Application of Point Counting Petrography for Provenance Determination; Implication for Tectonic Development from the Semilir Formation, Gunung Kidul

Alfathony Krisnabudhi[1], Aga Rizky[2], Ardhan Farisan[3], Desi Kumala Isnani[4], Sugeng Widada[5], Joseph Emmanuel Ardine[6], Muhammad Naufal Aiman[7], Brian Tony[8], Dani Mardiati[9]

[1,2,4,5,6,7,9] Department of Geological Engineering of UPN Veteran Yogyakarta, Indonesia
[3.] Research Centre for Geological Resources, National Research and Innovation Agency
[8] Department of Petroleum Engineering of UPN Veteran Yogyakarta, Indonesia

Email: [1]alfathony.krisnabudhi@upnyk.ac.id, [2]aga.rizky@upnyk.ac.id, [3]ardh005@brin.go.id, [4]rr.desi@upnyk.ac.id, [5]sugengwidada@upnyk.ac.id, [6]josephemmanuel3102@gmail.com, [7]naufalaiman2001@gmail.com, [8]brian.tony@upnyk.ac.id, [9]dani.mardiati@upnyk.ac.id

Received: 2025-08-27 Received in revised from 2025-09-03Accepted: 2025-09-10

Abstract

The provenance sediments have been analyzed to reveal tectonic development during the Semilir Formation deposition in the Southern Mountain of Yogyakarta area, using essential samples from field observation, petrography analysis, and the point counting method. Outcrop and sampling at two observation points revealed distinct lithological features, including sandstone and siltstone with mudclast structures and slump structures interbedded with siderite. Petrographic analysis using the point-counting method determined the mineral composition of four samples: 1A, 1B, 2A, and 2B. Samples 1A and 1B were categorized as Lithic Wacke, 2A Feldspathic Wacke, and 2B Lithic Wacke. Provenance analysis, crucial for understanding the sedimentary history and reconstructing the geological events preceding sediment deposition, identified that the sandstones in the Ngoro-oro region predominantly fall into the magmatic arc category. Hence, based on our analysis, the tectonic development during Semilir Fm deposition is linked with the convergence event of the first subduction on southern Java, which had huge volcanic influences and slope morphology common in volcanic areas. The findings of this study contribute to a deeper understanding of the tectonosedimentary processes and geological history of the Ngoro-oro region. The integrated approach of petrographic and provenance analyses provides a comprehensive view of the sedimentary rocks formation and evolution, enriching the geological knowledge of the area.

Keywords: *Ngoro-oro, Petrographic, Provenance, Sandstone*

1. Introduction

Sedimentary petrography remains a fundamental approach for reconstructing sediment provenance and unraveling basin evolution, particularly in tectonically active regions where complex depositional histories are recorded. Point counting petrography, which systematically quantifies framework grains in sandstones, has been widely applied to interpret sediment supply systems and to delineate paleogeographic reconstructions [1]. This method not only provides robust constraints on lithological sources but also allows for the evaluation of recycling processes, which are especially crucial in regions marked by multiple tectonic phases. In Southeast Asia, sedimentary basins preserve essential archives of past tectonic activity, where petrographic analysis has increasingly been used to bridge the gap between stratigraphy and regional geodynamics [2, 3].

In Java, the Tertiary–Quaternary formations constitute key archives of volcanic and sedimentary processes, shaped by the dynamic interaction of the Indo-Australian and Eurasian plates. The Semilir Formation, deposited during the Early Miocene, represents one of the most significant volcanic-sedimentary successions in Central Java, recording evidence of explosive volcanism interbedded with epiclastic sedimentation [4]. Recent provenance studies in Java have increasingly utilized petrography to decipher the evolution of forearc basins, subduction-related volcanism, and subsequent uplift processes [5, 6]. These advances emphasize the role of detailed petrographic analysis in enhancing our understanding of tectonic development, particularly in highly deformed volcanic–sedimentary successions.

Despite extensive mapping and stratigraphic knowledge of the Semilir Formation, its provenance and tectonic significance are still not well constrained. The key problem lies in the absence of a systematic framework that links sandstone composition to regional tectonic evolution. This study addresses that gap by applying point-counting petrography to quantify detrital compositions, enabling the reconstruction of sediment sources and their connection to tectonic processes active in southern Java.

Although recent studies in Central and East Java have demonstrated the applicability of petrographic and geochemical methods in provenance analysis, specific investigations focusing on the Semilir Formation remain limited [7, 8, 9]. This gap hinders a comprehensive understanding of how Early Miocene volcaniclastic sequences relate to the broader geodynamic framework of Java. By integrating point counting petrography with provenance analysis, this study contributes new insights into the tectonic development of Gunung Kidul, offering refined interpretations of source terranes and depositional processes. The novelty of this research lies in its ability to connect petrographic data with regional tectonic models, thereby providing a more holistic reconstruction of the Miocene tectonic evolution of southern Java.

2. Method

This research employed point counting petrography as the principal analytical method to determine the provenance of sandstone samples from the Semilir Formation. Representative sandstone samples were systematically collected from measured stratigraphic sections across the Gunung Kidul area to ensure coverage of lithological variations. A total of 30 thin sections were prepared using standard petrographic procedures, with each section examined under a polarizing microscope. Point counting was conducted using the Gazzi-Dickinson method, with a minimum of 300 framework grains identified per thin section to ensure statistical robustness. The classification of detrital components followed the scheme of Dickinson (1985) [10] as modified by Ingersoll et al. (2020), dividing grains into quartz, feldspar, lithic fragments, and accessory minerals.

To minimize operator bias, the counting procedure adopted a systematic grid traversing method. Framework grains were normalized into QFL (Quartz–Feldspar–Lithic) and QmFLt (monocrystalline quartz–feldspar–total lithic) ternary plots for provenance analysis. These data were then interpreted with respect to tectonic discrimination diagrams, allowing the sandstone compositions to be linked with potential source terranes and paleotectonic settings. The results were compared with published petrographic datasets from adjacent Miocene formations in Central and East Java to establish regional correlations.

The application of point counting petrography has proven effective in provenance analysis within complex tectonic provinces. Recent studies in Southeast Asia have demonstrated the robustness of this approach, particularly in volcaniclastic-dominated basins where geochemical signatures alone may not adequately reflect source variability [8, 6, 9]. Thus, the methodology adopted in this study provides a reliable basis for reconstructing the sediment sources of the Semilir Formation and assessing their tectonic significance in the context of Miocene basin development in southern Java.

3. Results and Discussion

3.1. Geology of the Research Area

The Semilir Formation represents one of the most prominent volcanic–sedimentary successions in the Southern Mountains of Java, particularly well exposed in the Gunung Kidul area. Stratigraphically, this formation belongs to the Early Miocene, deposited within a forearc basin influenced by the active subduction of the Indo-Australian Plate beneath the Eurasian Plate. Lithologically, it consists predominantly of volcanic breccias, tuffs, and volcaniclastic sandstones, interbedded with fine-grained mudstones. These deposits indicate high-energy mass flow and pyroclastic surge processes, alternating with periods of relatively quieter epiclastic sedimentation [4]. The lower part of the succession is generally dominated by thick pyroclastic flows, while the middle to upper portions are characterized by alternating volcaniclastic sandstones and finer-grained sediments, suggesting variable depositional environments ranging from proximal volcanic apron settings to more distal marine-influenced deposits [5].

Sedimentation of the Semilir Formation was strongly controlled by contemporaneous explosive volcanism associated with a Miocene magmatic arc system in southern Java. The abundance of volcanic lithic fragments, pumice, and glass shards reflects a provenance dominated by andesitic to dacitic arc volcanoes. The depositional architecture, comprising massive tuff layers interbedded with sandstones and siltstones, records episodic volcanic eruptions followed by reworking of pyroclastic material by marine and subaqueous gravity flows [7, 8]. This lithological variability highlights the dynamic interplay between volcanism and sedimentation during the Early Miocene in the Java forearc setting.

The Southern Mountains of Java, where the Semilir Formation is exposed, form part of the forearc high developed in response to the northward subduction of the Indo-Australian Plate. The regional tectonic framework is characterized by a complex interplay of subduction-related magmatism, thrusting, and extensional collapse. Structurally, the Semilir Formation is often fault-bounded and locally folded, reflecting syn-depositional tectonic instability. Fault orientations indicate both strike-slip and thrust components, consistent with oblique subduction processes [4, 11].

During the Early Miocene, the tectonic evolution of southern Java was dominated by arc volcanism and forearc basin development. The Semilir Formation records this geodynamic setting, as volcaniclastic input was derived directly from the uplifted magmatic arc to the south. Subsequent deformation, including folding and faulting, modified the original depositional architecture and influenced the distribution of facies. These tectonic processes not only shaped the stratigraphy of the Semilir Formation but also controlled sediment supply pathways, making petrographic analysis essential for reconstructing provenance and paleotectonic history [3, 6].

Despite its significance, the tectono-stratigraphic interpretation of the Semilir Formation remains debated. Some authors have argued that the formation represents predominantly deep-marine turbiditic deposits sourced from volcanic arc collapse [7], while others suggest a shallower forearc basin setting with significant subaqueous pyroclastic deposition [5, 9]. These contrasting views reflect the difficulty of distinguishing between primary volcanic and reworked volcaniclastic processes in the rock record. In this study, we argue that the Semilir Formation records a mixed depositional system, where explosive volcanic eruptions supplied abundant pyroclastic material that was subsequently redistributed in a marine forearc setting. Through point counting petrography, this research provides quantitative provenance constraints that help clarify the interplay between volcanism and sedimentation, thereby refining the tectonic interpretation of the Early Miocene evolution in southern Java.

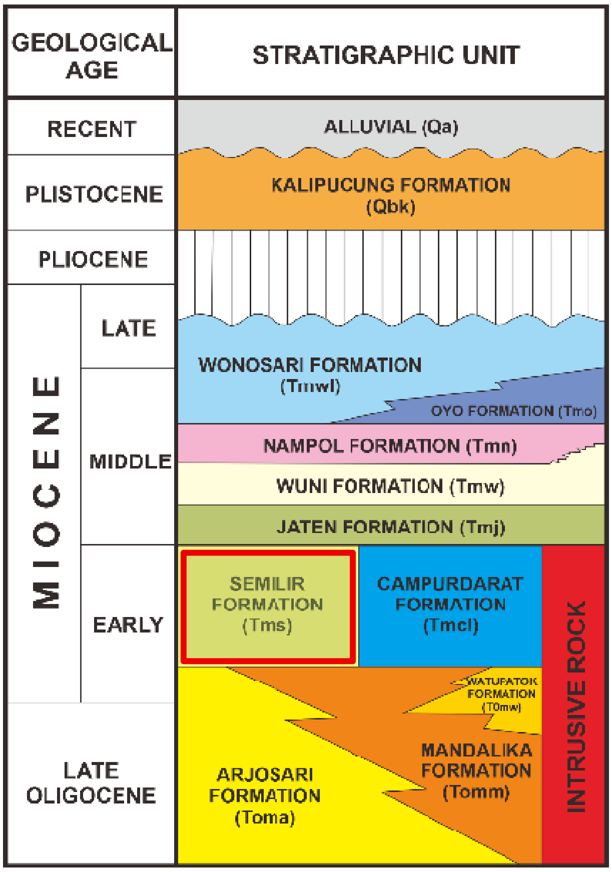

Figure 1. Stratigraphy of the west part of the Southern Mountain, study area marked by red square [4].

3.2. Outcrop and Sampling

Two representative outcrops of the Semilir Formation were selected for detailed field observation and sampling. The first outcrop, located along a 10 m north–south exposure with a height of approximately 5 m, is characterized by interlayered sandstone and siltstone beds containing well-developed mudclast structures (Figure 2 A). From this outcrop, two sandstone samples (1A and 1B) were collected for petrographic analysis (Figure 2 B,C).

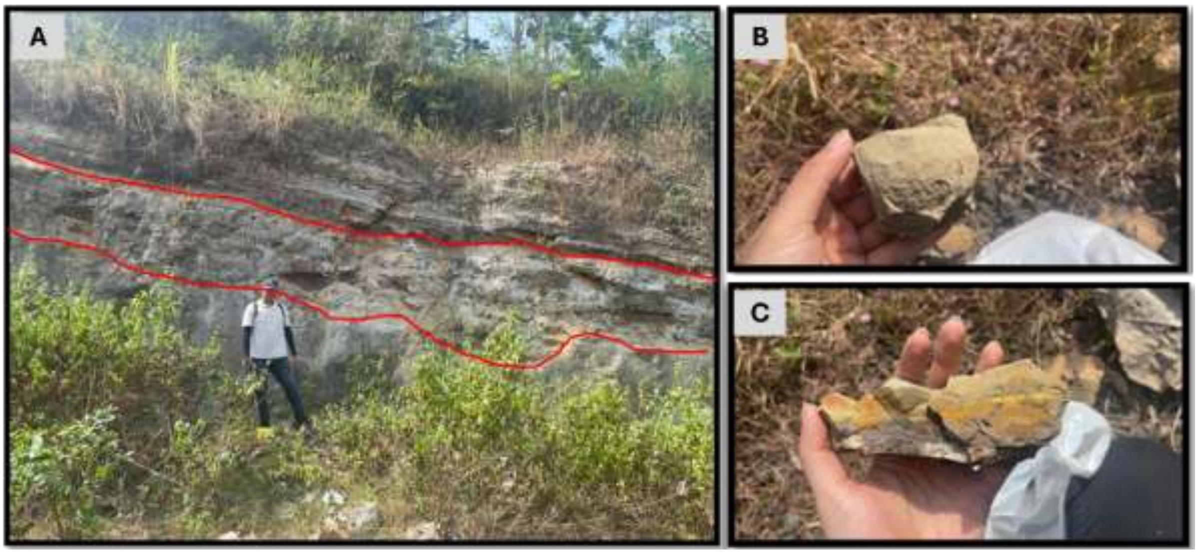

Figure 2. (A) Outcrop at Observation Point 1 showing interlayered sandstone and siltstone with mudclast structures; (B) hand specimen of sample 1A; (C) hand specimen of sample 1B.

The second outcrop extends for about 12 m in a north–south orientation and reaches a height of 5–6 m. This section displays prominent slump structures and consists of alternating sandstone beds intercalated with siderite horizons (Figure 3, top). Two additional samples, designated 2A and 2B, were obtained from this outcrop to represent its petrographic variation (Figure 3, bottom).

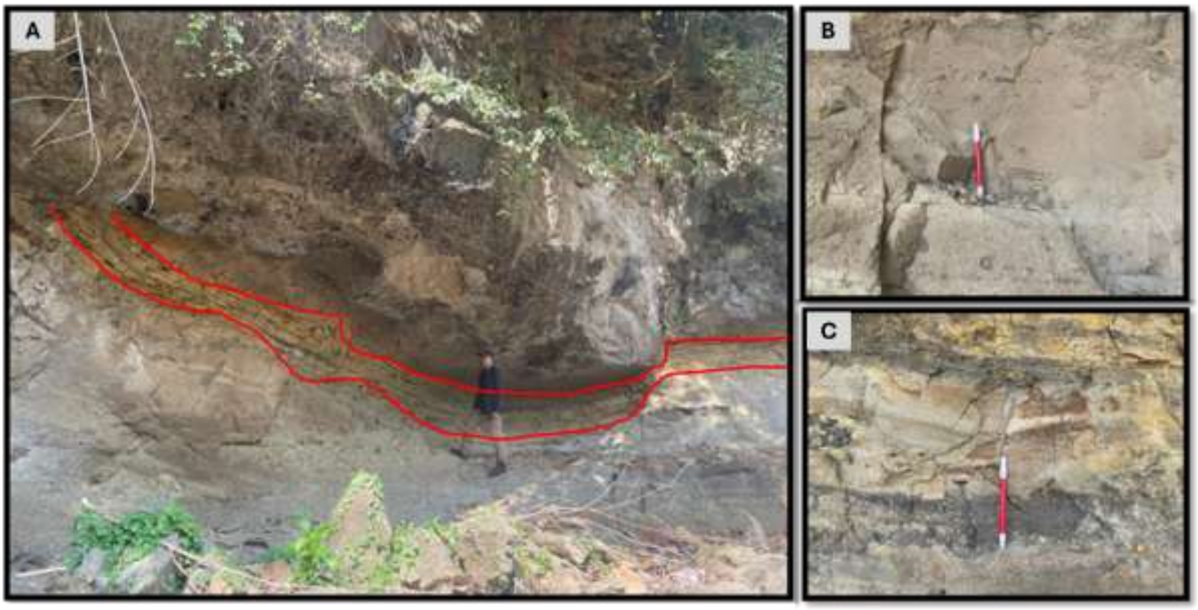

Figure 3. (A) Outcrop at Observation Point 2 displaying slump structures with interbedded sandstone and siderite layers; (B) hand specimen of sample 2A; (C) hand specimen of sample 2B.

3.3. Petrographic Analysis

Petrographic classification of the four representative sandstone samples follows the framework of Pettijohn (1975), emphasizing the relative proportions of quartz (Q), feldspar (F), and lithic fragments (L). Thin-section examination revealed that all samples are matrix-supported, poorly sorted, and generally composed of subangular to subrounded grains, with variable proportions of volcanic lithics, plagioclase, quartz, and mafic minerals such as hornblende and pyroxene.

Point-counting analysis demonstrates that samples 1A, 1B, and 2B are classified as lithic wacke, dominated by volcanic lithic fragments with subordinate feldspar and quartz. In contrast, sample 2A is identified as a feldspathic wacke, distinguished by its higher plagioclase content. These petrographic characteristics indicate a consistent supply of volcanic detritus, reflecting input from an active magmatic arc.

Detailed mineralogical counts for each sample are summarized in Table 1 and illustrated in Figures 4–11. The main petrographic outcome emphasizes the predominance of volcanic lithics across the dataset, which provides the basis for provenance interpretation discussed in the following section.

Table 1. Modal composition of sandstone samples from the Semilir Formation based on point-counting analysis.

Sample	Quartz (%)	Plagioclase (%)	Lithics (%)	Hornblende (%)	Pyroxene (%)	Opaque minerals (%)	Matrix (%)	Rock type (Pettijohn, 1975)
1A	9.34	14.48	76.16	5.25	5.50	1.50	34.25	Lithic Wacke
1B	28.57	21.76	49.65	2.50	2.00	1.50	34.25	Lithic Wacke
2A	10.62	46.25	43.10	7.00	6.75	–	–	Feldspathic Wacke
2B	25.20	25.95	48.85	4.25	3.25	–	–	Lithic Wacke

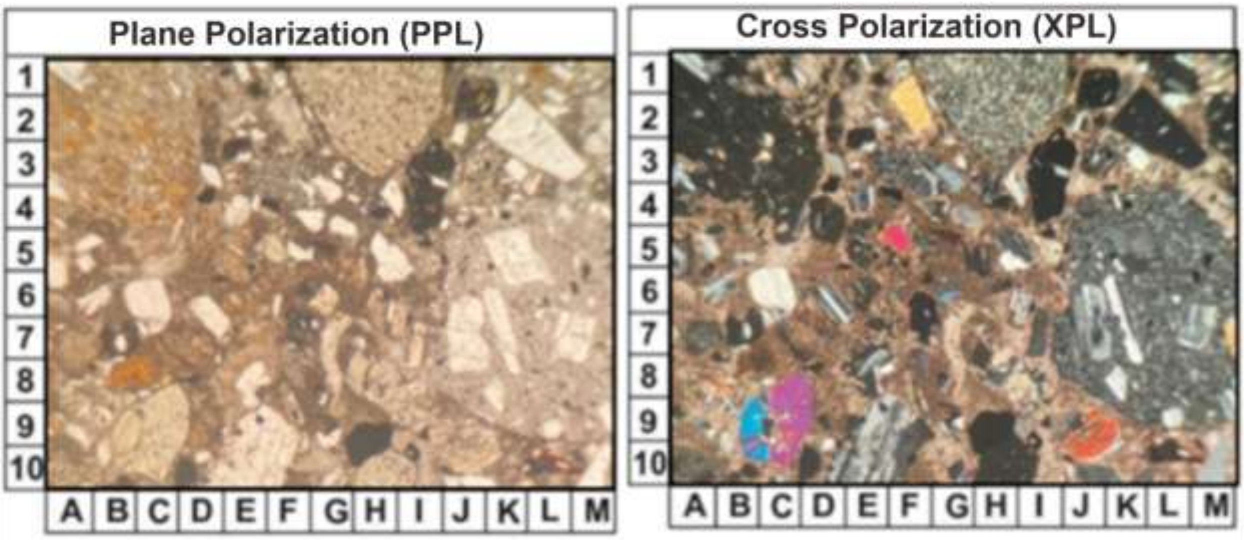

Figure 4. Plane-polarized (left) and cross-polarized (right) petrographic photos of sample 1A.

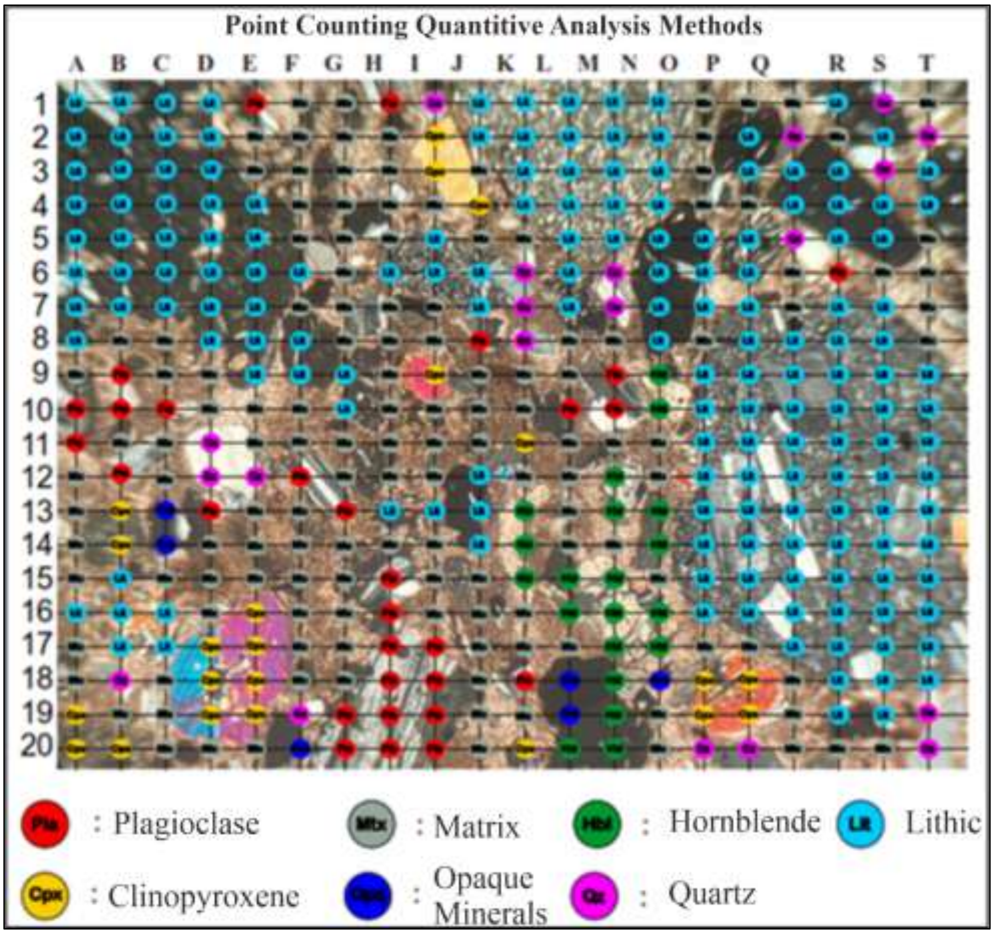

Figure 5. Point counting method and mineral description of Sample 1A.

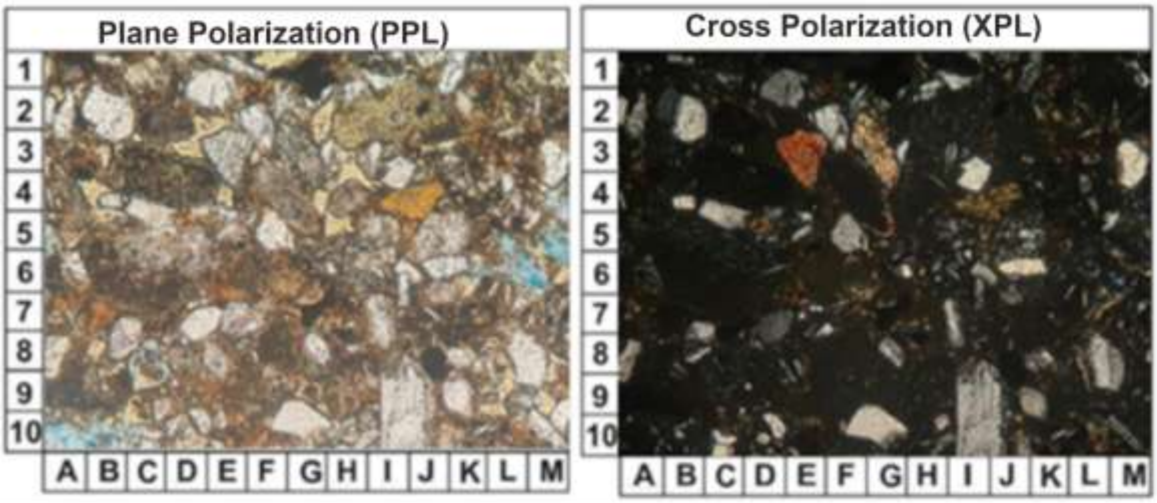

Figure 6. Plane-polarized (left) and cross-polarized (right) petrographic photos of sample 1B.

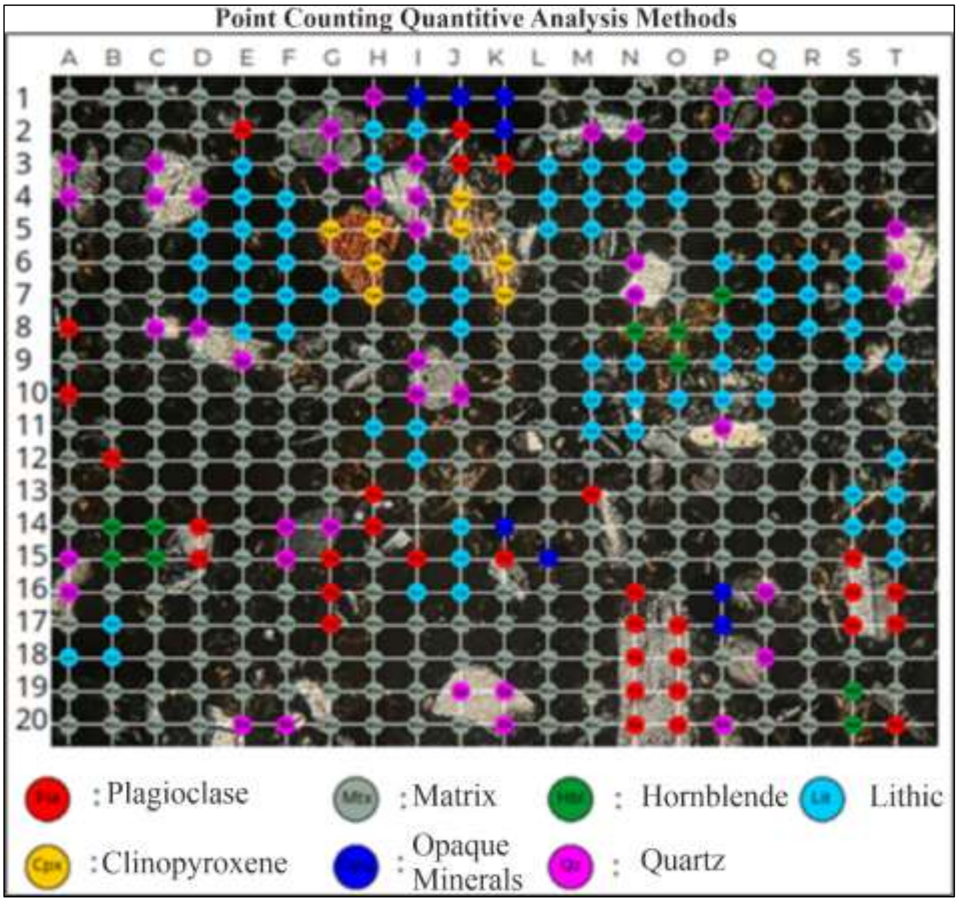

Figure 7. Point counting method and mineral description of Sampe 1B.

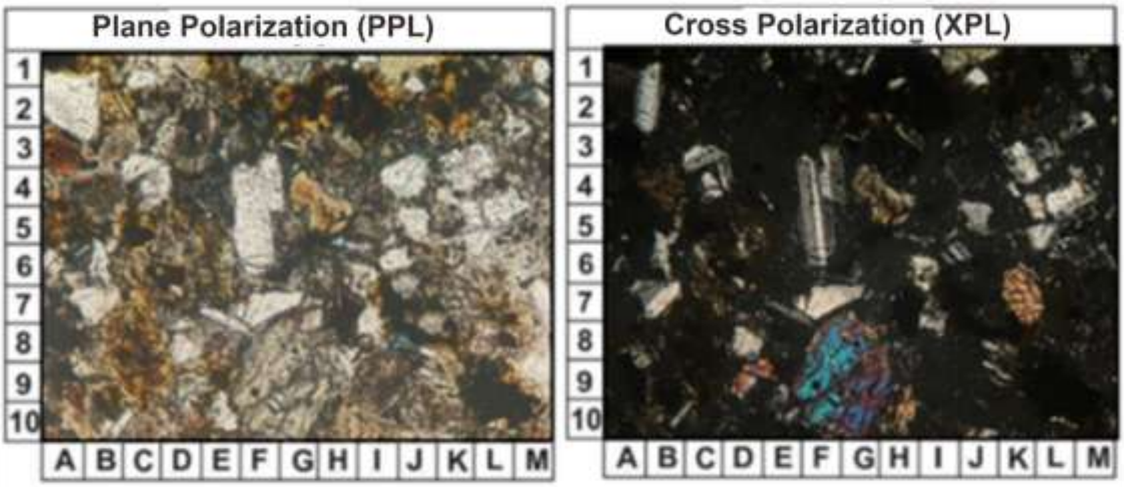

Figure 8. Plane-polarized (left) and cross-polarized (right) petrographic photos of sample 2A.

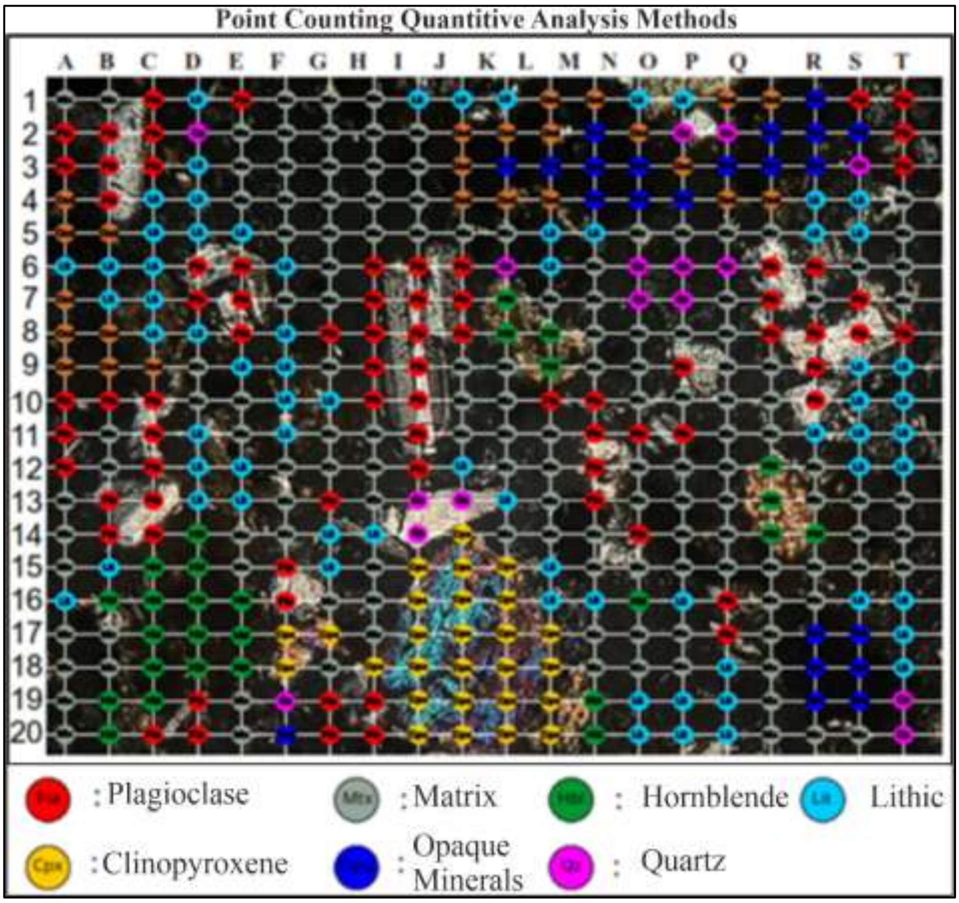

Figure 9. Point counting method and mineral description of Sampe 2A.

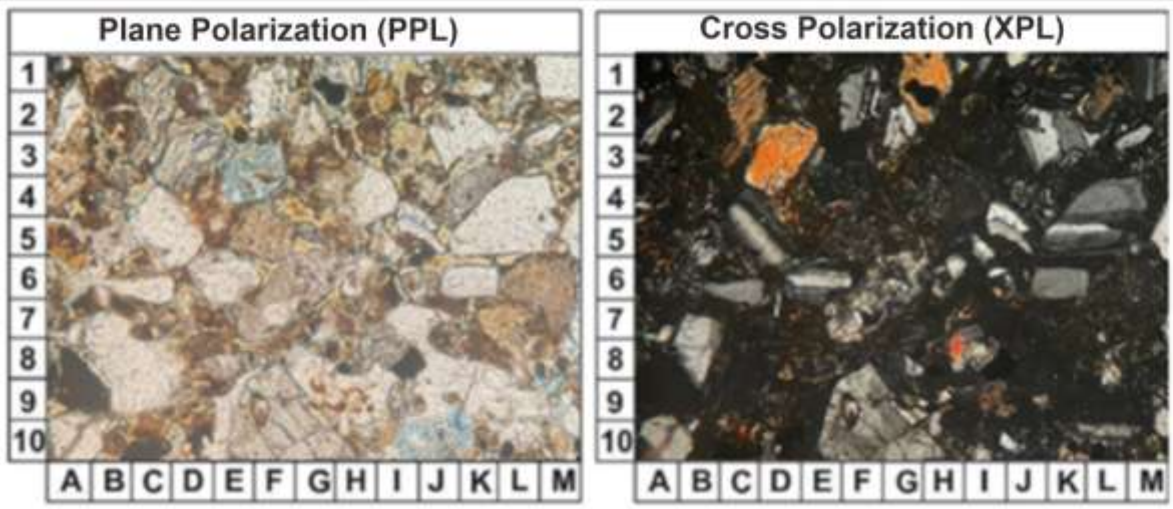

Figure 10. Plane-polarized (left) and cross-polarized (right) petrographic photos of sample 2B.

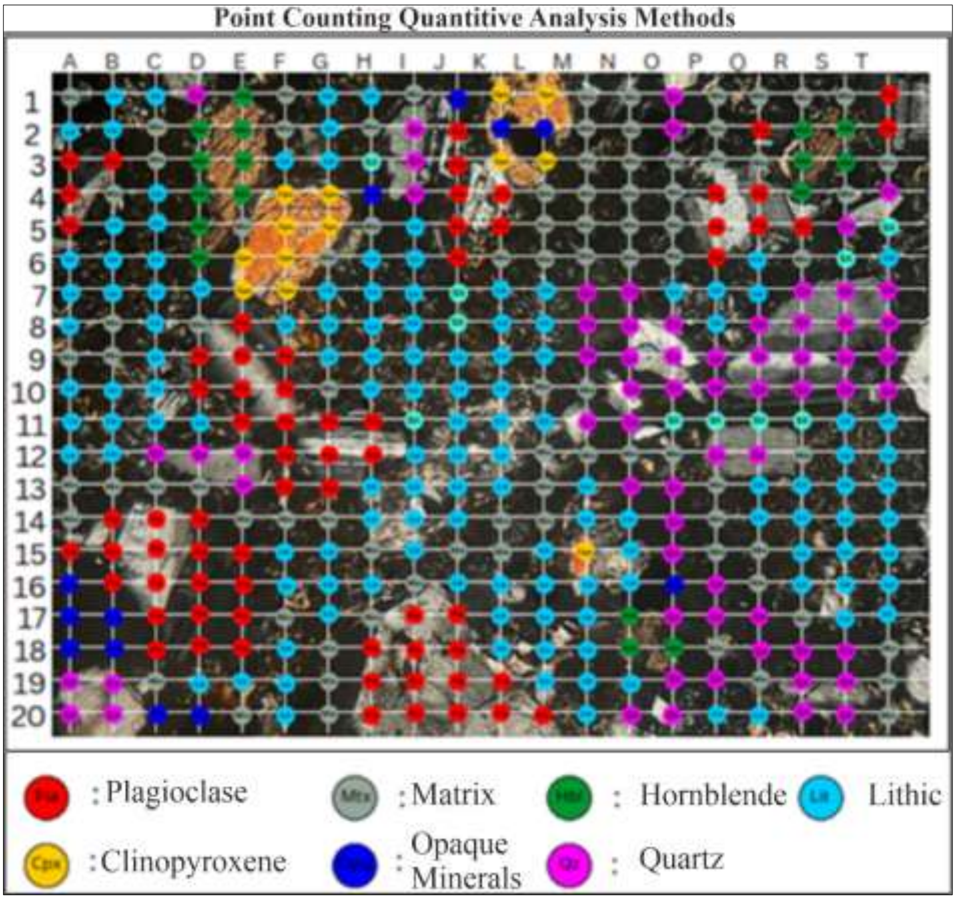

Figure 11. Point counting method and mineral description of Sampe 2B.

Table 2 summarizes the modal composition of the four analyzed samples and their classification using Pettijohn (1974) (Figure 13). Sample 1A contains 14.48% plagioclase, 9.34% quartz, and 76.16% lithics, and is classified as lithic wacke. Sample 1B has 21.76% plagioclase, 28.57% quartz, and 49.65% lithics, also falling within the lithic wacke field. Sample 2A, with 46.25% plagioclase, 10.62% quartz, and 43.1% lithics, is classified as feldspathic wacke. Sample 2B contains 25.95% plagioclase, 25.20% quartz, and 48.85% lithics, and is likewise categorized as lithic wacke.

Table 2. Data of petrographic observation

ID	Abundance (%)		
	Quartz	Plagioclase	Lithic
1A	9.34	14.48	76.16
1B	28.57	21.76	49.65
2A	10.62	46.25	43.10
2B	25.20	25.95	48.85

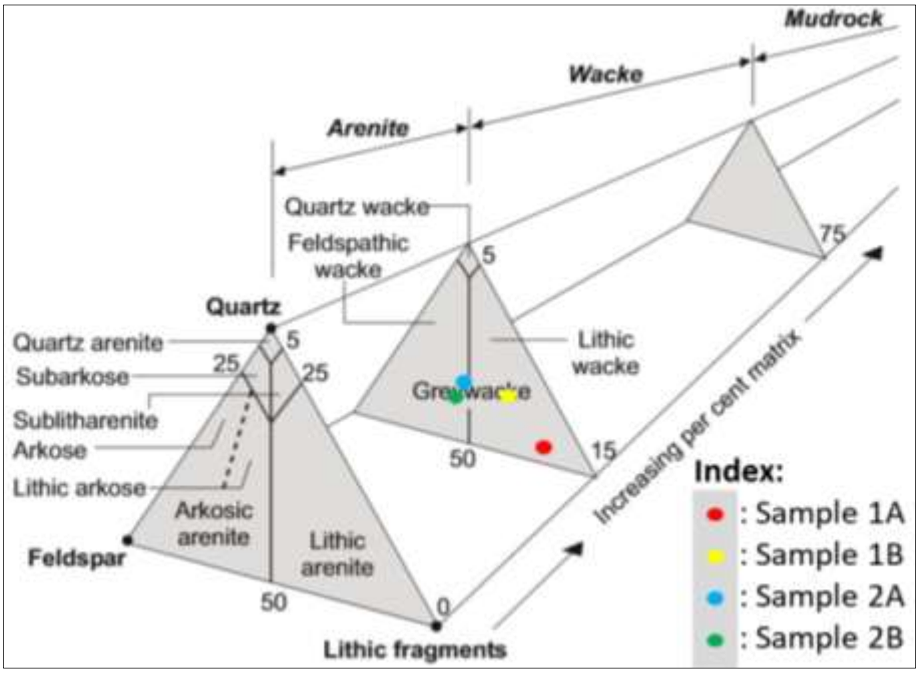

Figure 12. The classification of sandstone according to Pettijohn (1975).

3.4. Provenance Analysis

Point-counting analysis shows that the Semilir Formation sandstones are dominated by lithic and feldspathic wackes, with volcanic lithics and plagioclase as the main framework components. The abundance of volcanic fragments, coupled with poorly sorted textures and matrix support, reflects rapid deposition from proximal volcanic sources. The dominance of volcanic lithics in these sandstones is consistent with provenance from an undissected magmatic arc, as predicted by the Gazzi–Dickinson method [10]–[12].

The QFL and QmFLt compositions of the Semilir Formation overlap with sandstone suites described from other Neogene forearc basins. For example, the Miocene Bhuban Formation in India [13] and the Permian Tunas Formation in Argentina [14] both show arc-derived compositions deposited adjacent to active subduction zones. Similar volcanic arc provenance has also been reported from the Waterberg Group in South Africa [15], the Chaco–Paraná Basin in Uruguay [16], and the Muling Formation in northeastern China [17]. These parallels confirm that the Semilir sandstones share common compositional traits with globally recognized arc-related successions.

Within Indonesia, volcanic arc signatures are consistent across several Neogene units. The Waturanda and Penosogan Formations in Karangsambung, Central Java, record Early to Middle Miocene magmatic arc input [18], while the Kerek Formation in the Kendeng Basin reflects similar volcaniclastic influence [19]. More recent provenance studies of Paleogene and Neogene sandstones in Sumatra, including the Bukit Tigapuluh and Lemat Formations [20], further emphasize the persistence of arc-derived sedimentation in Indonesian basins. The petrographic similarities highlight that the Semilir Formation is part of a broader regional pattern of arc-related sediment dispersal during the Early Miocene.

Interpretations of the depositional setting remain debated. Some authors argue for a deep-marine turbiditic system derived from arc collapse [21], while others emphasize shallow forearc sedimentation with significant pyroclastic reworking [22]. The petrographic data from this study support a hybrid model: the Semilir sandstones were sourced from explosive volcanic eruptions and plutonic arc rocks, but their final deposition occurred in a forearc basin characterized by steep volcanic slopes. The presence of abundant matrix and poorly sorted textures suggests rapid downslope transport consistent with a forearc turbidite environment, while the dominance of volcanic lithics points to proximal arc derivation.

The Semilir Formation represents a mixed depositional system within a forearc basin, strongly influenced by undissected to transitional magmatic arc sources. The volcanic lithic dominance observed parallels findings from Neogene basins in Java [18], [19] and other arc-related settings such as the Bhuban Formation of India [13]. Thus, the sandstone composition provides further evidence of Early Miocene arc-derived sedimentation consistent with active subduction along southern Java.

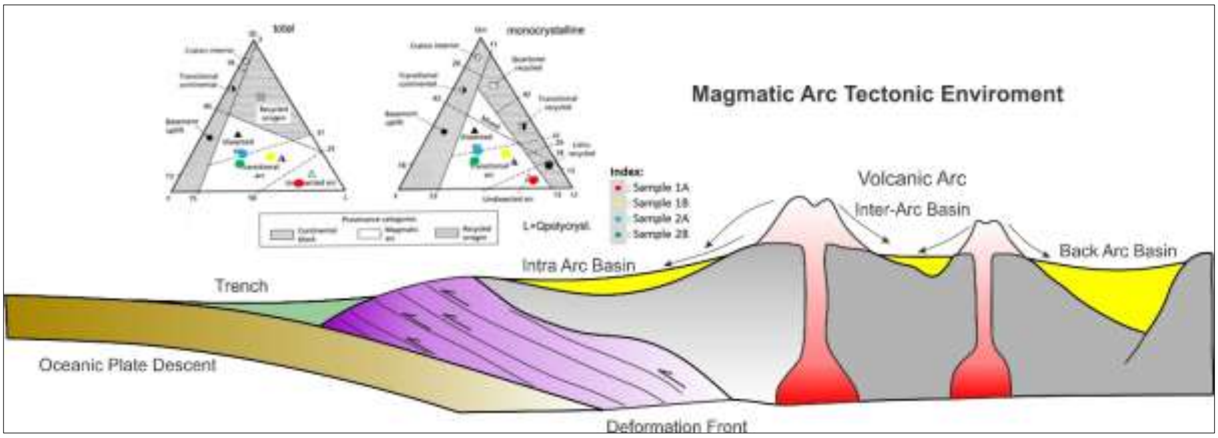

Figure 13. Provenance interpretation and tectonic environment of four samples from Semilir Fm.; (1) Sample 1A, undissected arc, (2) Sample 1B-2A and 2B transitional arc, all samples interpreted as clastic sediment from a magmatic arc system

4. Conclusion

Point-counting petrography of the Semilir Formation sandstones reveals compositions dominated by lithic wacke (samples 1A, 1B, and 2B) and feldspathic wacke (sample 2A). The framework is characterized by abundant volcanic lithics and plagioclase, reflecting sediment supply from undissected to transitional magmatic arc sources. These petrographic signatures demonstrate that the Semilir Formation records Early Miocene arc-derived detritus linked to active subduction along southern Java.

The combined evidence supports a hybrid depositional model. While the poorly sorted textures and abundant matrix indicate rapid downslope transport consistent with forearc turbidite systems, the dominance of volcanic lithics highlights strong input from proximal arc volcanoes. This integration of petrographic and tectonic interpretations refines the understanding of the Semilir Formation, showing that it formed within a forearc basin strongly influenced by explosive arc volcanism and steep volcanic slopes.

By establishing a detailed provenance framework, this study strengthens regional correlations and demonstrates that the Semilir Formation shares compositional and tectonosedimentary characteristics with coeval Neogene arc successions both within Java and globally.

Acknowledgments

The author extends gratitude for the funding provided by the Early Career Lecturer Research Grant (PDP) from the Ministry of Education and Culture Indonesia and also acknowledges the assistance from students of the Geological Engineering program at the University of Pembangunan Nasional "Veteran" Yogyakarta.

Reference

[1] Garzanti, E., Vermeesch, P., and Andò, S., “Petrographic classification of sand and sandstone: A systematic approach,” *Sediment. Geol.*, vol. 383, pp. 1–22, 2019, doi: 10.1016/j.sedgeo.2019.01.002.

[2] Wang, J., Chen, J., and Xu, W., "Provenance analysis of forearc basin sediments in tectonically active settings: Insights from petrography and geochemistry," *Tectonophysics*, vol. 791, 228554, 2020, doi: 10.1016/j.tecto.2020.228554.

[3] Rossetti, D. F., Góes, A. M., and Nogueira, A. C. R., "Petrography and provenance of Miocene siliciclastic deposits in equatorial South America: Implications for Andean tectonics," *Sediment. Geol.*, vol. 421, 105959, 2021, doi: 10.1016/j.sedgeo.2021.105959.

[4] Samodra, H., & Wiryosujono, S. (1989). Tinjauan tatanan stratigrafi dan tektonik Pegunungan Selatan Jawa Timur antara Pacitan–Ponorogo. P3G, Bandung..

[5] Utami, P., Nugraha, A. M. S., and Rahardjo, S., "Sandstone petrography and provenance of Miocene sequences from the Kendeng Basin, Central Java," *J. Southeast Asian Earth Sci.*, vol. 210, 104912, 2021, doi: 10.1016/j.jseaes.2021.104912.

[6] Setiawan, A., Wibowo, H., and Prasetyadi, C., "Petrographic and provenance analysis of volcaniclastic deposits in Central Java forearc basin," *Geosci. Front.*, vol. 13, no. 5, 101360, 2022, doi: 10.1016/j.gsf.2021.101360.

[7] Santoso, B., Utami, P., and Satyana, A. H., "Volcaniclastic sequences and their provenance implications in Central Java, Indonesia," *Indones. J. Geosci.*, vol. 7, no. 3, pp. 221–236, 2020, doi: 10.17014/ijog.7.3.221-236.

[8] Adhitama, F., Nugraha, A. M. S., and Santoso, B., "Provenance and depositional environment of volcaniclastic sandstones from the Southern Mountains, Java, Indonesia," *J. Asian Earth Sci.*, vol. 220, 104916, 2021, doi: 10.1016/j.jseaes.2021.104916.

[9] Sari, N. M., Setiawan, A., and Handoko, A., "Petrography and geochemistry of volcaniclastic sandstones from East Java: Implications for Miocene tectonic evolution," *Mar. Petrol. Geol.*, vol. 152, 106479, 2023, doi: 10.1016/j.marpetgeo.2023.106479.

[10] R. V. Ingersoll, T. F. Bullard, R. L. Ford, J. P. Grimm, J. D. Pickle, and S. W. Sares, "The effect of grain size on detrital modes: A test of the Gazzi–Dickinson point-counting method," J. Sediment. Res., vol. 54, no. 1, pp. 103–116, 1984, doi: 10.1306/212F83B9-2B24-11D7-8648000102C1865D.

[11] G. J. Weltje, "Quantitative analysis of detrital modes: Statistically rigorous confidence regions in ternary diagrams and their use in sedimentary petrology," Earth-Sci. Rev., vol. 57, no. 3–4, pp. 211–253, 2002, doi: 10.1016/S0012-8252(01)00076-9.

[12] P. Vermeesch, "Statistical models for point-counting data," Earth Planet. Sci. Lett., vol. 501, pp. 1–7, 2018, doi: 10.1016/j.epsl.2018.08.019.

[13] B. Kashyap and R. Sarmah, "Petrography and whole-rock geochemistry of the Miocene Bhuban Formation of Tripura Fold Belt, North District, Tripura, India: Implications for provenance, tectonic setting and weathering intensity," J. Sediment. Environ., vol. 7, pp. 333–346, 2022, doi: 10.1007/s43217-022-00092-9.

[14] M. Febbo, R. N. Tomezzoli, N. Cesaretti, G. Choque, N. Fortunatti, and G. Arzadún, "Petrography and tectonic provenance of the Permian Tunas Formation: Implications on the paleotectonic setting during the Claromecó Foreland Basin evolution, southwestern Gondwana margin, Argentina," J. Palaeogeogr., vol. 11, no. 3, pp. 271–287, 2022, doi: 10.1016/j.jop.2022.06.001.

[15] M. Melton, C. Baiyegunhi, and S. Masango, "Petrography, modal composition, and tectonic provenance of some selected sandstones from the Swaershoek and Alma Formations (Waterberg Group) and Glentig Formation, Limpopo Province, South Africa," Arab. J. Geosci., vol. 15, p. 1042, 2022, doi: 10.1007/s12517-022-09989-1.

[16] G. Blanco, P. Abre, H. Ferrizo, M. Gaye, P. Gamazo, J. Ramos, E. Alvareda, and A. Saracho, "Revealing weathering, diagenetic and provenance evolution using petrography and geochemistry: A case study from the Cretaceous to Cenozoic sedimentary record of the SE Chaco-Paraná Basin in Uruguay," J. South Am. Earth Sci., vol. 103, p. 102974, 2020, doi: 10.1016/j.jsames.2020.102974.

[17] Y. Song, Z. Liu, Q. Meng, Y. Wang, G. Zheng, and Y. Xu, "Petrography and geochemistry characteristics of the Lower Cretaceous Muling Formation from the Laoheishan Basin, Northeast China: Implications for provenance and tectonic setting," Mineral. Petrol., vol. 111, pp. 161–176, 2017, doi: 10.1007/s00710-016-0476-9.

[18] F. Safira, E. B. Purwasatriya, and A. K. Gibran, "Early to Middle Miocene dissected arc of Karangsambung Area: A case study of Waturanda and Penosogan Formations provenance," J. Earth Mar. Technol., vol. 3, no. 2, pp. 124–140, 2023.

[19] J. E. Ardine, S. U. Pratomo, C. Prasetyadi, M. O. B. Nugroho, and A. Rizky, "Depositional environment characteristic of the Late Miocene Kerek Formation in Kendeng Basin: A case from Cipluk Area, Kendal Regency, Central Java," J. Earth Mar. Technol., vol. 4, no. 1, pp. 41–48, 2023.

[20] Daryono, S. K., & Idarwati, I. (2024). Provenance and petrographic analysis of Paleogene sandstones in the Bukit Tigapuluh Area, Jambi Subbasin, Indonesia. Journal of Earth and Marine Technology, 4(2), 301–314.

[21] B. Santoso, P. Utami, and A. H. Satyana, "Volcaniclastic sequences and their provenance implications in Central Java, Indonesia," Indones. J. Geosci., vol. 7, no. 3, pp. 221–236, 2020, doi: 10.17014/ijog.7.3.221-236.

[22] N. M. Sari, A. Setiawan, and A. Handoko, "Petrography and geochemistry of volcaniclastic sandstones from East Java: Implications for Miocene tectonic evolution," Mar. Petrol. Geol., vol. 152, p. 106479, 2023, doi: 10.1016/j.marpetgeo.2023.106479.