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Geodiversity Inventory for Geotourism in Tanjung Api Central Sulawesi

Abd Rahman DM[1], Tati Fitriana[1], Muslimin U. Botjing[1]

[1] *Geological Engineering Study Program, Tadulako University, Jl. Soekarno Hatta, Palu, Central Sulawesi, 94148, Indonesia*

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Corresponding author:
Abd Rahman DM
Email:
abdrahman03032000@gmail.com

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ABSTRACT

This study investigates the geological diversity of the Tanjung Api region in Tojo Una-Una Regency, Central Sulawesi, with the aim of identifying potential sites for geotourism and geological heritage designation. Through field observations, lithological and geomorphological mapping, petrographic analysis, and structural interpretation, ten geological sites were inventoried. Among them, Gua Kehidupan and Tanjung Api were identified as fulfilling national criteria for geological heritage due to their exceptional features, including fossil-bearing caves, sinkholes, and active gas seeps related to tectonic brecciation. The remaining sites exhibit significant geotourism value, particularly in coastal, volcanic, and sedimentary contexts. Findings from this study highlight the relevance of geodiversity in supporting sustainable tourism and geoconservation. By integrating geological features with educational and community-based values, Tanjung Api demonstrates strong potential to be developed into a geotourism destination that balances scientific significance, cultural relevance, and ecological preservation. The inventory and qualitative assessment serve as a reference for future geoheritage planning and site management. The study recommends involving local stakeholders in the promotion and conservation of these sites to ensure long-term sustainability and community benefits.

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1. INTRODUCTION

Geodiversity, encompassing a variety of geological features such as rocks, minerals, fossils, and landforms, forms a fundamental basis for understanding the dynamic systems and processes of the Earth. Its significance extends beyond scientific enquiry to socio-economic applications, notably geotourism, which integrates geological heritage with sustainable tourism. Geotourism is known to promote awareness and conservation of geological features while fostering local economic growth (Eraku et al., 2023; Reinhart et al., 2023). In Indonesia, regions such as Tanjung Api in Central Sulawesi offer unique geological phenomena, such as natural eternal flames and diverse lithological exposures, which are underexplored and lack comprehensive documentation. Recognising the untapped potential of such regions is crucial for regional development strategies based on geoheritage conservation and environmental education.

Despite its rich geological endowment, the Tanjung Api region remains underutilised in terms of geotourism and lacks formal recognition of its geological heritage. The absence of a structured inventory and assessment has impeded the promotion and sustainable management of geodiversity. This situation reflects a broader challenge in Indonesia, where many potential geosites remain undocumented and unprotected, risking degradation or loss due to natural and anthropogenic factors (Pusat Survei Geologi, 2017a; Sunkar et al., 2022). Addressing this issue requires a

systematic approach involving geological inventory, heritage assessment, and strategic development planning to harness geotourism as a vehicle for education, conservation, and local empowerment.

Various methodologies have been proposed to assess and document geodiversity for tourism and conservation purposes. The integration of geological mapping with qualitative evaluation has been suggested as a means to identify geosites of high scientific, aesthetic, and educational value (Goy et al., 2023; Santos & Brilha, 2023). Geosite assessment criteria, including representativeness, rarity, and vulnerability, have been applied to develop geotourism potential, demonstrating how systematic inventory supports regional tourism enhancement (Febrianto et al., 2022; Pambudi et al., 2024). Structural geological analysis has also been effective in identifying and promoting geosites along tectonic lines, such as the Palu-Koro Fault (Permadi, 2021). These approaches collectively underscore the significance of multidisciplinary frameworks in transforming geological assets into educational and economic resources for sustainable development.

Although several studies have successfully developed geotourism models in various Indonesian regions, there remains a paucity of research focused on Tanjung Api, particularly in integrating detailed geological characterisation with heritage value assessment. Unique abiotic features such as abiogenic gas seepage from serpentinite have often been overlooked in previous studies (Gorsel & Subroto, 2022; Newsome & Ladd, 2022). Additionally, technical inventory standards from regulatory bodies have rarely been incorporated, despite their importance in establishing a site's eligibility as geoheritage (Pusat Survei Geologi, 2017b). This gap underscores the need for a case-specific, methodologically rigorous study to comprehensively evaluate the geodiversity of Tanjung Api.

This study aims to conduct a systematic inventory and evaluation of the geological diversity in the Tanjung Api area to identify its potential as a geotourism object and as a geological heritage site. The novelty of this study lies in the application of a multidisciplinary approach that combines field-based geological observations, laboratory analyses, and standard-based qualitative assessments aligned with national geoheritage guidelines. The scope encompasses lithological, structural, and geomorphological features within an approximately 31.2 km² area in the Tojo Una-Una Regency, Central Sulawesi. By elucidating the region's geological attributes and their relevance to conservation and tourism, this study contributes to broader efforts in sustainable geotourism development and geoheritage protection in Indonesia.

2. METHOD

2.1. Materials

The materials used in this study included field and laboratory equipment essential for geological surveys and analyses. The field tools comprised a base map, GPS device, geological compass, geological hammer, measuring tape, sample bags, and documentation tools such as cameras and stationery. Supporting laboratory and analytical instruments included HCl solution, a hand lens, and rock comparators. Several digital applications were also employed, including Google Earth, Global Mapper, ArcMap, and CorelDraw, along with a geological diversity inventory table aligned with the standards from the Geological Agency (Pusat Survei Geologi, 2017a). The research location map is shown in Figure 1.

2.2. Sample Preparation

Samples were collected from selected geosites across the Tanjung Api region to ensure comprehensive lithological representation. Each geological sample was carefully extracted using a geological hammer, labelled, and stored in a sample bag. Lithological specimens were subsequently cleaned and categorised according to their macroscopic features. The samples were then prepared for thin-section analysis to facilitate petrographic examination. Labelling and coding followed a systematic format to correspond with the site of origin, ensuring accurate reference during laboratory assessments.

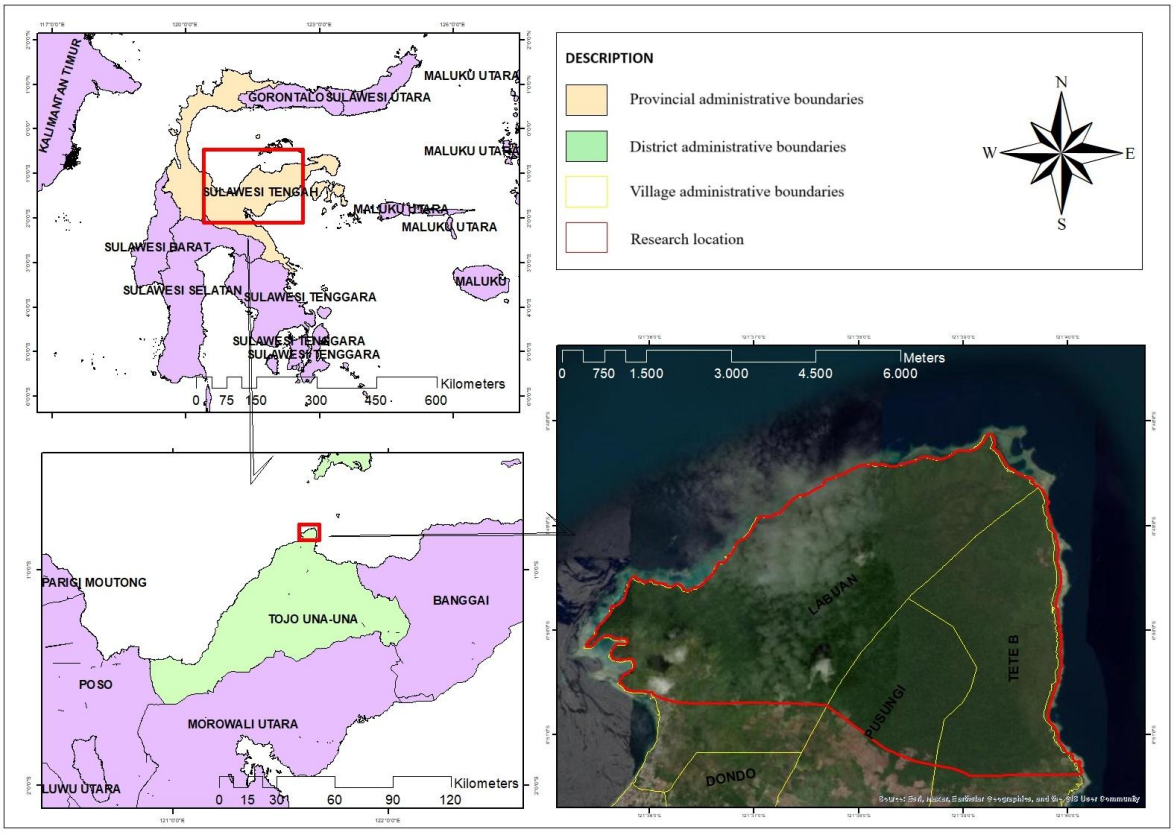

Figure 1. Map of the research location.

2.3. Field Observation and Geological Analysis

This phase comprised field observations, petrographic analyses, and structural measurements. Field data collection involved morphological and lithological descriptions at each location, as well as structural mapping using compass readings to identify bedding planes, joints, and faults. Geological structure analysis utilised bridle and brecciation measurements processed using Dips software to determine the orientation and magnitude of the stress fields acting upon the region. Petrographic analysis was performed using thin-section microscopy to identify the mineral composition, texture, and fabric of the rocks. Geomorphological classification involves the delineation of landform units based on morphometric, morphographic, and morphogenetic aspects.

2.4. Parameters

The parameters measured in this study included lithological composition, geomorphological units, and structural features. The lithological parameters included rock type, mineral composition, and petrographic textures. Geomorphological parameters focused on landform types and their spatial distribution. The structural geology parameters included the orientation data of fractures and faults, as well as brecciation intensity. These measurements were used to interpret geological processes and evaluate the geotourism and heritage potential of each site.

2.5. Data Analysis

Qualitative assessment techniques were applied to evaluate the significance and feasibility of geological objects as geotourism and heritage sites in the region. The assessment employed criteria including aspects such as uniqueness, representativeness, integrity, and accessibility (Pusat Survei Geologi, 2017a). Data from field observations, structural analyses, and petrography were triangulated to assign classification and valuation scores to each geosite. No inferential statistical methods were applied because the study relied on standardised geosite assessment procedures rather than hypothesis testing or predictive modelling.

3. RESULTS AND DISCUSSION

3.1. Results

The geomorphological classification of the Tanjung Api area was based on morphometry, morphography, and morphogenesis of the landforms. Two main geomorphological units were identified: the marine lowland unit (M3) and denudational hills unit (D1). The marine lowland unit, occupying approximately 0.89 km² or 2.64% of the total study area, is characterised by coastal landforms, such as cliffs, beaches, headlands, bays, sea stacks, sea caves, and bars. The denudational hills unit covers approximately 32.33 km² or 97.35% of the area and is typified by vegetated hills exhibiting signs of physical and biological weathering, rockslides, erosion, and sinkholes.

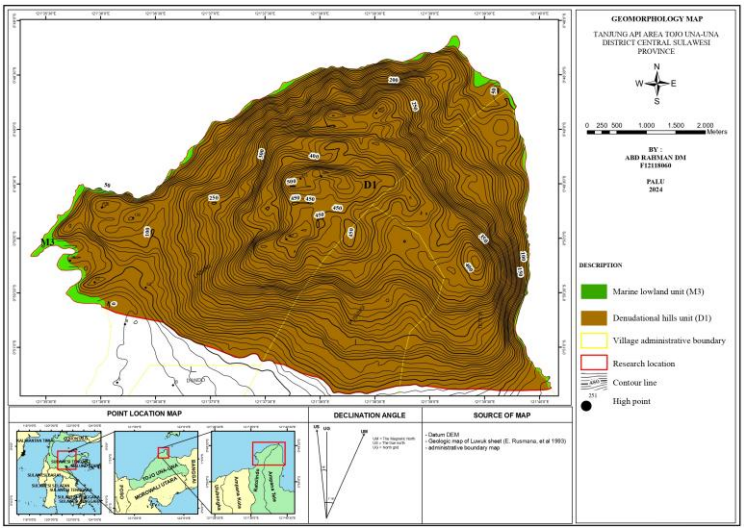

Figure 2. Geomorphology unit research area

The lithological composition of the study area includes five major rock types: serpentinised peridotite, amphibolite, basalt, calcarenite, and breccias. These rock types vary in their origin, mineral composition, and physical characteristics. Table 1 summarises the field and petrographic features.

Table 1. Summary of Lithological Characteristics in the Tanjung Api Area

Rock Type	Location	Main Minerals	Notable Features
Serpentinized Peridotite	Uenzori Peridotite	Serpentine, Pyroxene, Olivine	Holocrystalline, massive, greenish-black
Amphibolite	Amphibolite Outcrop	Hornblende, Quartz, Plagioclase	Nematoblastic texture, non-foliated
Basalt	Ujungtampo	Pyroxene, Plagioclase, Biotite	Aphanitic texture, massive, gray-black
Calcarenite	Tanjung Lawaka, Gua Kehidupan, Pantai Pasir Putih	Calcite, Bioclasts, Micrite	Well-sorted grains, carbonate-rich
Breccia	Tanjung Api, Ujungtampo	Igneous fragments, Chlorite	Angular clasts, silica/clay cement

These lithologies represent diverse geological environments and processes of igneous, sedimentary, and metamorphic origins. This variety illustrates the complex geodynamic history of the Tanjung Api area, from volcanic activity and marine sedimentation to tectonic deformation. This diversity not only enhances the scientific significance of the region but also provides valuable educational material for the development of geotourism. The physical and petrographic characteristics of each rock type that support this interpretation are shown in Figure 3–7. Petrographic features of rock samples.

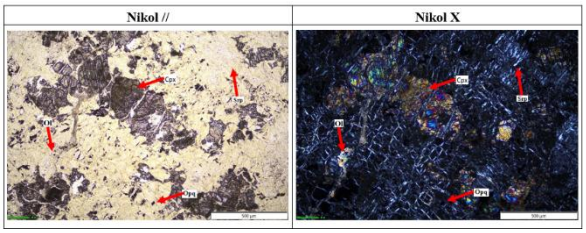

Figure 3. Petrographic features of the lithology of serpentinized peridotite (ST / 02 /SRP/ABD/UT D) with mineral composition clinopyroxine (Cpx), serpentine (Srp), opaque (Opq), and olivine (Ol)

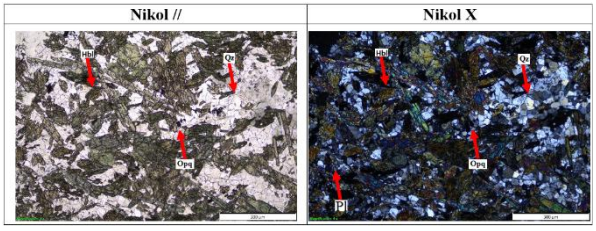

Figure 4. Petrographic features amphibolite lithology (ST/04/SKS/ABD/UTD) with mineral composition hornblende (Hbl), Quartz (Qz), plagioclase (Pl), and opaque (Opq)

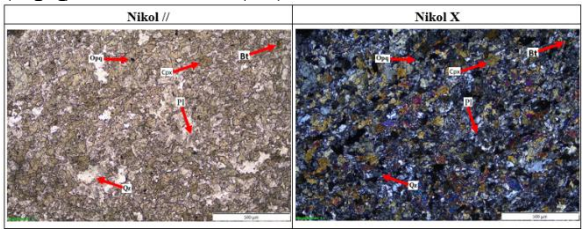

Figure 5. Petrographic features basalt lithology (ST/03/BSL/ABD/UTD) with mineral composition clinopyroxene (Cpx), biotite (Bt), plagioclase (Pl), Quartz (Qz) and opaque (Opq)

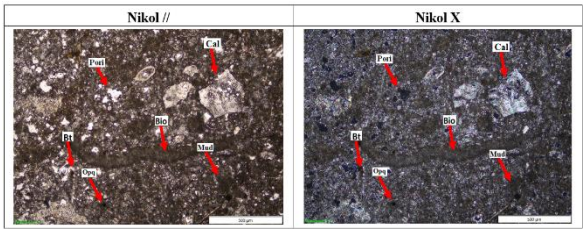

Figure 6. Petrographic features calcarenite lithology (ST / 05 / BTG / ABD / UTD) with composition of bioclast (bio), mud, pore, biotite (Bt), calcite (Cal) and opaque (Opq)

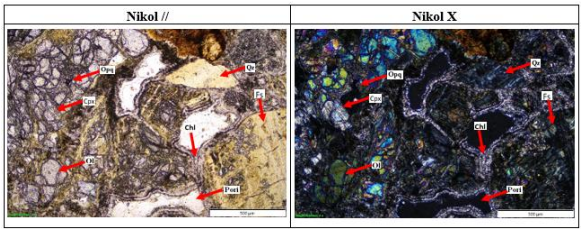

Figure 7. Petrographic appearance of breccia lithology (ST/01/BRK/ABD/UTD) with mineral composition of olivine (Ol), clinopyroxene (Cpx), feldspar (Fs), quartz (Qz), chlorite (Chl), pore and opaque (Opq).

The structural analysis identified primary features such as brecciation and bridles in Tanjung Api and Ujungtampo, reflecting the influence of past tectonic activities. These structures align with regional tectonic trends and are indicative of the stress regimes active in the area. Two major faults, the Ampana Fault to the east and the Barone Fault to the west, play a significant role in shaping the local geology and structural configuration. The tectonic regime in this region is characterised by compressive forces oriented predominantly in the northwest-southeast direction. This is supported by stereographic projections of brittle structural data collected from peridotite and basalt outcrops, which illustrate the consistent orientations of principal stresses, as shown in Table 2.

Table 2. Comparison of Burly Data on Uenzori Peridotite and Ujungtampo Basalt

Parameter	Uenzori Peridotite	Ujungtampo Basalt
Max Stress (σ1)	56°, N 111°E	39°, N 202°E
Medium Stress (σ2)	31°, N 309°E	33°, N 326°E
Min Stress (σ3)	8°, N 214°E	32°, N 81°E

The results of the stress orientation analysis were further visualised using stereographic projection to better understand the patterns of geological structures. These projections help

illustrate the distribution and orientation of the stress axes acting on the peridotite and basalt outcrops. Figure 8 shows the stereographic projection of the Uenzori peridotite, and Figure 9 shows the projection result for the Ujungtampo basalt.

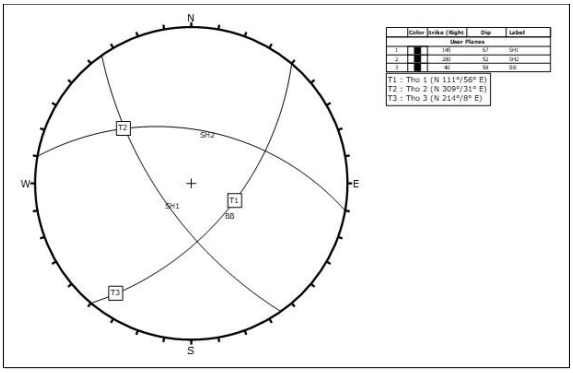

Figure 8. The results of data analysis using stereograph projection burly

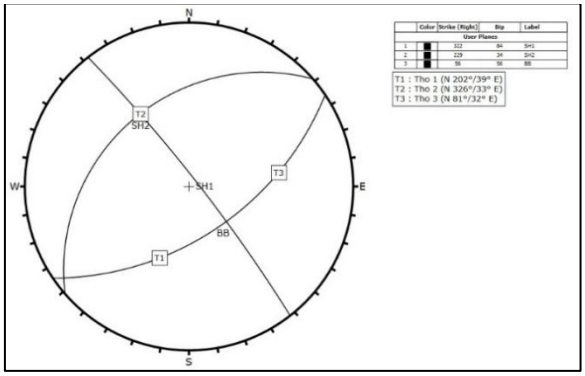

Figure 9. The results of data analysis using stereograph projection burly

Ten geological sites were documented in the Tanjung Api area and selected through a comprehensive field inventory process. The selection was guided by standardised criteria focusing on the uniqueness of the rock formations, complexity of the structural features, and potential for educational use in geotourism. These geosites showcase a wide spectrum of geological phenomena, from fossil-bearing caves and metamorphic outcrops to active geological processes such as gas seepage and tidal coral exposure.

Table 3. Summary of Geological Sites in the Tanjung Api Area

No	Site Name	Dominant Feature	Geological Component
1	Pantai Pasir Putih	Coastal morphology, lapies karst	Reef limestone
2	Gua Kehidupan	Fossil-bearing cave, sinkhole	Coelenterate fossils, limestone
3	Tanjung Lawaka	Headlands and bays	Calcarenite with microfossils
4	Singkapan Amphibolit	Metamorphic exposure	Amphibolite
5	Batugamping Tanjungkapal	Fossiliferous limestone beach	Reef limestone with fossils
6	Tanjung Api	Eternal flame, tectonic features	Breccia, gas seepage
7	Peridotit Uenzori	Marine erosion and coarse sediments	Serpentinized peridotite
8	Breksi Ujungtampo	Rocky beach, tectonic brecciation	Breccia
9	Basal Ujungtampo	Igneous lithology with fractures	Basalt
10	Karang Timbul	Marine corals, tidal feature	Coral reef

A geotrack was designed to connect key geological sites within the area to support educational, recreational, and conservation-oriented tourism activities. This integrated route not only enhances accessibility to each geosite but also facilitates a structured interpretation for geotourism development. The map of this geotrack, illustrating the spatial distribution and linkage of the geological sites, is shown in Figure 10.

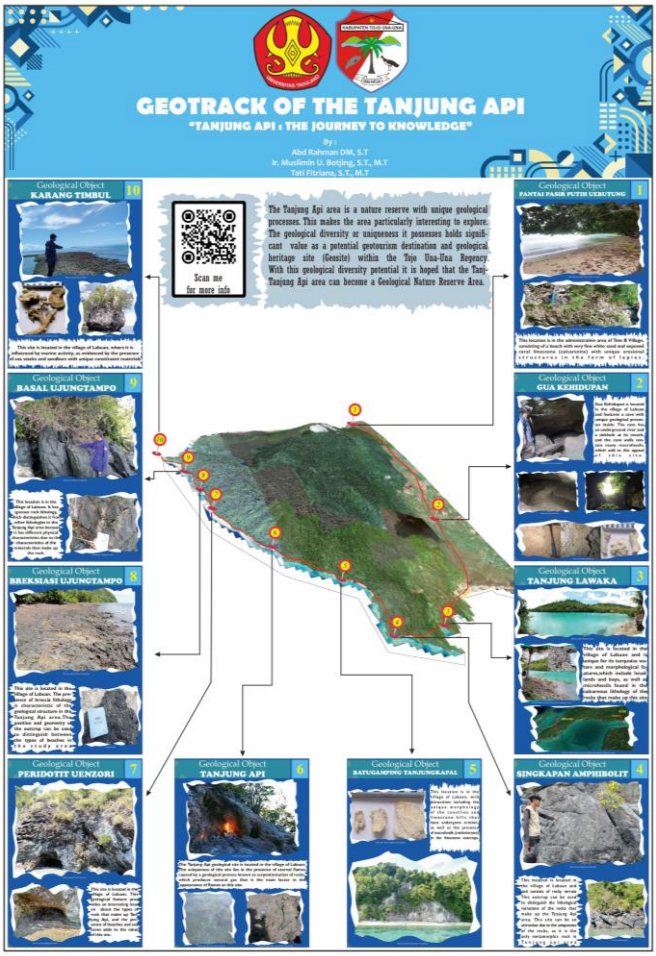

Figure 10. Map of geotourism path or geotrack of Tanjung Api Area

An evaluation found that among ten geodiversity sites in Tanjung Api, only Gua Kehidupan and Tanjung Api met the standards for geological heritage designation based on criteria from the Geological Agency (Pusat Survei Geologi, 2017a). The other eight, while not qualifying as heritage, hold strong geotourism potential because of their unique features and educational value.

Table 3. Summary of Geological Sites in the Tanjung Api Area

Site Name	Key Features	Potential Status
Tanjung Api	Eternal flame, brecciated rock, gas seep	Geological Heritage
Gua Kehidupan	Fossil cave, sinkhole, underground river	Geological Heritage
Tanjung Lawaka	Headlands and bays, fossil-bearing limestone	Geotourism Site
Singkapan Amphibolit	Exposed metamorphic rock	Geotourism Site
Batugamping Tanjungkapal	Fossiliferous limestone hills	Geotourism Site
Pantai Pasir Putih	White sand beach, lapies structure	Geotourism Site
Peridotit Uenzori	Coarse sediments, marine erosion features	Geotourism Site
Breksi Ujungtampo	Rocky coast, tectonic breccia	Geotourism Site
Basal Ujungtampo	Basaltic exposure, jointed structure	Geotourism Site
Karang Timbul	Coral mound, tidal feature	Geotourism Site

3.2. Discussion

The evaluation of geological diversity in Tanjung Api revealed the presence of ten distinctive geosites, two of which, Gua Kehidupan and Tanjung Api, met the comprehensive standards required for geological heritage designation. This finding confirms that Tanjung Api embodies rich geodiversity and holds significant potential for developing structured geotourism initiatives rooted in scientific, educational, and conservation principles. The spatial spread and uniqueness of features across the region highlight their capability to support integrated geoconservation and sustainable tourism models.

Compared with similar coastal and tectonic landscapes worldwide, the geodiversity of Tanjung Api aligns well with global geoconservation strategies. For instance, coastal areas such as the Itapeva dune fields in Brazil demonstrate how aeolian landforms serve as both tourism attractions and conservation priorities (Rockett et al., 2022). Similarly, the eternal flame and brecciated zones in Tanjung Api, indicative of ongoing tectonic activity, mirror landscapes like Menoreh Mountains in Indonesia, which have been positioned as foundations for geopark development through their tectonic distinctiveness (Reinhart et al., 2023).

Globally, the UNESCO Global Geoparks framework provides a structured path for incorporating geoheritage into sustainable regional development strategies, emphasizing education, community involvement, and ecological preservation (Wang et al., 2022). This aligns with the local aspirations for Tanjung Api, especially considering the potential for integration with regional cultural identities and biodiversity. Such integration has proven effective in regions like the Eure Valley in France, where combined geoarchaeological and geomorphological approaches have enriched heritage value and community engagement (Piau et al., 2023).

Efforts to formalise geoheritage also reflect broader national trends in this regard. Countries increasingly utilize standardized assessment frameworks that, while aligned with international guidelines, are adapted to local contexts such as in Morocco's Tata Province or Romania's participatory mapping initiatives (Berred et al., 2022; Morariu et al., 2023). Indonesia's Geological Agency similarly follows this principle, allowing the potential of Tanjung Api to be evaluated within a national framework while referencing global standards.

Additionally, Tanjung Api exemplifies how geodiversity stimulates sustainable economic growth. Echoing cases like Kazakhstan's Altynemel National Park and Ethiopia's tourism segmentation models, geotourism here can serve as a catalyst for local economic revitalization while advancing conservation objectives (Febrianto et al., 2022; Tessema et al., 2022) (Koshim et al., 2023; Tessema et al., 2022). The active participation of local communities is crucial. For example, in Menoreh, integrating geological, cultural, and ecological attributes has fostered a strong sense of ownership and pride (Reinhart et al., 2023). This community-centred approach should be adopted in Tanjung Api to ensure that development efforts are scientifically and economically viable and socially inclusive and culturally relevant..

4. CONCLUSIONS

The study conducted in the Tanjung Api region successfully identified and inventoried ten geological sites, with Gua Kehidupan and Tanjung Api meeting the criteria for geological heritage designation based on national and international standards. These sites exhibit exceptional geological features, including fossil records, sinkholes, and active tectonic phenomena, underscoring their scientific, educational, and conservation values. The remaining geosites possess significant geotourism potential because of their unique coastal, lithological, and geomorphological characteristics.

This study highlights the importance of integrating geodiversity into sustainable development frameworks. Tanjung Api stands as a promising candidate for geotourism and geoheritage development. By adopting participatory planning, involving local communities, and promoting geoconservation, the region can achieve a balance between economic growth, environmental stewardship, and cultural preservation. Further studies are recommended to expand the inventory and design a detailed geotourism roadmap for the effective management and promotion of Tanjung Api's geological wealth.

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