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RESEARCH ARTICLE

# Study of Boalemo Red Limestone for Geotourism Development based on Lithological, Geochemical Analysis and Geological Heritage Assessment

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**Abstract**

Indonesia has very diverse and unique rocks that have the potential to become a geological heritage. Based on the existing potential, an integrated management system is needed so that it can be utilized for the welfare of the community, one of which is a geopark. Gorontalo has a rock distribution consisting of several formations, one of which is the Tinombo Formation which is the oldest formation. In this formation there is red limestone which has great potential due to its rarity so that it can be developed into a site in the development of a geopark in Gorontalo. The purpose of this research is to conduct a geosite assessment of geological features in Boalemo Regency as a basis for developing geotourism in Boalemo Regency, Gorontalo. The research site is located in Dimito Village, Wonosari Subdistrict and Lahumbo Village, Tilamuta Subdistrict, Boalemo Regency, Gorontalo Province. The methods used in this research are lithological analysis, Geochemical analysis and geosite potential analysis using the technical guidelines for geological heritage resource assessment by the Geological Survey Center. The results showed that the red color-controlling minerals in limestone are hematite and rodoxite, the red color-controlling chemical elements in limestone are SiO2, MnO, Fe2O3, Sr and CaO. The results of the assessment of geological features explain that the Wonosari Red Limestone Site and the Tilamuta Red Limestone Site are included in the medium category. Geosite Red Limestone can be developed as an object of study in the field of education by utilizing natural laboratories for the development of geoparks in Gorontalo.

Keywords: Geotourism, Geological Features, Scientific Value Assessment, Education, Tourism, Risk of Degradation

## 1. Introduction

Indonesia has many potential geological heritages spread from Sabang to Merauke that are very interesting and beautiful. The presence of this potential geological heritage also has an important role for the development of the tourism sector in Indonesia. One of the tourism sectors that can be developed is Geopark. Geopark is a national protected area that has several Geological Heritage sites that have a value of beauty, rarity and can be developed through an integrated concept of conservation, education and economic development of the surrounding community (Henriques & Brilha, 2017; Arifin et al, 2021; Manyoe et al, 2021). Geoparks are very useful as part of the promotion of existing geological features through several media, as well as conservation, education and for sustainable tourism development (Newsome and Dowling, 2018;Sahara and Setiawan, 2022). Geotourism is one of the solutions for Indonesia to utilize the existing geological wealth for tourism activities and an environmentally-based economy (Hermawan and Ghani, 2018).

Based on the regional stratigraphy of the Tilamuta Sheet (Bachri et al., 1993), the study area consists of 5 formations. The formations of the study area if sorted from old to young are Tinombo Formation (Teot), Dolokapa Formation (Tmd), Tmbo Formation (Bolihutuo Diorite), Qpl Formation (Lake Deposits) and Qal Formation (Aluvium).

The oldest rock formation in Gorontalo is the Tinombo Formation (Teot) which is Eocene to Oligocene in age (Bachri et al., 1993). There are several rocks scattered in the formation, one of which is red limestone. Red limestone has such great potential that it was developed into one of the geosite sites in the development of geopark in Gorontalo. The red limestone is thought to have formed in a deep-sea marine environment (Bachri, 2006 ; Badaru et al., 2019). Unfortunately, until now, there has been no research on red limestone in Gorontalo.

This is the background for researchers to conduct research in Tilamuta and Wonosari Subdistricts, Boalemo Regency, Gorontalo Province regarding the potential of red limestone geosite to be developed as one of the sites in the Geopark area. This research aims to analyze the potential of red limestone geosite based on lithological and geochemical analysis.

Administratively, the research location is located in two different sub-districts, namely Tilamuta Sub-district in Lahumbo Village and Wonosari Sub-district in Dimito Village, Boalemo Regency, Gorontalo Province.

## 2. Data and Methodology

The methods used in this research are lithological analysis, Geochemical analysis and geosite potential analysis. The tools and materials used are Geological Stationery, GPS, Geological Hammer, Loupe, Geological Compass, HCL, Sample Bags and Sample Bags.

Lithological analysis in the form of petrological analysis, petrographic analysis and microfossils. Petrological and petrographic analysis using Dunham's classification (1962). Microfossil analysis using Bolli et al (1985), Holbourn et al (2013), Bandy (1967) and Blow (1969). Geochemical analysis using X-Ray Fluoresence (XRF) analysis. Based on the analysis of lithological and geochemical data can support to analyze the potential of the geosite. Geosite analysis using the

quantification method according to (Geological Survey Center, 2017).

## 3. Result and Discussion

### 3.1 Wonosari Red Limestone

#### 3.1.1 Petrography

The megascopic characteristics of this Wonosari red limestone are brownish red, grain size 1/6 - 1/256 mm, mud-supported, vein filled with calcite minerals with unobservable packing and sorting.

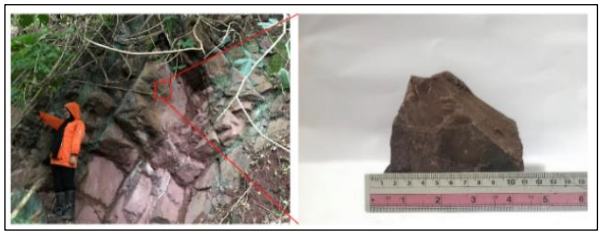

Fig 1. Outcrop and hand specimen of Wonosari Red Limestone

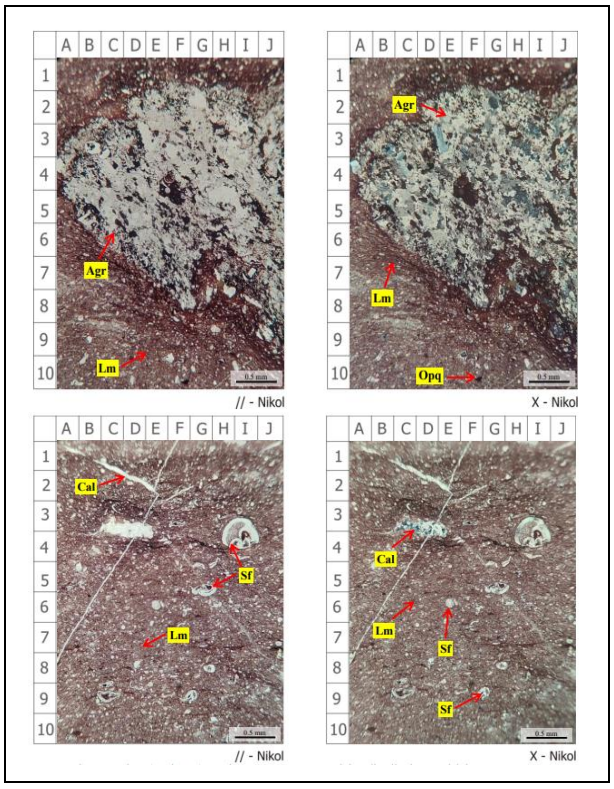


Fig 2. Thin section of Wonosari Red Limestone in nikol parallel and nikol cross position. Notes: SF = Small Foraminifera, Agr = Agrerat, Opq = Opaque Mineral, Lm = Carbonate Mud, Cal = Calcite.

From the results of petrographic observations, in general the incision shows a dark red color (parallel and cross niches) with a relatively angular shape, has good sorting with closed packing, and there is a mixture of volcanic material. The rock composition consists of skeletal grain types in the form of small foraminifera (12%), non-skeletal grain types in the form of agrerat (15%), opaque minerals are found (3%), grains embedded in carbonate mud micrites (60%) have generally recrystallized into calcite or microcrystalline calcite (10%) which are also present as sparites / cementation in rocks. The rock composition is dominated by fine mud (mud supported).

#### 3.1.2 Geochemical

Geochemical analysis of wonosari red limestone shows several chemical elements presented in the table below.

Table 1. Chemical Content of Wonosari Red Limestone

| No | Element | Concentration |
|---|---|---|
| 1 | $SiO_2$ | 29,84% |
| 2 | MnO | 0,524% |
| 3 | $Fe_2O_3$ | 6,86% |
| 4 | Sr | 0,056% |
| 5 | CaO | 51,82% |

The presence of Silicon oxide (SiO2) in this wonosari red limestone sample is also the cause of the appearance of red color in red limestone

The presence of (MnO) indicates the presence of the mineral rodoxite (MnCO3) in the red limestone sample. Rodoxite mineral (MnCO3) is one of the minerals that have pink to red color characteristics, this is what can give the limestone a red color (Atmoko et al, 2016).

The presence of iron oxide (Fe2O3) indicates the presence of hematite minerals. When the compound is in the form of a hematite mineral (Fe2O3), it will cause a red color in the rock. The presence of this compound is one of the causes of the red color in limestone (Atmoko et al., 2016). The presence of Mn also indicates that this limestone was formed in a deep-sea environment (Rompas and Rumampuk, 2014).

The presence of Strontium (Sr) in this wonosari red limestone sample is also the cause of the appearance of red color in red limestone (Nassau, 1978). The presence of CaO compounds in the sample is present as the main constituent compound of limestone derived from seawater and contained in limestone when precipitation takes place (Atmoko et al, 2016).

#### 3.1.3 Microfossils

The results of microfossil analysis there is one benthonic foraminifera fossil species namely Nodosaria spp. Seven species of planktonic foraminifera fossils are Globigerina pseudovenezuelana, Globigerinatheka index index, Globigerinatheka semiinvoluta, Globorotalia increbescens, Pseudohastigerina naguewichiensis, Pseudohastigerina micra, Turborotalia cerroazulensis cerroazulensis.

Based on the abundance of planktonic foraminifera fossils above, we can determine that the age of this rock is Late Eocene (P15). Then based on the abundance of benthonic foraminifera, it can be known that the depth of deposition of this rock is in the 100 m depth zone.

### 3.2 Tilamuta Red Limestone

#### 3.2.1 Petrography

The megascopic characteristics of this Tilamuta red limestone are brownish red, grain size 1/6 - 1/256 mm, mud-supported, vein filled with calcite minerals with unobservable packing and sorting.

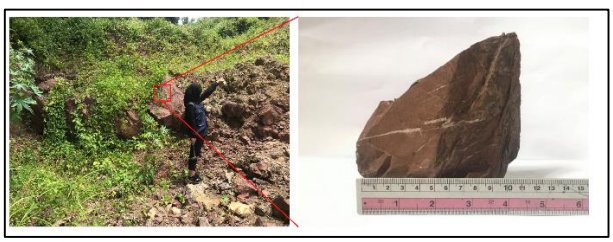

Fig 3. Outcrop and hand specimen of Tilamuta Red Limestone

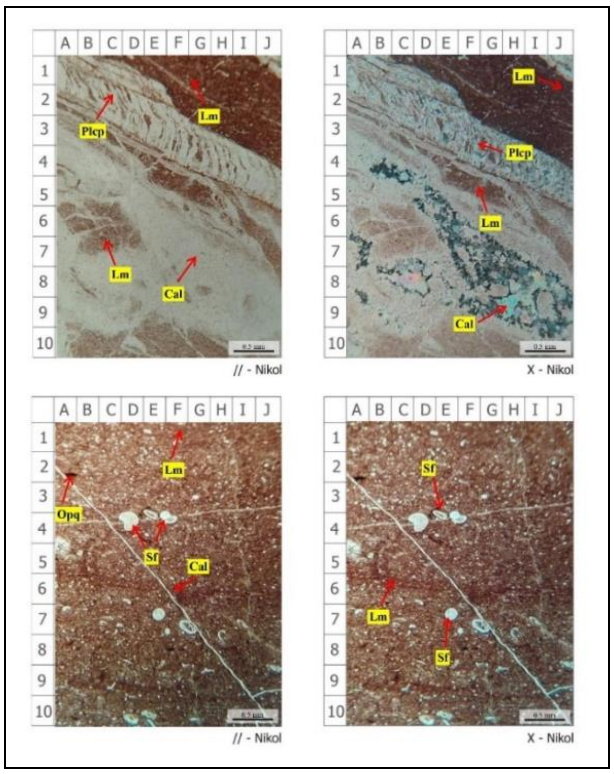


Fig 4. Thin section of Tilamuta Red Limestone. Type: SF = Small Foraminifera, Plcp = Pelecypod shell, Opq = Opaque mineral, Lm = Carbonate mud, Cal = Calcite.

The results of the petrographic analysis show that the red limestone found in Tilamuta District is dominated by mud (mud supported), pelecypod shells (8%), as well as non-skeletal grains in the form of opaque minerals (2%), which are embedded in carbonate mud micrites (60%), sparites in the form of microcrystalline calcite (20%) recrystallization results scattered as cementation. The sorting is relatively good, the grains consist of skeletal fragments in the form of small foraminifera (10%) and pelecypod shell fragments (8%), and non-skeletal grains in the form of opaque minerals (2%), embedded in carbonate mud micrites (60%), microcrystalline calcite sparites (20%) recrystallized scattered as cementation.

### 3.2.2 Geochemical

The presence of Silicon oxide (SiO2) in this tilamuta red limestone sample is also the cause of the appearance of red color in red limestone.

The presence of (MnO) indicates the presence of the mineral rodoxite (MnCO3) in the wonosari red limestone sample. Rodoxite mineral (MnCO3) is one of the minerals that have pink to red color characteristics, this is what can give the limestone a red color (Atmoko et al, 2016). The presence of Mn also indicates that this limestone was formed in a deep-sea environment (Rompas and Rumampuk, 2014).

The presence of iron oxide (Fe2O3) indicates the presence of hematite minerals. When the compound is in the form of a hematite mineral (Fe2O3), it will cause a red color in the rock. The presence of this compound is one of the causes of the red color in red limestone (Atmoko et al., 2016).

The presence of Strontium (Sr) in the tilamuta red limestone sample reaches 0.04%. The presence of this compound is also the cause of the red color in red limestone (Nassau, 1978).

The presence of CaO compounds present as the main constituent compound of limestone comes from seawater and is contained in limestone when precipitation takes place (Atmoko et al., 2016).

Geochemical analysis of tilamuta red limestone shows several chemical elements presented in the table below.

Table 2. Chemical Content of Tilamuta Red Limestone

| No | Elemen | Kosentration |
|---|---|---|
| 1 | $SiO_2$ | 30,66% |
| 2 | MnO | 0,624% |
| 3 | $Fe_2O_3$ | 10,28% |
| 4 | Sr | 0,0276% |
| 5 | CaO | 42,55% |

### 3.2.3 Microfossils

The results of microfossil analysis found one benthonic foraminifera fossil species namely Cyclammina cancellate. Three species of planktonic foraminifera fossils include Pseudohastigerina Micra, Turborotalia cerroazulensis and Turborotalia cerroazulensis possagnoensis. Based on the abundance of planktonic foraminifera fossils above, we can determine that the age of this unit is Middle Eocene (P12). Then based on the abundance of benthonic foraminifera fossils, it can be known that the depth of deposition of this unit is in the depth zone of 1500 - 3000m (Bandy, 1967).

### 3.3 Assessment of Geosite Potential

### 3.3.1 Assessment of Wonosari Red Limestone Site

#### 3.3.1.1 Scientific Value

Table 3. Assessment of the Scientific Value of the Wonosari Red Limestone Site

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Locations that represent the framework | 30 | 4 | 30 |
| 2 | Key research locations | 20 | 2 | 10 |
| 3 | Scientific understanding | 5 | 0 | 0 |
| 4 | Geological site conditions | 15 | 2 | 3,25 |
| 5 | Geological diversity | 5 | 3 | 2,5 |
| 6 | Presence of geological heritage sites | 15 | 4 | 15 |
| 7 | Barriers to site use | 10 | 3 | 7,5 |
| | Total | 100 | | 68,25 |

1. The criterion of Sites representing the framework is worth 30 because the red limestone sites in wonosari are the best examples in the study area that can illustrate the features and processes associated with the geologic framework being considered.
2. The key research location criterion is worth 10 because there is only 1 (one) national scale publication
3. The scientific understanding criterion is worth 0 because the research area has no articles or reports published by national or international scientists on red limestone sites related to the geological framework.
4. Condition criteria of the location or geological site is worth 3.25 because the location of the red limestone geological heritage site is not very well preserved by the surrounding community and the outcrops have undergone little change.
5. The geological diversity criterion is 2.5 because the wonosari red limestone site has 3 geological features or geological processes that are scientifically interconnected, namely rocks, minerals and fossils.

6. The criterion of geological heritage site existence is worth 15 because the red limestone outcrops are only found in one village in Wonosari sub-district.
7. The criterion of obstacles to the use of the location is worth 7.5 because to be able to conduct field activities and sampling, several research permits must be completed.

#### 3.3.1.2 Educational Value

Table 4. Assessment of Educational Value of Wonosari Red Limestone Site

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Vulnerability | 10 | 1 | 2,5 |
| 2 | Site Accessbility | 10 | 3 | 7,5 |
| 3 | Barriers to Site Utilization | 5 | 4 | 5 |
| 4 | Security Facilities | 10 | 2 | 5 |
| 5 | Supporting Facilities | 5 | 3 | 3,75 |
| 6 | Population Density | 5 | 2 | 2,5 |
| 7 | Relationship with other values | 5 | 4 | 5 |
| 8 | Location status | 5 | 0 | 0 |
| 9 | Distinctiveness | 5 | 4 | 5 |
| 10 | Condition on observation of geological elements | 10 | 3 | 7,5 |
| 11 | Potential for education/research information | 20 | 1 | 5 |
| 12 | Geological diversity | 10 | 3 | 7,5 |
| | Total | 100 | | 56,25 |

1. This vulnerability criterion has a score of 2.5 because there is a possibility of damage to one or more geological features or all geological features in the study area caused by the activities of the surrounding community. This is caused by the presence of red limestone near people's plantations.
2. The achievement criterion of this location has a value of 7.5 due to the existence of a red limestone location that is located not far from the village road, which is about < 500 meters.
3. The location utilization obstacle criterion has a value of 5 because there are no obstacles at all if this location is used by students or tourists.
4. The security facilities criterion has a score of 5, this is because there are no security facilities but can be reached by telephone signal and the location of this feature is located less than 50 km from the emergency department. The closest emergency room to this red limestone location is the wonosari health center which is located approximately 5.4 km from the location of the geological feature.
5. The supporting facilities criterion has a score of 3.75 because some lodgings and restaurants can be occupied by 50 people within a distance of less than 50 km. The Grand Amalia Hotel lodging is about 42.5 km away and the restaurant is about 13 km from the location of the geological feature.
6. The population density criterion has a value of 2.5 due to the location of the red limestone site in Boalemo district which has a population density of around 100-250 people/km2. The location of red limestone site is located in Boalemo Regency with a population density of 147,038 people/km2 (Boalemo Regency in Figures, 2022).
7. The criterion of relationship with other values has a value of 5 because, around the geological feature, there are many cultural values less than 5 km from the location of the red limestone site. The cultural values that exist close to the site are several temples found in every rice field and house that is passed.
8. The location status criterion has no value because the location of this geological feature has not been used as a tourist attraction by the surrounding community.
9. The distinctiveness criterion has a value of 5 because the geological feature in the research area is one of the unique geological features and is also rarely found in this country or neighboring countries.
10. The condition criterion on the observation of geological elements has a value of 7.5 because there are some obstructions such as bushes that make it a little difficult to observe some geological features.
11. Criteria for potential education/research information are worth 5 because the existing geological features are only taught at the college level.
12. Geological diversity criteria are worth 7.5 because the location of the geological heritage site has 3 geological diversity features, namely mineralogy, fossils, and rocks**.**

#### 3.3.1.3 Tourism Values

Table 5. Tourism Value Assessment of Wonosari Red Limestone Site

| **No** | **Criteria** | **Weight (%)** | **Score** | **Value** |
|---|---|---|---|---|
| 1 | Vulnerability | 10 | 1 | 2,5 |
| 2 | Site accessibility | 10 | 3 | 7,5 |
| 3 | Barriers to site utilization | 5 | 4 | 5 |
| 4 | Security facilities | 10 | 2 | 5 |
| 5 | Supporting facilities | 5 | 4 | 5 |
| 6 | Population density | 5 | 2 | 2,5 |
| 7 | Relationship with other values | 5 | 4 | 5 |
| 8 | Location status | 15 | 0 | 0 |
| 9 | Distinctiveness | 10 | 4 | 10 |
| 10 | Condition on observation of geological elements | 5 | 3 | 7,5 |
| 11 | Interpretative potential | 10 | 2 | 5 |
| 12 | Economic level | 5 | 0 | 0 |
| 13 | Close to recreation area | 5 | 3 | 3,75 |
| | Total | 100 | | 58,75 |

1. The vulnerability criterion has a value of 2.5 because there is a possibility of damage to some geological features in the research area caused by the activities of the surrounding community. This is because the red limestone site is located near the plantations of the people in the area.
2. The location achievement criterion has a value of 7.5 because the location of this red limestone site is located less than 500 meters from the village road.
3. The location utilization obstacle criterion has 5 because there is no interference or obstacles if used by students or tourists who will visit the location of the red limestone site.
4. The security facility criterion has a score of 5 because there is no security service but at this location, it can reach a telephone signal to be used as a communication tool and is located less than 50 km from the emergency room. The nearest emergency room is the wonosari health center which is located approximately 5.5 km from the location of the geological feature.
5. The supporting facilities criterion has a score of 5 because around the red limestone site, some inns and restaurants can bear a quota of 50 people with a distance of less than 15 km. From the location of the red limestone site to the nearest inn can be reached at a distance of about 6.6 km while to get to the restaurant can be reached at a distance of about 5.6 km.
6. The population density criterion has a value of 2.5 because the location of the red limestone site is in a district that has a population density of around 100-250 people/km2. The location of this red limestone site is located in Boalemo

Regency with a population density of around 147,038 people/km2 (Boalemo Regency in Figures, 2022).

7. The criterion of relationship with other values has a value of 5 because there are many cultural values < 5 km from the location of the red limestone site. The cultural values that exist close to the site are several temples found in every rice field and house that is passed.
8. The location status criterion is 0 or has no value at all because the location of the red limestone site has never been visited by tourists as a tourist spot.
9. The distinctiveness criterion has a value of 10 because the feature (red limestone) is a unique feature and is rarely found in Indonesia and neighboring countries.
10. The condition criterion on the observation of geological elements has a value of 7.5 because there are some obstructions such as bushes that make it a little difficult to observe some geological features at the red limestone site.
11. The interpretative potential criterion has a score of 5 because people need deeper geological knowledge to understand the existing geological features.
12. The economic level criterion has a value of 0 or no value at all because the location of the geological heritage site is not located in the city and has no income at all.
13. The criterion of proximity to recreational areas has a value of 3.75 because the red limestone geological feature site is < 10 km away from recreational or tourist attractions. The attractions around the geological feature are Cakra Buana Tourism and Garden Stone.

#### 3.3.1.4 Degradation Risk

1. Criteria for damage to geological elements is 17.5 because this geological site has the possibility of damage to secondary geological features and also this site is rarely touched by human activities. The site is in an earthquake-prone area (Manyoe et al, 2019).
2. The criterion of proximity to areas or activities that have the potential to cause degradation is 10 because the location of the site is less than 1 kilometer from areas or activities that cause degradation such as mining activities, industrial facilities, recreational areas and others.
3. Legal protection criteria are worth 20 because the site is located in an area that has no legal protection and no access control.
4. The accessibility criterion is 11.25 because the site is located less than 500 meters from a paved road.
5. The population density criterion is 5 because the location of the red limestone site is in a district that has a population density of around 100-250 people/km2. The location of this red limestone site is located in Boalemo Regency which has a population density of 147,038 people/km2 (Boalemo Regency in Figures, 2022).

Table 6. Degradation Risk Assessment of Wonosari Red Limestone Site

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Damage to geological elements | 35 | 2 | 17,5 |
| 2 | Adjacent to areas/activities that could potentially cause degradation | 20 | 2 | 10 |
| 3 | Legal Protection | 20 | 4 | 20 |
| 4 | Accessbility | 15 | 3 | 11,25 |
| 5 | Population density | 10 | 2 | 5 |
| | Total | 100 | | 63,75 |

### 3.3.2 Assessment of Tilamuta Red Limestone Site

#### 3.3.2.1 Scientific Value

Table 7. Assessment of the Scientific Value of the Tilamuta Red Limestone Site

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Damage to geological elements | 35 | 2 | 17,5 |
| 2 | Adjacent to areas/activities that could potentially cause degradation | 20 | 2 | 10 |
| 3 | Legal Protection | 20 | 4 | 20 |
| 4 | Accessbility | 15 | 3 | 11,25 |
| 5 | Population density | 10 | 2 | 5 |
| | Total | 100 | | 63,75 |

1. The criterion of Sites representing the framework is 30 because the red limestone sites in tilamuta are the best examples in the study area that can illustrate the features and processes associated with the geological framework under consideration.
2. The key research site criterion is worth 5 because the location of the geological heritage site is mentioned in the report but not published.
3. Scientific understanding criterion scores 0 because no articles were published or presented at national science events.
4. The condition of the location or geological site criterion is worth 3.25 because the location of the red limestone geological heritage site is not very well preserved by the surrounding community and the outcrops have undergone little change.
5. Geological diversity criterion is worth 2.5 because the tilamuta red limestone site has 3 geological features or geological processes that are scientifically interconnected, namely rocks, minerals, and fossils.
6. The criterion for the existence of a geological heritage site is worth 15 because the red limestone outcrops are only found in one village in Tilamuta sub-district.
7. The criterion of obstacles to the use of the location is worth 7.5 because to carry out field activities and sampling, several research permits must be completed.

#### 3.3.2.2 Educational Value

Table 8. Assessment of Educational Value of Tilamuta Red Limestone Site

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Vulnerability | 10 | 1 | 2,5 |
| 2 | Site Accessbility | 10 | 4 | 10 |
| 3 | Barriers to Site Utilization | 5 | 4 | 5 |
| 4 | Security Facilities | 10 | 3 | 7,5 |
| 5 | Supporting Facilities | 5 | 4 | 5 |
| 6 | Population Density | 5 | 2 | 2,5 |
| 7 | Relationship with other values | 5 | 0 | 0 |
| 8 | Location status | 5 | 0 | 0 |
| 9 | Distinctiveness | 5 | 4 | 5 |
| 10 | Condition on observation of geological elements | 10 | 4 | 10 |
| 11 | Potential for education/research | 20 | 1 | 5 |
| 12 | information Geological diversity | 10 | 3 | 7,5 |
| | Total | 100 | | 60 |

1. The vulnerability criterion has a value of 2.5 because there is a chance of damage to geological features in the study area caused by the activities of the surrounding community. This is because the red limestone site is located in front of the main road that can be accessed by anyone.

2. The location achievement criterion has a value of 10 because the location of this red limestone site is located < 100 meters from the road and bus parking lot.
3. The location utilization barrier criterion has a score of 5 because there is no disturbance if it is used by students or tourists.
4. The security facilities criterion has a score of 7.5 because there are security facilities available, there is a telephone signal that can be used to communicate and it is located less than 25 km from the Emergency Room (IGD). The existing security facility around the red limestone site location is a security fence built on the right side of the red limestone site location. The emergency department located near the site is the provincial hospital which is located approximately 7.5 km from the red limestone site.
5. The supporting facilities criterion has a score of 5 because some inns and restaurants can accommodate 50 people that have a distance of < 15 km from the red limestone site. The inn is approximately 6.3 km and the restaurant is approximately 4.4 km from the location of the geological feature.
6. The population density criterion has a value of 2.5 because the location of the red limestone site is in a district that has a population density of around 100-250 people/km2. The location of red limestone site is in Boalemo Regency which has a population density of 147,038 people/km2 (Boalemo Regency in Figures, 2022).
7. The criterion of relationship with other values has no value because there are no ecological values or cultural values found around the red limestone site.
8. The location status criterion has no value because the location of the red limestone site has never been used as a tourist destination.
9. The distinctiveness criterion has a value of 4 because this red limestone site is a unique feature and is rarely found in Indonesia and neighboring countries.
10. The condition criterion on the observation of geological elements has a value of 10 because all features at this red limestone site can be observed properly because there are no obstructions.
11. Criteria for potential educational/research information is worth 5 because the existing geological features are only taught at the college level.
12. The geological diversity criterion is worth 7.5 because the tilamuta red limestone site has 3 (three) geological features or geological processes that are scientifically interrelated, namely rocks, fossils, and minerals.

**3.3.2.3 Tourism Values**

1. The vulnerability criterion has a value of 2.5 because there is a chance of damage to the red limestone site in the research area which can be caused by several activities of the surrounding community. This is because the red limestone site is located in front of the main road that can be accessed by anyone.
2. The location achievement criterion has a score of 10 because the location of the red limestone site is located < 100 meters from the village road and bus parking lot.
3. The location utilization obstacle criterion has a value of 5 because there are no disturbances or obstacles if used by students and tourists who come to the location of the red limestone site.
4. The security facilities criterion has a value of 7.5 because there are security facilities available, there is also a telephone signal that can be used to communicate and is located < 25 km from the emergency room (emergency room installation). The security facility found at the red limestone site location is a security fence built on the right side of the red limestone site. The emergency room is a provincial hospital located approximately 7.5 km from the location of the geological feature.
5. Supporting facilities criteria have a score of 5 because there are inns and restaurants that can accommodate 50 people with a distance of about 15 km from the red limestone site. The inn is about 6.3 km away and the restaurant is about 4.4 km from the location of the geological feature.
6. The population density criterion has a value of 2.5 because the location of the red limestone feature site is in a district that has a population density of around 100-250 people/km2. The location of the red limestone site is in Boalemo Regency which has a population density of 147,038 people/km2 (Boalemo Regency in Figures, 2022).
7. The criterion of relationship with other values has no value because there is no ecological or cultural value found around the red limestone site area.
8. The location status criterion has no value because the location of the red limestone site has never been used as a tourist attraction.
9. The distinctiveness criterion has a score of 3.75 because this red limestone site is a unique feature and rarely found in this country.
10. The condition criterion on the observation of geological elements has a score of 7.5 because all features at this red limestone site can be observed properly because there are no obstructions.
11. The interpretive potential criterion has a score of 5 because people need deeper geological knowledge to understand the geological features.
12. The economic level criterion has no value because the location of the red limestone site is not located in the city and has no income at all.
13. The criterion of proximity to recreational areas has a value of 2.5 because the red limestone site is < 15 km from a recreational or tourist attraction. Attractions located around the red limestone site are Ratu Beach and Tenilo Waterfall.

Table 9. Tourism Value Assessment of Tilamuta Red Limestone Site

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Damage to geological elements | 35 | 4 | 35 |
| 2 | Adjacent to areas/activities that could potentially cause degradation | 20 | 4 | 20 |
| 3 | Legal Protection | 20 | 4 | 20 |
| 4 | Accessbility | 15 | 4 | 15 |
| 5 | Population density | 10 | 2 | 5 |
| | Total | 100 | | 95 |

Table 10. Degradation Risk Assessment of Tilamuta Red Limestone Site

| No | Assessment Criteria | Wonosari Red Limestone Site | Tilamuta Red Limestone Site |
|---|---|---|---|
| 1 | Scientific Values Assessment | 68,25 | 63,25 |
| 2 | Education Values Assessment | 55 | 53,75 |
| 3 | Tourism Values Assessment | 51,25 | 50 |
| 4 | Degradation Risk Assessment | 63,75 | 95 |
| Geological Heritage Site Values Assessment Classification | | 238,25 medium | 262 medium |

#### 3.3.2.4 Degradation Risk

1. The criterion for damage to geological elements is 35 because this geological site has the possibility of damage to all geological features due to its vulnerability to human activities.
2. Criteria adjacent to areas/activities that have the potential for degradation or damage is worth 20 because this geological site is adjacent to areas or activities that have the potential to cause degradation, this site is adjacent to industrial facilities (pertamina), roads and urban areas.
3. Legal protection criteria is worth 20 because the site is located in an area that does not have legal protection and does not have access control.
4. The accessibility criterion is 15 because the red limestone site is located < 100 meters from a paved road and has a parking lot for buses.
5. The population density criterion is worth 5 because the location of the red limestone site is in a district that has a population density of around 100-250 people/km2. The location of the red limestone site is in Boalemo Regency which has a population density of 147,038 people/km2 (Boalemo Regency in Figures, 2022).

### 3.4 Classification of Geosite Potential Assessment

Table 11. Total Score of Geological Sites in the Study Area

| No | Criteria | Weight (%) | Score | Value |
|---|---|---|---|---|
| 1 | Vulnerability | 10 | 1 | 2,5 |
| 2 | Site accessibility | 10 | 3 | 7,5 |
| 3 | Barriers to site utilization | 5 | 4 | 5 |
| 4 | Security facilities | 10 | 2 | 5 |
| 5 | Supporting facilities | 5 | 3 | 3,75 |
| 6 | Population density | 5 | 2 | 2,5 |
| 7 | Relationship with other values | 5 | 4 | 5 |
| 8 | Location status | 15 | 0 | 0 |
| 9 | Distinctiveness | 10 | 3 | 3,75 |
| 10 | Condition on observation of geological elements | 5 | 3 | 7,5 |
| 11 | Interpretative potential | 10 | 2 | 5 |
| 12 | Economic level | 5 | 0 | 0 |
| 13 | Close to recreation area | 5 | 2 | 2,5 |
| | total | 100 | | 50 |

Based on the weighting results of scientific value, educational value, tourism value, and risk of degradation, the research area is classified to determine the feasible or not feasible status of geosite development in the research area. As for the results of quantitative research on four assessments, namely scientific value, educational value, tourism value, and risk of degradation, the classification of the assessment can be seen in the table below.

Based on the assessment table data above, it can be seen that the research area is included in the Medium value classification (201-300), with an assessment of the Wonosari Red Limestone Site worth 238.25 and the Tilamuta Red Limestone Site worth 262. From the results of scientific research, education, tourism, and degradation risk, it can be seen that the research area has the potential to be developed as a geosite area. Thus, to encourage the progress of existing geosites in the research area, it is necessary to pay attention to geological features, minimize activities that cause degradation or decrease in the values of science, and education, and increase accessibility to the location of the geotourism development area.

### 3.5 Geological Site Potential for Geopark Development

The potential of geological sites can be determined based on the results of geological value observations and geological site assessments carried out to determine the level of each site in the research area. From the results of the field, research obtained 2 geological sites that have the opportunity to be developed as a geosite in Gorontalo Province.

Geological sites in the research area that can be developed as geosite areas are Wonosari Red Limestone Site and Tilamuta Red Limestone Site. From the assessment results, each site in the study area has an average value of medium.

Site and Tilamuta Red Limestone Site. From the assessment results, each site in the study area has an average value of medium.

#### 3.5.1 Wonosari Red Limestone Site

This site is located in Dimito Village, Wonosari Sub-district, Boalemo Regency, Gorontalo Province with coordinates 0°41' 24.4" N, 122°24' 55.9" E. Based on the geosite assessment, this site has a science value of 68.25%, an education value of 55%, a tourism value of 51.25%, and a degradation risk value of 63.75% so the overall value is 238.25% with a medium classification.

#### 3.5.2 Tilamuta Red Limestone Site

This site is located in Lahumbo village, Tilamuta sub-district, Boalemo district, Gorontalo province with coordinates 0°33' 11.7" N, 122°22' 51.8" E. Based on the geosite assessment, this site has 63.25% science value, 53.75% education value, 50% tourism value, and 95% degradation risk value so the overall value is 262% with medium classification.

Table 12. Identification of Wonosari Red Limestone Geosite

| Name of Geological Heritage Site (Geosite) | Coordinates | Featured Geological Component (Mineral/Rock/Fossil) | Criteria Result |
|---|---|---|---|
| Wonosari Red Limestone | 0°41' 24,4" N, 122° 24' 55,9" E. | Rocks: At this location, there are outcrops of red limestone with clay grain size with the main composition being carbonate minerals and has undergone an advanced diagenesis process. Chemical elements controlling the red color of limestone are SiO2, MnO, Fe2O3, Sr, and CaO. Several Bentonic Foraminifera and Planktonic Foraminifera fossils were also found. The appearance of this red limestone was influenced by tectonic activity which resulted in this red limestone being lifted to the surface. This red limestone was formed in the Late Eocene or around 55.8 million years ago. | a) Has a high value of the set of aspects of the realm of rocks, tectonics, and temporary evolution<br>b) Has a prominent value because it contains scientific records, and geological order and is meant as evidence of important geological events. |

Tabel 13. Identification of Tilamuta Red Limestone Geosite

| Name of Geological Heritage Site (Geosite) | Coordinates | Featured Geological Component (Mineral/Rock/Fossil) | Criteria Result |
|---|---|---|---|
| Tilamuta Red Limestone | 0°33' 11,7" N, 122° 22' 51,8" E | Rocks: At this location, there are red limestone outcrops with clay grain size with the main composition being carbonate minerals, and have undergone an advanced diagenesis process. Chemical elements controlling the red color of limestone are SiO2, MnO, Fe2O3, Sr, and CaO. There are some Bentonic Foraminifera and Planktonic Foraminifera fossils. This red limestone is associated with a relatively deep marine depositional environment as evidenced by the presence of several fossil contents characterized as formed in the deep sea. The appearance of this red limestone was influenced by tectonic activity that resulted in this red limestone being lifted to the surface. This red limestone was formed in the Middle Eocene or around 55.8 million years ago. | a) Has a high value of the set of aspects of the realm of rocks, tectonics, and temporary evolution<br>b) Has a prominent value because it contains scientific records, and geological order and is meant as evidence of important geological events. |

### 3.6 Red Limestone Potential Geosite for Sustainable Tourism

The readiness of an area is very influential in the development of geosite potential, this can be seen from several aspects, namely the geological heritage that exists in the area, the role of the surrounding community which will create a good geosite environment and also assistance from the government which in this case becomes the driving force (Martania et al, 2022). In developing the attractiveness of a geotourism, there needs to be supporting factors in the form of good management, adequate facilities and infrastructure to fulfill the needs of tourists (Duarte et al., 2019; Putra et al., 2020).

Geological, biological and cultural diversity are important factors in the development of geotourism based on sustainable tourism (Wulung et al., 2021). Red Limestone Geosite has the uniqueness of rocks that are rare and difficult to find elsewhere which is very potential and has good prospects for development. When viewed from the results of the scientific values assessment, education values assessment and red limestone geosite is suitable to be used as an education-based tourism area. The role of education in the development of tourist areas can be done by providing educational information to increase conservation awareness for the community and visitors.

Management of education-based tourism areas also has various risks. Judging from the degradation risk assessment which has a value above 50, this indicates that the lack of public awareness of the existence of this red limestone site. This lack of awareness will cause the loss of uniqueness and variety of geological, biological and cultural wealth that will hinder the development of sustainable tourism areas. From the aspect of tourism values assessment, it is necessary to hold several supporting facilities, transportation, accommodation and the construction of various supporting facilities. In addition, promotional efforts are needed in disseminating information both in print, electronic media and through the sale of souvenirs related to this site.

## Conclusions

Based on the results and discussion, the analyses that have been carried out, and the literature study, the authors can conclude, namely: Red color-controlling minerals in limestone are hematite and rodoxite. Chemical elements controlling the red color in limestone are SiO2, MnO, Fe2O3, Sr, and CaO. The research area has 2 geological sites including Wonosari Red Limestone Site and Tilamuta Red Limestone Site. Based on the geosite assessment, the final results of the geosite assessment are, Wonosari Red Limestone Site is superior in the scientific field (68.25) and Tilamuta Red Limestone Site is superior in the scientific field (63.25) Wonosari Red Limestone Site and Tilamuta Red Limestone Site can be developed as an object of study in the field of education by utilizing natural laboratories for the development of geoparks in Gorontalo. The role of the Boalemo Regency government is very important for the development of tourism at the Red Limestone Geosite. The role of the government here is expected to create infrastructure, accommodation, transportation and several supporting facilities that will support sustainable tourism in this geosite area.

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