type of flow-boundary zone causing block-sized lava fragments well deposited at the proximal area. Depletion of mlBr facies thickness to the distal area may reflect a low aggradation rate from the deposition process. Heat expansion process during emplacement process was recorded by the occurrences of elutriation gas pipe structure at the top of mlBr layer

Implication

An explosive eruption occurred 0.205 million years ago, causing significant changes in the topography that passed by Sunda PDC. The Sunda ignimbrite deposition mechanism described in this paper can be used as a reference for volcanic disaster mitigation if an explosive eruption produces PDC with unstable flow characteristics on relatively steep slopes (16°-55°). The increase in PDC energy that develops in an unstable flow can cause widespread destruction throughout the valley through which the PDC passes. The significant thickness of the mlBr facies implies that PDCs with similar characteristics to the Sunda ignimbrite transport not only ash materials but also block-sized fragments of angular lava fragments capable of effectively destroying settlements throughout the valley. The deposition of Sunda ignimbrite with a moderately moist atmosphere does not reduce the level of danger from the PDC that carries the material.

Despite substantial potential dangers, the Sunda ignimbrite depositional model can be utilized as a reference for groundwater aquifer and geothermal fluid reservoir exploration. According to the depositional model, groundwater aquifers and geothermal reservoirs formed of Sunda ignimbrite have heterogeneous rock properties.

Conclusion

The deposition of Sunda ignimbrites 0.205 million years ago caused changes in the surface topography in the southern valley of the Sunda Volcano's body. The steep slopes caused by the emplacement of Sundanese lava flows descending coupled with the transit of PDC caused by the Sunda Volcano's explosive eruption. The distinctions in parallel river flow patterns in the lava flow ridge and sub-parallel patterns in the Sunda pyroclastic flow ridge reveal the topographic change that occurs.

Sunda ignimbrites are developed in unstable PDCs, according to the results of internal architectural reconstruction, detailed facies analysis, and the use of unconformity bounded stratigraphic units (UBSU) principles. The second-order unconformity that restricts the three PDC flow subunits records the occurrence of PDC flows from the same eruption column. Waxing energy from the Sunda eruption generates a forestepping accumulation pattern, with each flow sub-unit deposited distally. The presence of the dsLT, mLT, mlBr, and xsLT facies indicates the energy instability that occurs during Sunda ignimbrite deposition. There are at least three types of flow-boundary zones that formed during the deposition of Sunda ignimbrite: granular-flow dominated, fluid-escape dominated, and traction-flow dominated. From the bottom to the top of the PDC, the three flow-boundary zones change gradually. Sunda ignimbrite deposition takes place in a moist environment with an ambient temperature of 100˚C. Because of the moderately wet environmental conditions, accretion and armored lapilli formed in the mLTacc and dbLTacc facies near the bottom of flow sub-unit 1, which is in direct contact with the surface. Aside from the mLTacc and dbLTacc facies, moist environmental circumstances were recorded by the xsLT facies deposition with a steep cross-stratification angle, showing that deposition under traction conditions occurred intensively in the mixed flow PDC zone.

We also saw the gas escape from the mlBr facies, which was recorded by the existence of the elutriation gas pipe structure. The gas released in the mlBr facies is the gas retained during sedimentation in the fluid-escape dominated flow-boundary zone. When gas is released, ash-sized fragments are pushed out through the created gas pipes.

Moreover, the Sunda explosive eruption 0.205 million years ago can serve as a model for excellent mitigation if an eruption with a similar mechanism to the Sunda PDC flow occurs again in the future on hills with slopes of 16°-55°. Increased energy in PDCs with internal structures comparable to Sunda ignimbrites can be much more destructive considering bomb and block-sized fragments carried during PDC transportation could even effectively destroy settlements around the valleys they pass through. Understanding the deposition mechanism of Sunda ignimbrite can provide us with a clear picture of the potential for groundwater aquifers and geothermal reservoirs in PDC deposited rocks, where the characteristics of aquifers and reservoirs in these rocks will be heterogeneous, ranging from breccias to ash-sized pyroclastic rock.

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