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GEOLOGICAL TOURISM OF THE GODEAN BRIGADE ANCIENT VOLCANO, SLEMAN, YOGYAKARTA

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ABSTRACT
Yogyakarta's natural tourism has become increasingly popular since the easing of the COVID-19 pandemic restrictions, with diverse destinations such as the Palace, the South Coast, and the Mount Merapi Museum. To support its world geopark qualification and meet the demand for educational tourism, the development of geology-based destinations is necessary. The Godean Ancient Volcano in Sleman offers significant potential for geotourism with scientific and educational value. Mapping results indicate that Godean is the remains of an ancient volcano in the form of a caldera, composed of extrusive igneous rocks, intrusions (basalt, andesite, dacite, microdiorite), and pyroclastic products such as tuff, lapilli, and pumice. Hydrothermal alteration with distinctive mineralogy indicates post-eruptive magmatic activity and the potential for economically valuable mineralization. The caldera landscape, displaying the remains of ancient volcanic eruptions, serves as a visual attraction and a means of interpreting geoscience. Through geotrail routes, interpretation boards, and the integration of local crafts, this area can be developed as a center for geological educational tourism. Supported by access to YIA Airport, this research will enhance the understanding of Godean's geological evolution while creating sustainable geotourism opportunities for the local community.
Keywords: *geotourism, ancient Godean volcano, volcanic caldera, hydrothermal alteration.*

1. Introduction

The Godean Ancient Volcano is in the Godean District of Sleman Regency, Yogyakarta, which is southwest of Sleman Regency (Figure 1). This area is in a strategic location because it is next to the active lowlands of Mount Merapi to the north and east. The Godean Hills are isolated geological structures that are surrounded by young Quaternary deposits of lava and pyroclastic material from Mount Merapi's activity (Surono et al., 2012). These hills look like a geological oddity in this young volcanic plain. They are made up of intrusive andesite and diorite igneous rocks from the Old Andesite Formation (Hartono et al., 2016). These older rocks show that there was volcanic activity in the past that is different from the Merapi volcanic system, which is still active (Yoellanice et al., 2024). These kinds of things happen a lot in active subduction zones like Java, where younger volcanic activity can hide older volcanic systems (van der Beek, 2013; Defant & Drummond, 1990).

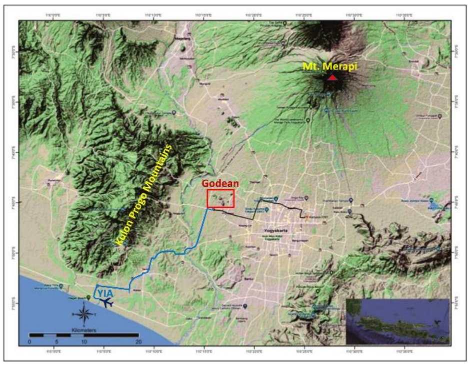

Figure 1. The location of the study area is indicated in a red box, the blue line is the path taken from the airport (YIA) and the blue line is the path taken from ITNY.

2. Literature Review

Initially, the intrusive rocks in the Godean were considered merely a mass of typical diorite that had intruded into the basement (Rahardjo et al., 1995). However, as our comprehension of geology advanced, this region was reclassified as the remnants of an ancient volcano (paleovolcano) that was active during the Miocene epoch. Bronto (1999) stated that the Godean was a component of an ancient volcanic system that extended over the northern structural band of the Southern Mountains. This explanation is consistent with observations in other areas of Java, where solitary formations are often linked to ancient eruption sites that have been eroded and concealed by more recent deposits (van Bemmelen, 1949; Ashwell et al., 2013; Smyth et al., 2007). The manifestation of hydrothermal alteration at the surface, encompassing silicification and propylitization, constitutes substantial evidence of magmatic activity and hydrothermal processes associated with the underlying volcanic system (El-Desoky et al., 2022; Arribas, 1995). This suggests that the Godean is not simply a static intrusion; it is probably a remnant of a previously active volcanic complex that may include caldera structures or historical eruption sites, characteristic of island ancient volcanic systems (Jackson, 2013; Corbett & Leach, 1998).

The geological interpretation in the Godean region is exceedingly challenging due to the restricted visibility of older rocks obscured by the Quaternary volcanic deposits from Mount Merapi. This cover complicates the identification of the ancient morphology and distribution of the key lithologies of the ancient volcanic system. Nemeth (2010) and Delcamp et al. (2011), asserts that assessing ancient volcanic formations, which have undergone erosion and are obscured by subsequent volcanic activity, requires a multidisciplinary methodology involving stratigraphy, geochemistry, and geomorphology. Consequently, to understand the initial characteristics of the Godean ancient volcano, foundational research utilizing surface data is necessary. This study encompasses lithological analysis, morphotectonic investigations, and geological cartography. This study aims to identify structural and stratigraphic models that may explain the formation of lithological clusters in the region, as established in the geological research by Tchamabe et al. (2014) and Branca et al. (2008), and to reconstruct the early geological conditions of the ancient volcano using surface data.

The geological finds in the Godean have great potential as a destination for geological tourism, or geotourism, which aims to educate tourists about ancient volcanology, in addition to their scientific significance. Using the idea of a "ancient volcanic caldera," or, in stratigraphic terms, a section of a volcanic brigade, this region can be developed as an educational geotourism site that demonstrates the evolution of volcanism in southern Java. According to Dowling and Newsome (2010) and Farsani et al. (2011), geotourism focused on ancient volcanic sites can increase public knowledge of Earth history and mitigate the effects of volcanic disasters. The expansion of geological educational tourism in Godean can enhance local communities via science-based ecotourism and foster environmental sustainability (Kurniawan et al., 2023; Suyanto & Haryono, 2020). Dhamayanti et al. (2023) and Brilha (2016) assert that geological locations transforming scientific artifacts into educational venues, such as the Gunung Sewu Geopark, demonstrate that geotourism serves as an effective instrument in earth science education. The Godean Ancient Volcano could serve as a paradigm for integrating earth science with educational tourism in urban environments, provided that geological interpretation is executed accurately.

3. Research Methods

The data obtained in this study include basic surface geological data, including observations of morphology, lithology, geological structure, and hydrothermal alteration conditions on rock outcrops. Outcrop data were collected from locations that were still fresh (not yet intensively weathered) and those that had experienced partial weathering, to ensure an accurate representation of the original rock characteristics and geological processes that occurred. Field observations were carried out systematically using surface geological mapping methods based on the walk-over survey and traverse mapping approach with the help of GPS (Global Positioning System) and a geological compass to determine the location, direction of slope, and position of rock layers (strike and dip). This approach is derived on the principle of ancient volcano mapping, which highlights the recognition of relict landforms, the distribution of unique lithology, and evidence of hydrothermal activity as indicators of historical eruption sites (Bronto, 1999; Hampton & Cole, 2009). The secondary data utilized comprise a geological map of the Yogyakarta sheet at a scale of 1:100,000 (Center for Geological Research and Development, 1995), high-resolution satellite imagery (Google Earth Pro, 2023), and DEM (Digital Elevation Model) data from DEMNAS in 2018 for morphometric analysis and reconstruction of the ancient volcano's morphology.

The results of the mapping and field analysis were then used as the basis for reconstructing the initial model of the Godean Ancient Volcano, including estimating the dimensions of the caldera or ancient eruption center based on rock distribution patterns and radial structures. Advanced erosion processes that occurred over millions of years have destroyed most of the original morphological forms, leaving only intrusive bodies and volcanic edifice fragments scattered across the Godean area. This phenomenon is consistent with the characteristics of ancient volcanoes that have undergone post-volcanic phases and intensive erosion, as explained by Nemeth (2010) in a study of degraded monogenetic and polygenetic volcanic systems. This geological reconstruction provides a crucial foundation for designing geotourism educational content, particularly in developing a scientific narrative about the evolution of volcanism in southern Java.

Upon concluding the geological reconstruction, the research results were associated with the prospective advancement of geological educational tourism in the Godean region. A geo-interpretation methodology was employed to pinpoint critical sites suitable for designation as geosites, including andesite-diorite outcrops exhibiting hydrothermal alteration, radial structures, and topographies indicative of caldera remnants. The integration of educational aspects and geological data was carried out in line with geotourism principles, which prioritize the use of geological heritage for community empowerment, conservation, and education (Dowling & Newsome, 2010). This approach aims to create geological interpretation boards, geotrail routes, and educational modules for students about the history of Earth and the dynamics of historical volcanism. The study advances scientific understanding of the Godean region's geological evolution and facilitates the creation of sustainable, scientifically informed educational geotourism destinations (Dhamayanti et al., 2023).

4. Research Findings and Discussion

Image analysis shows that the geomorphology of the Godean area consists of denudational hills stretching northwest-southeast, with a height difference of 32-57 meters from the surrounding plains. The morphology of Godean appears as isolated hills, indicating the presence of resistant rocks surrounded by Merapi deposits. This morphology is interpreted as ancient volcanic remains composed of volcanic rocks (Figure 2). Geological studies usually show the presence of volcanic igneous rocks, pyroclastic rocks formed by volcanic activity, intrusive rocks, and extrusive igneous rocks. A variety of lithologies are present in the intrusive rocks, such as microdiorite and andesite porphyry, with dacite and basalt occurring in some places. Extrusive igneous rocks were found to be the remains of slightly altered andesite lava-dacite in the study area. Lapilli-tuff, pumice lapilli, and tuff are the pyroclastic rocks found in the study area.

All volcanic and intrusive rocks (Figure 3) form a system of volcanic activity, where shallow intrusive rocks can be interpreted as the result of magma release or as an intrusion into the volcanic body. The presence of volcanic igneous rocks with aphanitic texture characteristics and the discovery of gas vents indicate that these rocks are lava products of local volcanic activity. However, their condition is quite weathered, and some have undergone alteration. Pyroclastic rocks, ranging from fine to coarse fractions, found in the study area indicate the presence of quite explosive eruptions.

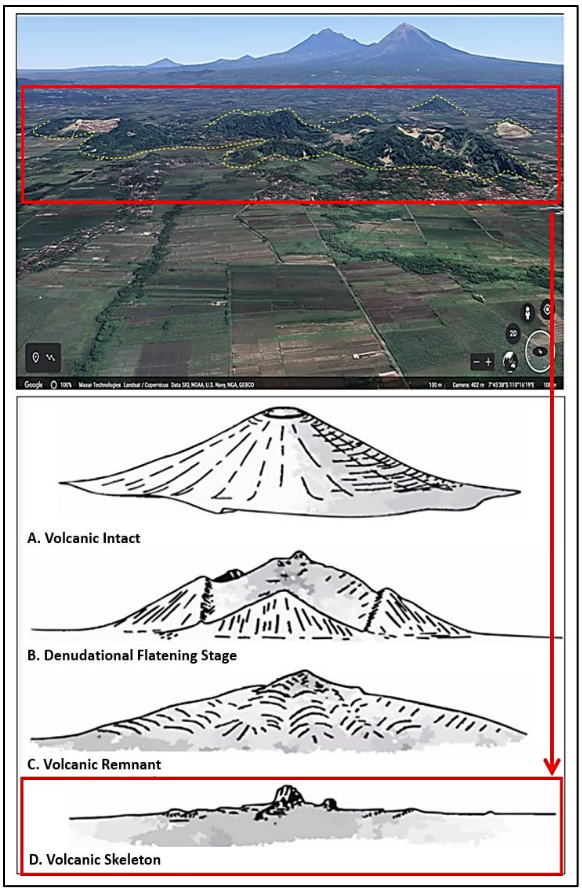

Figure 2. The skeletal landscape of the Godean Ancient Volcano from satellite image analysis (1) shown above, compared to the model of the development of volcanic landforms (Hartono, 2011) shown below.

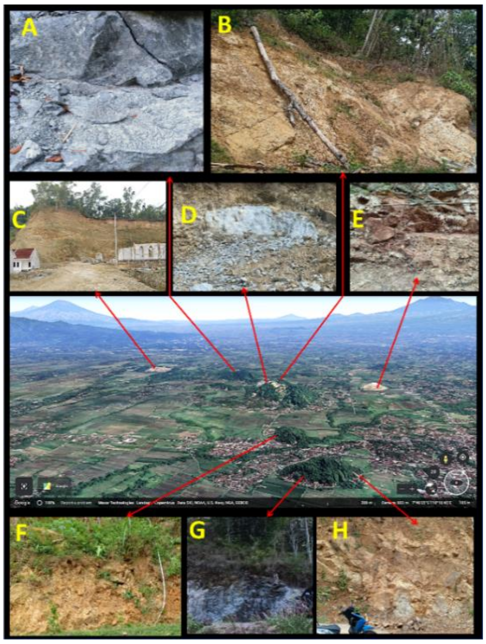

Figure 3. Volcanic rocks, pyroclastic rocks and intrusions that make up the research area consist of: (A) dacite-dacite porphyry; (B) lapilli pumice and lapilli-tuff; (C) tuff and lapilli-tuff; (D) dacite; (E) andesite-microdiorite (F) altered andesite (G) dacite – basalt; (H) microdiorite – andesite

Based on the observation of thin section (petrography) on andesite igneous rocks (Figure 4), it can be seen that the rock has the presence of many metal minerals (opaq minerals) which are shown to have a dark appearance during Plane Polarized Light (PPL) and cross polarized light (XPL). This indicates that the alteration process is developing in the research area.

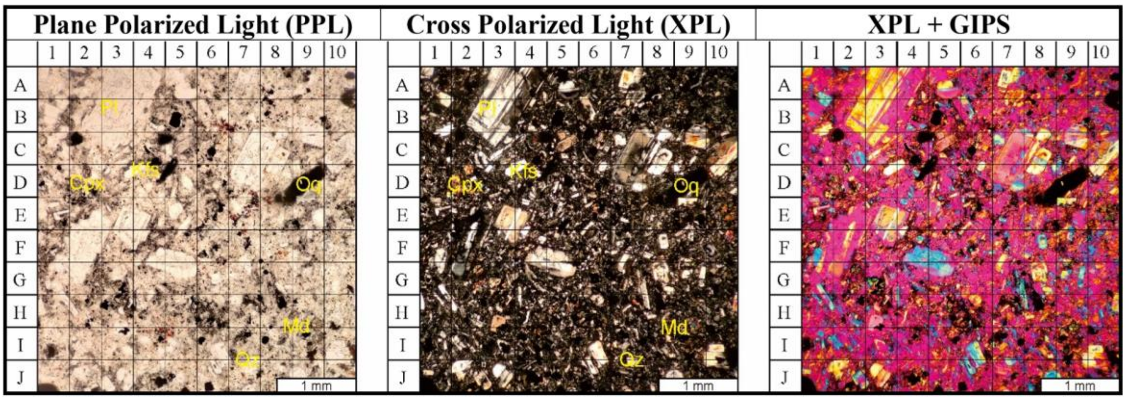

Figure 4. The appearance of thin sections on andesite during Plane Polarized Light (PPL) and cross polarized light (XPL) with description : Cpx (Clinopiroxene), Pl (Plagioclase), Kfs (K- Feldspar), Md (Ground Mass), Qz (Quartz) and Oq (opaq minerals).

The existence of lava and pyroclastics signifies volcanic eruptive activity, varying from effusive to explosive, hence creating a composite volcano. A composite volcano will gradually form the volcanic structure until a highly explosive eruption transpires, leading to a caldera that continues to display volcanic activity (Figure 5). The Indonesian Stratigraphic Code (SSI) (1996) designates the stratigraphic unit linked to a caldera volcanic system as a brigade.

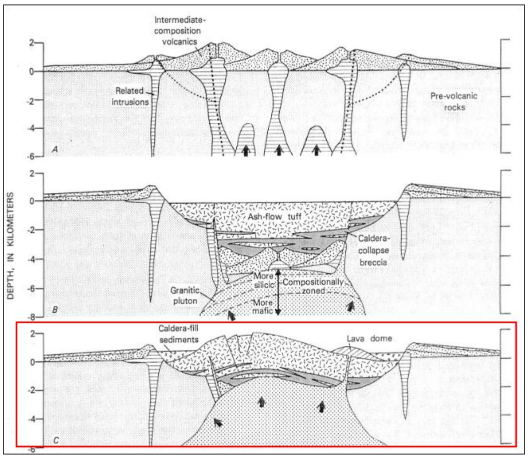

Figure 5. Interpretation of the formation of the Godean Brigade (shown red square) compared to the caldera evolutionary model (Lipman, 2000)

Calderas developed in crater regions typically create alteration systems due to their concave morphology, which facilitates the recharge of meteoric water. Simultaneously, subdued volcanic activity continues within the volcano following a significant eruption. This establishes a hydrothermal alteration system wherein meteoric water infiltrating the subsurface is thermally influenced by magmatism and intrusions, leading to the circulation of heated water that modifies the adjacent rocks. This perspective is corroborated by the various modification features identified in the research area.

The presence of hydrothermal alteration supports the hypothesis that the Godean region is a former volcano that underwent a magmatic process subsequent to an explosive eruption. The hydrothermal alteration found in the study area is argillaceous and propylitic, and it has a mineralogical makeup that includes halloysite-smectite-paragonite, illite-smectite, kaolinite-smectite-chlorite, chlorite-epidote, and silica-kaolinite. The distribution pattern of alteration is thought to be influenced by lithological distribution and is supported by geological features including fracture zones, joints, and destruction.

The study area has quartz veins, hydrothermal breccia, silicification, skarn-replacement minerals, and opaque minerals, which means that mineralization has happened there.

The potential for geological tourism as an educational tool in the Godean area and its surroundings is very attractive. The general public and tourists can more easily understand the existence of former volcanic calderas (Figure 6). Tourists can identify rocks produced by volcanoes or explosive calderas, learn about the history of their formation, and explore the distribution and approximate extent of ancient volcanic slopes.

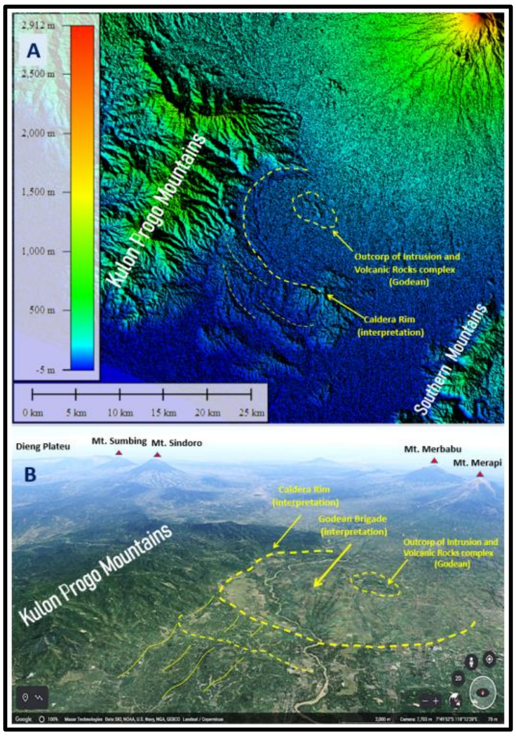

Figure 6. A simple interpretation of the existence of the Ancient Godean Volcano is seen from (A) Digital Elevation Model (DEM) images and (B) satellite images (google earth, 2023).

Based on the analysis and discussion of field data, there are substantial indications of the existence of the Ancient Godean Volcano, composed of intrusive rocks, volcanic rocks, pyroclastic rocks, and alteration rocks resulting from past volcanic activity. Based on volcanostratigraphy, the research area is included in the brigade associated with caldera-type volcanoes. The potential for geological educational tourism in the Godean Region and its surroundings is quite promising, as it offers aspects of understanding volcanoes, economic mineral formation, and craft tourism, in addition to accessible roads and transportation, which are also supportive.

Godean distinctly highlights volcanic history, caldera formation, and hydrothermal alteration, unlike other prominent geotourism sites in Indonesia, such as the Gunung Sewu UNESCO Global Geopark. This recognition elevates Yogyakarta's status as a hub for geoscience education and designates. Godean as an additional geotourism site that expands regional tourism. Cooperation among regional stakeholders is essential for realizing this potential. The local government may facilitate the establishment of rules, infrastructure, and tourism marketing. Locals can actively participate by managing geotourism, manufacturing items from altered minerals, and preserving cultural heritage. Vacation packages that integrate scientific education with natural and cultural attractions may encompass Godean. Academic institutions can contribute by conducting continuous research, developing interpretive tools, and offering field-based learning modules. By establishing a formal multi-stakeholder partnership, Godean will establish itself as a model for integrative and sustainable geotourism development in Indonesia, ensuring community benefits, sustainability, and coordinated action.

Furthermore, with the completion of the alteration and mineralization processes in the research area, tourists can also learn about how economically valuable minerals such as gold, silver, and copper are formed. The explanation of the alteration system in the Godean region is fascinating due to the presence of alteration minerals dominated by clay minerals, which residents widely use to make clay crafts such as roof tiles, bricks, statues, cups, teapots, jugs, and so on. This is a particular attraction for tourists considering the many handicraft tourism villages in Godean (Figure 7).

Figure 7. Some "gerabah" handicrafts come from clay minerals due to the alteration process in the Godean Region and its surroundings, handicrafts made by local residents to be sold and used for handicraft tourism villages.

On the other hand, the natural scenery in the Godean area is beautiful. Many natural tourist attractions are located in and around Godean, offering stunning views (Figure 8). Furthermore, road access to this location is relatively easy. From Yogyakarta International Airport (YIA), it can be reached in approximately 1 hour, covering a distance of roughly 40 km. The research area can also be reached from Yogyakarta city in approximately 35 minutes, covering a distance of roughly 15 km. To access the research area, tourists can use various forms of land transportation, including motorcycles, cars, and buses.

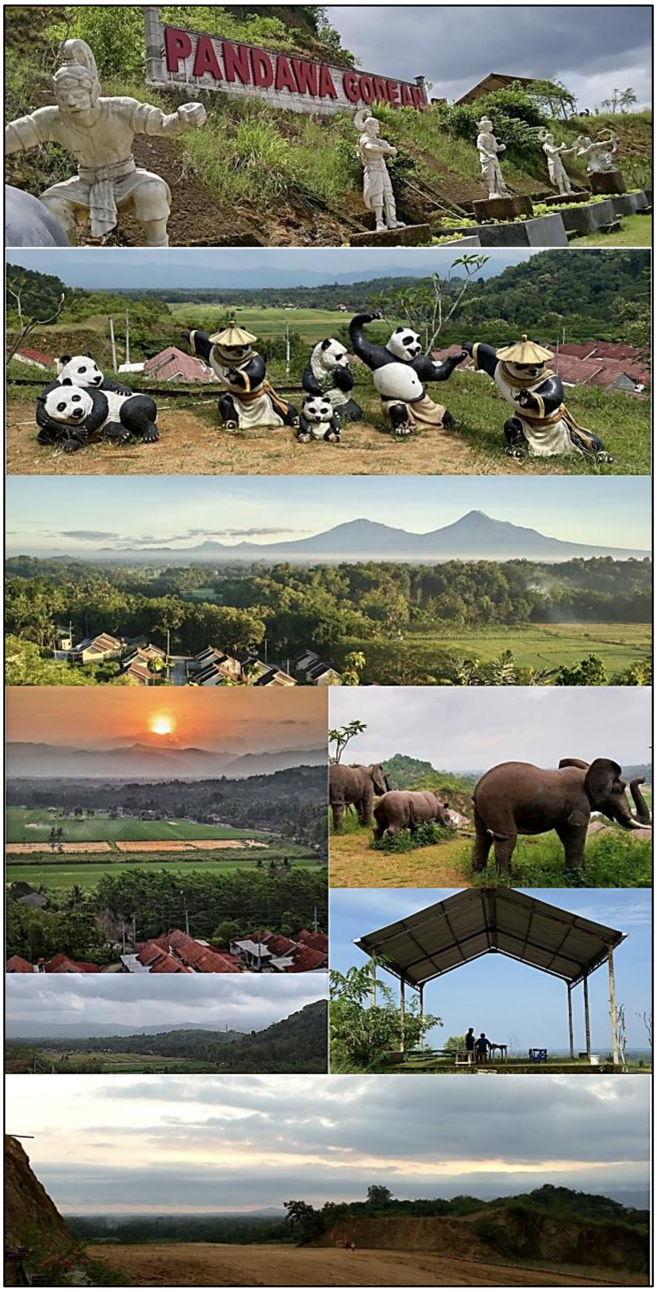

Figure 8. Tourism potential with beautiful natural scenery from several hilltops in the Godean Region.

From the summit of the Godean Hills, tourists can see the Kulon Progo Mountains to the west. They can also enjoy views of Mount Merapi, which lies to the north of the Godean area. Furthermore, to the east, on clear days, tourists can see the mountains to the south. This entire area is still part of the Yogyakarta region, so Godean's tourism potential can contribute to the growth of tourism in Yogyakarta.

5. Conclusion

Based on the analysis and discussion of field data, it shows substantial indications of the existence of the Ancient Godean Volcano, composed of intrusive rocks, volcanic rocks, pyroclastic rocks, and alteration rocks as a result of past volcanic activity. Based on volcanostratigraphy, the research area is included in the brigade associated with caldera-type volcanoes. The potential for geological educational tourism in the Godean Region and its surroundings is quite promising, as it offers aspects of understanding volcanoes, economic mineral formation, and craft tourism, in addition to accessible roads and transportation, which are also supportive. Compared to other successful geotourism sites in Indonesia, such as the Gunung Sewu UNESCO Global Geopark which is characterized by karst landscapes and cave systems, Godean offers a distinct focus on volcanological heritage, caldera morphology, and hydrothermal alteration. This uniqueness positions Godean as a complementary geotourism destination that enriches regional tourism diversity and strengthens Yogyakarta's reputation as a geoscience education hub.

To realize this potential, strong collaboration among local stakeholders is essential. The government can provide regulatory support and infrastructure, local communities can contribute through guiding and handicrafts based on altered minerals, the tourism industry can design integrated tour packages, and academic institutions can support with continuous research and educational content. Establishing a collaborative platform among these actors will ensure that Godean evolves into a sustainable geotourism model that balances conservation, education, and economic development.

6. Recommendation

To maximize the potential of education-based geotourism, it is recommended that the Godean Ancient Volcano area be developed through collaboration between the community, academics, and the local government. This development could be achieved with the support of a geological information center, geotrail trails, and interpretation boards explaining the history of ancient volcanism and geological processes. Combining scientific elements with regional economic opportunities, including the production of ceramics from altered minerals, would encourage tourism and community development. To achieve this, regulatory support, promotion, and sustainable funding are necessary so that this area can develop into a leading geotourism destination that contributes to earth education and promotes tourism growth in Yogyakarta.

In practice, collaboration among local stakeholders is essential. The local government can provide regulatory frameworks, infrastructure development, and promotional platforms at regional and national levels. Local communities can be actively involved through training in geotourism guiding, handicraft production, and cultural performance, ensuring that geotourism also strengthens community identity and income. The tourism industry, including private operators and tour agencies, can design packages that integrate geological education with cultural and natural attractions, thereby broadening the market appeal. Universities and research institutions can play a role in continuous monitoring, providing updated scientific interpretations, and developing educational materials for visitors. By establishing a multi-stakeholder forum or partnership, these actors can coordinate strategies, share resources, and create a sustainable geotourism model that balances conservation, education, and economic growth.

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