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# The Existence of Faults that Cause Earthquakes on Lombok Island: A Critical Literature Review

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**Abstract:** This study qualitatively elaborates fault characteristics causing earthquakes in Lombok Island. Historically, Lombok Island has been 12 destructive and significant earthquakes in period of 1979 – 2018. Therefore, the island is in an earthquake-prone region. The hazard factor is one of the key factors in assessing risk. This study become important as their potential to have a big impact. A source of activity that has not been fully investigated in detail was the location of the recent major and devastating earthquake (East Lombok earthquake 2019). Consequently, there is a chance that the level of risk on the Island of Lombok will rise. According to the study's results, a thorough investigation is required to identify and pinpoint the cause of the 2019 Lombok earthquake in order to improve the earthquake risk index and help the local government to reduce losses due to earthquakes.

**Keywords:** Earthquake; Seismic risk; Lombok

## Introduction

The fact of Indonesia has a high seismicity level is significant proof that the country is located in a tectonically active area. The Australian Plate, the Pacific Plate, the Philippine Plate, and the Sunda Plate are four main plates that are actively converging in the Indonesia area (Hamilton, 1979). This is apparent from the fact that Indonesia has recently suffered more significant and destructive earthquake events as a result of an increase in seismic activity (Hutchings dan Mooney, 2021). The Lombok Island, which is not an exception, is one of the areas in Indonesia with a high level of seismicity. In addition to regional tectonics, the existence of secondary impacts in the form of faults that appear to surround the Island of Lombok has an effect on earthquakes in Lombok (Irsyam et al., 2017).

According to history, the Lombok Island has had at least 12 significant earthquakes between 1979 and 2018 (Sadly et al., 2019). The northern region of Lombok and its surrounds experienced all of the destructive earthquakes. According to the *b*-value study, the northern part of Lombok has lower *b*-value variations than other regions in West Nusa Tenggara (Ernandi and Madzalim, 2020; Istikomah et al., 2019). This value is associated with the accumulation of high stress due to homogeneous rock composition. These kinds of rocks have a relatively higher potential to produce large earthquakes in a fairly long period of time (Wandono et al., 2004; Scholz, 1968).

The Lombok Island and its surrounds were severely shaken by a sequence of destructive earthquakes in 2018. Starting with M 6.4 on 28 July 2018 and ending with M 6.9 on 19 August 2018 (Irsyam et al., 2018). Overall, the sequence of earthquakes caused surface deformation in the form of an uplift of up to 70 cm (Agustan et al., 2019), surface shocks with a maximum intensity of VII-VIII MMI (Robiana et al., 2018), 564 fatalities, 1,584 injuries, and building damage reached 22,026 (Lavigne et al., 2020).

The threat of this earthquake has worried many parties. Especially if an earthquake (such as the 2018 Lombok earthquake which was recorded as one of the strongest earthquakes) occurs at a time when the

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population is increasing (Lavigne et al., 2020). Jalaludin and Fahri (2013) stated that NTB Province has the third largest population in Indonesia, and the largest population growth is in East Lombok Regency which continues to grow annually by 55,967 people throughout the 2018–2020 period (BPS, 2021). In addition, Lombok Island is one of Indonesia's top 10 tourist destinations. So that the current government continues to build infrastructure and facilities to become a tourist attraction and provide investment opportunities for investors (Jalaludin, 2020). This is shown by the increase in visitors by 8.16% or 415,446 tourists annually, between 2014 and 2019 (West Nusa Tenggara Culture and Tourism Office, 2020).

Due to potential hazards and increased disaster vulnerability, Lombok Island has a "medium" earthquake risk index (BNPB, 2021). However, the earthquake that occurred in northern Lombok in 2019 raised the possibility of an increase in the "risk" factor. Two large 2019 earthquakes (M 5.4 & M 5.1) with epicenters were categorized as shallow earthquakes due to faults near Mount Rinjani. There were 26 injured, 3 fatalities, and 527 houses damaged by the series of earthquakes (BMKG, 2019). Even more interesting if it is compared to the 2018 Lombok earthquake, where the two events are located and occur in close proximity. The analysis of the fault as the cause of the 2019 Lombok earthquake has not been carried out explicitly. Do the 2018 and 2019 Lombok earthquake have the same fault system? Was the 2019 Lombok earthquake triggered by a new and independent structure with pre-existing faults? In addition, the 2019 earthquake can also provide new information regarding earthquake threat zones as well as updated earthquake risk analysis on Lombok Island. All stakeholders and future research may expected be benefit from this study.

## Method

In this study, a critical analysis of literature reviews from several publications of national and international journal as well as available archives is carried out. The method used includes several stages. First, search for publications and archives related to the topic. Furthermore, a critical analysis is carried out by correlating several literatures to find concepts to analyze and identify gaps in the formulation of the problem. It is hoped that from this critical study new topics will emerge for further study.

## Result and Discussion

In the eastern part of the Sunda Arc, one of the islands is Lombok Island (Curray et al., 1977; Puspito & Shimazaki, 1995; Metrich et al., 2017). According to Widiyantoro et al. (2011), the Sunda Arc marks the subduction between the Australian Plate and the Eurasian Plate, with the direction of convergence approximately perpendicular to the arc. As a result of the collision, a thrusting zone known as the back-arc thrust fault is also created in the north of the island arc (McCaffrey & Nabelek, 1987). This fault, which has two segments: the Flores thurst (450 kilometers) and the Wetar thrust (350 kilometers), extends from Wetar in the east to the Bali Basin (Silver et al., 1983). Koulali et al. (2016) offered a different interpretation, claiming that the fault can be extended to part of East Java. Because of this type of fault, Lombok Island is a hanging wall block. Additionally, Lombok Island is located closer to the Flores back-arc thrust rather than the subduction zone (Sulaeman et al., 2019). Meanwhile, the Lombok Strait Fault and Sumbawa Strait Fault, two strike-slip faults with a north-south orientation to the west and east of Lombok Island, respectively, were also formed (Irsyam et al., 2017).

The fault structures in the Lombok area are recorded as an active fault. The convergence rate of the subduction zone is around 70 mm/year based on the GPS measurement (Altamimi et al., 2017; Bock, 2003). The Australian Plate is moving at varying velocities to the east (Koulali et al., 2016; Nugroho et al., 2009; Robiana et al., 2018). While the north's back-arc thrust fault moves at a rate of roughly 5.6 to 6 mm/year (Koulali et al., 2016; Susilo et al., 2018). While the two strike-slip faults, which are located in the west and east of island, move at roughly 0.5 mm/year (Irsyam et al., 2017). The primary transformation activity alters the deformation on Lombok Island, which shifts to the northeast horizontally at a rate of 6.65 mm/year to 24.95 mm/year and vertically at a rate of 0.57 mm/year to 559.86 mm/year (Sulaeman et al., 2019). Thus, this region has active geodynamics and complicated geological structure as a result of the tectonic activity.

The existence of a subduction zone in the south has been established based on the value of the high seismic velocity anomaly of the earthquake wave tomogram performed by Nugraha et al. (2014) and Palupi et al. (2019). The back arc lithosphere in the region north of Lombok exhibits the same anomaly value (Widiyantoro et al., 2011). Based on the findings of seismic profiles analysis, the study was enhanced by Yang et al. (2020) in the form of a seabed surface structure in the Flores Arc Back-Arc Thrust zone. The same results are demonstrated by the distribution of earthquake hypocenter relocation data that are categorized into regional (subduction) and local (Flores Back-Arc Thrust) fault systems (Setiadi et al., 2018; Taruna and Banyunegoro, 2018; Bunaga et al., 2015; Devalentino and Sunardi, 2015). Meanwhile, north-south trending strike-slip faults in the east and west of Lombok Island were identified based on their seismic history (Irsyam et al., 2017).

Lombok Island's geological structure is dominated by normal faults and shear faults, where tectonic activity takes place at the end of the Tertiary or early Quaternary (Soetoyo, 2008). On the Lombok Island, specific investigations in the form of analysis based on geological information, field observations, magnetic anomalies, and remote sensing have been conducted. Soehaimi et al. (2021) interpret the appearance of faults in several areas, namely: The Batujahe strike-slip fault that is oriented northeast-southwest, the normal fault of Lombok Island is oriented east-west, and the Alas strike-slip fault is oriented north-south. In Sembalun, faults are mapped based on topography and lineaments, according to Sundhoro et al. (2000) and Soetoyo (2008). These faults almost have a north-south, northeast-southwest, west-east, and northwest-southeast orientation. According to the remote sensing method used by Agung et al. (2021), the region has a major fault that generally trends northeast-southwest. Meanwhile, Zubaidah et al. (2014) carried out an examination based on magnetic anomalies that two normal faults in the southern part of the island were parallel to the lineaments previously described by Mangga et al. (1994).

According to the catalogue of significant and destructive earthquakes for the years 1821–2018 (Sadly et al., 2019) and 1612–2014 (Supartoyo et al., 2014), no significant or destructive earthquake distribution has been found in the geological structures that have been identified by previous researchers with regard to fault activity on the Lombok Island. However, the lineaments and faults on the mainland of Lombok can be assumed to be potentially active, activity uncertain, and tentatively active. This is based on the study of Cluff et al. (1972) and Slemmons & McKinney (1977), who stated that an area is considered to be "possibly active" if an earthquake's epicenter aligns with the fault or is close to it but the position of the earthquake has a low level of confidence. It is referred to "activity uncertain" when there is not enough concrete data (historical, geological, and seismological) about a fault's past activity and needs additional research to provide clear evidence. While "tentatively active" when the time between earthquake recurrence is very long or not clearly defined.

According to McCaplin (1996) and Daryono (2016), historical earthquake occurrences, return periods, deformation velocity, earthquake patterns, and fault kinematics can be used to identify the characteristics of active faults. For instance, Irsyam et al. (2017) have summarized the active faults on the Island of Lombok based on the seismicity that occurred. For instance, a destructive earthquake in 1979 and 2004 (M 6.1 & M 6.2) that damaged thousands of homes and numerous people died occurred in the Flores back-arc thrust zone, where the zone has the potential for an earthquake of a maximum magnitude of M 7.4-8.0. The M 6.5 earthquake in 1982 took place on the southern or at the subduction zone, which had a maximum potential magnitude of 9.0. A significant earthquake with a magnitude of 5.7 and a potential magnitude of M 7.0–7.4 occurred in the Sumbawa Strait Fault Zone in 2017, while the Lombok Strait Fault can produce earthquakes with a maximum potential magnitude of M 7.5 to M 7.6 (BMKG, 2022; Irsyam et al., 2017).

Additionally, Supendi et al. (2020), Yang et al. (2020), and Sasmi et al. (2020) identified a new structural activity that indicates a thrust fault based on the distribution of earthquake hypocenters. This structure develops along the basalt fault of the Flores oceanic crust (FOC), which creates a certain structure. This sequence of large earthquakes occurred at shallow depths and was unusually distributed to the south of the Flores Back-Arc Thrust with rupture zones to the east and west (Lythgoe et al., 2021; Sasmi et al., 2020). According to Widyarta et al. (2020), the results of the tomography model show that the thrust fault occurs in a different segment from the Flores back-arc thrust but has similar characteristics (dip 20° - 35°). This is supported by Priadi et al. (2021), who found that the mechanism of the 2018 Lombok earthquake transformed identically to the Flores back-arc thrust. However, the difference is in the structure's location, which is in Lombok's northern region (Widyarta et al., 2020). Another tomographic study by Afif et al. (2021) and Priyono et al. (2021) found that aftershocks formed an east-west cluster due to the low seismic velocities of the local medium. High temperature, fluid, and numerous fractures are indicated by this. The phenomenon is increasingly intriguing to further understand since the observation of surface faults created after the 2018 Lombok earthquake by the Geological Agency Emergency Response Team with a dominant thrust movement and a vertical offset between 2 cm and 50 cm (west - east orientation) in the northern of Lombok Island (PVMBG, 2018). However, nobody has yet clarified whether or not these faults are related to the previous studies.

Compared to the 2019 Lombok Earthquake, this is different. Shortly after the previous earthquake in 2018, a major and destructive earthquake struck. This suggests that the 2018 Lombok earthquake series could have released energy that could have caused the earthquake (Gunawan et al., 2020). The report of source mechanism study revealed that the 2019 Lombok earthquake has a normal fault mechanism (BMKG, 2019). Meanwhile, the thrust fault is located on the earthquake source zone in the northern part of Lombok Island (Karima et al., 2020; Priadi et al., 2021; Supendi et al., 2020). No exception, every single aftershock (M4) displayed thrust fault mechanism (Wardani et al., 2021). According to the aftershock pattern, the 2018 Lombok earthquake was distributed in an east-west direction (Sasmi et al., 2020). In contrast, the 2019 Lombok earthquake's distribution has a northeast to southwest orientation (BMKG, 2019).

A tentative hypotetic can be made that the 2019 Lombok earthquake differs from the 2018 Lombok earthquake in regards to its characteristics. Both events, interestingly, were distributed and occurred next to closed each other. However, the analysis of the fault as a source of 2019 Lombok earthquake has not yet been examined in more detail.

## Conclusion

Lombok Island is situated in an active tectonic zone as a result of geodynamic conditions of the Australian Plate subducting beneath the Sunda Plate. On the Lombok Island, earthquakes are generated by these active faults. Because the characteristics of the 2019 earthquake source are unique from those of the Island of Lombok's common earthquake sources, the 2019 Lombok earthquake's cause is still a mystery. In order to better understand about the existence of an active fault on the Lombok Island, additional analysis on the 2019 Lombok earthquake must be made. It could be a sign that the "risk" of an earthquake is increasing with the increase in the earthquake source zone in the Lombok region, as well as a recommendation to local governments to prepare for and reduce the impact of an earthquake.

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