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ANALYSIS AND QUANTITATIVE ASSESSMENT OF GEODIVERSITY AT KARYA MURNI, GORONTALO, INDONESIA

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Abstract: Karya Murni is one of the areas in the northern arm of Sulawesi that has been tectonically influenced. Tectonic processes have implications for the formation of rocks and geological features that have the potential to be developed into geodiversity sites. The development of geological features as a geodiversity site in aspiring geopark Gorontalo can protect valuable geological features from frequent degradation. This research aims to analyze and conduct quantitative assessments of geological diversity in Karya Murni, Gorontalo. The research method used is field observation, laboratory analysis, and geodiversity assessment. Field observations included observing landform, collecting rock samples, and measuring geological structures. Field observations were also carried out to observe aspects of the geodiversity assessment which included science, education, tourism, and risk degradation. Laboratory analysis consists of geomorphological analysis, petrographic analysis, and geological structure data analysis. Geodiversity assessment uses the Geological Survey Center of Indonesia assessment. The results suggest that the geomorphology of the study area can be divided into four geomorphic units - the volcanic hills, denudational hills, Karst hills, and fluvial plain units. The stratigraphy of the research area is divided into four units from the age of the early Eocene to the Holocene - the andesite lava, volcanic breccia, reef limestone, and alluvial deposit units. The geological structure of the study area is a trending northeast–southwest to northwest–southeast. Active faults at the location of the study area consist of the Apitalawu normal fault. At recent states, generally geosites of the Karya Murni have moderate scientific values, the low educational and touristic values and high risk of degradation. The geodiversity potential of the research area can be utilized for further research and education.

Key words: Geodiversity potential, andesite, volcanic breccia, reef limestone, normal fault

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INTRODUCTION

The geological diversity and uniqueness of Indonesia generates the potential of immense geological heritage in the area. Geological diversity can be identified and analyzed in rocks, landscapes and their constituent materials and active tectonic processes. This potential is very strategic and supports the geological resource conservation program and the development of the geological-based tourism sector through the geopark concept. An integrated management system is required so that it can be utilized for community welfare (Garcia et al., 2022; Pusat Survei Geologi, 2017). Geodiversity is defined as the diversity of geology, geomorphology, and soil features. Geological diversity includes rocks, minerals, and fossils. Geomorphological diversity includes landforms and processes (Gray and Gordon, 2020; Gray, 2013; Li, 2021). Geodiversity is the basis for geoheritage, conservation (Crofts, 2018; Ibáñez et al., 2019; Németh and Gravis, 2022), geopark, and geotourism (Koh et al., 2014; Kubalíková, 2013; Louz et al., 2022; Sallam et al., 2018). The assessment of the feasibility of geological diversity into a geological heritage is based on its internationally, national, or local ranking.

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This ranking is based on the determination and assessment of the main aspects of geological diversity in the form of rocks, fossils, geological structures, landscapes, and geological evolution processes (Louz et al., 2022; Pusat Survei Geologi, 2017). The Gorontalo region is included in the northern arm of Sulawesi. Based on the lithotectonic structure of the Gorontalo area, it is included in the West Mandala as a magnetism route at the eastern end of the Sunda Shelf.

Gorontalo is part of the volcanic-plutonic belt of north arm of Sulawesi Island in Eastern Indonesia, which is controlled by tectonics, Eocene-Pliocene volcanic rocks, and intrusion rocks (Tolodo et al., 2019; Zhang et al., 2022). The active magmatic and tectonic route causes this area to have a complex geology both in structure and lithology, resulting in the potential of geological diversity (Andri Kurniawan et al., 2020; Manyoe et al., 2021; Thumkaew et al., 2022).

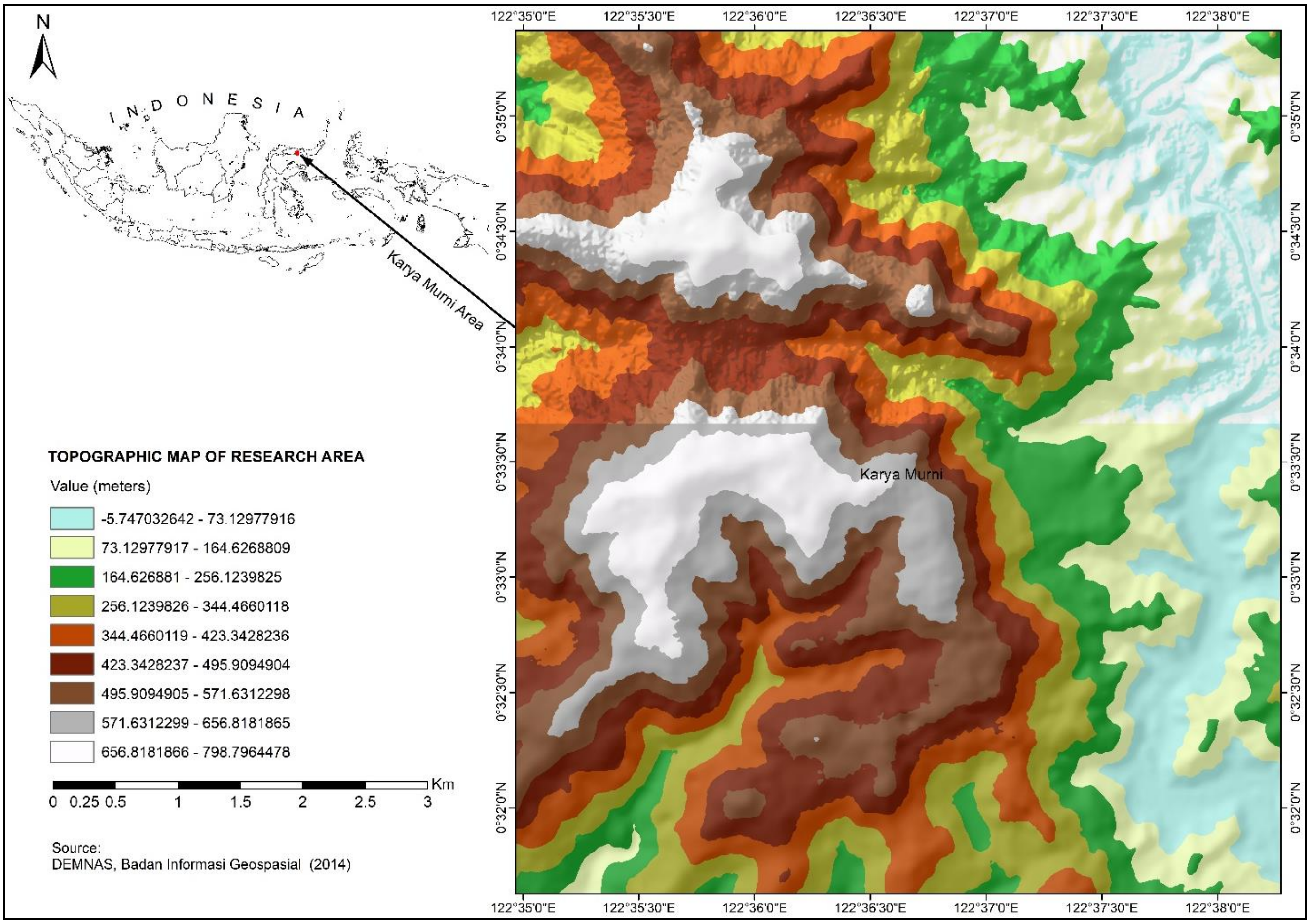

Figure 1. Research locations

Geological research in the Karya Murni area of Boalemo regency with a regional scale of 1:250,000 conducted by (Bachri et al., 1993). Several areas namely Saripi (Rusdi et al., 2022) and Dimito (Badaru et al., 2019) in Boalemo regency has been studied. The Karya Murni area has a varied topography, flat, undulating, and hilly (Figure 1). Each unit has distinctive characteristics and appearance both from the shape of mountains, hills, slopes, and flow patterns. The Karya Murni area has a stratigraphic arrangement with the oldest formation being the Tinombo formation.

This geological condition causes Karya Murni to have geodiversity potential which can be developed into a potential site for a geopark or for geotourism purposes. However, this development cannot be carried out due to a lack of detailed geodiversity information in the Karya Murni area. Therefore, the purpose of this research is to analyze and carry out a quantitative assessment of geodiversity in the Karya Murni area, Gorontalo, Indonesia. Geodiversity analysis includes analysis of geomorphology, stratigraphy, geological structures, and geological history.

METHODOLOGY

Geological diversity survey, laboratory analysis, and quantitative assessments were used in this study. Geological diversity survey was conducted in the form of observations of geomorphology, observations of lithology, and a measurement of the elements of the geological structure of the landscape (Brilha, 2015, 2018). Analysis of geological diversity was then followed by a quantitative assessment (Pusat Survei Geologi, 2017). The analysis of geological diversity and the stages of the quantitative assessment carried out at Karya Murni can be seen in Table 1.

Geomorphological observations were used to determine the slope, valley shape, ridge shape, river genetic type, river stage, and controlling factors such as lithology and structure (Van Zuidam, 1985). The observation of outcrops was undertaken to determine the characteristics and types of lithology, distribution and thickness, the environment of deposition or formation, and their relationship with other lithologies that can be observed in the field (Travis, 1955).

The observation of geological structures includes structural elements in the form of three-dimensional images that must be examined for their type and their position (Rickard, 1972). Rock samples gathered at each observation station were analyzed in the geological laboratory to determine the type of lithology, thickness, and the depositional environment present. Data processing and analysis includes paleontological analysis, petrographic analysis, and sedimentological analysis. Paleontological analysis was undertaken to determine the age and environment of deposition. Petrographic analysis was undertaken to determine rock composition and the type of lithology of the rock samples. Sedimentological analysis was performed to determine the mechanism and environment of deposition. An analysis of structural data was undertaken to determine the deformations that have occurred in the study area. The following stage was a quantitative assessment of the geological diversity within the Karya Murni area. The quantitative assessment of geological diversity included the assessment of the values of science, education, tourism, and the risk of degradation in the study area (Arifin et al., 2021; Manyoe et al., 2021). The quantitative assessment refers to the assessment of the Pusat Survei Geologi (2017). The research flowchart can be seen in Figure 2.

Table 1. Geological diversity analysis and quantitative assessment stages carried out at Karya Murni (Brilha, 2015, 2018; Pusat Survei Geologi, 2017)

Geological Diversity	
Field observation	- Geomorphology - Lithology - Geological structure
Laboratory analysis	- Geomorphology - Petrography - Sedimentology - Paleontology - Geological structure
Quantitative Assessment	
Assessment criteria	- Scientific values - Education values - Tourism values - Risk degradation values

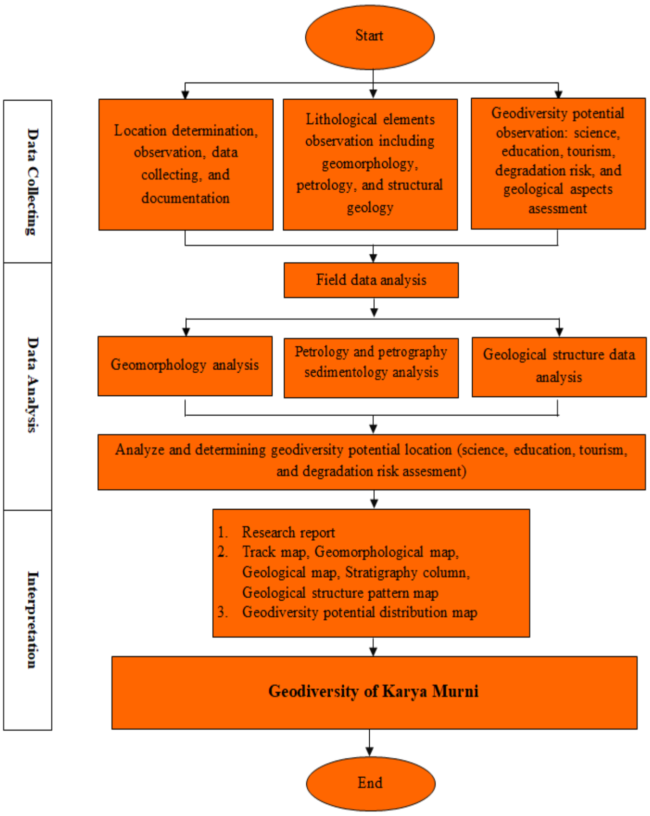

Figure 2. Research flow chart

RESULTS AND DISCUSSION

Geological Diversity

Geomorphology

The geomorphology of the study area includes a landscape dominated by mountains, hills, and plains. The lowest elevation is in the eastern region, while the highest elevation is in the western region. Landscapes are generally controlled by lithology, structure, and erosion processes (Chevigny et al., 2014; Gonnet et al., 2023; Medina-Cascales et al., 2021). Based on these factors and geomorphology unit classification (Van Zuidam, 1985), the research area is divided into four morphological units, the volcanic hill unit, denudational hill unit, karst hill unit, and fluvial plains unit (Figure 3).Volcanic hill units are formed from volcanic sediment and volcanic fragments. This unit is west of the Paguyaman River—this river is the primary river in the study area. This geomorphological unit encompasses the region bordering the southern part of the study area, with an area of ± 25 km^2, with elevations ranging from 300–890 mamsl and slopes ranging from 24–35%. The lithology is dominated by volcanic products, namely andesite lava, with moderate to strong rock resistance. The river flow pattern consists of a trellis flow pattern, flowing east and west. This area is used by the community as a place for settlements and plantations. Denudational hill units cover ± 30% of the study area, having an elevation of 50–240 mamsl. This unit is in the eastern and southern parts of the Paguyaman River. This unit is influenced by the joint structure.

The river flow pattern is dendritic. There is an intensive level of erosion and weathering here, and the valley is V-shaped with substantial mass wasting. The lithology consists of andesite lava. The Karst hill units result from solusional processes in carbonate rocks. This unit is controlled by the geological structure, the nature and type of carbonate rock, climatic conditions, and the hydrogeological characteristics of the area. This unit has a height of ± 197–533 mamsl. Karst hill units are located around the Apitalawu and Girisa Villages. This unit is used as a residential area by residents. The lithology in this unit consists of Reef Limestone. The fluvial plain unit has a flat slope of 0–2°. This unit is composed of fine-grained materials, such as clay, silt, and boulder deposited in the point and channel bars found along the Paguyaman River. The process of erosion and weathering remains ongoing in this area. Many of the rivers in this study area are periodic, due to the reduction in river water during the dry season. Consequently, they flood at the commencement of the rainy season. This unit is used by the community as a place for settlement and agriculture.

Stratigraphy

The stratigraphy of the study area is measured from old to young, namely andesite lava, volcanic breccia, reef limestone, and alluvial deposit units.

Figure 3. Geomorphology unit (a) Volcanic hills in Tangkobu Village (b) Denudational hills in Tangkobu Village (c) Karst hills in Apitalawu Village (d) Fluvial plain in Apitalawu Village (Source: Field documentation, March 2019)

Figure 4. (a) Hand specimen of andesite lava in Karya Murni Village (b) Pillow lava structure on andesite outcrop in Karya Murni Village, (c) Photomicrograph of andesite rocks. Photomicrograph shows the minerals found in andesite rocks. The photomicrograph on the left uses polarized light (c1 and c3) while the photomicrograph on the right uses x-polarised light (c2 and c4). The minerals visible in the photomicrograph are plagioclase, orthoclase, and pyroxene (Source: Field documentation and research data analysis, 2019)

Andesite Lava Units

This unit is indicated by the existence of a pillow lava structure at the observation station and generally occupies 40% of the research area. This unit is exposed along the road of the Karya Murni, Juria, and Girisa villages, and parts of the Tangkobu Village. Andesite appears brownish gray under the microscope, and the vesicular structure measures 0.1–0.2 mm. The sample suggests an intergranular texture dominated by plagioclase minerals and alkaline feldspar (Figure 4a and 4b). Plagioclase minerals—and slightly alkaline feldspar—are subhedral and 0.1–0.5 mm in size. Pyroxene has a size of 0.1–0.2 mm. Moderate altered rocks are approximately 35%. Rocks are composed of an alteration mineral association of carbonate-sericite-chlorite-mineral opaque (Figure 4c). Based on the similarity in the physical characteristics of the lithology, this unit can be compared to the Tinombo Formation. This unit was formed because of an underwater volcanic eruption process. This unit was deposited in the Eocene-Oligocene based on the Regional Geological Map of the Tilamuta Sheet by (Bachri et al., 1993).

Volcanic Breccia Units

This unit occupies 20% of the research area. Opened vertically on a steep hillside (300–890 m), this unit is located on the Pulubala and Laleo Rivers. In general, this unit consisted of fresh to very weathered conditions (Figure 5a). In megascopic, this rock consists of a blackish gray color, weathered igneous rock fragments, igneous cement, poorly sorted, subangular, poor porosity, compact, a grain size above 1/16 mm, quartz minerals, and plagioclase (Figure 5b). The appearance under the microscope indicates that this rock has a porphyritic texture, anhedral – subhedral, inequigranular, hypidiomorph – allotriomorph, and holocrystalline structure. Based on the petrographic analysis, this unit has felsic minerals in the form of plagioclase measuring 0.4–1.2 mm and euhedral –subhedral (Figure 5c). This unit is equated with the Pliocene-Pleistocene Pinogu Volcano Formation on the Regional Geological Map of the Tilamuta Sheet (Bachri et al., 1993).

Figure 5. (a) Outcrops of volcanic breccias in Lito Village (b) Hand specimens of volcanic breccias in Lito Village (c) Photomicrographs of volcanic breccias. Photomicrograph shows the minerals found in volcanic breccias. The photomicrograph on the left uses polarized light (c1 and c3) while the photomicrograph on the right uses x-polarised light (c2 and c4). The minerals visible on the photomicrograph are plagioclase (Pl), hornblende (Hb), opaque (Opq/Op), carbonate (Cb), and sericite (Ser) (Source: Field documentation and research data analysis, 2019)

Reef Limestone Unit

Coral limestone is in the southern part of the study area. It occupies a hilly Karst morphological unit. The outcrops have dimensions of ± 45 meters in length and ± 1–3 meters in height. These units were in fresh to very weathered conditions (Figure 6a-6b). Light gray in color, these units are compact, with a primary composition of coral, carbonate minerals, calcite cement, and secondary porosity (Figure 6c).

There is reverse graded bedding, with the position N114°E/45SW. These rocks are primarily composed of micrite carbonates, which have undergone a neomorphism process. The secondary porosity found in this rock is vuggy and fracture porosity. Vuggy porosity generally forms in the supratidal zone. These rocks form in the vadose meteoric diagenetic environment. This porosity is formed by the dissolving process. Similarly, neomorphism occurs within the diagenetic environment. Neomorphism is characterized by a change in the size of a mineral or crystal—which is influenced by changes in the diagenetic environment. Additionally, there are fossils in the form of foraminifera.

This unit is deposited above the Volcanic Breccia unit and the Andesite Lava unit. Based on the physical characteristics of lithology—where the main components are reef and layered—this unit is equated with the Holocene Limestone Formation on the Geological Map of the Tilamuta Sheet by (Bachri et al., 1993).

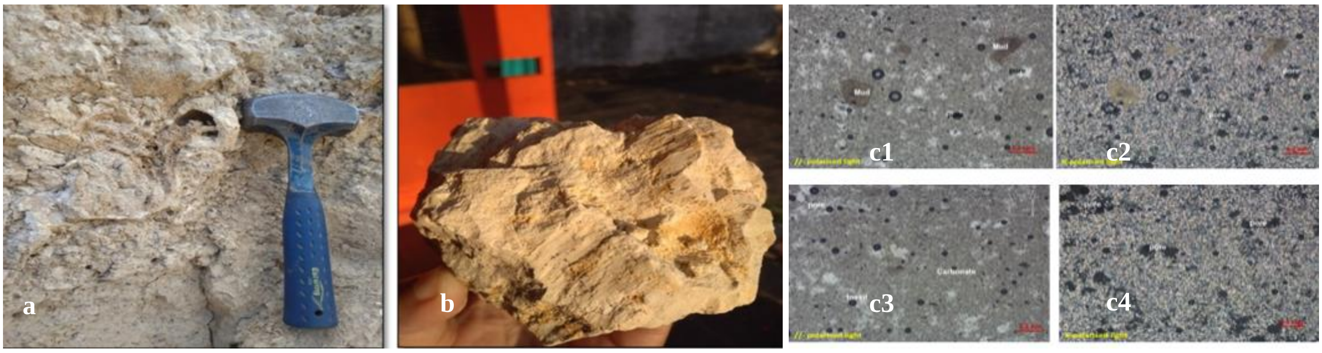

Figure 6.(a) Coral limestone in Apitalawu (b), Hand specimen of reef limestone (c), Photomicrograph of reef limestone, Photomicrograph shows the minerals found in reef limestone. The photomicrograph on the left uses polarized light (c1 and c3) while the photomicrograph on the right uses x-polarized light (c2 and c4). Photomicrograph shows. the presence of mud, pores, and carbonates (Source: Field documentation and research data analysis, 2019)

Alluvial Deposit Units

This unit is located along the Paguyaman River. It is a loose material with a size range from sand to pebble, and boulder. It is formed due to river activity and sediment accumulation from the rubble of the surrounding rock. Rock fragments consist of basalt, andesite, and dacite. This material was produced by the activities of the Tua, Laleo, and Bolangga Rivers. The alluvial unit consists of loose uncompacted sediment and igneous rock fragments in the form of andesite, basalt, and dacite. It is dominated by clay-sized textures (with partly sand to boulder sizes).

Textures are composed of sediments from various types of unconsolidated rock formation. The grain shape consists of rounded to subangular. This unit is equated with the Alluvium Formation. It is Holocene in age on the Geological Map of the Tilamuta Sheet by (Bachri et al., 1993). The deposition by river activities remains ongoing and is deposited unconformity over the older unit (Figure 7).

Geological Structure

The results of the stereonet analysis indicate that the Apitalawu fault is a Normal Right Slip Fault, with a position of N 24°E/57°SE (Figure 8). This fault is thought to have formed in the Quaternary. The naming of the Apitalawu normal fault reflects the location on which the fault is found. The direction of the main stress is east west. This fault intersects the Reef Limestone unit. The direction of structure in the Karya Murni area is different from the direction of structure or lineament in many areas in Gorontalo (Abduh et al., 2021; Robot et al., 2021). This is due to the location of the Karya Murni area which is far from the Gorontalo Fault and is influenced by different forces.

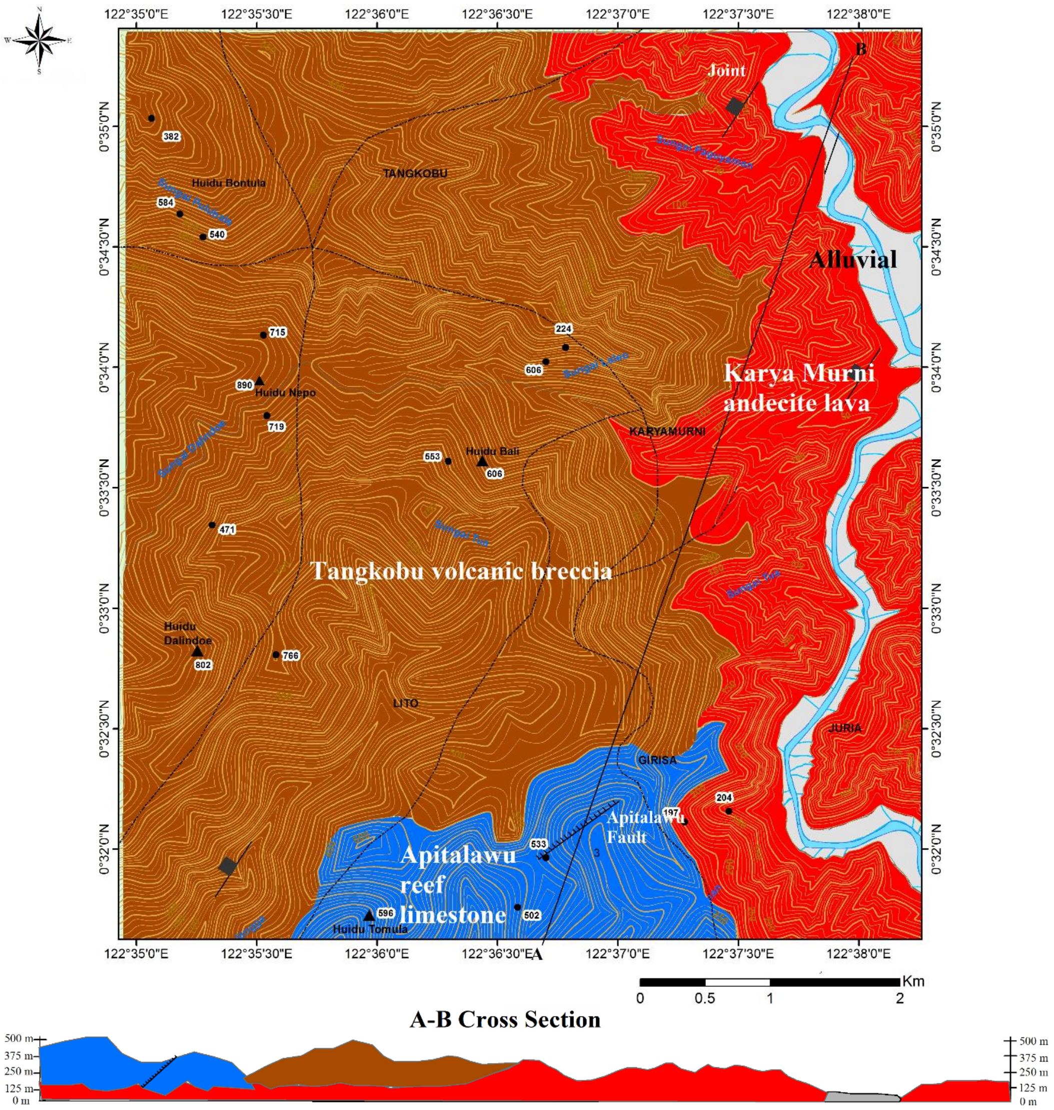

Figure 7. Geological map of research area

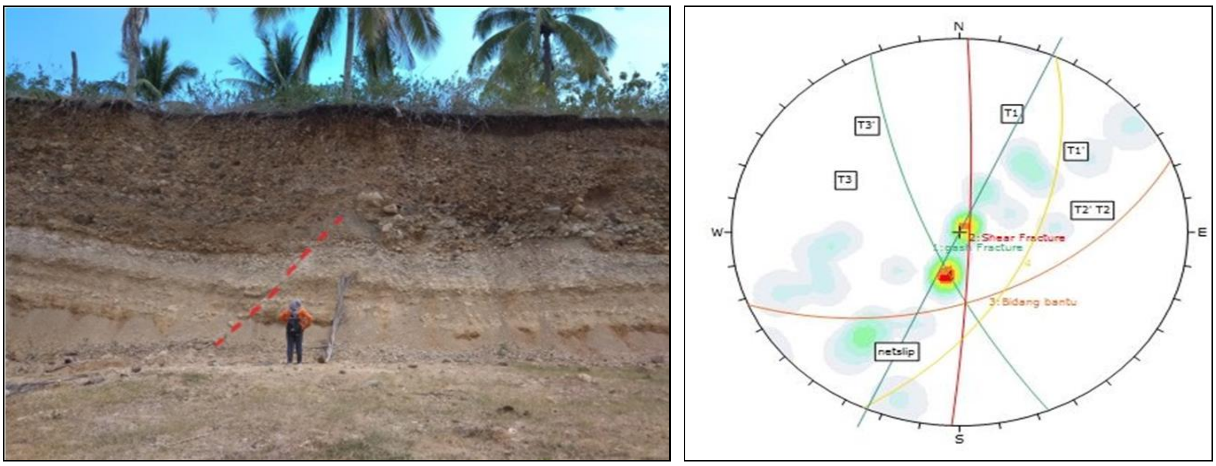

Figure 8. An outcrop showing the Apitalawu Fault (left) and fault data processing results (right)
(Source: Field documentation and research data analysis, 2019)

Geological History

The geological history of the Karya Murni area and its surroundings begins in the Eocene to the Holocene, where the Andesite Lava Unit was formed (equivalent to the Tinombo Formation). This unit forms the base rock in the study area. In the early Pliocene, magmatism occurred which was influenced by subduction from the north which formed the Pinogu Volcano. The lithology obtained in the research area consists of volcanic breccias which are deposited above the older unit.

In the quaternary era (during the Holocene) subduction resulted in an uplift in the North Arm of Sulawesi (Dong et al., 2022). The lithology obtained—because of this uplift—is the reef limestone unit. Subduction also resulted in the formation of a normal fault in the form of the Apitalawu Fault. This dissects the coral limestone unit. The reef limestone unit is deposited unconformity over the volcanic breccia and andesite lava units. In addition, there are exogenous processes in the form of weathering and erosion. Exogenous processes produce alluvial deposits that cover pre-existing rock units.

Quantitative Assessment of Geological Diversity

The geological potential assessment is achieved by quantitively assessing the geological features in the study area. The assessment criteria include the values of science, education, tourism, and the risk of degradation in the research area (Brilha, 2015, 2018; Pusat Survei Geologi, 2017). The assessment is commonly used to determine the potential of each Geosite to become geopark (dos Santos et al., 2016). In the process of quantitative assessment each geosite classified using 37 factors which is distributed into 4 categories (scientific, educational, toruistic and risk degradation). Each category will describe in detail as follows:

a. Scientific value

The factors used in conducting a quantitative assessment of scientific values include locations that represent the geological framework, key research locations, scientific comprehensive, geological site conditions, geological diversity, distribution of geological heritage sites within an area, and obstacles in use of the location of geological heritage sites (Table 2 and Table 3). The value of science in the research area is 210 and is categorized moderate.

In addition to the several things above, the reason for the value of science in the research area is 210 because the geological diversity in the study area is quite common in Gorontalo, as well as a lack of knowledge about geology.

Table 2. Scientific value

No.	Factors in the science values asessment	Geological heritage sites capacity				Description
		1	2	3	4	
1	Locations that represent the geological framework		√			Location of geological heritage sites is a common example in the study area to illustrate some feature or process related to the geological framework under consideration (when applicable)
2	Research key location		√			The location of the geological heritage site is used as a research reference related to the geological framework, scientific publication national scale.
3	Scientific comprehension			√		An article in a national science publication regarding the location of this geological heritage site is related to the geological framework
4	Condition/geological site	√				The location of the geological heritage site is not well maintained, and the geological features have undergone changes or modifications.
5	Geological diversity (rocks, minerals, landscapes, structures and fossils)				√	The location of the geological heritage site has more than 4 geological features that are scientifically related.
6	Geological diversity (rocks, minerals, landscapes, structures and fossils)		√			In the research area there are three other locations which are the same as geological heritage sites, related to the geological framework
7	Location constraints			√		Fieldwork and sampling can be carried out at the location of this geological heritage site, after completing constraints (permits, physical barriers, etc.).

Table 3. Assessment weight for science value in study area

No.	Criteria	Score	Weight	Values
1	Location that represented the geological framework	2	30	60
2	Research key location	2	20	40
3	Scientific comprehension	3	5	15
4	Condition/geological site	1	15	15
5	Geodiversity	4	5	20
6	Existence of geological heritage sites in an area	2	15	30
7	Location constraints	3	10	30
	Total		100	210

b. Educational value

The factors used in assessing educational values (educational values) include the vulnerability of a geological heritage site to damage, site attainment, barriers to site utilization, security facilities, supporting facilities, population density, relationships with other elements (Table 4 and Table 5).

Based on the assessment above, the value of education in the research area is 190 (falls into low value) because it contains important scientific records that can be used for research and education.

Table 4. Educational value

No.	Factors in the educational values assessment	Geological heritage sites capacity				Description
		1	2	3	4	
1	Vulnerability		√			There is a possibility of damage to the main geological elements in the location of the geological heritage site
2	Location accessibility				√	The location of the geological heritage site is located less than 100 m from the village road and the parking lot
3	Obstacle to site utilization	√				Use by students and tourists is very difficult because of the obstacles that are difficult to overcome
4	Security facility	√				The location of the geological heritage site has no security facilities (fences, stairs, handrails, etc.), is not within the range of telephone signals, and is more than 50 km from an emergency installation.
5	Supporting facilities	√				Lodging and restaurants for groups of less than 25 people are less than 50 km from the site of the geological heritage site.
6	Population density		√			Locations of geological heritage sites are found in districts/cities with a population density of 100 - 250 people/km. (BPS Kabupaten Boalemo, 2016)
7	Relations with other values					There isn't any
8	Location status	√				Locations of geological heritage sites are sometimes used as local tourist destinations.
9	Peculiarity	√				Sites of geological heritage sites are common throughout the country
10	Conditions on the observation of geological elements			√		There are several barriers that make it difficult to observe some geological features
11	Potential educational/research information	√				The location of this geological heritage site displays geological features that are taught at the university level.
12	Geological diversity				√	The location of the geological heritage site has more than 3 features of geological diversity (mineralogy, paleontology, geomorphology).

Table 5. Assessment weight for educational value in study area

No.	Factors in the educational values assessment	Score	Weight	Value
1	Vulnerability	2	10	20
2	Location accessibility	4	10	40
3	Obstacle to site utilization	1	5	5
4	Security facility	1	10	10
5	Supporting facilities	1	5	5
6	Population density	2	5	10
7	Relations with other values	0	5	0
8	Location status	1	5	5
9	Peculiarity	1	5	5
10	Conditions on the observation of geological elements	3	10	30
11	Potential educational/research information	1	20	20
12	Geological diversity	4	10	40
	Total		100	190

Table 6. Tourism value

No.	Factors in the tourism values asessment	Geological heritage sites capacity				Description
		1	2	3	4	
1	Vulnerability		√			There is a possibility of damage to the main geological features at the site of the geological heritage site as a result of human activities.
2	Location accessibility				√	The location of the geological heritage site is located less than 100 m from the village road and the bus parking lot. (BPS district of Boalemo, 2016)
3	Obstacle to site utilization	√				Use by students and tourists is very difficult due to barriers that are difficult to overcome (permits, physical barriers, tides, floods, etc.).
4	Security facility		√			The location of the geological heritage site has no security facilities (fences, stairs, handrails, etc.), but is within range of a telephone signal, and is less than 50 km from an emergency installation.
5	Supporting facilities	√				Lodging and restaurants for groups of less than 25 people are less than 50 km from the site of the geological heritage site.
6	Population density		√			Locations of geological heritage sites are found in districts/cities with a popu- lation density of 100 - 250 people/km (2) (BPS Kabupaten Boalemo, 2016)
7	Relations with other values					There isn't any
8	Location status	√				Locations of geological heritage sites are sometimes used as local tourist destinations.
9	Peculiarity	√				Sites of geological heritage sites are common throughout the country.
10	Conditions on the observation of geological elements			√		There are several barriers that make it difficult to observe some geological features.
11	Interpretive potential	√				The location of a geological heritage site presents geological features that only geologists can understand.
12	Economic level		√			The location of the geological heritage site is in a city with a household income similar to the national average.
13	Close to recreation area					There isn't any

Table 7. Assessment weight for tourism value in study area

No.	Factors in the tourism values assessment	Score	Weight	Value
1	Vulnerability	2	10	20
2	Location accessibility	4	10	40
3	Obstacle to site utilization	1	5	5
4	Security facility	2	10	20
5	Supporting facilities	1	5	5
6	Population density	2	5	10
7	Relations with other values	0	5	0
8	Location status	1	15	15
9	Peculiarity	1	10	10
10	Conditions on the observation of geological elements	3	5	15
11	Interpretive potential	1	10	10
12	Economic level	2	5	10
13	Close to recreation area	0	5	0
	Total		100	160

c. Tourism value

The factors used in conducting a quantitative assessment of tourism values (tourism values), include the vulnerability of a geological heritage site, location attainment, barriers to site utilization, security facilities, supporting facilities, population density, relationships with other elements, location status, peculiarities, conditions on observation of geological elements, interpretive potential, economic level and proximity to recreational areas (Table 6 and Table 7).

The value of tourism in the research area has a low value, which is at 160, because the research location does not have nearby tourist attractions and most of the research location area is only plantations and settlements.

d. Risk Degradation

The factors used in conducting a quantitative assessment of degradation risk include damage to geological elements, proximity to areas/activities that have the potential to cause degradation, legal protection, accessibility, and population density (Table 8 and Table 9).

Table 8. Degradation risk

No.	Factors in the degradation risk values assessment	Geological heritage sites capacity				Description
		1	2	3	4	
1	Damage to geological elements				√	Possible damage to all geological features
2	Adjacent to areas/activities that have the potential to cause degradation				√	The location point is less than 50 m with areas/activities that cause degradation
3	Legal protection				√	A location point located in an area that has no legal protection and no access control
4	Accessibility		√			The location point is accessible by bus via a gravel road
5	Population density		√			The location point is in a city with a population density of between 100-250 inhabitants/km^2

Table 9. Assessment weight for degradation risk in study area

No.	Factors in the tourism values assessment	Score (S)	Weight (W)	Values (V=S*W)
1	Damage to geological elements	4	35	140
2	Adjacent to areas/activities that have the potential to cause degradation	4	20	80
3	Legal protection	4	20	80
4	Accessibility	2	15	30
5	Population density	2	10	10
	Total		100	340

Table 10. Quantitative assessment final result

No.	Criteria	Score	Category
1	Scientific values	210	Moderate
2	Educational values	140	Low
3	Tourism values	160	Low
4	Risk degradation values	340	High

Table 11. Quantitative value classification (Guidelines for Assessment of Geological Heritage Resources Techniques, 2017)

Total Value	Scientific Assessment
<200	Low
200-300	Medium/Moderate
301-400	High

For the risk of damage in the study area, it has a high value of 340 because many human activities can unknowingly damage the main geological features in the study area, for example plantations, agriculture, and new land clearing.

The total scientific values (Table 3), educational values (Table 5), tourism values (Table 7), and risk degradation values (Table 9) obtained are presented (Table 10).

Based on the results of the quantitative assessment, the geodiversity potential of the Karya Murni area and its surroundings has moderate scientific value, has low education and tourism values and very high risk of degradation values. The same condition has been reported for Paleontological sites in Brazil (Dos Santos et al., 2016). This is in accordance with the classification contained in the following table 11. This can be used for research and educational opportunities to further understand the geographic processes of the planet as Geopark (Mehdioui et al., 2020).

CONCLUSION

The geomorphology of the research area consists of volcanic hills, denudational hills, Karst hills, and fluvial plains units. The rocks uncovered are composed of material ranging from the Eocene to the Holocene. These rocks consist of andesite lava, volcanic breccia, reef limestone, and alluvial deposit units. The structure formed in the study area consists of a normal fault, namely the Apitalawu Fault, which intersects the coral limestone unit.

Based on the results of the quantitative assessment, the geodiversity potential of the Karya Murni area and its surroundings is of moderate in terms of the scientific value, while low for educational value and tourism value and high degradation risk. However, at the present condition it has the potential of geodiversity in the area is useful for education and research only. Further development is needed to increase the potential for education and tourism purposes.

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