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Identification of Paleovolcanic Centers in the Bima District, East Sumbawa Island (Indonesia) as Guidance for Future Exploration of Cu-Au Deposits

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ABSTRACT. The formation of Cu-Au mineralization, such as porphyry and epithermal deposits, is strongly associated with volcanic processes in specific tectonic settings, such as subduction zones. Identifying the presence of ancient volcanoes is one of the important steps to delineate the mineral deposits. This study aims to identify the presence of ancient volcanoes in the Bima District, the eastern part of Sumbawa Island, as a step toward determining the potential indication of Cu-Au mineralization. The research methods include a literature study, image analysis and remote sensing, field survey and data collection, and petrographic analysis. Image analysis using DEMNAS (Digital Elevation Model), including texture and pattern analysis using the concept of volcanic anatomy, aims to identify the remaining forms of ancient volcanoes. Field surveys and data collection include volcano geomorphology, lithology, sampling, and geological structures. Petrographic analysis is conducted to qualitatively characterize volcanic rocks' texture, structure, and mineralogy. The identification results show that there are at least ten volcanoes (crown) identified through image analysis, namely Doro Mbangga, Doro Baku, Doro Donggo Masa, Doro Rompo, Doro Sape, Doro Kowo, Doro Jia, Doro Sambori, Doro Mangge, and Doro Lambu. Each of these volcanoes has one or more eruption centers (hummock). The eruption center was identified in the volcano's central, proximal, and distal facies, even superimposing one volcano product with another, and spread around 80-90% in the study area.

The volcanic facies in the study area are characterized by the central part comprising lithologies such as intrusive rocks, lava, and phreatomagmatic breccia. In contrast, the proximal and distal facies comprise breccia, volcanic breccia, and tuff. Hydrothermal alteration zones are identified in the central and proximal facies of the volcano. These alterations were associated with eruption centers, where the abundance of eruption centers means that hydrothermal alterations are particularly well-developed and pervasively formed—argillic and advanced argillic alteration associated with stockworks formed a lithocap environment. In addition, the presence of intrusive rocks such as diorite and dacite with chloritic and sericitic modifications in the central facies of Doro Baku is interpreted to be associated with porphyry and high sulphidation epithermal systems. Hence, identifying ancient volcanic eruption centers in the Bima district has implications for discovering potential Cu-Au mineralizations.

Keywords: Paleovolcano · Volcanic facies · Cu-Au mineralization · Bima · Sumbawa Island.

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1 INTRODUCTION

Exploration of mineral resources, especially gold and copper, is carried out in magmatic arcs. Indonesia has at least six magmatic arcs that are the target of mineral exploration activities, namely the Central Borneo, Sumatra-Meratus, Sulawesi-Mindanao, Halmahera, Central Papua, and Sunda-Banda arcs. (Carlile & Mitchell, 1994). The Sunda-Banda arc is one of the most potential magmatic arcs in Indonesia, as proven by the discovery of large world-class deposits, such as Tumpang Pitu, Batu Hijau, Elang, and Onto (Hu'u) (Idrus, 2007; Maryono *et al.*, 2018).

Mineralization in Indonesia, especially in the Sunda-Banda arc, is generally formed in volcanic rocks and associated with ancient volcanic eruption centers. (Setijadji & Maryono, 2012; Maryono *et al.*, 2018) Such as porphyry and epithermal deposits that have genetic and spatial relationships with stratovolcano-type volcanic landforms (Sillitoe, 1984). This makes the identification of ancient volcanoes one of the most important factors in mineral exploration programs.

This research is conducted to identify the presence of ancient volcanoes in Bima district, West Nusa Tenggara province, Indonesia. Bima is dominated by Miocene to Holocene-aged volcanic rock sequences (Ratman & Yasin, 1978). Miocene-aged rocks are concentrated in the southern part of Sumbawa Island, composed of andesitic to dacitic tuff, basalt, andesite, dacite, and intrusive rocks such as diorite, quartz diorite, and tonalite, while the northern part is composed of Holocene-aged volcanic stones, which are characterized by active volcanism, namely Tambora and Sangiang volcanoes (Ratman & Yasin, 1978; Garwin, 2000). Physiographically, the southern mountainous zone of Bima is still in line with the south mountainous zone of the eastern Sunda arc, extending from East Java to Nusa Tenggara – Sumbawa Island (Setijadji & Maryono, 2012; Maryono *et al.*, 2018)The mountain range is associated with volcanic systems of the Oligocene – Miocene age, while in the north, it is associated with volcanic rocks of the Quaternary age (Figure 1) (Verdiansyah *et al.*,2021).

The Southern Mountains of Java identified several ancient volcanic centers, such as Gadjah Mungkur and Batur Wediombo. Towards the east, Setijadji *et al.* (2006) reconstructed ancient volcanic centers and their relationship with the existence of mineralization trends, such as in the Pacitan, Tulungagung, Trenggalek, Blitar, Lumajang, and Merubetiri. In line with the identification of ancient volcanic eruption centers, several deposits associated with the central system of ancient volcanoes are found, such as the Randu Kuning porphyry deposits related to the central facies of Gadjah Mungkur (Sutarto *et al.*, 2015) and epithermal high-sulfidation and porphyry deposits in Tumpang Pitu associated with volcanic rocks (Harrison *et al.*, 2018). In Lombok and Sumbawa Island, epithermal and porphyry deposits associated with Miocene to Holocene age volcanic center systems are also identified, such as the Brambang, Batu Hijau, Elang, and Onto (Hu'u) porphyry deposits (Maryono *et al.*, 2018; Burrows *et al.*, 2020; Rompo *et al.*, 2022). In Hu'u district, Verdiansyah (2023) described it as a brigade, or remnant of an ancient caldera, which is composed of several eruption centers, one of which is Humpa Leu East (HLE), which is also a porphyry deposit in the Hu'u district.

Identifying ancient volcanoes in the eastern part of Sumbawa Island, especially in the Bima district, has never been done, so this research is a very important step to starting mineral exploration programs. The aim is to understand the existence of ancient volcanic eruption centers, which will provide information on the potential for mineralization in the Bima district. The approach used in this research is volcanostratigraphy and remote sensing to identify morphological patterns of ancient volcanic remains. Then, field surveys are carried out to prove the presence of volcanic material and its relationship with volcanic facies, which has implications for hydrothermal alteration, especially in identified eruption centers.

2 METHODOLOGY

The method consists of a literature study, image analysis, and remote sensing, where this analysis is based on the concept of volcanostratigraphy to identify the centers of ancient volcanic eruptions so that it will delineate one volcanic system from another. This identification is determined by the texture or relief of the mor-

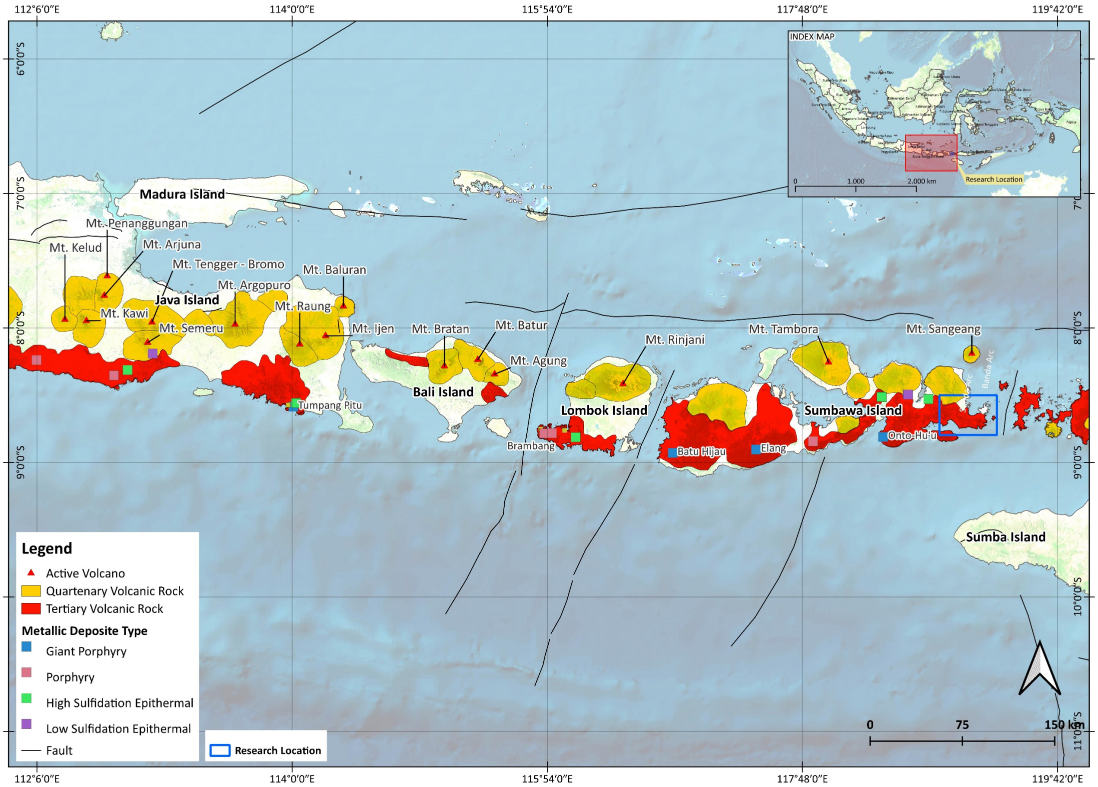

FIGURE 1. Distribution of active volcanoes in the eastern Sunda arc and their association with Tertiary volcanic rocks in the south and Quaternary volcanic rocks in the north (modified from Verdiansyah *et al.*, 2021).

phology and the presence of morphological patterns, including straightness, slope, and circular or half-circular patterns of mountains, hills, and watersheds (Bronto, 2010). Based on the analysis, the level of the volcanos is identified as the stratigraphic unit, which consists of a crown and hummock, as well as several other features such as the volcanic rim or post-caldera. The terminology of crown and hummock is based on the nomenclature of the Indonesian National Standard on Stratigraphic Units of Volcanoes (Bronto *et al.*, 2016). A crown is a basic unit in the volcanostratigraphic classification. This consists of rock or deposits from one eruption point or more (Bronto *et al.*, 2016). Field surveys and data collection are conducted to confirm the remote sensing analysis, consisting of geomorphology, lithology, geological structure, alteration, and mineralization features. This data collection is only carried out at representative locations, such as the central-proximal and distal parts of the identified ancient volcanoes, so that it will provide an overview of the reconstruction of ancient volcanic facies (Bogie, 1998; Bronto, 2006). The sampling method using spot sampling on outcrops is carried out selectively at the location of the eruption center (central - proximal facies), such as on intrusions, wall rock, or sub-volcanic rocks identified as having been altered. The samples were prepared for thin sections with a thickness of 0.003 mm (Gribble, 2012). The thin section is analyzed petrographically to qualitatively determine the mineralogical composition of the rock's texture, structure, and name. The process of preparation and making thin sections, as well as petrographic analysis, is carried out using a Bestscope BS-5062BR trinocular polarizing microscope at the Geological Engineering Laboratory of Universitas Gadjah Mada.

3 RESULTS

3.1 Regional Geology Analysis

The study area is generally composed of volcanic rocks. The distribution of volcanic rocks occupies around 80–90% of the study area (Figure 2). Based on regional geological data analysis (Ratman & Yasin, 1978), the lithology consists of pyroclastic, volcanic, and intrusive rocks. Tuff is widely distributed in the study area, with a relative slope to the northwest and northeast. The tuff is intruded by dacite, diorite, and tonalite (Figure 2).

Geological structures in the study area develop in a dominant northwest-southeast trend; tectonic processes most likely influence these structures. Due to volcanic activity, the structure develops in a concentric pattern at the center of the volcanic system (Figure 2). In addition to the presence of ridges or structures of the caldera remnant or post-eruption (volcanic rims), this structure is west-east oriented and has a circular pattern to the south and southeast. This indicates that, in contrast to morphological patterns and rock distribution, the pattern of geological structures due to volcanic processes is a positive indication of the identification of ancient volcanoes in the study area.

Analysis of regional geological data shows that the distribution of volcanic rocks that are very dispersed can be an indicator in the identification of paleovolcanoes, and the presence of intrusive rocks may indicate eruption centers.

3.2 Geomorphology of Paleovolcanic Features

The geomorphological expression in Bima District is dominated by undulating hills, valleys, and steep to very steep slopes. The morphology of ancient volcanic remnants is easily visible in various parts of Bima. The cone shape of the volcano, which is thought to be a remnant of stratovolcano-type volcanic activity, is still clearly visible, such as on Mount Doro Jia, Doro Mbangga, Doro Baku, and Doro Donggo Masa (Figure 3a–d). The appearance of the central, proximal, and distal facies is still very well-identified from the morphology; this is influenced by rock resistance, especially in the central and proximal facies, which are composed of lithologies in the form of sub-volcanic intrusions, lavas, and breccias that have a high resistance level (Figure 3b). The image analysis results using DEMNAS (Digital Elevation Model) identify ten ancient volcanoes in the study area, all of which developed in the southern part of the Bima region. Based on the level of volcano stratigraphic units, the research area is composed of crown and hummock. Crowns identified in the study area are Doro Mbangga, Doro Baku, Doro Donggo Masa, Doro Rompo, Doro Sape, Doro Kowo, Doro Jia, Doro Sambori, Doro Mangge, and Doro Lambu (Figure 5). The identification of the crown can be seen from the image pattern, which shows relief with a rough circular and semi-circular morphological texture, reflected by the slope pattern and the ridge forming a curved alignment (Figure 5). The pattern is indicated to be the central part of an ancient volcanic body. Identification using a river flow pattern approach shows the development of radial and dendritic flow patterns characteristic of flow patterns that develop in volcanic areas. There is a centralized form, both upstream and downstream (Figure 4a–j). There is also a circular flow pattern, indicating the center of the volcanic system (Figure 4a–j).

Specifically, at each volcano, several eruption centers, or hummocks, have been identified (Figure 5). Identifying these eruption centers still uses a geomorphological approach, DEMNAS (Digital Elevation Model) analysis, and developed flow patterns. In Doro Mbangga, two eruption centers are located in the central part. In Doro Baku, seven central, proximal, and distal eruption centers are developed. In Doro Donggo Masa, three eruption centers have been developed in the central part. In Doro Rompo, two eruption centers were developed in the central part. In Doro Sape, there are five eruption centers developed in the central and proximal parts; in Doro Kowo and Doro Jia, there is one eruption center developed in the central part, and there are three eruption centers developed in the central and proximal parts in Doro Sambori. Whereas in Doro Mangge and Doro Lambu, the eruption center cannot be determined because the morphological shape only leaves a semi-circular shape of the coastline, but the assumption is that the eruption center has been abrasion further, so it is likely to be in the middle of the sea (Figure 5).

3.3 Volcanic Products

The results of rock identification in several locations that represent the research area show the distribution of volcanic rocks, both pyroclastic and intrusive rocks. Sub-volcanic stones, in the form of porphyry andesite, are found in the western part of the proximal facies of Doro Mbangga (Figure 6a). Basaltic lava with columnar joint structure was identified in the

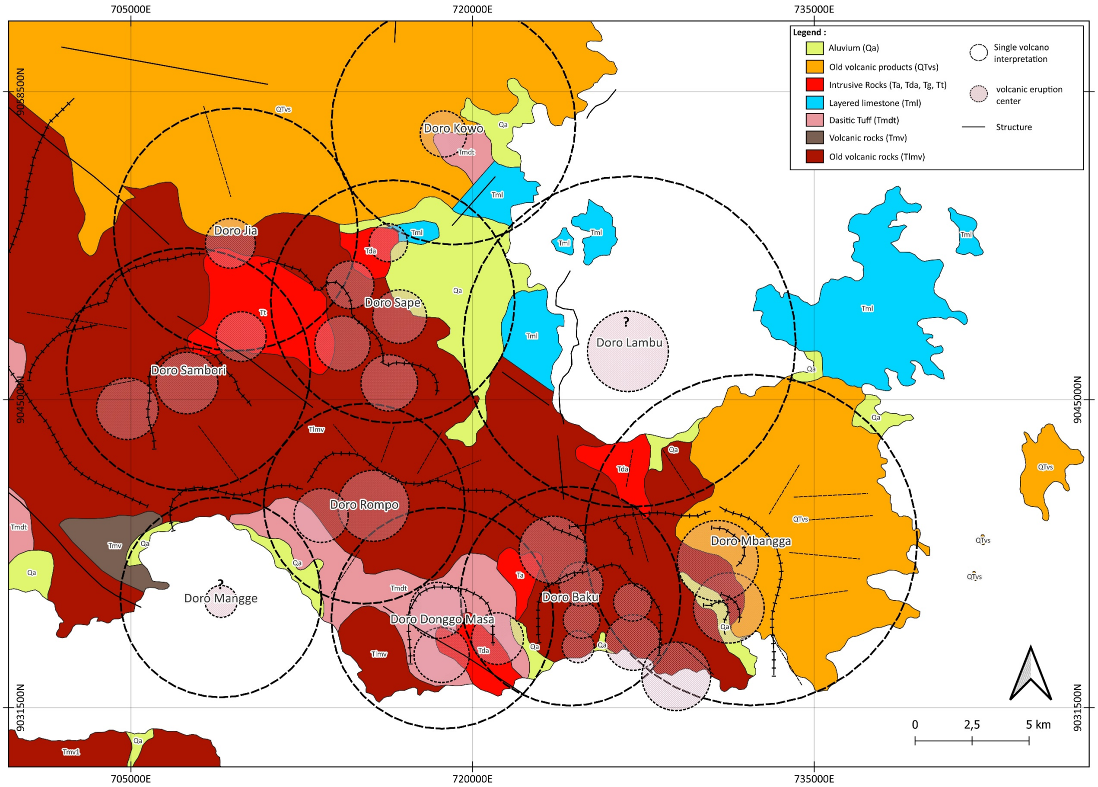

Figure 2. Regional geological map overlaid with the paleovolcanic center interpretation (modified from Ratman & Yasin, 1978).

northeastern part of the distal facies of Doro Mbangga (Figure 6c–d). Volcanic breccias are widely scattered in the distal facies of Doro Sape and Doro Kowo, especially in the eastern part of the area, with characteristics of angular-shaped fragments with a diameter of >65 mm (representing volcanic bombs or blocks). The matrix part is dominated by finer-sized laharic and pyroclastic products (Figure 6e–h).

Phreatomagmatic breccia has been identified in Doro Donggo Masa, in the southwestern part bordering the southern sea. This breccia has been characterized by polymictic fragments, sub-rounded to well-rounded shapes, 5–20 mm in diameter. The fragments consist of wall rocks or intrusive rocks with andesitic to dacitic compositions. The matrix between the fragments shows a compact shape due to the welded process of magmatic processes (Figure 6i). Intrusive rocks are also widely distributed in the study area, both in the central and proximal facies of the volcanic system (Figure 2). Intrusive rocks in the form of diorite have been identified in the central part of Doro Baku. The diorite has a coarse grain texture (phaneritic) with little alteration due to hydrothermal alteration (Figure 3b). The presence of phreatomagmatic breccia and intrusive rocks is one of the characteristic features of the eruption center of a volcanic system.

Petrographic analysis was carried out on selective rocks, limited to Doro Mbangga and Doro Baku, especially at the volcanic center, to correlate with hydrothermal alteration formed at the volcanic center. The diorite in the central part of Doro Baku shows characteristics of a phaneritic texture, equigranular, composed of plagioclase (40-60%), quartz (10-20), biotite and secondary biotite (10-15%), alteration minerals such as chlorite (5-10%), sericite (<5%), and opaque minerals indicated to be magnetite and pyrite (<5%) (Figure 7a-b). The dacite in the central part of Doro Baku shows porphyritic in equigranular phenocrysts (20-40%) composed of quartz and plagioclase minerals. In contrast, the groundmass comprises plagioclase minerals and altered minerals such as sericite and clay (Figure 4c). Basalt collected at a columnar joint in the distal part of Doro Mbangga shows characteristics of a porphyritic texture, which is

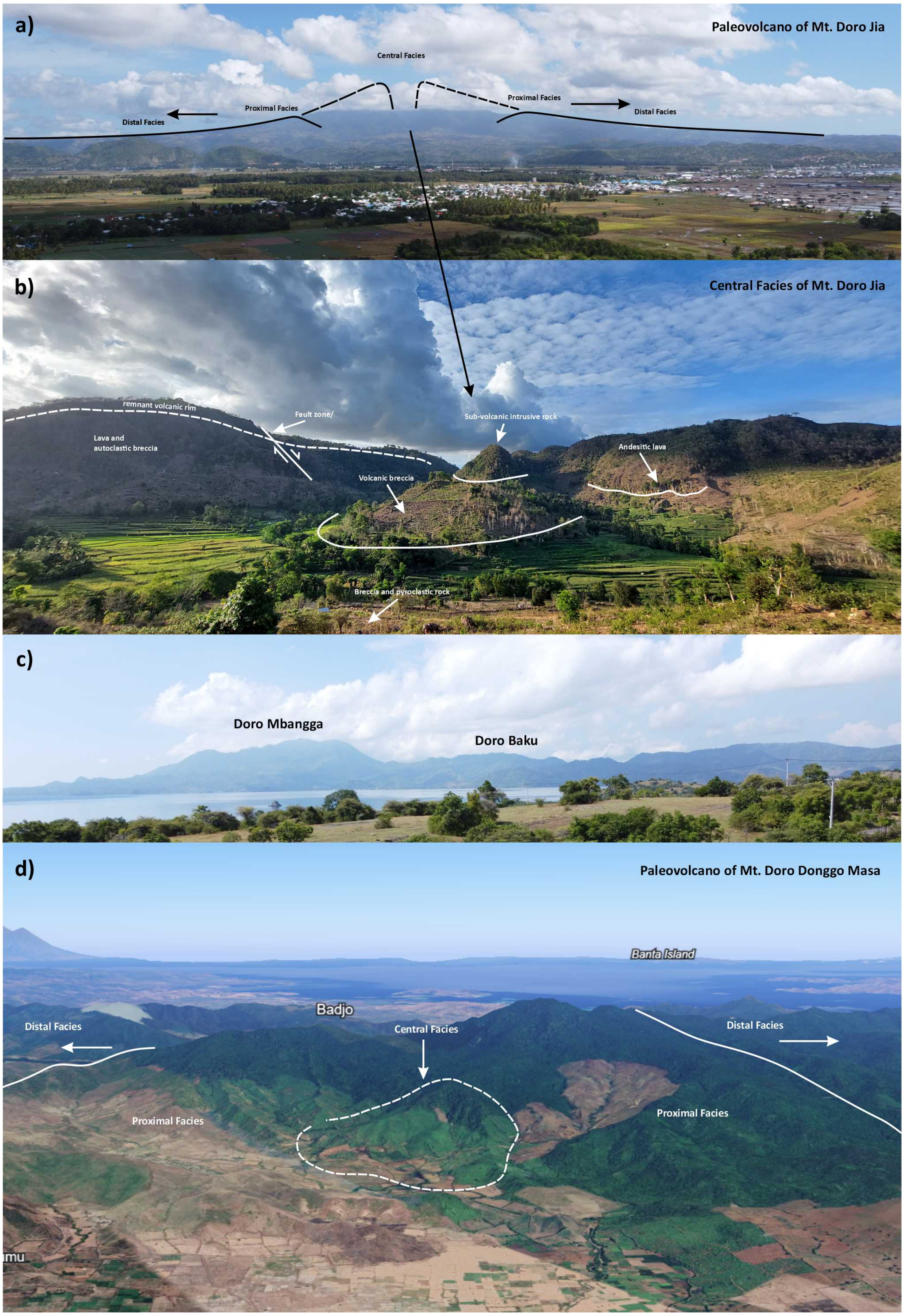

FIGURE 3. Morphology of ancient volcanoes in the study area, a) shows the crown of Doro Jia volcano, b) morphology of the central part of the volcano, which is composed of intrusive rocks, lava, and volcanic breccia, c) undulating morphology of Doro Mbangga and Doro Baku, d) circular shape of the volcano of Doro Donggo Masa.

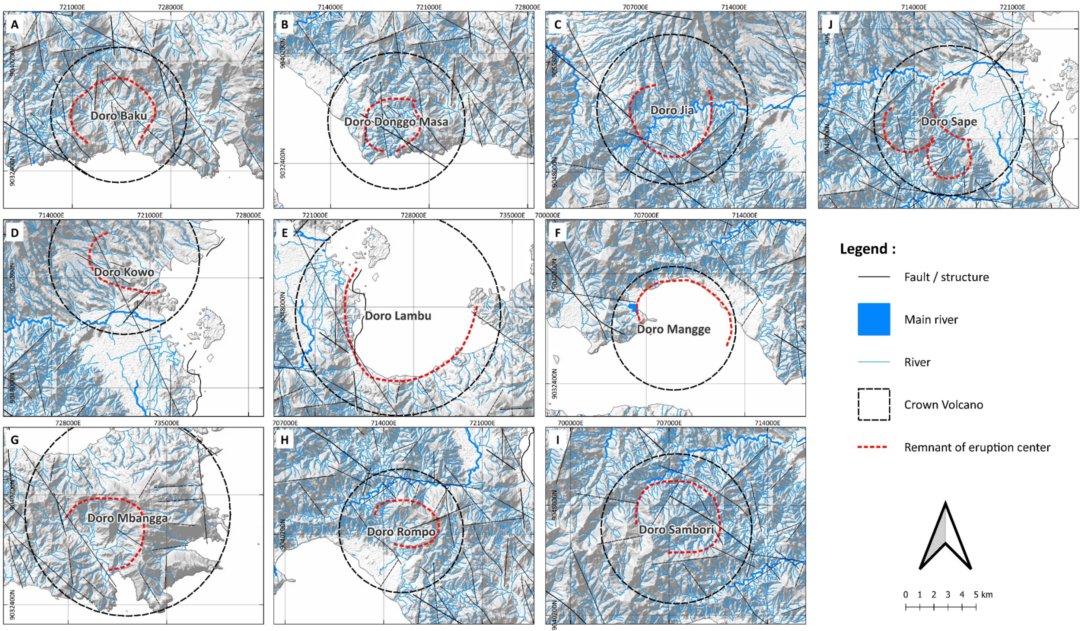

FIGURE 4. Analysis of river flow patterns at each volcano. Shows a centralized pattern from the flank of the eruption center, characterized by a parallel flow pattern, while at the center of the eruption it is characterized by a dendritic flow pattern with a circular or half-circular pattern, a) Doro Baku, b) Doro Donggo Masa, c) Doro Jia, d) Doro Kowo, e) Doro Lambu, f) Doro Mangge, g) Doro Mbangga, h) Doro Rompo, i) Doro Sambori, j) Doro Sape.

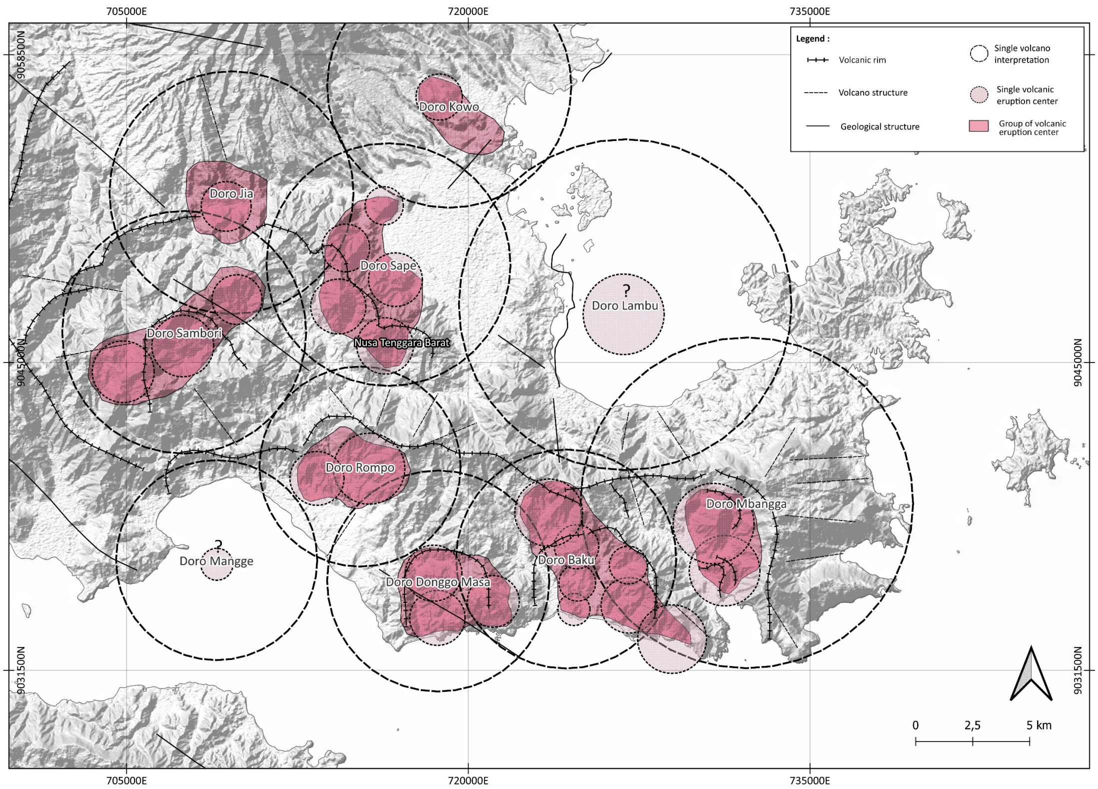

FIGURE 5. Paleovolcano interpretation map of the study area. It shows ten ancient volcanic bodies that developed in the study area and several eruption centers that developed on the facies of the ancient volcanic centers.

FIGURE 6. Volcanic products in the study area, a) tuff intruded by sub-volcanic rocks in the form of dike in Doro Mbangga, b) diorite intrusion in Doro Baku, c–d) basaltic lava with columnar joint structure in Doro Mbangga, e–h) pyroclastic breccia in Doro Sape and Kowo, i) phreatomagmatic breccia with polymictic fragments in Doro Donggo Masa.

in equigranular and composed of a dominant of mafic minerals such as pyroxene, biotite, and hornblende (Figure 7d).

3.4 Alteration Footprint

Hydrothermal alteration is associated with the central facies of the ancient volcano, where eruption centers are identified. Field surveys show that massive alterations have occurred, such as at Doro Jia, which developed at the volcano's center. Pervasively altered dacite, composed of clay-silica alteration, and intense stockwork structures filled by quartz minerals and oxides are visible (Figure 8a). Doro Baku also shows the hydrothermal alteration in the central facies, in dacitic tuff, composed of clay-silica alteration, and intensity of stockwork structures filled by quartz minerals and oxides (Figure 8b). At Doro Donggo Masa, hydrothermal alteration was developed on dacitic tuff, which is composed of clay-silica alteration. The stockwork intensity was also very high at this location (Figure 8c). A quartz-carbonate vein type with a 1–2 mm diameter was also identified as associated with the stockwork zone at Doro Mbangga (Figure 8d).

4 DISCUSSION

Volcanic products, both in the north and south, dominate the area of Bima District. The southern region, the research location, is composed of old volcanic products from the Tertiary age. The landscape of the volcano's morphology can be easily identified. At least ten crowns were identified through DEMNAS (Digital Elevation Model) image analysis, namely Doro Mbangga, Doro Baku, Doro Donggo Masa, Doro Rompo, Doro Sape, Doro Kowo, Doro Jia, Doro Sambori, Doro Mangge and Doro Lambu. Each of these volcanoes has more than one hummock or eruption center. The eruption centers develop in the central, proximal, and distal facies of the volcano body, even superimposing the products of one volcano on another. The identification of crown and hummock are characterized by circular and semi-circular morphological shapes and patterns interpreted as former eruption centers (Figure 9). In addition, centralized parallel-radial and dendritic flow patterns

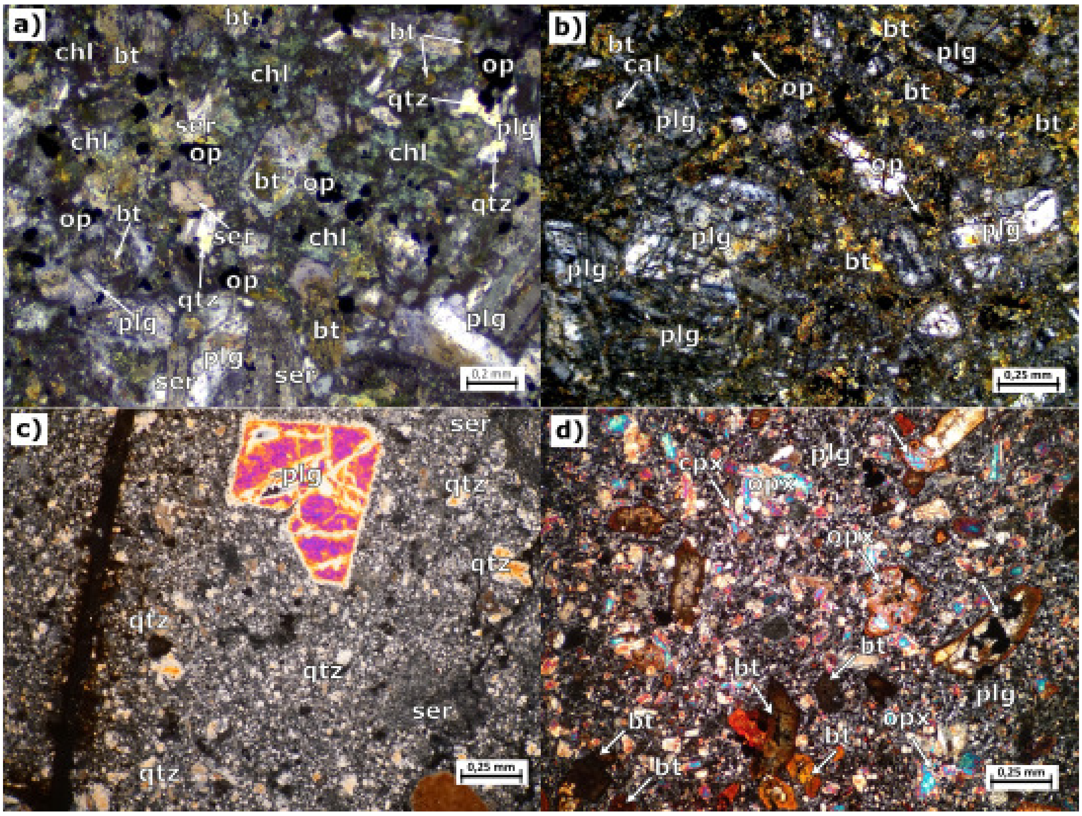

FIGURE 7. Representative images of the petrographic observation. a) diorite with chloritic alteration in intrusive rocks of Doro Baku, b) diorite with chlorite-biotite alteration, indicating potassic alteration in intrusive rocks of Doro Baku, c) dacite with porphyritic texture, sericitic alteration in rocks of Doro Baku, d) basalt with porphyritic texture in rocks of Doro Mbangga.

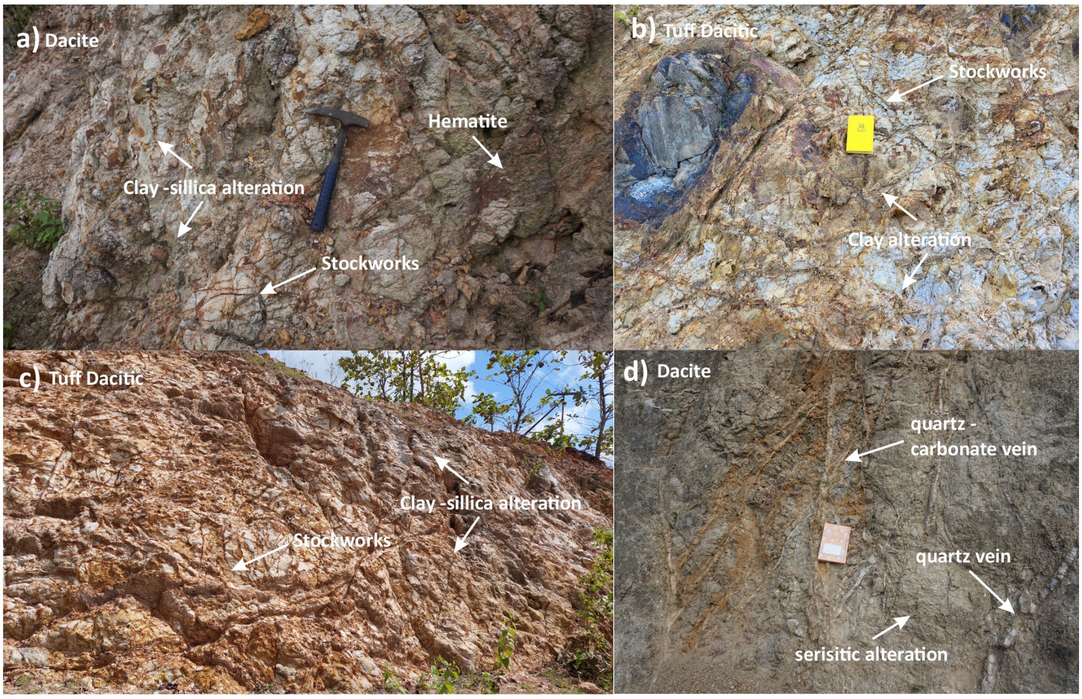

FIGURE 8. The appearance of hydrothermal alteration in the study area is associated with the central facies of the volcano. a–c) pervasive clay-silica alteration with stockwork in the central facies of Doro Jia, Doro Baku, and Doro Donggo Masa, d) quartz-carbonate veins associated with clay-silica altered stockwork in Doro Mbangga.

are well-developed in the study area. These flow patterns characterize the eruption center in the central and proximal facies. A summary of the identification of the eruption center of the ancient volcano can be seen in (Table 1). The morphological form of ancient volcanic remains can still be observed well in several corners of Bima, such as the morphological form of Doro Jia, which can still be reconstructed. Most likely, it is a stratovolcano type with a cone shape.

Volcanic products spread at around 80–90 % in the study area. If associated with the facies of the volcano, the central part is composed of lithology in the form of intrusive rocks, lava, and phreatomagmatic breccia, and the proximal to distal facies are composed of volcanic breccia and tuff.

Hydrothermal alteration is very well developed in the central and proximal facies of the volcano body. This alteration is associated with eruption centers or volcanic mounds; the more eruption centers there are, the better hydrothermal alteration will be formed. Several alteration zones are factually identified in the field, such as in Doro Baku, Doro Donggo Masa, Doro Rompo, Doro Jia, and Doro Kowo. The alteration characteristics show clay-silica alteration associated with stockworks forming a lithocap domain of argillic to advanced argillic alteration zones. In addition, the presence of intrusive rock such as diorite and hypabyssal dacite in the central facies of Doro Baku is interesting due to the hydrothermal alteration process. These rocks have already developed chloritic to sericitic alteration, which can be associated with deposits such as porphyry and epithermal.

The presence of eruption centers (crown and hummock), as well as the identification of hydrothermal alteration that develops in the facies of ancient volcanic centers in the Bima region, will be able to provide a significant explanation of the potential for gold and copper mineralization in the area. Generally, hydrothermal alteration in the study area indicates an acidic environment characterized by vuggy textures that develop in the altered rocks. In addition, its association with several intrusions confirms that hydrothermal alteration is occurring in the central facies of ancient volcanoes. Recommendations for exploration areas can be made in the zone of the ancient volcanic eruption center (Figure 9).

5 Conclusion

The identification of paleovolcanic centers in Bima District shows the presence of several ancient volcanic bodies that developed in the southern part of Bima District. Ten ancient volcanic bodies were identified, each with an eruption center that grows in the central facies of volcanoes. The presence of these ancient eruption centers is associated with the presence of hydrothermal alteration zones that form lithocap environments (advanced argillic to argillic alteration zones). In addition, several intrusion bodies and sub-volcanic intrusion rocks showing potassic, sericitic, and chloritic alteration can guide the discovery of hydrothermal deposits such as porphyry and high-sulfidation epithermal. Further research, such as mineralogical, geochemical, and geophysical studies, should be conducted to support regional exploration data and detailed exploration.

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References

Bogie, I. (1998). The Application of A Volcanic Facies Model To An Andesitic Stratovolcano Hosted Geothermal System At Wayang Windu, Java, Indonesia. *Proceedings 20th NZ Geothermal Workshop*, 265–270.

Bronto, S. (2006). Fasies gunung api dan aplikasinya. *Jurnal Geologi Indonesia*, 1(2), 59–71.

Bronto, S. (2010). Geologi Gunung Api Purba. Badan Geologi, Kementrian Energi dan Sumber Daya Mineral.

Bronto, S., Sianipar, J. Y., and Pratopo, A. K. (2016). Volcanostratigraphy for supporting geothermal exploration. In *IOP Conference Series: Earth and Environmental Science* (Vol. 42, No. 1, p. 012014). IOP Publishing.

Burrows, D. R., Rennison, M., Burt, D., & Davies, R. (2020). The onto Cu-Au discovery, eastern Sumbawa, Indonesia: A large, middle Pleistocene lithocap-hosted high-sulfidation covellite-pyrite

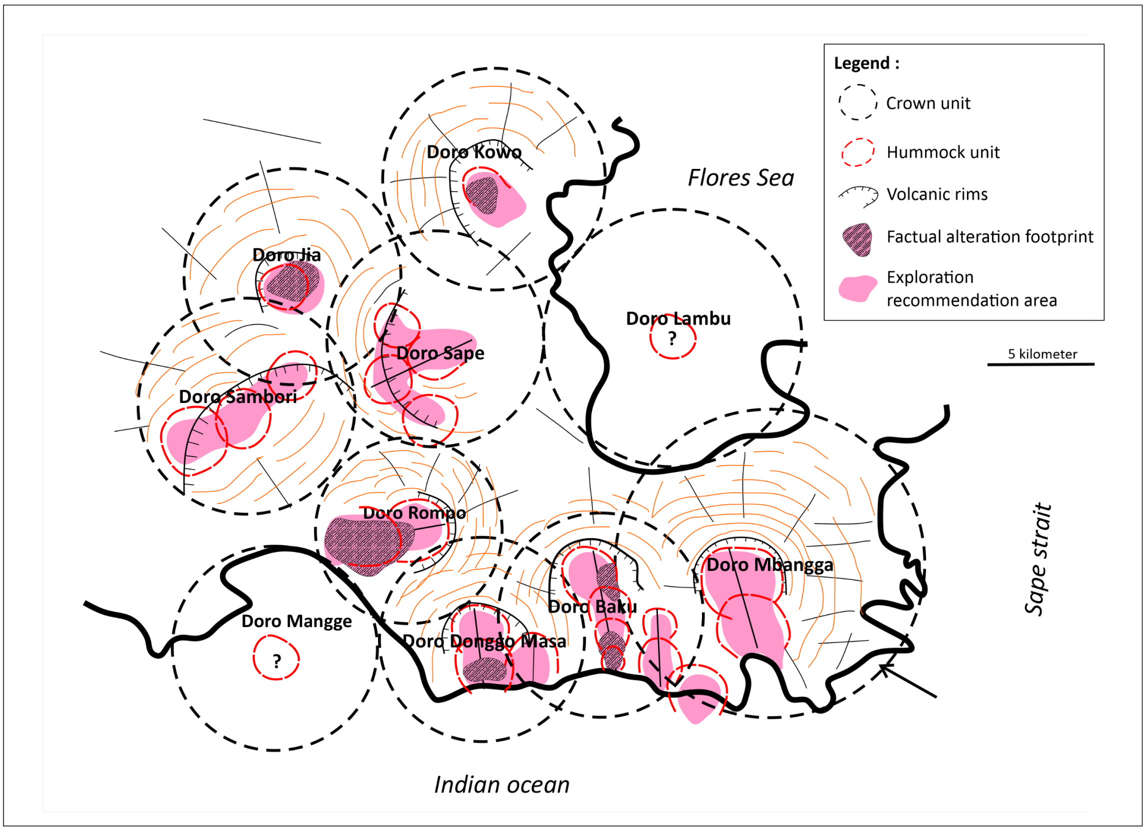

FIGURE 9. Interpretation of paleovolcanic center association to alteration and Cu-Au mineralization indication in the study area.

TABLE 1. Summary of the identification of ancient volcanic features and their association with the presence of hydrothermal alteration.

No	Volcano	Volcanic unit	Amount of eruption center/hummock	Paleovolcanic feature		Alteration footprint
				Morphology	Drainage pattern	
1	Doro Mbangga	Crown	3	Half circular	radial	ND
2	Doro Baku	Crown	6	Half circular	dendritic	Clay-silica with stockwork
3	Doro Donggo Masa	Crown	3	Circular	dendritic	Clay-silica
4	Doro Rompo	Crown	2	Circular	dendritic	Clay-silica
5	Doro Mangge	Crown	ND	Half circular	ND	ND
6	Doro Sambori	Crown	3	Circular	dendritic	ND
7	Doro Sape	Crown	5	Half circular	dendritic	ND
8	Doro Jia	Crown	1	Circular	dendritic	ND
9	Doro Kowo	Crown	1	Half circular	dendritic	Clay-silica
10	Doro Lambu	Crown	ND	Half circular	ND	Clay-silica with stockwork

*ND = unknown data

porphyry deposit. *Economic Geology*, 115(7), 1385–1412. DOI: 10.5382/ECONGEO.4766

Carlile, J. C., & Mitchell, A. H. G. (1994). Magmatic arcs and associated gold and copper mineralization in Indonesia. *Journal of Geochemical Exploration*, 50(1–3), 91–142. DOI: 10.1016/0375-6742(94)90022-1

Garwin, S. (2002). *The geologic setting of intrusion-related hydrothermal systems near the Batu Hijau porphyry copper-gold deposit, Sumbawa, Indonesia*.

Gribble, C. D. (2012). *Optical mineralogy: Principles and practice*. Springer Science & Business Media.

Harrison, R. L., Maryono, A., Norris, M. S., Rohrlach, B. D., Cooke, D. R., Thompson, J. M., Creaser, R. A., & Thiede, D. S. (2018). Geochronology of the Tumpangpitu porphyry Au-Cu-Mo and high-sulfidation epithermal Au-Ag-Cu deposit: Evidence for pre-and postmineralization diatremes in the Tujuh Bukit district, Southeast Java, Indonesia. *Economic Geology*, 113(1), 163–192.

Idrus, A., Kolb, J., & Meyer, F. M. (2007). Chemical Composition of Rock-Forming Minerals in Copper–Gold-Bearing Tonalite Porphyries at the Batu Hijau Deposit, Sumbawa Island, Indonesia: Implications for Crystallization Conditions and Fluorine–Chlorine Fugacity. *Resource Geology*, 57(2), 102-113.

Maryono, A., Harrison, R. L., Cooke, D. R., Rompo, I., & Hoschke, T. G. (2018). Tectonics and geology of porphyry Cu-Au deposits along the eastern Sunda magmatic arc, Indonesia. *Economic Geology*, 113(1), 7–38. DOI: 10.5382/econgeo.2018.4542

Ratman, N. and Yasin, A. 1978. Regional Geologic Map of Komodo, Nusa Tenggara. scale 1:250,000.

Rompo, I., Maula, S., & Maryono, A. (2022). The Brambang Porphyry Cu – Au Mineralization Style in West Lombok, Nusa Tenggara Barat - Indonesia.

Setijadji, L. D., Kajino, S., Imai, A., & Watanabe, K. (2006). Cenozoic island arc magmatism in Java Island (Sunda Arc, Indonesia): Clues on relationships between geodynamics of volcanic centers and ore mineralization. *Resource Geology*, 56(3), 267-292.

Setijadji, L. D., & Maryono, A. (2012). Geology and Arc Magmatism of the Eastern Sunda Arc, Indonesia. *Proceeding of Banda and Eastern Sunda Arcs 2012 MGEI Annual Convention*, 26–27.

Sillitoe, R. H. (1984). *Volcanic Landforms and Ore Deposits*. 79, 1286–1298.

Sutarto, S., Idrus, A., Harijoko, A., Setijadji, L., & Meyer, F. M. (2015). Veins and hydrothermal breccias of the Randu Kuning porphyry Cu-Au and epithermal Au deposits at Selogiri area, Central Java Indonesia. *SE Asian Applied*, 7(2), 80–99.

Verdiansyah, O., Hartono, H. G., & Sugarbo, O. (2021). Review of the volcano setting concept to discover the precious metal mineralization in Sunda Arc, Indonesia: An approach proposal for Mineral Exploration. *Proceedings of the 2nd International Conference on Industrial and Technology and Information Design, ICITID 2021*, Yogyakarta, Indonesia.