

Delineation of the Cibojong Fault based on Morphotectonic analysis and UAV imagery in the Pamulihan area, Southern Garut, Indonesia

Ghina H Fahira^{1*}, *Brany Kurnianto*^{1,2}, *Emi Sukiyah*³, *Dicky Muslim*³, *Ekbal Hussain*⁴, and *Kibar M. Suryadana*^{1,5}

¹Postgraduate Program of Geological Engineering, Universitas Padjadjaran, Bandung, Indonesia

²Geological Study Program, Institut Teknologi Nasional Yogyakarta, Indonesia

³Faculty of Geological Engineering, Universitas Padjadjaran, Sumedang, Indonesia

⁴British Geological Survey (BGS), Keyworth, United Kingdom

⁵Geological Agency, Ministry of Energy and Mineral Resources, Bandung, Indonesia

Abstract. The Cibojong Fault in Pamulihan, Southern Garut, is an active tectonic structure whose existence has not been well defined due to dense vegetation cover and rapid weathering processes. This study aims to delineate the fault using a combination of morphotectonic analysis, UAV-based photogrammetry, and fracture orientation measurements. UAV imagery acquired at the Ciarinem and Cisompang rivers provided high-resolution topographic models that highlight geomorphic anomalies such as offset valleys, escarpments, and drainage deflections. Field observations and joint orientation analysis confirmed dominant NW–SE fracture trends consistent with a strike-slip stress regime, supported by fracture density measurements indicating localized deformation zones. These findings demonstrate that the Cibojong Fault cuts across stratigraphic units ranging from the Pliocene to the Holocene, indicating persistent tectonic activity into recent geological times. The integrated approach of morphotectonic indices, UAV mapping, and structural field data provides a more accurate delineation of the Cibojong Fault and contributes to understanding its role in risk mitigation strategies and hazard assessment.

1 Introduction

Southern West Java is part of the tectonically active Sunda Arc, formed by the subduction of the Indo-Australian Plate beneath the Eurasian Plate [1]. The region has experienced continuous deformation since the Paleogene [2], with a convergence rate of about 5 cm/year [3]. During the Plio-Pleistocene, regional stress fields oriented north–south produced dominant fault trends in the northeast–southwest and northwest–southeast directions, shaping the present-day landscape [4]. These tectonic processes have resulted

* Corresponding author: ghina17006@mail.unpad.ac.id

in numerous active faults, some of which remain poorly investigated due to dense vegetation and rapid weathering.

As defined by [5], an active fault is one that has moved during the last 10,000 years. A fault that has migrated during the last two million years is considered possibly active. The active fault, on the other hand, is defined as a fault that moves during the Quaternary period and may move again in the future [6]. South Garut is a region with high tectonic complexity due to ongoing fault and tectonic activity [7]. One of the less-defined structures is the Cibojong Fault in Pamulihan, South Garut. Although geomorphic features suggest tectonic control, direct evidence confirming its characteristics is limited. Tectonic geomorphology studies using a quantitative approach, particularly through morphotectonic analysis, can be used to identify pixel patterns recorded in landforms [8] from digital elevation models (DEMs). Meanwhile, UAV (Unmanned Aerial Vehicle) imagery allows detailed surface observation, complementing geomorphic analysis with high-resolution spatial data [9].

This study aims to delineate the geomorphic signature and confirm the activity of the Cibojong Fault through the integration of morphotectonic indices, UAV-based surface interpretation, and joint orientation analysis [10]. The research area, located in the southern Garut region, comprises lithostratigraphic units ranging from the Late Miocene to Holocene, including volcanic and tuffaceous formations derived from several volcanic centers. Integrating field data with geomorphic and geological analyses is expected to clarify the fault geometry, deformation pattern, and tectonic significance of the Cibojong Fault within the active tectonic framework of southern West Java.

2 Materials and Methods

This study was carried out in the Pamulihan area, South Garut, focusing on identifying geological structures that control the Cibojong Fault. The main datasets included field measurements of fracture orientations and UAV (Unmanned Aerial Vehicle) imagery acquired from two key observation sites representing different morphological segments along the suspected fault trace.

Fracture data were collected directly from outcrops using a geological compass to record strike and dip, which were then analyzed to determine dominant joint orientations and their relation to regional stress fields. The data were processed using Dips software to visualize plane and line distributions, allowing structural interpretation and assessment of fault-related deformation patterns. UAV-based photogrammetry complemented field observations by providing high-resolution spatial data for detailed surface analysis.

Drone imagery was obtained through flights at approximately 300 m altitude, and processed using Agisoft Metashape to generate orthophotos and digital elevation models (DEMs) [13]. Morphological lineaments, drainage anomalies, and fault-related landforms were visually interpreted from these products. The integration of joint orientation data and UAV-derived morphotectonic interpretation enabled a more accurate delineation of the Cibojong Fault trace and its structural characteristics within the study area.

2.1 Study Area

The research location is included in the regional geological map of Garut and Pameungpeuk [11] and is mostly included in the geological map of Burangrang [12] as the latest reference. The rocks in the study area date from the Late Miocene to the Holocene. The stratigraphy of the study area (Figure 1) consists of twelve (12) lithostratigraphic units (from oldest to youngest) with the following descriptions: (1) Nmbt – Bentang Formation Tuff (Late Miocene). (2) Npvbx – Tuff Breccia (Early Pliocene). (3) Npvt – Tuff (Early Pliocene). (4) Npva – Gedogan Volcanic Andesite (Early Pliocene). (5) Ppvt – Old Volcanic Tuff (Late Pliocene). (6) Ppva – Old Volcanic Andesite (Late Pliocene). (7) Ppan – Andesite Intrusion (Pliocene-Pleistocene). (8) Qpvgk – Kendang Volcano Loose Debris (Pleistocene). (9) Qppbx – Old Volcano Pumice Breccia (Holocene). (10) Qpvot – Old Volcano Tuff (Holocene). (11) Qhka – Fractured Andesite from Mount Kencana (Holocene). (12) Qhvp – Unweathered Loose Debris Deposits from Mount Papandayan (Holocene).

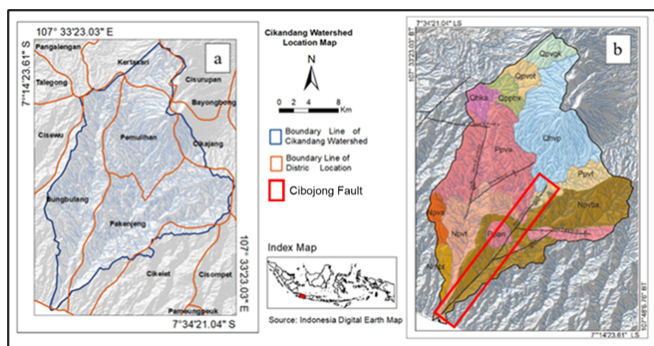


Fig 1. a) Location of Cibolang fault in Cikandang Watershed as study area. (modified from Indonesia digital earth map/peta rupa bumi indonesia (RBI)) b) regional geological map of the research area (modified from [11] and Bungbulang area geological map by [12])

3 Results and discussions

The observation site was located near Sasak Halimun Bridge, Jayamekar Village, Bungbulang (7°24'36.80"S, 107°43'8.80"E; 817 meter above sea level). UAV photogrammetry using a DJI Mavic Enterprise 3 and Agisoft processing produced a detailed 3D map of the Ciarinem River valley, revealing distinct topographic variations (Figure 2). The river forms a deep, narrow valley with steep slopes in the central part and gentler morphology toward the north and east, which are mainly used for agriculture. These morphological contrasts provide valuable insight into the tectonic and geomorphic controls within the Cikandang watershed.

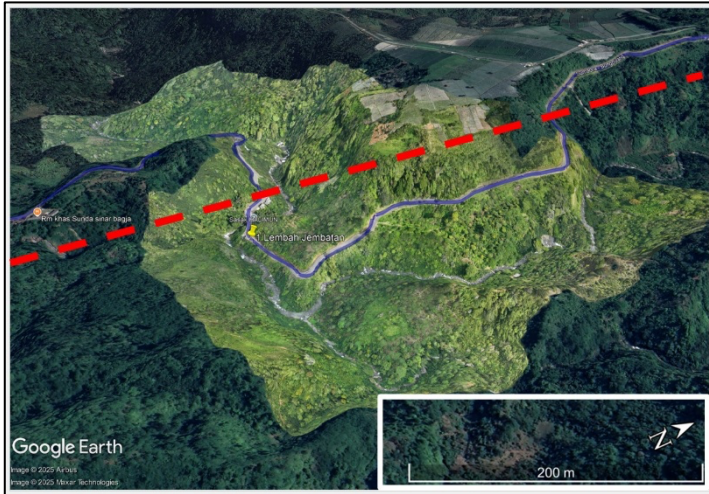


Fig 2. Photogrammetric image map of the Ciarinem River, red line indicates the Cibojong fault line.

The main outcrop at location 1 laying on the Ppvt (Old Volcanic Tuff - Late Pliocene) consisting of Tuff produced by Late Pliocene volcanic eruptions, greyish white (fresh) and brownish grey in colour, fine-grained, rounded to subrounded in shape, well-sorted, friable, and massive in structure (Figure 3). The tuff composition consists of glass, quartz, pyroxene, and hornblende. Joint orientation data processed using Dips software indicate a dominant σ_2 plunge direction consistent with a strike-slip fault regime, in agreement with the Bungbulang regional geological map identifying the Cibojong Fault as a strike-slip structure.

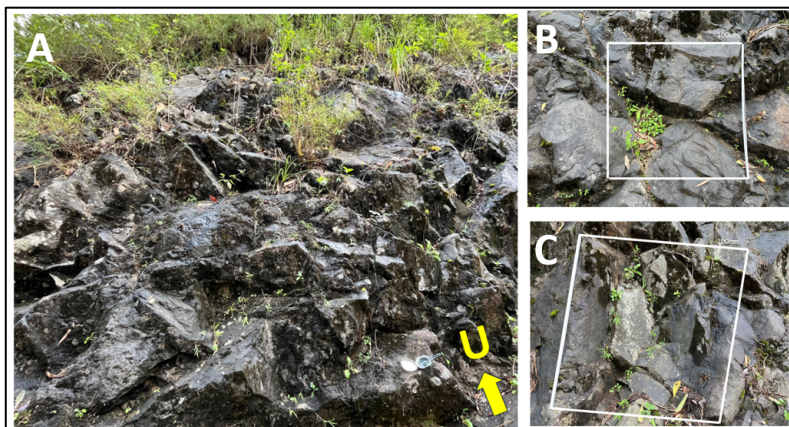


Fig 3. (A) Outcrop at location 1 (Ppvt unit, Old Volcanic Tuff - Late Pliocene geological age) with analysis results indicating a strike-slip fault along the Cibojong Fault. Outcrop photograph, (B–C) fracture density measurement details (0.0458 and 0.0593).

Fracture density measurements from 100×100 cm grids yielded values of 0.0458 and 0.0593, showing local variations in fracture intensity. The higher density at point B suggests stronger deformation near the fault zone. Combined with UAV-based

geomorphic interpretation, these findings confirm the presence of a strike-slip fault component along the Cibojong Fault trace (Figure 4).

Table 1. Strike and Dip data obtained from joint measurements

No	Strike (N-E)	Dip	No	Strike (N-E)	Dip
1	100	68	18	33	56
2	102	66	19	90	82
3	98	70	20	105	75
4	104	64	21	65	78
5	96	72	22	185	72
6	99	67	23	45	52
7	101	69	24	100	55
8	103	65	25	150	86
9	186	64	26	100	72
10	185	65	27	140	62
11	187	63	28	115	58
12	163	68	29	140	58
13	148	72	30	95	55
14	39	90	31	45	72
15	115	84	32	94	78
16	188	82	33	96	82
17	35	70			

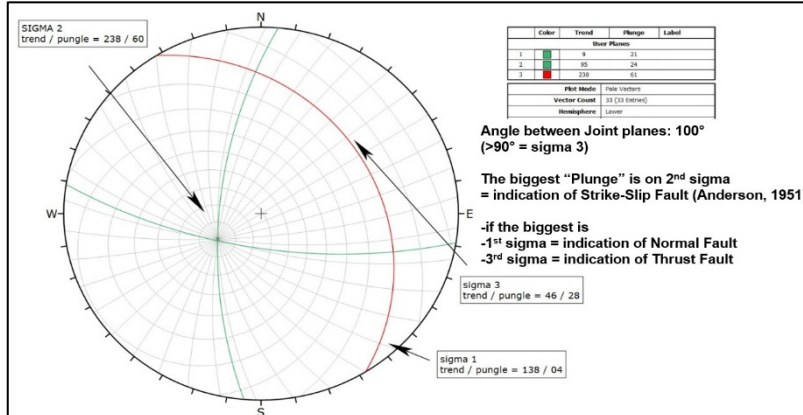


Fig 4. Results of data processing at location 1 showing indications of a strike-slip fault based on [14]

The second observation site is located along the Cirompang River (7°27'38.00"S, 107°40'13.00"E; 270 meter above sea level). UAV photogrammetry using a DJI Mavic Enterprise 3 and Agisoft processing produced detailed 3D maps showing variations in valley morphology (Figure 5). The river flows through a narrow upper reach and a wider downstream valley, cutting across hilly terrain with steep slopes. The imagery clearly

illustrates contrasts between natural landforms and surrounding human land use, such as agricultural fields and vegetated slopes.

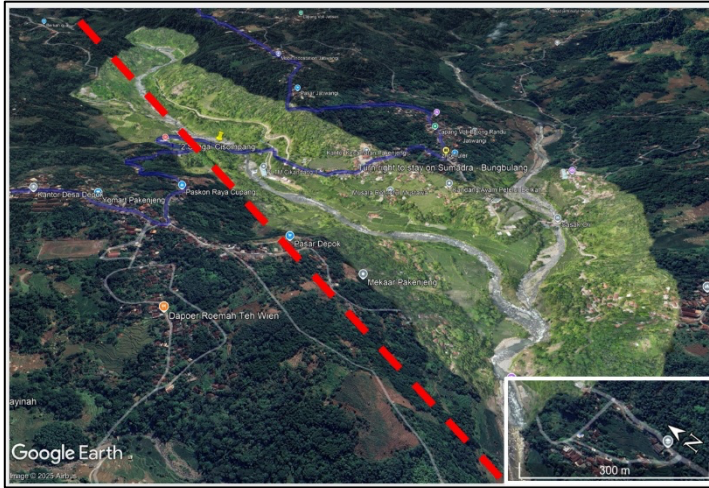


Fig 5. Photogrammetric Image Map of the Cirompang River, red line indicates the Cibojong fault line

According to the Bungbulang regional geological map [12], the exposed rocks belong to the Npvbx unit (Early Pliocene Tuff Breccia), composed of poorly sorted volcanic breccia with andesitic fragments and fine tuff matrix. The material is hard, massive, and brittle, indicating strong volcanic influence and susceptibility to fracturing. These lithological characteristics are significant for understanding how the Cibojong Fault may control local geomorphology and drainage patterns.

Field observations show that the Cirompang River channel is approximately 40 m wide with a bed dominated by alluvial deposits of gravel, sand, and cobbles, characteristic of an active fluvial system. The presence of a broad channel, flat sections, and scattered boulders suggests a mature river morphology in dynamic equilibrium between erosion, transport, and deposition. Vegetation and slope conditions contribute to sediment input through surface runoff and small landslides, further shaping the riverbed and adjacent floodplain.



Fig 6. The morphology of the Cirompang River shows a flow width of ± 40 m with a riverbed consisting of many alluvial rocks, characteristic of an active fluvial flow system.

The integration of UAV-based photogrammetry, morphotectonic indices, and fracture orientation data provides a clearer understanding of the geometry and activity

of the Cibojong Fault. Photogrammetric maps of the Ciarinem and Cirompang rivers reveal geomorphic anomalies—such as offset valleys, linear escarpments, and deflected drainages—that are typical indicators of strike-slip faulting. These surface lineaments correspond well with field-measured fracture orientations, confirming a strong structural control on the local topography [15].

Fracture analysis at Site 1, developed within the Late Pliocene Old Volcanic Tuff (Ppvt unit), reveals dominant NW–SE fracture orientations with σ_2 plunge directions indicative of a strike-slip stress regime. Fracture density values ranging from 0.0458–0.0593 cm/cm² suggest localized zones of deformation along the fault trace. Although the affected lithology is Late Pliocene in age, the deformation patterns and their alignment with geomorphic features observed in UAV imagery indicate post-Pliocene reactivation of the Cibojong Fault, likely extending into the Quaternary period.

At the Cirompang River site, deformation affects Early Pliocene volcanic breccia (Npvmx unit), suggesting that the Cibojong Fault cuts across a broad stratigraphic range from the Early to Late Pliocene. This cross-cutting relationship demonstrates long-term tectonic reactivation influencing landscape evolution, including river incision and valley morphology. Regionally, the strike-slip nature of the fault corresponds to the oblique subduction setting of the southern Sunda Arc, emphasizing its role as a component of the active forearc fault system. The recognition of this reactivated fault has important implications for earthquake hazard assessment and slope stability within the tectonically active region of southern Garut.

4 Conclusions

The integrated approach combining morphotectonic analysis, UAV-based photogrammetry, and fracture orientation measurements has effectively delineated the Cibojong Fault in the Pamulihan area, Southern Garut. UAV imagery successfully revealed geomorphic features such as offset valleys, escarpments, and deflected drainages, which are consistent with a strike-slip fault mechanism. Field-based fracture analysis showed dominant NW–SE structural trends with a σ_2 plunge direction, indicating a horizontal stress regime. The deformation observed in Pliocene volcanic units and variations in fracture density suggest that the fault has undergone post-Pliocene reactivation, continuing to influence surface morphology until the present.

These findings confirm the Cibojong Fault as an active strike-slip structure that significantly shapes the landscape of southern West Java. The cross-cutting relationships among lithostratigraphic units and geomorphic anomalies refine previous geological interpretations and highlight the value of high-resolution UAV data in identifying subtle tectonic features beneath dense vegetation. Overall, the results provide important insights for regional seismic hazard assessment and contribute to improving disaster risk mitigation strategies in tectonically active areas.

References

1. H T Verstappen, Indonesian landforms and plate tectonics Indonesia. *J. Geosci.* **5**, 197–207 (2010) <https://doi.org/10.17014/ijog.5.3.197-207>

2. R Hall, Late Jurassic-Cenozoic reconstructions of the Indonesian region and the Indian Ocean. *Tectonophysics*. 570-571, 1-41 (2012)
<https://doi.org/10.1016/j.tecto.2012.04.021>
3. Metcalfe I. Tectonic evolution of Sundaland. *Bull. Geol. Soc. Malaysia*. **63**, 27-60(2017)
4. F. Hilmi, I. Haryanto, Geological Structure Pattern of Regional West Java, Scientific Contribution, Universitas Padjadjaran, Bandung, **6** (1)1, 88-95 (2008)
5. E Keller, A Pinter, Nicholas, Active tectonics: Earthquakes, uplift, and landscape. New Jersey, Prentice Hall, USA (1996)
6. E. Sukiyah, I. Syafri, J. B. Winarto, M. R. B. Susilo, A. Saputra, E. Nurfadli, Active faults and their implications for regional development at the southern part of West Java, Indonesia, in Federation Internationale des Geometres Working Week, Christchurch, New Zealand, Proceedings, 1-12. (2016)
7. J. Winarto, E. Sukiyah, A. D. Haryanto, I. Haryanto, Morphotectonic study of a watershed controlled by active fault in Southern Garut, West Java, Indonesia. *Journal of Himalayan Earth Sciences*. **52**(2), 96 (2019)
8. Z. Liu, S. Zhou, H. Yu, W. Zhang, F. Guo, X. Chen, J. Guo, Quantitative analysis of tectonic geomorphology research based on Web of Science from 1981 to 2021. *Remote Sens*. **14**, 5227 (2022). <https://doi.org/10.3390/rs1420522>
9. H. Yao, R. Qin, X. Chen, Unmanned aerial vehicle for remote sensing applications—A review. *Remote Sens*. **11**, 1443 (2019)
10. S.A. Mahmood, R. Gloaguen, Appraisal of active tectonics in Hindu Kush: Insights from DEM derived geomorphic indices and drainage analysis. *Geosci. Front*. **3**, 407–428 (2012)
11. A. Alzwar, N. Akbar, Geological Map of Garut and Pameungpeuk Sheet, Java, scale 1:100,000 Geological Survey Centre, Bandung (1992)
12. E. Sukiyah, S. Rijani, A.D. Haryanto, M.L. Fatturakhman, D. Muslim, E. Nurfadli, Geological Map of Bungbulang Sheet (1208-61), Java, Faculty of Geological Engineering, Padjadjaran University and Geological Survey Centre (2024)
13. A. Farisan, N. A. Nurwantari, P. D. R. Fadlin, E. Puswanto, K. Widiyanto, D. Wibowo, A, Investigating the Structural Geology Control of the Opak Fault on the Semilir Formation in Yogyakarta, Indonesia. *ЛИТОСФЕРА*. **25**(1), 44-60 (2025)
14. Anderson E.M, The Dynamics of Faulting and Dyke Formation with Application to Britain. Oliver and Boyd, London (1951)
15. B. Kurnianto, E. Sukiyah, A. D. Haryanto, B. Muljana, The role of Fracture Density in Manifestations of upflow and outflow zones of Mount Ungaran geothermal system. *GEOMATE Journal*. **28**(130), 149-159 (2025)