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Explosive Signature of The April 30th, 2024 Ruang Volcano Eruption in The Sangihe Arc, Indonesia, Inferred from Erupted Material Characteristics: A Preliminary Assessment

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Abstract - The 2024 eruptions of Ruang Volcano in North Sulawesi, Indonesia, represent one of the most explosive and impactful volcanic events in the region's recent history. The eruption sequence, which commenced on April 16th and peaked with significant explosive episodes on April 17th and 30th, resulted in the evacuation of over 9,000 residents and demonstrated the volcano's capacity for high-energy eruptive activity. This preliminary analysis of the April 30, 2024, Ruang Volcano eruption emphasises the importance of ejected materials—such as high-vesicular juvenile fragments, crystal-rich components, and megacrysts of amphibole (hornblende)—in revealing the eruption's explosive signature. Geochemical analysis of juvenile materials indicates a basaltic andesite composition, with SiO_2 contents ranging from 53.02% to 54.27%. Petrographic examination and SEM observations reveal high vesicularity, ruptured bubble walls, and microlite-rich groundmass textures, indicative of rapid ascent and intense degassing, which facilitated efficient magma fragmentation. These features suggest that the magma underwent rapid decompression. Understanding these properties provides important clues about the mechanisms underlying the explosiveness of the Ruang eruption.

Keywords: Ruang Volcano, Sangihe, Sulawesi, juvenile, megacryts amphibole, crystal-rich

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Introduction

Ruang Volcano, also called as Duang or Duwang, is a stratovolcano situated in The Sangihe-Talaud Archipelago, North Sulawesi, Indonesia. It lies at an elevation of 725 m above sea level, and is geographically located at 2°19′18.30″ N and 125°24′30.42″ E (Figure 1). The volcano is administratively part of Tulusan Village, Tagulandang Subdistrict, Sitaro Regency.

Ruang Volcano is part of the Sangihe volcanic arc, which extends approximately 500 km from

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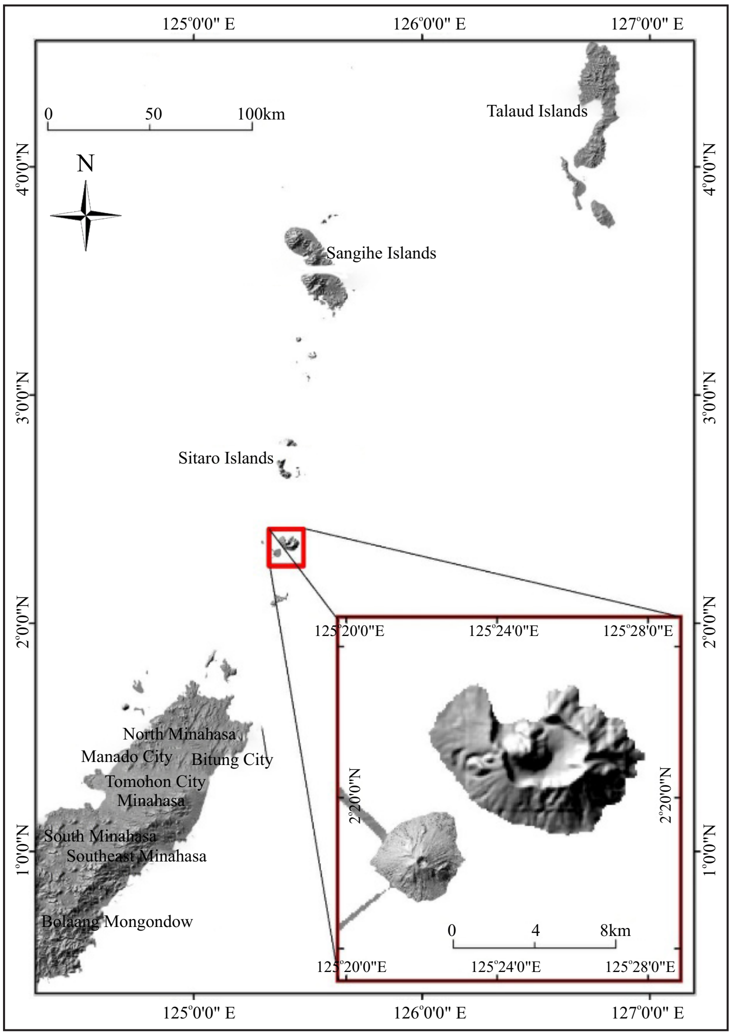

Figure 1. Locality map of Ruang Volcano.

northeastern Sulawesi to the island of Mindanao in the Philippines. This arc is positioned above the westward-dipping Benioff Zone of the Molucca Sea Plate subduction system. The volcanic front lies approximately 100-110 km above the subducting slab and includes over 25 Quaternary volcanic centres, with eight currently active volcanoes concentrated in the southern section of the arc (Morrice *et al*., 1983). The location of Ruang within this tectonic setting explains its potential for explosive volcanism due to magma ascent in a highly compressional environment.

Historically, Ruang Volcano was recognized as an active volcanic island as early as 1603, although no eruptions were recorded during the 17th and 18th centuries. Eruptions were first documented in 1808, and since then, the volcano has exhibited an eruptive frequency with recurrence intervals ranging from 1 to 30 years (Kusumadinata, 1979; Siswowidjojo, 1990).

Significant eruptive events in Ruang history include the deadly 1871 eruption, which was preceded by a powerful earthquake that triggered a catastrophic sector collapse and a tsunami with wave heights reportedly reaching 25 m. This tsunami caused an estimated 300-400 fatalities across Tagulandang and neighbouring islands. The 2002 eruption was also explosive and produced pyroclastic flows that led to residential displacement (Global Volcanism Programme, 2024).

The 2024 eruptions, however, represent one of the most powerful and complex eruptions in the volcano recorded history, necessitating an in-depth investigation into its eruptive charac-

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teristics and associated hazards. However, the primary objective of this study is to present an initial assessment for the highly explosive nature of the April 30th, 2014 eruption of Ruang Volcano, based on a preliminary investigation of the characteristics of the erupted materials.

This study aims to elucidate the factors responsible for the highly explosive nature of the April 30th, 2024 eruption of Ruang Volcano. It is hypothesized that elevated vesicularity, ruptured bubble walls, and crystal-rich juvenile textures reflect rapid magma decompression and efficient fragmentation processes during the eruption.

The April 30th, 2024 Eruptive Sequence

The 2024 eruptive episode at Ruang Volcano commenced on April 16th with a noticeable increase in both visual and seismic activity. In response to this, the Centre for Volcanology and Geological Hazard Mitigation (CVGHM), Geological Agency, raised the alert level from Level I (Normal) to Level II (Advisory) at 10:00 WITA (local time), and to Level III (Watch) by 16:00 WITA on the same day (Hidayati *et al*., 2024). The first explosive eruption occurred at 21:45 WITA ejecting an ash column approximately 2,000 m above the summit. This was followed by a more intense eruption at 01:08 WITA on April 17th, which produced pyroclastic flows, ballistic ejections, and a 5,000 m eruption column. Volcanic lightning and continuous tremors were observed throughout the day.

Subsequently, on April 17th, a series of continuous explosive activity persisted in generating ash emissions, seismic activity, and ground tremors. The alert level was elevated to Level IV (Warning) by 21:00 WITA. Although the activity briefly decreased and was downgraded to Level III on April 22nd, a new major explosive eruption occurred at 01:15 WITA on April 30th. This event generated another 5,000 m ash column and was strongly felt on neighbouring Tagulandang Island. The alert status was promptly reinstated to Level IV by 01:30 WITA. The 2024 eruption sequence caused the evacuation of over 9,000 people, including the complete displacement of two villages on Ruang Island, highlighting the urgent need for effective mitigation and response strategies (Hidayati, 2024).

The eruptive activity at Ruang Volcano on April 30th, 2024, is estimated to have produced a net accumulation of approximately 9.78 million m^3 of volcanic material (Purnamasari, 2025, in prep). This Figure was derived from a topographic comparison using UAV-based Digital Elevation Models (DEMs) processed via cut-and-fill analysis, focusing on the summit and proximal areas affected by the eruption. While this volume may appear modest compared to other VEI 4 eruptions. It likely underrepresents the total erupted mass due to unaccounted distal ashfall and significant pyroclastic deposits that entered the surrounding marine environment. Therefore, the reported volume should be considered a minimum estimate, pending further integration with broader depositional and marine surveys.

Sample and Analytical Methods

A total of four samples of pyroclastic fall deposits from Tagulandang Island (Sample Nos. TGL-5, TGL-7, TGL-8, and TGL-11) and two block-sized ballistic rock samples from Ruang Island (R1 and R2) were collected for chemical, petrographic, SEM, and componentry analyses.

This composite image (Figure 2) documents the systematic field sampling following the April 2024 eruptions of Ruang Volcano. Volcanic materials were collected from numerous sites across Ruang and Tagulandang Islands, representing both proximal and medial depositional environments.

Laboratory analyses conducted at the Geological Agency's Petrology and Geochemistry Laboratory involved XRF, petrographic microscopy, SEM, and componentry analyses. Samples underwent X-Ray Fluorescence (XRF) spectrometry to determine major and trace element compositions, while petrographic thin sections were used to assess mineralogy and textures. Additional Scanning Electron Microscope (SEM) imaging revealed surface microtextures and vesicle morphology, particularly in ash-sized particles.

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Figure 2. Sample collection and laboratory analysis following the 2024 Ruang eruption aimed to investigate volcanic material characteristics.

Result and Discussion

XRF analysis indicates that the products erupted during the April 2024 events are compositionally dominated by basaltic andesite, with SiO_2 contents ranging from 53.02 % to 54.27 %. Based on the Total Alkali-Silica (TAS) diagram (Figure 3a), all samples, except one plot within the basaltic andesite field, indicating a subalkaline magma series. Using AFM diagram, geochemical data further classify the erupted rocks as belonging to the tholeiitic magma series, which is characteristic of island-arc settings such as The Sangihe Arc (Figure 3b). However, one sample plots within the calc-alkaline field; this sample is interpreted as a lithic fragment likely derived from older pre-existing rocks. These findings are consistent with the results of Morrice *et al.* (1983), who reported that volcanic rocks from Ruang Volcano belong to the tholeiitic suite. As noted by Murphy (2007), tholeiitic magmas tend to dominate during the initial stages of oceanic arc evolution, particularly near the trench in young oceanic island arcs.

Petrographic analysis of juvenile from the 2024 Ruang Volcano eruption suggests that the composition of rocks is hornblende-bearing andesite with porphyritic texture. Microscopic observations indicate inequigranular and intergranular to trachytic textures, consisting of phenocrysts (~15 %) set in microlites groundmass. Hornblende (8 %) appears as euhedral to subhedral crystals (0.3-1 mm), showing strong pleochroism and features such as thermal fractures and dark inclusions, likely melt inclusions or vesicles. Plagioclase (5 %) also presents zoning and broken textures, while opaque minerals (~2 %) are irregular in shape. The groundmass (~85 %) is dominated by microlites plagioclase arranged in a trachytic texture, indicating of rapid cooling near the surface (Figure 4).

In addition, petrographic analysis identified plagioclase phenocrysts surrounded by microlithic groundmass within individual ash grains, suggesting partial crystallization and pre-eruptive magma differentiation. The co-existence of crystalline and glassy phases within the same particles indicates a complex magmatic history involving both deep and shallow processes. These microtextural features, together with the presence of thermal fractures, imply rapid magma ascent and decompression. Textural

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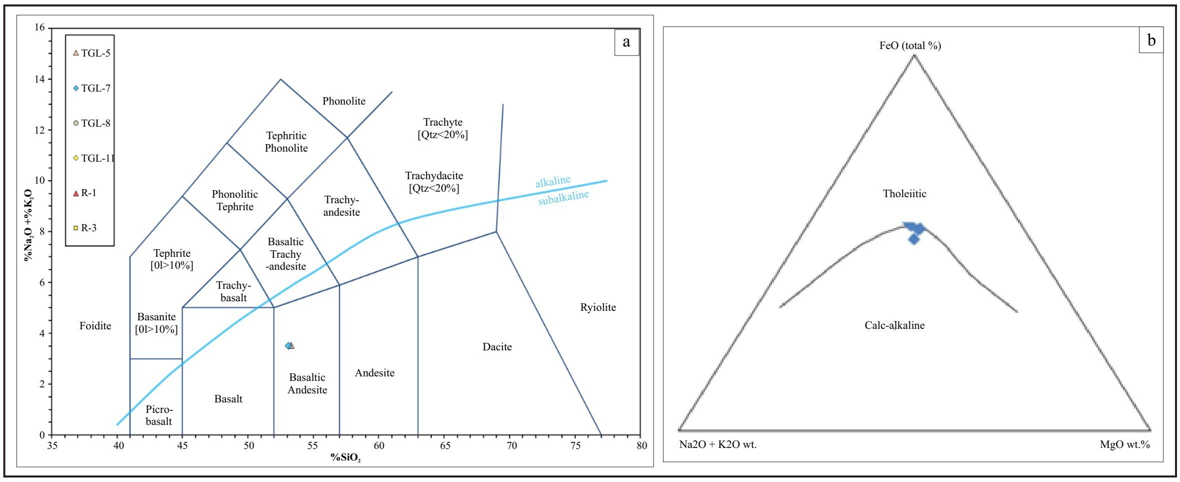

Figure 3. a). TAS (Total Alkali–Silica) diagram based on the classification by Le Bas *et al.* (1986) showing the positions of six rock samples from Ruang Volcano (TGL-5, TGL-7, TGL-8, TGL-11, R-1, and R-3); b). AFM diagram plot of rock samples from the April 30th, 2024 Ruang Volcano eruption.

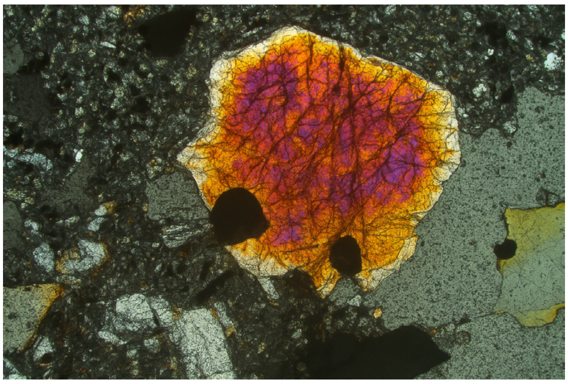

Figure 4. Microscopic view of hornblende under cross-polarized light showing strong colour interference and thermal fractures, indicating crystallization under high-pressure and high-temperature conditions.

features such as melt inclusions, pleochroism, and thermal fractures suggest early-stage crystallization within a water-rich magma chamber at depth.

SEM analysis at 200× magnification revealed a variety of ash grain morphologies, including juvenile fragments, microlithic textures, and grains featuring a thermal fracture typically associated with rapid cooling and mechanical fragmentation. Preliminary SEM analyses of tephra and pyroclastic materials from the 2024 Ruang Volcano eruption reveal a dominance of high vesicularity textures, with ash particles displaying sponge-like structures and irregular bubble walls (Figure 5a). These features suggest extensive volatile exsolution prior to fragmentation and support a model of rapid magma ascent with high decompression rates. SEM imaging shows angular ash morphologies and ruptured vesicle walls, typical indicators of brittle fragmentation during violent degassing at shallow depths.

Notably, large amphibole megacrysts, particularly hornblende, were observed within several ash particles. Hornblende occurrence (Figure 5b) is tentatively interpreted as evidence of crystallization under high-pressure and hydrous conditions, consistent with subduction-related magma storage. The euhedral to subhedral crystal shapes and lack of abrasion suggest juvenile origin and in-situ crystallization prior to eruption.

The presence of hornblende in these basaltic andesitic samples is tentatively interpreted as evidence for crystallization under moderate to high temperatures and elevated water pressures, conditions commonly associated with volatile-rich magma.

Componentry analysis is a fundamental approach in volcanic petrology that aims to identify and to quantify the types of fragments present within pyroclastic deposits, particularly those are produced by explosive eruptions. Common components analyzed include juvenile clasts, lithic fragments, volcanic glass, and free crystals (Figure 6a) providing insights into

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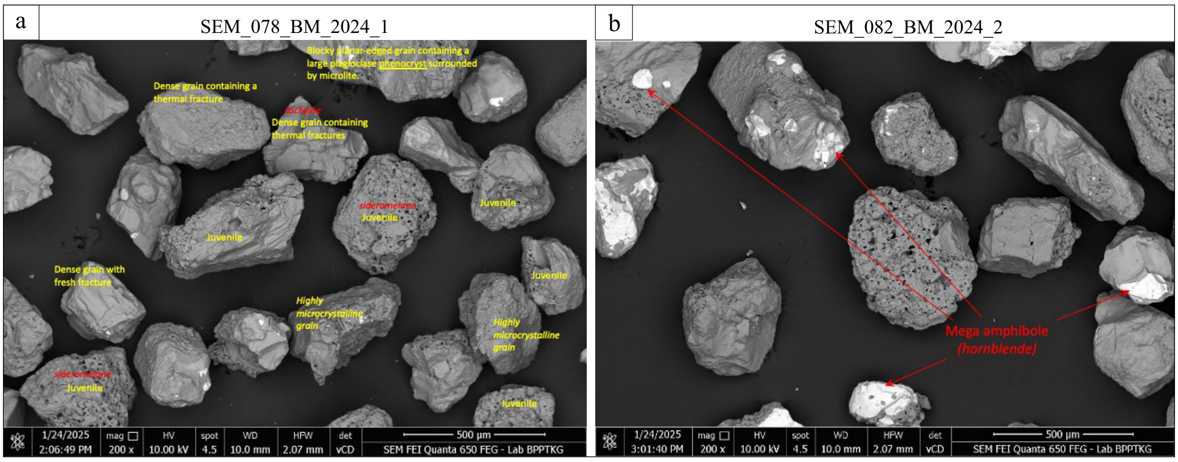

Figure 5. a). The Scanning Electron Microscope (SEM) image of volcanic ash sample from Ruang Volcano (code: SEM_078_BM_2024_1) displays a variety of grain morphologies; b). Volcanic ash grains from Ruang Volcano containing large megacrysts of amphibole (hornblende).

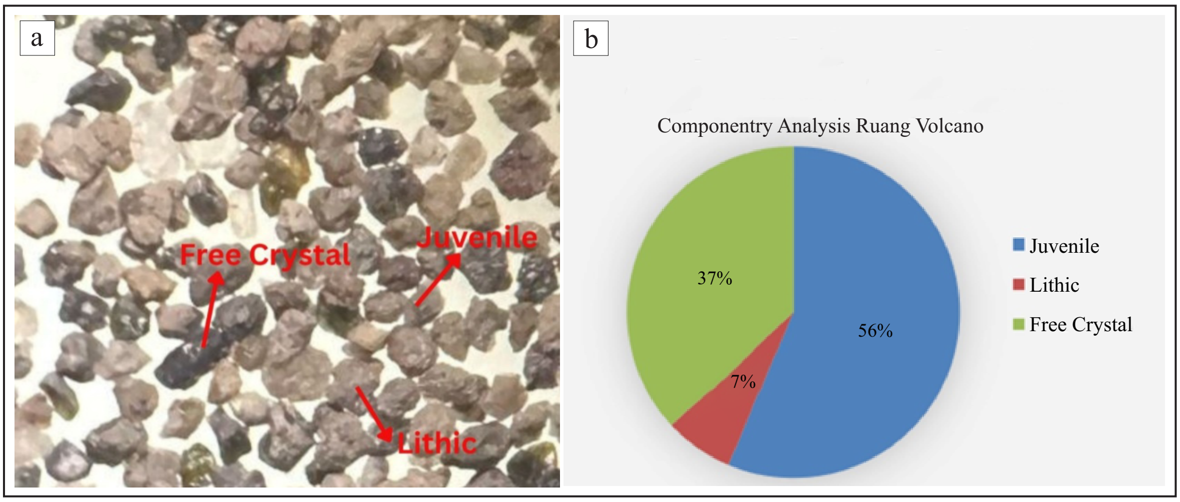

Figure 6. a). Tephra grains of April, 20th 2024 erupted material under binocular microscope; b). Pie chart of tephra volume composition from Ruang Volcano based on componentry analysis of TGL-6, showing the volume percentage distribution of the three main components: juveniles, lithics, and free crystals.

the physical and chemical processes occurring during eruption and magma storage (Cas and Wright, 1987).

Analysis of the componentry of tephra samples (Figure 6b) indicates that the juvenile portion constitutes 56%. This high proportion of juvenile material indicates a magma-driven eruption characterized by substantial fragmentation of fresh magma. Free crystals also display notable abundance, peaking at 37 % in the same sample, suggesting extensive fractional crystallization and degassing prior to eruption. In contrast, lithic content remains relatively low, typically at 7 %, implying limited involvement of conduit or crater wall collapse during the eruptive process.

Conclusion

Geochemical analysis of the ejected materials from the April 30th, 2024 eruption reveals a basaltic andesite composition, with SiO_2 contents ranging from 53.02 % to 54.27 %. These rocks are part of the tholeiitic magma series, commonly associated with island arc environments such as The Sangihe Arc.

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The presence of hornblende is tentatively interpreted as conditions that was commonly associated with volatile-rich magma.

The observed petrological characteristics align with field-based tephra componentry, which also showed high juvenile and crystal content, suggesting a magma-driven explosive eruption.

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