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THE GREAT SUMATRAN FAULT DEPRESSION AT WEST LAMPUNG DISTRICT, SUMATRA, INDONESIA AS GEOMORPHOSITE FOR GEOHAZARD TOURISM

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Abstract: Two approaches can be taken to understand geotourism, namely the geological approach and the geographical approach. This approach will lead to the creation of new geotourism products, initiatives, and experiences, one of which is geohazard tourism involving faults and earthquakes. To identify geomorphosites, the researchers examined rocks, outcrops, and geomorphology. Then various thematic maps are created using mapping software and other drawing applications to simplify textual material and aid synthesis. A synthesis of all that is then carried out to reconstruct the geological and geomorphological history of the study area. Furthermore, the West Lampung geomorphosite candidate was compared to the worldwide fault and earthquake geomorphosite theme. The Great Sumatran Fault depression landscape can be found in Balak Pekon, Batubrak Regency, and Pekon Padang Dalom, Balik Bukit District, West Lampung Regency. This depression is caused by both endogenous and exogenous factors. The endogenous activity takes the form of sediment from volcanism and fault movement, whereas exogenous activity takes the form of river water erosion. The valley's sediments are ignimbrite tuffs/sandy tuffs that form a cliff morphology with a height of + 75 meters and a trend of Southeast-Northwest. In the case of geotourism, initiatives have grown over time around two complementary approaches (geological and geographic) and the result is a geomorphosite in the geohazard area. One of the areas is the Sumatran Great Fault depression geomorphosite, this area was formed due to the movement of the Sumatran fault which caused the 1908, 1933, and 1994 earthquakes. Situations like these can be used as opportunities to enhance learning about the relationships between people, land use, natural processes, and large-scale events by providing real-life examples, this can be packaged into the form of geohazard tourism.

Key words: Geotourism, geomorphosite, geohazard, geological, geographic, Great Sumatran Fault depression

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INTRODUCTION

Geotourism is a form of tourism that is growing rapidly around the world. This tourism is creative tourism that utilizes the specific natural conditions of an area through geosciences. This type of tourism has experienced growth in recent decades as a result of the creation and expansion of UNESCO's global network of geoparks (Dryjańska, 2014; Tessema et al., 2019; Kyriakaki and Kleinaki, 2022). Two approaches can be taken to understand geotourism, namely the geological approach and the geographical approach. The approach includes elements of geology (geodiversity), biology (biodiversity) (natural), and culture (cultural diversity). This approach will lead to the creation of new geotourism products, initiatives, and experiences (Dowling and Newsome, 2018) one of them is disaster tourism and/or geohazard tourism related to faults and earthquakes (Rucińska and Lechowicz, 2014; Muslim et al., 2022). In general, natural disasters have destroyed many livelihoods and caused casualties, as well as leaving evidence of destruction. However, on the other hand, according to researchers, natural disasters are a good opportunity to study natural processes

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and the role of the human factor in nature (Korstanje and George, 2015; Martini and Buda, 2020; Ilies et al., 2020; Sunkar et al., 2022). Migoń and Pijet-Migoń (2019) argue that disasters leave some evidence of positive effects to be studied, and understood, and can help the recovery of affected areas, and they have investigated the relationship between hazards, disasters, geoheritage, and geotourism further. This relationship is referred to as geohazard tourism in this paper.

To understand geohazard tourism in an area, it is necessary to assess which hazard dominance is possible to be appointed as a tourism destination. One of the elements of the assessment is to determine a specific geomorphosite through a quantitative index. The geomorphosite assessment process is carried out after literature study, field verification, making thematic maps, and analysis of geological-geographical parameters.

In determining the specific geomorphosite of an area, data synthesis is carried out (Reynard and Panizza, 2005; Panizza and Piacente, 2008; González Amuchastegui et al., 2013; Santos et al., 2019; Jafar et al., 2022; Ilie and Grecu, 2023; Sánchez-Almodóvar et al., 2023). As an example of a case in the study area, the specific geomorphosite is fault geoforms (Evelpidou et al., 2021; Puswanto et al., 2022; Dóniz-Páez and Becerra-Ramírez, 2023).

The fault geoforms in the study area have a direct impact on the rest of the natural and cultural heritage. Furthermore, the diversity of geoforms in fault zones will be very appealing to visitors, particularly those interested in geohazard tourism, and can be used to help conserve natural diversity. The purpose of this study is to identify and select representative, well-maintained, and easily accessible fault geoforms in the West Lampung Region using a geological and geographic approach. This will help to promote West Lampung's natural and cultural heritage, while also varying tourism in the area. It will also help West Lampung's economic development by promoting geohazard tourism.

MATERIALS AND METHODS

West Lampung Regency is located on Sumatra Island's western coast (yellow box in Figure 1). This location has an altitude of 300 to 1100 meters above sea level, mountainous topography, a temperature of +24.5^o Celsius, and a humidity level of +85% (Iqbal et al., 2022). According to the climatic classification, this region has a tropical wet climate (Huat et al., 2013). The Great Sumatran Fault (GSF) of the Suoh-Komering Segment runs through the study area. This fault has a northwest-southeast trend (Figure 1) (Aribowo, 2018; Natawidjaja, 2018; Rafie et al., 2023). According to historical records (Hurukawa et al., 2014; Soehaimi et al., 2015), the fault has been a source of major earthquakes and natural disasters in Sumatra (Figure 5). Until now, the GSF take a part in creating the geomorphology of the study area.

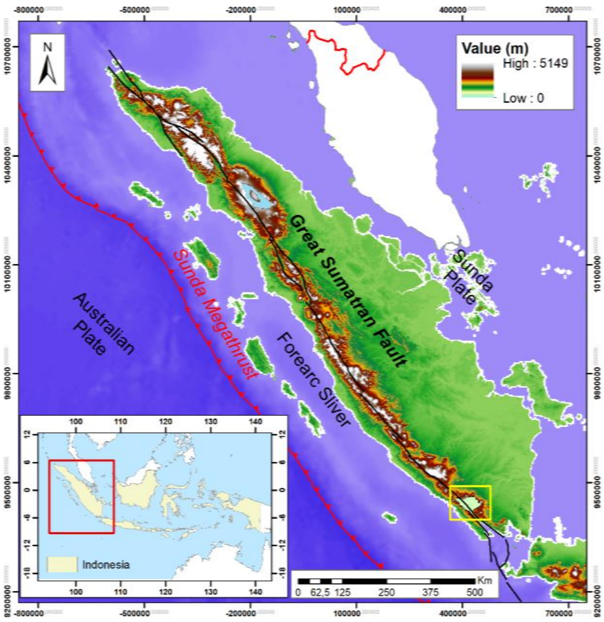

Figure 1. The Great Sumatran fault; yellow box: study area

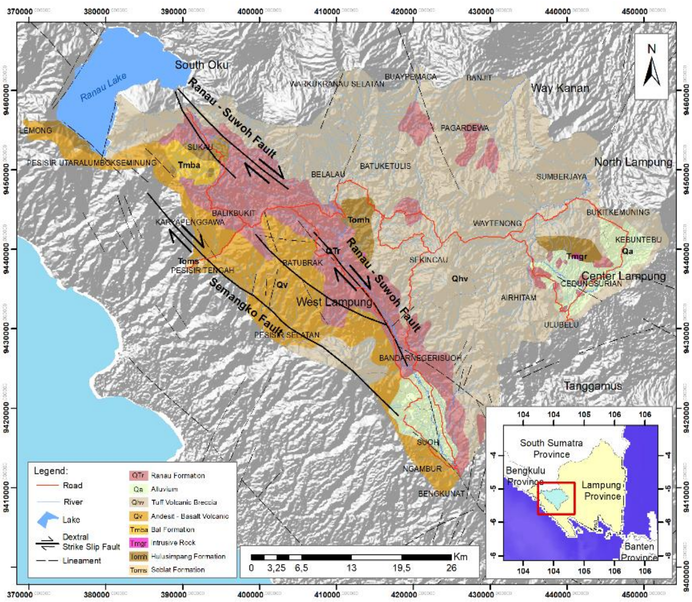

Figure 2. Geological setting of West Lampung, Sumatra, Indonesia (Source: Muslim et al., 2022)

The West Lampung region and its surroundings are geologically composed of Neogene to Quaternary volcanic rocks and soil deposited in the mountains. The constituent rocks of the study area are volcanic rock types of ignimbrite tuff/sand tuff and crystalline glass tuff from Ranau Volcano, as well as volcanic residual soils that are brownish gray to brownish red which are the result of weathering of volcanic rocks (Koswara and Santoso, 1995; Soehaimi et al., 2015; Iqbal, 2013; Iqbal et al., 2020a; Iqbal et al., 2020b; Iqbal et al., 2021) (Figure 2).

This study includes several activities such as a literature review and regional studies of geology, geography, and geomorphosite, field studies, data analysis, and synthesis (Figure 3). The literature review includes a study of international papers on the development of geotourism, especially geohazards tourism in various parts of the world. Field studies were carried out in the West Lampung region to observe and characterize through topographical, geomorphological, and geological mapping at various scales, followed by photography and rock/soil sampling. To identify geomorphosites, the researchers examined rocks, outcrops, and geomorphology. Then various thematic maps are created using mapping software and other drawing applications to simplify textual material and aid synthesis. A synthesis of all that is then carried out to reconstruct the geological and geomorphological history of the study area. Furthermore, the West Lampung geomorphosite candidate was compared to the worldwide fault and earthquake geomorphosite theme.

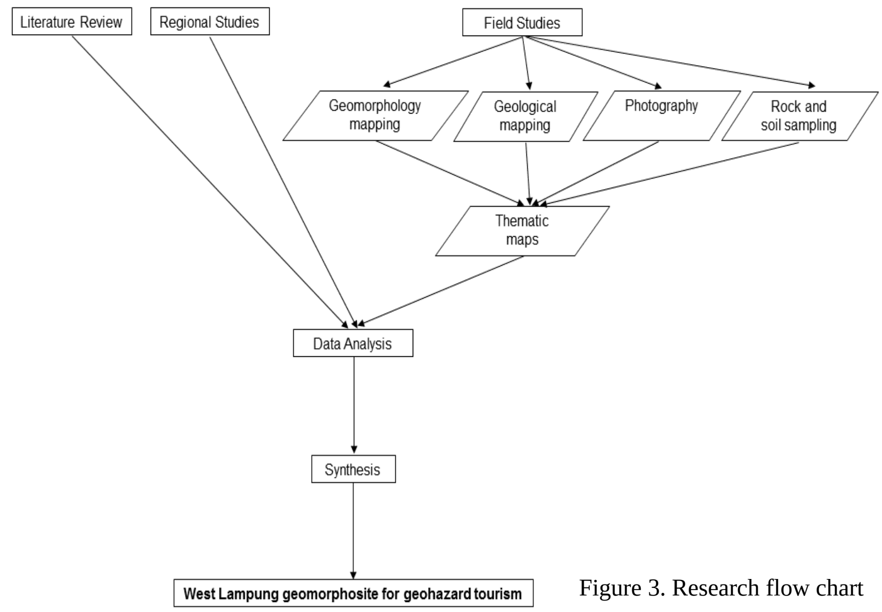

Figure 3. Research flow chart

The morphogenetic approach is used for geomorphosite assessment, with six parameters: morphology, lithology, hydrology, tectonics, land use, and cultural landscape.

This method is a modification of the geomorphosite assessment category developed by researchers worldwide (Pellitero et al., 2011; Melelli et al., 2017; Dóniz-Páez et al., 2020; Santos et al., 2020; Datta and Sarkar, 2022).

Because the previous geomorphosite assessment category was conducted in a different landscape and not in a tropical climate, adjustments were required.

RESULTS

The Landscape of the Great Sumatran Fault depression is in Pekon Balak, Batubrak District, (Figure 4); and in Pekon Padang Dalom, Balik Bukit District (Figure 5) West Lampung Regency. This depression is caused by both endogenous and exogenous factors. The endogenous activity takes the form of sediment from volcanism and fault movement, whereas exogenous activity takes the form of river water erosion. The valley's sediments are ignimbrite tuffs/sandy tuffs that form a cliff morphology with a height of ± 75 meters and a trend of Southeast-Northwest. The cliff has a slope of up to 90^{o}. The land use that develops around the area is paddy farming.

Table 1. Study area main geomorphosite (Source: https://drive.google.com; https://docs.google.com)

No	Location	Geomorphosite Parameter					
		Morphology	Lithology	Hydrology	Tectonic	Land Use	Cultural Landscape
1	Pekon Balak, Batubrak District	Incised valley	sandy tuff/ ignimbrite tuff	Semangka river	Fault depression	Paddy field	walai to store the harvest
2	Pekon Padangdalom, Balikbukit District	Incised valley	sandy tuff/ ignimbrite tuff	Way Robok river	Fault depression	Paddy field	walai to store the harvest

DISCUSSION

The island of Sumatra, with an area of approximately 474,000 km^2, is the largest island in the Indonesian and the world's fifth largest island. The island stretches for about 1650 kilometers from northwest to southeast across the equator and can be 100-400 kilometers wide (see Figure 1). Sumatra Island is located in the western archipelago of Indonesia. The island is bounded by the Bay of Bengal in the north, then in the south by the Sunda Strait, while in the east the island is bounded by the Malacca Strait, and in the west by the Indian Ocean (Barber and Crow, 2003; Barber et al., 2005).

Sumatra, an Indonesian island, is situated in a seismically active region of the world. Aside from the subduction zone off the island's west coast, Sumatra has a large strike-slip fault, the Great Sumatran Fault (GSF), also known as the Semangko Fault (see Figure 1), that runs the entire length of the island. The majority of the strike-slip motion associated with the convergence of the Indo-Australian and Eurasian plates is accommodated by this fault zone (Bellier et al., 1997; Natawidjaja and Triyoso, 2007; Sahara et al., 2018; Amir et al., 2021). As previously stated, the Sumatran Fault shaped the study area's surface. Tectonic-volcanic evolution has resulted in distinct and one-of-a-kind geological features.

Some of the geological features formed are volcanoes and fault valleys/fault depressions. According to Bellier et al. (1999) and Bellier and Se'brier (1994), The Ranau volcano caldera is one of the major calderas in southern Sumatra, located along the Sumatra Fault. The shape and size are due to the geometric development of the Sumatra Fault segmentation. they hypothesized that the Ranau volcano erupted amidst the inactive Sumatran fault.

The Ranau caldera produces the Ranau tuff, one of the most common sandy tuffs in Sumatra, which is commonly found in the study area (Figure 4). Furthermore, the Great Sumatran Fault correlates with a prominent NW trending active shear fault that crosses Lake Ranau and shifts the current geomorphic structure horizontally, allowing us to see the distribution of sandy tuff/ignimbrite tuff forming incised valleys at several locations throughout the study area (Figure 4 and 5).

According to its history, the Great Sumatran Fault frequently shifts and becomes a source of large earthquakes (Natawidjaja and Triyoso, 2007) (Figure 6). Over the last 130 years, there have been several 25 earthquakes with magnitudes greater than 6 Mw (1893-2022) (Hurukawa et al., 2014). Buildings were damaged and people were killed in various parts of Sumatra, including the study area (earthquakes of 1908, 1933, and 1994) (Soehaimi et al., 2015).

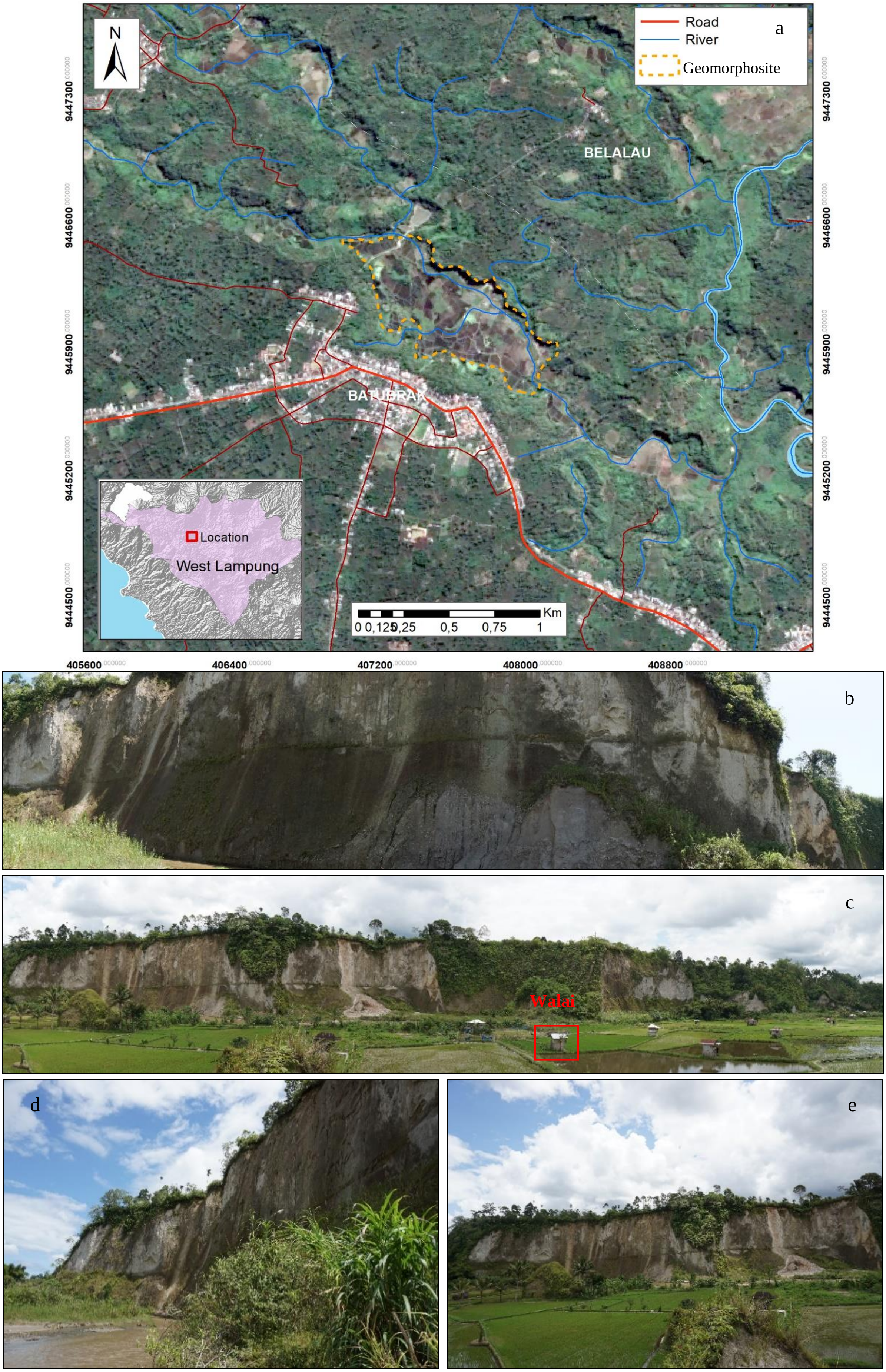

Figure 4. The Great Sumatran Fault depression at Pekon Balak, Batubrak District (a-e). a. geomorphosite location; b. cliff morphology; c. The Great Sumatran Fault depression panorama and 'walai'; d. exogenous activity by Semangka river water erosion; e. paddy farming around fault depression

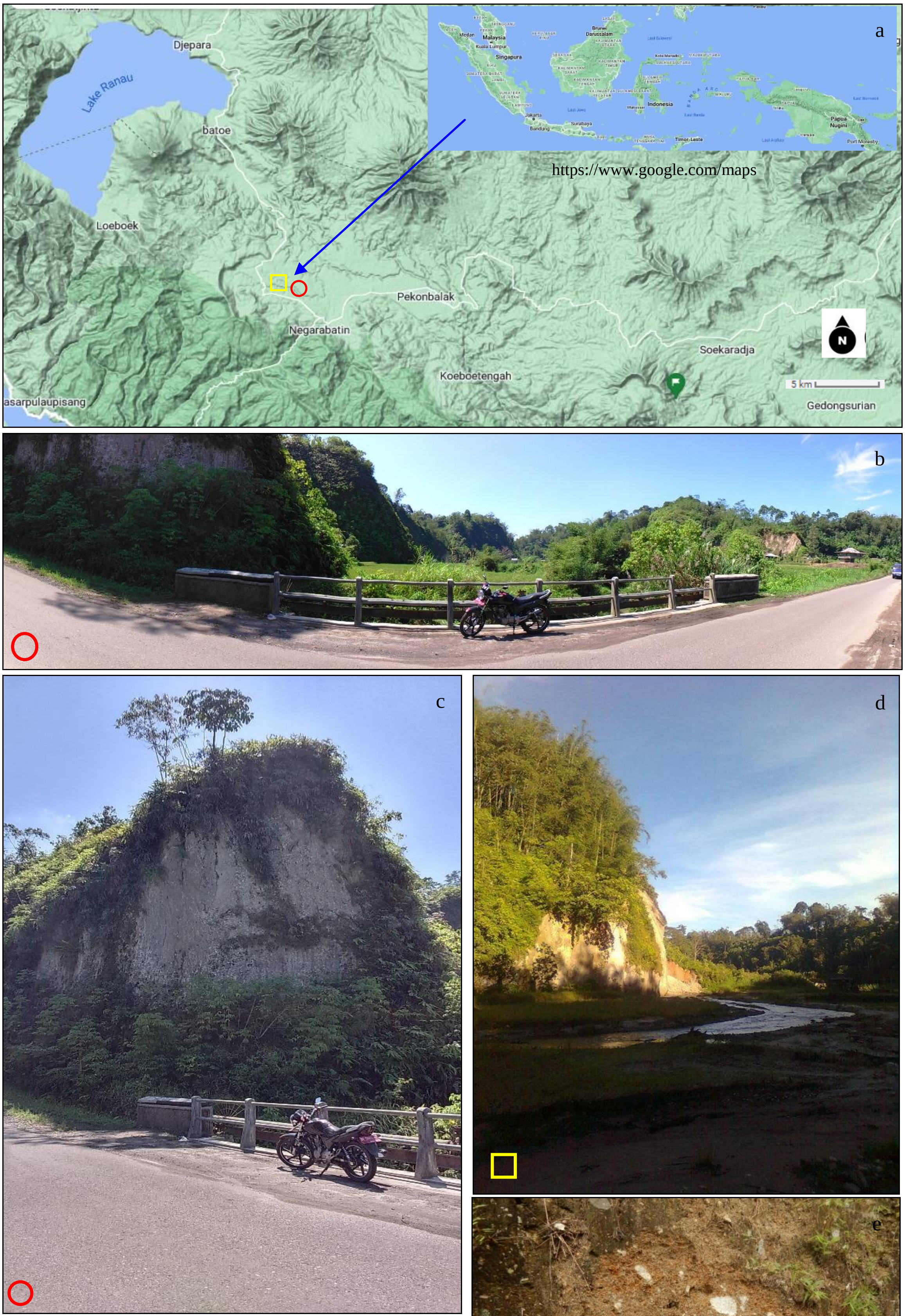

Figure 5. The Great Sumatran Fault depression at Pekon Padangdalom, Balikbukit District (a-e). a. geomorphosite location; b. cliff morphology panorama side Way Robok river; c-d. cliff morphology, red circle and yellow box refer to different location at Figure 5a; e. sandy tuff/ignimbrite tuff

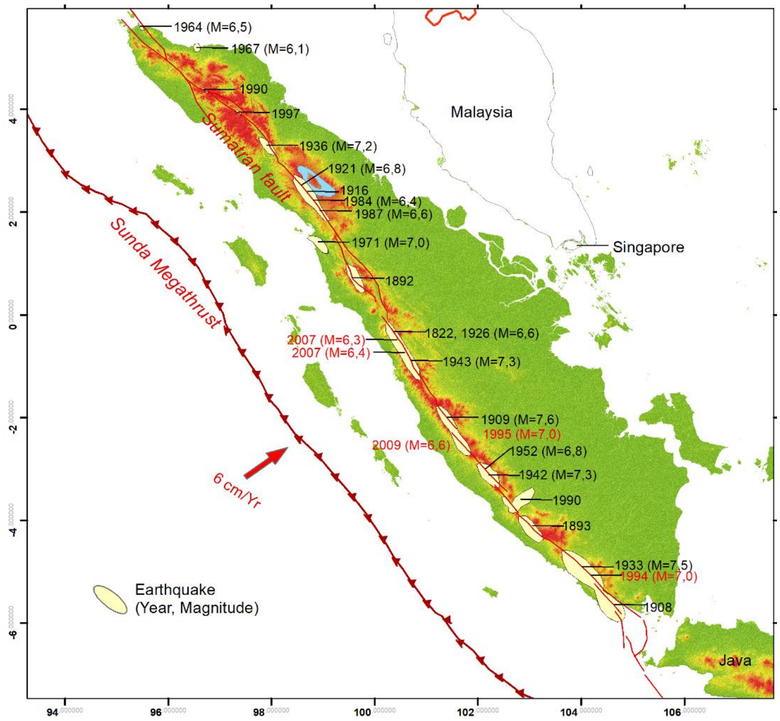

Figure 6. The Great Sumatran Fault earthquake history (Source: Natawidjaja and Triyoso, 2007)

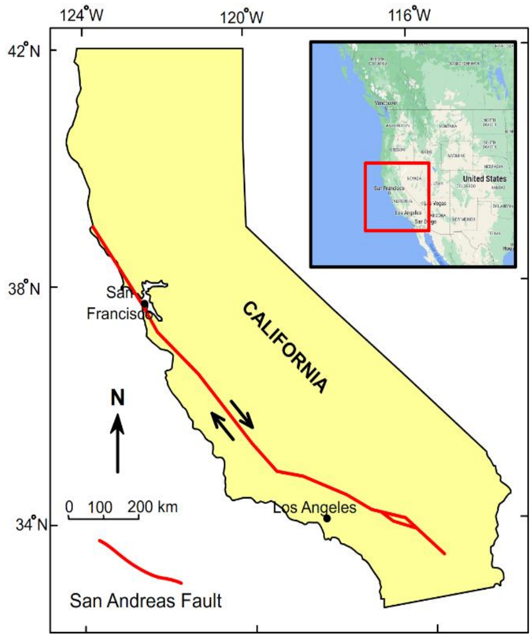

Figure 7. San Andreas fault (Source: Lynch, 2009)

The following are some of the major earthquakes with epicenters on the Great Sumatran Fault (https://earthquake.usgs.gov/earthquakes/ last visited on 01.02.2023): Padang Panjang earthquakes of 1926, measuring 6.6 and 6.4, killed at least 411 people. The 1933 Liwa earthquake, an Mw 7.5 event in southern Sumatra, more than 76 people were killed, and two towns were destroyed. On June 8 and 9, 1943, the Alahan Panjang earthquakes, with moment magnitudes of 7.3 and 7.5, occurred within 7 hours of each other southeast of Lake Singkarak.

The 7.0 Mw Liwa earthquake in 1994 killed 207 people near Sumatra's southern tip. The 1995 Kerinci earthquake, with a moment magnitude of 7, killed at least 84 people and injured 1,868 others. Sumatra earthquakes in March 2007, two hours apart with moment magnitudes of 6.4 and 6.3 northeast of Lake Singkarak. The 2022 Sumatra earthquake, measuring 6.2 on the Richter scale, damaged dozens of infrastructure and killed six people while injuring 32 others.

It was felt in Malaysia and Singapore. The incident along the Great Sumatran Fault is not the first of its kind in the world. The San Andreas Fault in California, as well as the Chelongpu Fault in Taiwan and the Nojima Fault in Japan, have all caused large destructive earthquakes. The takeaway from all of this is that the area was turned into a conservation area to remind and raise awareness. The San Andreas Fault is a transform fault that connects the Pacific and North American plates (Lynch, 2009). From Cape Mendocino to the Mexican border, it divides California in half. The Pacific Plate includes San Diego, Los Angeles, and Big Sur, while the North American Plate includes San Francisco, Sacramento, and the Sierra Nevada (Wallace, 1990; Gizzi, 2015; Scharer and Streig, 2019) (Figure 7).

In the past, the San Andreas Fault has been the site of some significant earthquakes (https://earthquake.usgs.gov/earthquakes/, accessed on 01.02.2023): The moment magnitude of the 1857 Fort Tejon earthquake was 7.9, and two people were killed. At least 3,000 people were killed in the 1906 San Francisco earthquake, the large number of victims was also due to fires after the earthquake; the magnitude was estimated to be 7.8. The 1957 San Francisco earthquake had a magnitude of 5.7 and was located in the ocean west of San Francisco and Daly City on the San Andreas fault. The 1989 Loma Prieta earthquake killed 63 people and caused moderate damage in certain vulnerable areas of the San Francisco Bay Area; the moment magnitude was approximately 6.9. On September 28, 2004, a magnitude 6.0 earthquake struck the Parkfield area, and it was felt throughout the state, including the San Francisco Bay Area.

Can easily reveal the existence of the San Andreas fault. From the air, the linear arrangement of lakes, bays, and valleys around the fault is striking. Faults can be identified in the field by carefully inspecting the landscape. The San Andreas fault is often a stunning natural landscape, especially in places like Wallace Creek, Tomales Bay, and the area near Devil's Punchbowl, but the fault's symbolism as the edge where two great tectonic plates meet adds a mystical element to each visit. It's like climbing a chasm through which new worlds will emerge (DiPietro, 2013; 2018). According to various sources, those features are unique and serve specific geotourism functions. Along with the reviews, they created a tour package called A Guide to Earthquake Tourism Along the San Andreas Fault (Hemmerlein, 2015).

On September 21, 1999, at 1:47 a.m., Taiwan experienced one of the worst natural disasters in its history: a 7.3-magnitude earthquake that devastated the island's center. The movement of the Chelungpu fault was responsible for the occurrence (Mori et al., 2003; Chen et al., 2004) (Figure 8). The Chelungpu Fault ripped through Wufeng District, Taiwan, destroying nearly all of the school buildings (http://www.nmns.edu.tw/nmns eng/04exhibit/permanent/Chelungpu.htm accessed on 02.02.2023). The incident was then documented and preserved in a museum. The 921 earthquake museum in

Taiwan's Wufeng District preserved the damage caused by the Chi-Chi earthquake, such as collapsed infrastructures (school, buildings), fault rupture, and river terrace. Following the route of the visit, one can see how the fault passed through and how the land was deformed (. The storyline of the Chi-Chi earthquake connected the five separate exhibition halls altogether (Keeling, 2011; Li et al., 2019). The exhibition halls were built around the geological changes, the wrecked landscape, and the impaired structures. Thus museums serve as valuable teaching resources for the natural sciences.

The Nojima Fault in Japan is another example of a geotourism fault zone (Nishiwaki et al., 2018) (Figure 9). They turned the fault zone into a museum (Nojima Fault Preservation Museum). The museum houses memorials and evidence of fault movement during The Great Hanshin Earthquake, also known as the Kobe earthquake (https://www.nojima-danso.co.jp/, accessed on February 2, 2023). This occurrence occurred on January 17, 1995, in the southern part of Hyogo Prefecture, Japan, including the Hanshin region. It had a moment magnitude of 6.9 and a maximum intensity of 7 on the JMA Seismic Intensity Scale (XI-XII on the Modified Mercalli Intensity Scale).

The epicenter of the earthquake was 17 kilometers beneath the surface of Awaji Island, 20 kilometers from the center of Kobe. This earthquake killed approximately 6,434 people, approximately 4,600 of whom were from Kobe. Kobe, with a population of 1.5 million, was the closest major city to the epicenter and experienced the strongest tremors (Mizoguchi et al., 2008; Lockner et al., 2009; Nishiwaki et al., 2018). The Great Hanshin-Awaji Earthquake occurred more than 25 years ago, and memories of the disaster are gradually fading. If you forget, the disaster will happen again. We would like you to avoid that as a disaster victim, as a disaster-stricken area. I don't want you to squander your irreplaceable life or make an irreplaceable sacrifice for future generations (https://www.nojima-danso.co.jp/, accessed February 2, 2023). That concludes the Museum manager's message. They remind us that life must continue.

In their paper, Muslim et al (2022) stated that the study area has a geodiversity value of 347.02. This value combines scientific value (103.27), education (68.75), tourism (80), and degradation risk (95). This implies that the study area has a high added and selling value as a geotourism site, specifically geohazard tourism.

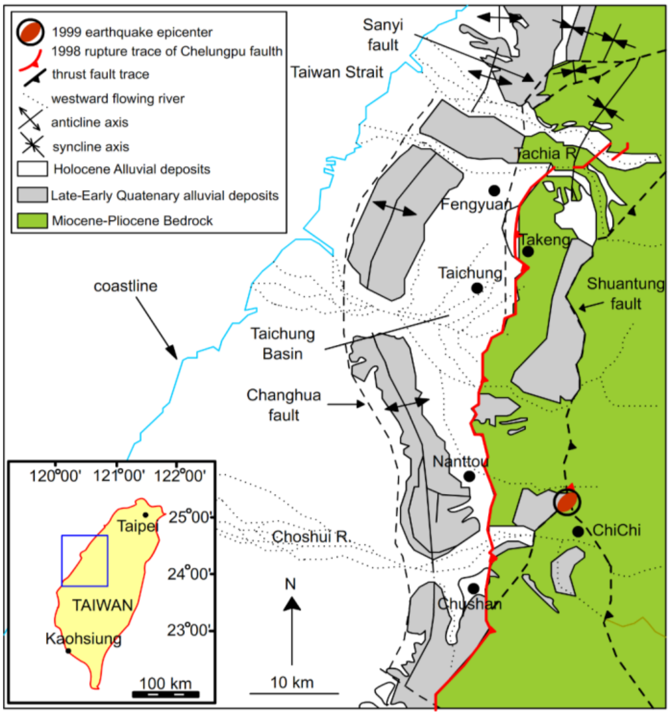

Figure 8. The Chelungpu fault, Taiwan
(Source: Mori et al., 2003; Chen et al., 2004)

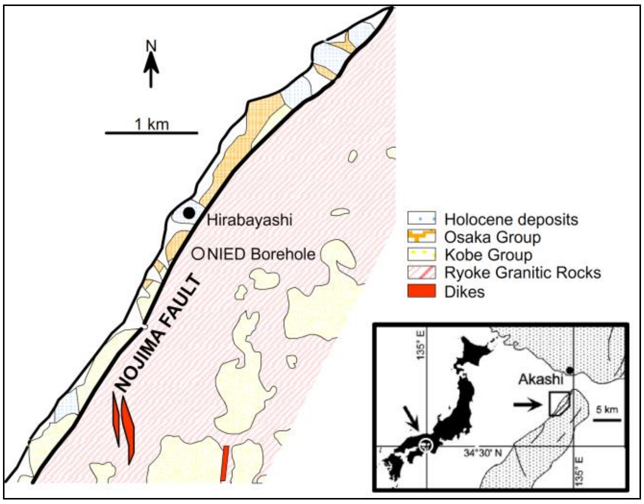

Figure 9. Nojima fault in Japan
(Source: Nishiwaki et al., 2018)

Reflecting on the above review, the Great Sumatra Fault depression geomorphosite deserves to be a site in geotourism. The functions carried out by the site can be in the form of tourism functions, environmental, and disaster education functions, as well as spiritual functions (increasing gratitude and strengthening faith). Piacente (2005); Panizza and Piacente (2008); Kubalíková and Kirchner (2016); Reynard and Coratza (2016); Ilies et al. (2017); Barbalata and Comanescu (2021); AbdelMaksoud et al. (2022) in their paper stated that Lesser-known regional geomorphosites (for example, study areas) can be used as a source of geotourism activities that can help local communities by supporting economic development. This is possible due to the educational and environmental conservation value of the location.

Through geotourism the Great Sumatra Fault depression geomorphosite, people and visitors will be better able to live side by side in harmony with nature. The site will increase the awareness of local people and visitors that the earth has a history, moves and breathes, and has order. This will increase the resilience of the community and visitors to disasters. On the other hand, the public and visitors will be presented with exotic natural scenery. They can rest and calm their souls for a moment from the bustle and routine.

Of course, all of the above will work and be implemented properly if the Regional Government and the local community cooperate well. Fulfillment of local creative economy and information centers, geo-interpreters/tour guides, halfway houses, publications, and documentation is absolute. Given the field conditions, the first thing to consider for construction and development is the road from the West Lampung road to the two sites. The first site is 500 meters long in

Pekon Balak, and the second site is + 1 km long in Pekon Padangdalom. Information centers are another type of infrastructure that must be built. This infrastructure can be built and developed in hotels located throughout West Lampung, as well as in the Regional Government Complex, which includes a hawker center and a restaurant, and in Rest Areas located along the West Lampung road, such as the Jami' Aminatul Mosque rest area. West Lampung, Jannah, Sumberjaya. One more infrastructure that must be built is a ground interpreter. Interpreters should be trained so that they are proficient in popular geoscientific languages. This interpreter functions as the front guard in explaining West Lampung geotourism.

CONCLUSION

In the case of geotourism, initiatives have grown over time around two complementary approaches (geological and geographic). One result is a geomorphosite in the geohazard area. One of the areas is the Sumatran Great Fault depression geomorphosite. The area was formed due to the movement of the Sumatran fault which caused the 1908, 1933, and 1994 earthquakes. It is recognized that natural disasters have long-term consequences, and it is understood that rescue and rebuilding operations are undertaken to return life to normal as quickly as possible. In this context, recovery efforts are carried out with two objectives: rehabilitation and reconstruction.

Reconstruction was carried out to meet the need for shelter and water. While rehabilitation is carried out to overcome psychological trauma. However, in the case of a major disaster, which involves substantial changes in the shape of the land over a large area, such as: a volcanic eruption, large landslide, or surface rupture, then this effort may not be feasible. Situations like these can be used as opportunities to enhance learning about the relationships between people, land use, natural processes, and large-scale events by providing real-life examples.

This can be packaged into the form of geohazard tourism. Of course, it is dependent on the willingness of the local community and stakeholders to seize opportunities that will benefit the area in the future.

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