

EXPOSING THE INTERESTING STONE BASED ON GEOCHEMICAL AND MAGNETIC SUSCEPTIBILITY AS AN EFFORT FOR ENHANCE THE ATTRACTIVENESS OF LENGGOKSONO BEACH GEOTOURISM IN INDONESIA

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Abstract: Geotourism sites often receive little attention from the general public as interesting object to visit. Tourists generally come just to enjoy the scenery. In addition, there are many geotourism sites that are less interesting to visit, even though they have high scientific value and a wealth of knowledge stored as natural laboratories. This research aims to package exploration data of interesting stones in transport igneous rocks and beach sand for exposure to enhance tourist attraction. In this research, magnetic and geochemical methods applies to igneous transport rocks and beach sand were subjected to geochemical and magnetic susceptibility tests to provide information to tourists about the geotourism object. The geochemical test was conducted using X-Ray Fluorescence (XRF), and resulting the presence of chemical elements Si, K, Ca, Ti, V, Cr, Mn, Fe, Cu, Eu, Re, Mo, and Zn. The dominant elements with a content of more than 5% (wt) are Si, Fe, and Ca, with average values of 56.78 wt%, 24.20 wt%, and 8.41 wt%, respectively. The high Si content confirms that the contribution of igneous rocks is more dominant in the beach sand compared to coral rocks. This implies that the plate subduction in that area is relatively deep. The magnetic susceptibility test shows a magnetic susceptibility value ranging from 13 to $4143 \times 10^{-8} \text{ m}^3/\text{kg}$, with average $1182 \times 10^{-8} \text{ m}^3/\text{kg}$ indicate that igneous rocks and beach sand are rich in magnetic minerals that can be utilized as industrial raw materials. The exploration data was packaged as promotional materials and presented to tourists. In addition, perfectus and location videos are presented for public access. Finally, the research network was communicated to the general public and productive communities of tourism business owners and received positive feedback regarding the benefits of this research and activities.

Keywords: geochemical, geotourism, interesting stone, Lenggoksono, magnetic susceptibility

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INTRODUCTION

Lenggoksono Beach in South Malang, East Java Indonesia is one of the unique beaches where various types of transport stones with smooth, oval, flat shapes blend seamlessly with the sand along the shoreline. This beach was frequently visited by tourists before COVID 2019 and was used as a surfing training venue due to its very specific shape, which is relatively flat contour (Figure 1). The shape of this beach is very safe for tourist areas and surfing attractions. In some previous studies, many efforts have been made to enhance geotourism objects, including analyzing and highlighting infrastructure, access routes, and so on (Widawski et al., 2018). For Indonesian people, the attraction of geotourism objects actually lies more in legends, mystical stories, and historical tales (Hakimah et al., 2023). Those stories have not yet touched on the scientific aspect that invites the community to gain deeper knowledge. Efforts to enhance the appeal are also presented by various YouTubers to highlight the beauty of the tourist location (Hariadi, 2024; Malang Strudel, 2016; Trans TV Official, 2019) and are widely covered by various media outlets if you enter the keyword Lenggoksono. In this study, efforts to enhance geotourism objects are conducted through scientific research, specifically by examining geochemical data and magnetic properties, particularly the magnetic susceptibility of the geotourism objects, and correlating the results with the geological studies of the area. The emphasis on this geochemical study is also based on the examination of other geotourism objects, such as mountains in Indonesia, such as Mount Arjuno Welirang (Zakly et al., 2024), Mount Merapi (Wulaningsih et al., 2013), Mount Wayang Windu (Shoedarto et al., 2018), and Mount Telomoyo (Syabi et al., 2018). This effort is undertaken to achieve conditions in line with educational geotourism, which imparts geological knowledge to visitors through guided tours,

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interpretative exhibits, and educational activities (Lovendianto & Defiana, 2023). Meanwhile, efforts to develop geotourism can also be undertaken from the perspective of cultural geotourism, which focuses on visiting geological sites with a strong emphasis on the cultural history associated with those places (Freire-Lista et al., 2022), adventure geotourism (Garofano & Govoni, 2012), sustainable geotourism (Martínez-Graña et al., 2017), and recreational geotourism (Ogezi et al., 2010).

Educational geotourism, which includes scientific geotourism, involves the participation of geologists and professionals in the research and study of specific areas (Tomić et al., 2020), as well as photographic geotourism (Larwood, 2016).

The development of geotourism can also be viewed from the perspective of urban geotourism, which focuses on exploring geology within urban environments, highlighting geological features present in buildings and monuments (Carrillo-Hernández et al., 2024; Dóniz-Páez et al., 2015; Kubalíková et al., 2021; Liccardo et al., 2012). On the other hand, to enhance the attractiveness of geotourism object we try to expose some sample of stone and beach sand for measuring of geochemical and rock magnetic properties, that are generally combined to trace the presence of heavy metals in polluted areas with various backgrounds (Jordanova et al., 2021; Oudeika et al., 2020; Yu et al., 2020; Yunginger et al., 2018). However, there is a study combining both methods in the hot spring source area, which has become a geotourism object, to trace the source of deep hot water that emerges on the surface (Zulaikah et al., 2023). The initial aim of the study was to test the combination of both methods to differentiate two sources of hot water from upflow or outflow. However, it is unwittingly realized that this data can also be exposed as a tourist attraction if it is packaged very well on a geotourism information website. In this study, the geochemical analysis and magnetic susceptibility of igneous rocks and beach sand stored on the beach are exposed to serve as scientific information for tourists, gradually shifting its appeal from mystical stories or legends to scientific narratives.

Geochemical analysis will guide the content of chemical elements that point to the possible presence of important minerals and the analysis of geological events in the past (Balaram, 2021; Balaram et al., 2023). This has the opportunity to raise awareness to protect geotourism objects from human damage to realize SDGs 14 on marine ecosystems.

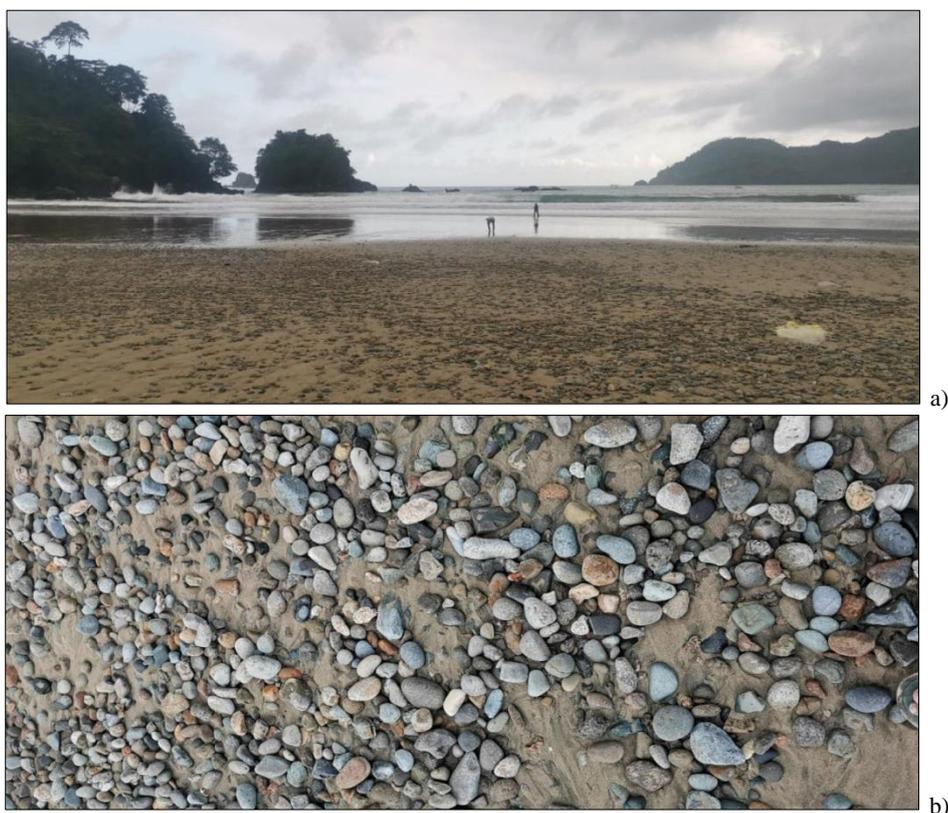


Figure 1. (a) A beautiful view of Lenggoksono Beach and (b) illustration of the presence of various types of transport stones on Lenggoksono Beach (Lenggoksono beach, southeast Malang, June 8th 2024. SZ documentation)

MATERIALS AND METHODS

Geological Setting

This research object is located in the Lenggoksono area, located in South Malang, East Java Indonesia. Geographically, Lenggoksono is located at coordinates 112°49.920' E and 8°21.720' S. The Lenggoksono area is close to Mount Semeru, specifically on the southern side of Mount Semeru. The geomorphology of Lenggoksono consists of hills, mountains, and beaches scattered throughout the Lenggoksono area, that was formed by magmatic activity processes which have occurred since the Eocene epoch to the present (~45 million years ago) (Smyth et al., 2007). These magmatic processes caused the magmatic arc to move from west to east-southeast and produced the dominant magmatic product in South Malang, forming the Mandalika Formation (Tomm) (Hall et al., 2007; Satyana & Purwaningsih, 2003; Sujanto et al., 1992) (Figure 2).

Additionally, the magmatic processes that occurred resulted in hills and mountains composed of karst and limestone. The potential of Lenggoksono's geomorphological diversity is becoming increasingly interesting, especially due to the

presence of coastal features, which are one of the potential areas for geosites in South Malang karst (Susilo et al., 2021). Lenggoksono is highly potential as a natural laboratory, which could potentially be developed into a geotourism destination or serve as an initiative for the establishment of a geopark. The geological diversity (geodiversity) in this area is one of its significant potentials that needs to be explored.

This geodiversity is formed through very complex geological processes, starting with the uplift of rocks containing limestone, igneous rocks, and coral reefs from the seabed (Smyth et al., 2007). As a result of this process, the area has a diversity of rock types scattered along Lenggoksono's beaches. The types of rocks, as previously explained, are dominated by igneous rocks due to the significant influence of the Mandalika Formation, which is very prominent in Loenggksono Bay. Additionally, intrusive rocks can also be found, consisting of diorite, granodiorite, and dacite (Elissa & Putra, 2024).

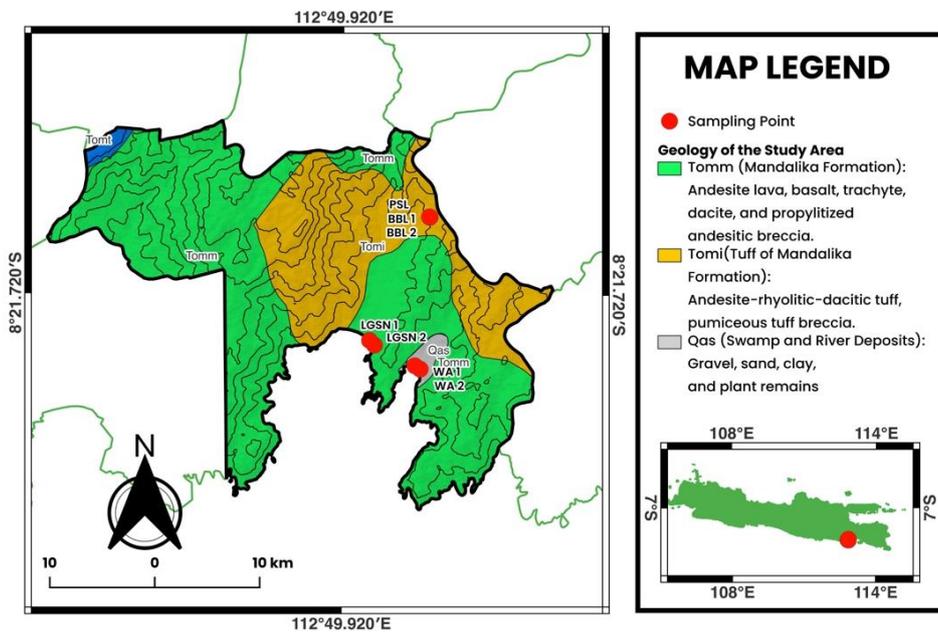


Figure 2. Sampling point and geology formation of Lenggoksono



Figure 3. a) visual of Lenggoksono igneous rock sample; b) visual of Wedi Awu Beach sand sample; c) visual of Lenggoksono Beach sand sample; d) visual model of beach sand and Lenggoksono igneous rock samples (Sampling process and market exposure for tourism information. Rock Magnetic Laboratory, December 20th. SZ documentation)

Sampling and Analysis Process

Based on this geological information, the beach sand of Lenggoksono is contributed to by igneous rocks, which are sources of silica (Si), iron (Fe), and titanium (Ti), and coral reefs, which are sources of calcium (Ca). In this case, the contribution of igneous rocks is very dominant, causing the beach sand in Lenggoksono and its surroundings, such as Wedi Awu Beach, to appear dark brown in color. The profile of Lenggoksono Beach is very unique, where the beach sand stretches along the shoreline, blending with various types of transported stone that are oval and flat in shape. In this study, several types of representative rocks and beach sand were determined for their geochemical content using X-Ray Fluorescence (XRF). Samples can be seen in Figures 3a, 3b, and 3c. The analysis results are focused on the critical mineral content of beach sand and various types of transport stone found along the beach stretch and are linked to the geological study of the area (Figure 3d). This study will provide new insights for tourists. This has implications for increasing economic income generating and raising public awareness to maintain the sustainability of the beach.

RESULTS AND DISCUSSION

Materials from Lenggoksono which include in Mandaika formation have been the chemical element content tests using XRF and magnetic susceptibility from the 9 tested samples can be seen in Table 1. The geochemistry of beach sand and transport igneous rocks from Lenggoksono beach consists of elements Si, K, Ca, Ti, V, Cr, Mn, Fe, Cu, Eu, Re, Mo, and Zn. The dominant elements with a content of more than 5% (wt) are Si, Fe, and Ca, with average contents of 56.78 wt%, 24.20 wt%, and 8.41 wt%, respectively. No major Aluminum element was found, unlike beach sand in Indonesia in general. The presence of silica is very high, around 56.78 wt%, which is also very different from beach sand in Indonesia, where the average Si content is around 20-30% (Sumari et al., 2020; Waalidain et al., 2024).

The very high presence of silica confirms the dominant contribution of igneous rocks. Igneous rocks with high silica content are classified as high and medium-acid igneous rocks, where the silica content ranges from 52% to > 65%. This is also confirmed by tested igneous rock samples showing silica content between 41.90 wt% to 64.90 wt%. The Ca content ranges from 4.89 wt% to 18.30 wt%, while the Fe content ranges from 13.50 wt% to 25.50 wt%. The high Fe content in the sample measurement results proves that the sample originates from the Lenggoksono lithology. Based on the geological map, Lenggoksono is dominated by the Mandalika Formation (Tomm), which includes igneous rocks heavily influenced by volcanic activity. The high iron content is not only present in the igneous rock samples but also in the beach sand samples (LGSN 1, LGSN 2, WA 1, and WA 2). The presence of iron in the beach sand samples indicates sedimentation from local volcanic igneous rock sources (Bela et al., 2022; Janpou et al., 2022). Meanwhile, the element Molybdenum (Mo) content is only found in one sample in small amounts (3.7%) out of the nine samples tested.

Table 1. Magnetic susceptibility and chemical element content of beach sand and transport rocks from Lenggoksono Beach, South Malang, East Java, Indonesia

No	Sample ID	χ_{lf}	χ_{hf}	χ_{fd}	Content (Wt%)													
		($10^{-8}m^3/kg$)	(%)	(%)	Al	Si	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Eu	Re	Zn	S
1	LGSN 1	346.67	345.00	0.35	0.00	60.00	1.60	11.00	3.15	0.15	0.08	0.40	22.90	0.14	0.20	0.20	0.07	0.00
2	LGSN 2	661.03	659.40	0.29	0.00	58.50	1.50	10.50	2.80	0.16	0.07	0.41	25.50	0.16	0.30	0.00	0.00	0.00
4	WA 1	4143.47	4137.00	0.13	0.00	62.10	1.90	4.69	1.76	0.08	0.07	0.54	24.30	0.16	0.30	0.20	0.00	0.00
5	WA 2	1015.37	1013.40	0.16	0.00	67.20	1.50	5.95	1.99	0.08	0.07	0.49	21.80	0.16	0.40	0.30	0.08	0.00
7	PSL	161.13	160.30	0.62	11.00	42.90	2.49	3.58	1.48	0.10	0.09	0.83	35.90	0.19	0.50	0.20	0.26	0.00
8	BBL 1	1936.23	1935.50	0.05	9.80	41.90	0.76	18.3	1.45	0.11	0.08	0.31	25.50	0.10	0.20	0.00	0.00	1.40
9	BBL 2	13.27	12.00	8.27	11.00	64.90	1.10	4.89	1.23	0.05	0.05	0.39	13.50	0.12	0.20	0.10	0.05	2.10
Average		1182.45	1180.37	1.41	4.54	56.78	1.55	8.41	1.98	0.10	0.07	0.48	24.20	0.147	0.30	0.14	0.06	0.50

Based on these geochemical measurements, it shows that Lenggoksono has unique geotourism object characteristics. The unique characteristics of the Lenggoksono area can also be shown from the magnetic susceptibility data presented in Table 1. This data provides information on the average low-frequency magnetic susceptibility (χ_{lf}) with a value of $1182.45 \times 10^{-8}m^3/kg$, high-frequency magnetic susceptibility (χ_{hf}) with a value of $1180.37 \times 10^{-8}m^3/kg$, and dependent-frequency magnetic susceptibility (χ_{fd}) with a value of 1.41%. The highest low-frequency magnetic susceptibility (χ_{lf}) value is found in sample WA 1 ($4143.47 \times 10^{-8}m^3/kg$), with the lowest value found in sample BBL 2 ($13.27 \times 10^{-8}m^3/kg$). Meanwhile, the highest χ_{fd} value is found in sample BBL 2 (8.27%) and the lowest value is found in sample BBL 1 (0.05%).

Based on this data, sample BBL 2 has the lowest χ_{lf} value and the highest χ_{fd} value. The BBL 2 sample was reviewed from a geological perspective, indicating that the sampling location is within the Tuff of Mandalika (Tomi) formation, which is composed of andesite, rhyolite, dacite tuff, and pumice tuff. Generally, based on the classification of χ_{fd} values according to Dearing (1999), the Lenggoksono area sample is classified as low (average < 2.00%) at only one point, with a moderate classification (2.00%-10.00%) at sample BBL 2 (8.27%) (Dearing, 1999). These results generally indicate that the Lenggoksono samples contain almost no superparamagnetic content. In addition, the average value range of χ_{fd} < 2.00% and the average value of χ_{lf} between 400 and $1200 \times 10^{-8}m^3/kg$ indicate that the measured samples are andesite to basalt rock types, which is certainly consistent with the geology of Lenggoksono, which is dominated by igneous rocks, including andesite (Ayoubi et al., 2019). The data's compatibility with the Lenggoksono Geological Map can serve as one of the scientific bases for interpreting geodiversity characteristics. Additionally, this can offer ideas about the potential of

geological heritage-based geotourism objects that hold many stories of geological events that have occurred in the past. Furthermore, the Pearson correlation test shows a significant correlation between several chemical elements, such as potassium (K) with manganese (Mn) and copper (Cu). Mn also has a significant correlation with Eu, and Fe has a significant correlation with Cr (Table 2). These findings indicate that magmatic processes played a significant role in the enrichment of mineral elements found in the study area (She et al., 2015; Tang et al., 2017; Xie et al., 2020). Additionally, the K-Cu-Mn correlation indicates weathering affecting the chemical composition on the surface (Liu et al., 2014; Shi et al., 2020).

Table 2. Pearson Correlation between Magnetic Susceptibility and XRF Elements

Correlations																	
	χ_{lf}	χ_{hf}	χ_{fd}	Al	Si	K	Ca	Ti	V	Cr	Mn	Fe	Cu	Eu	Re	Zn	S
χ_{lf}	1																
χ_{hf}	1.000**	1															
χ_{fd}	-0.391	-0.391	1														
Al	-0.336	-0.336	0.517	1													
Si	0.043	0.043	0.331	-0.599	1												
K	0.000	0.000	-0.312	-0.125	-0.104	1											
Ca	0.058	0.058	-0.326	0.027	-0.442	-0.685	1										
Ti	-0.168	-0.168	-0.447	-0.763*	0.287	0.093	0.234	1									
V	-0.147	-0.147	-0.603	-0.477	-0.213	0.041	0.534	0.850*	1								
Cr	-0.181	-0.181	-0.757*	-0.018	-0.655	0.471	0.230	0.286	0.546	1							
Mn	-0.068	-0.068	-0.190	0.198	-0.287	0.924**	-0.682	-0.244	-0.201	0.481	1						
Fe	0.046	0.046	-0.679	0.105	-0.726	0.674	-0.005	0.034	0.358	0.882**	0.714	1					
Cu	-0.050	-0.050	-0.354	-0.287	0.055	0.934**	-0.696	0.182	0.095	0.441	0.851*	0.608	1				
Eu	-0.095	-0.095	-0.346	0.030	-0.194	0.787*	-0.581	-0.174	-0.133	0.549	0.889**	0.692	0.868*	1			
Re	0.054	0.054	-0.153	-0.322	0.411	0.552	-0.642	0.036	-0.339	0.131	0.505	0.069	0.537	0.509	1		
Zn	-0.490	-0.490	-0.022	0.419	-0.378	0.721	-0.500	-0.210	-0.162	0.566	0.858*	0.607	0.622	0.750	0.466	1	
S	-0.182	-0.182	0.783*	0.700	-0.070	-0.703	0.233	-0.604	-0.517	-0.609	-0.481	-0.593	-0.782*	-0.576	-0.486	-0.257	1

** . Correlation is significant at the 0.01 level (2-tailed); * . Correlation is significant at the 0.05 level (2-tailed)

The data on the chemical element content and magnetic susceptibility are subsequently exposed in the form of a model (Figure 3d) and geological maps, which can be collected in a science corner in the tourist area to provide direct information to visitors or on a dedicated website. In addition, informational brochures can also be created for tourists to better understand the scientific aspects that have been researched from the beach. The same can be done with the mountains in Indonesia, where almost all the mountains have become interesting tourist attractions. The aspect of novelty in the model of rock and beach sand samples is that generally, models are only equipped with information about the name and origin of the displayed rocks. In this study, the model is made more comprehensive with information on the chemical composition and origin of the rocks, as well as their implications in geological events. The model created is the work of students in the Geology course at Universitas Negeri Malang. Besides serving as a media for introducing science to tourists, it can also be used as a learning media that can be sold to elementary and secondary schools. This approach not only strengthens campus engagement with the community but also opens up opportunities for creative science-based businesses. Thereby generating income for the campus as a geo-educational approach similar to what is done in Colombia (Carrillo-Hernández et al., 2024).

In addition to geoeducation, several interesting geological conditions can also be highlighted, such as the presence of joints in the Lenggoksono sea area and a small waterfall (Figure 4). This object is located at Banyu Anjlok Beach, which is still part of the Mandalika Formation (Tomm). Several rock outcrops are found at this site, including andesite-basaltic rocks formed through lava flow processes (Labib et al., 2024; Pradana et al., 2016; Pratama et al., 2025). Additionally, this coastal site also features outcrops of monomict conglomerate rocks (Pradana et al., 2016). The exposure of the road or track leading to both locations can be done and is very suitable for adventure geotourism (Garofano & Govoni, 2012). Scientific explanations for geological formations such as waterfalls and joints in the Lenggoksono area can add value and attractiveness to geotourism objects with the completeness of scientific geotourism (Tomić et al., 2020). Therefore, geotourism objects not only offer beautiful scenery but can also serve as geoeducation about natural processes that have occurred and as a natural laboratory rich in scientific knowledge (Georgousis et al., 2021; Saurabh et al., 2021).

All research results and products created are also utilized as community service materials with the topic of training and exploration of geotourism objects for productive communities of tourism business owners and local communities around the beach. The response from the geotourism business owners to this activity has been very positive. Out of 15 respondents, 90% of business owners and prospective business owners expressed that they gained new insights by participating in this activity. The participants admitted to receiving positive impacts from the activities that had been conducted. The emergence of new creative ideas can revive tourism in Indonesia by providing new insights into a geotourism object (Rachmat & Hendratno, 2012). In addition, the participants feel quite help by the results of this activity and are confident that the impact of this activity will increase income generating in their businesses.

Collaboration between training participants and the driving community is essential to further discuss strategies, methods, techniques, and procedures for translating geotourism to tourists, as well as in China (Li et al., 2022).

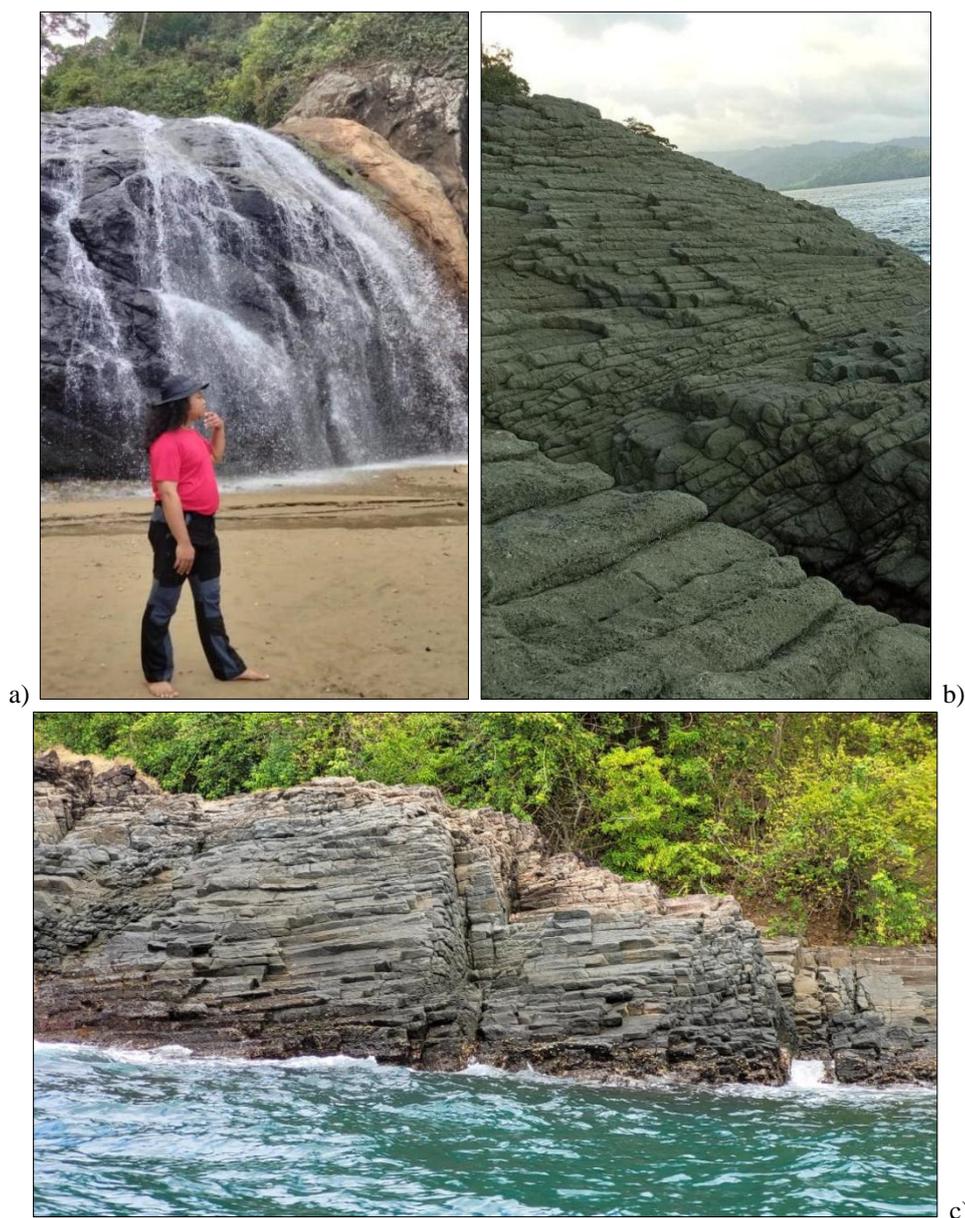


Figure 4. a) Small beautiful waterfall; b) Joint geological formation represented in different angle which have more interesting; c) view (Lenggoksono beach, Spetember 11th 2023, MFR documentation)

CONCLUSION

There are many effort to enhance the attraction of tourists to a geotourism site. This study offers an approach through the exploration of the interesting stone due to geochemical and magnetic properties to exposing the educational geotourism object. Chemically, the composition of the sand and transport rocks at Lenggoksono beach includes Si, K, Ca, Ti, V, Cr, Mn, Fe, Cu, Eu, Re, Mo, and Zn. The dominant elements with a content of more than 5 wt% are Si, Fe, and Ca, with average contents of 56.78 wt%, 24.20 wt%, and 8.41 wt%, respectively.

Geologically, this beach has some interesting formation like joint and small beautiful waterfall that may have a specific interesting and attraction and supporting the adventure geotourism object. The socialization of this evidence to the public is carried out through the creation of a perfectuse book, models in the form of information, and videos uploaded on social media. This effort was also communicated with policymakers, community leaders, and geotourism business owners, and 90% of participants stated that the information obtained was very beneficial and important.

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