



Static Stress Transfer from The 2010 Mw 7.8 Sinabang Earthquake and Its Role in Triggering the Mw 7.2 Meulaboh Event

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ABSTRACT

This study investigates the mechanical relationship between the 6 April 2010 Sinabang earthquake (Mw 7.8) and the subsequent 9 May 2010 Meulaboh earthquake (Mw 7.2) along the Sumatra–Andaman Subduction Zone (SASZ) using static Coulomb Stress Change (Δ CFS) analysis. Earthquake source parameters and focal mechanisms were obtained from the United States Geological Survey (USGS) catalog. Aftershock sequences associated with the Sinabang earthquake were identified using the Gardner and Knopoff declustering algorithm, while fault geometry was constrained using focal mechanism solutions and empirical scaling relationships. Static stress transfer was modeled using Coulomb 3.3 assuming a homogeneous elastic half-space. The results indicate that the Sinabang earthquake generated a positive Δ CFS lobe extending toward the Meulaboh segment, with stress increases penetrating the seismogenic depth range of approximately 20–40 km. Receiver-fault analysis yielded positive Δ CFS values of 0.022 bar and 0.011 bar for Meulaboh Nodal Plane 1 (NP1) and Nodal Plane 2 (NP2), respectively, with NP1 showing better agreement with the regional tectonic setting and aftershock distribution. Validation using 107 aftershocks showed that 63 events (58.88%) occurred within positive Δ CFS regions, supporting a spatial association between stress increase and postseismic seismicity. Although the calculated stress perturbations remain below the commonly adopted static triggering threshold of 0.1 bar (0.01 MPa), the positive Δ CFS values suggest that static stress redistribution may have increased the failure potential of the Meulaboh fault. The 33-day interval between the Sinabang and Meulaboh earthquakes further implies that additional time-dependent postseismic processes may have influenced the timing of fault failure, although these mechanisms were not explicitly modeled in this study. These findings highlight the probabilistic nature of earthquake interactions within active subduction systems and provide insights for future investigations of delayed earthquake triggering and seismic hazard assessment.

KEYWORDS: Coulomb Stress Change; Static Stress Transfer; Delayed Triggering; Sinabang Earthquake; Meulaboh Earthquake

INTRODUCTION

The western region of Sumatra is one of the most tectonically active areas in the world, located within the major convergent boundary between the Indo-Australian Plate and the Eurasian Plate (Sieh & Natawidjaja, 2000). Subduction occurring at a rate of approximately 50–60 mm/year results in the accumulation of significant tectonic stress, generating a series of large earthquakes along

the Sumatra megathrust zone from Aceh to Mentawai (Widiyantoro et al., 2024). The tectonic complexity of this region is further enhanced by the interaction between the megathrust interface, the forearc region, the right-lateral Sumatra Fault, and the active Mentawai Fault system, all of which contribute to the variability of seismic activity and stress distribution. These dynamic tectonic processes promote interactions among faults and

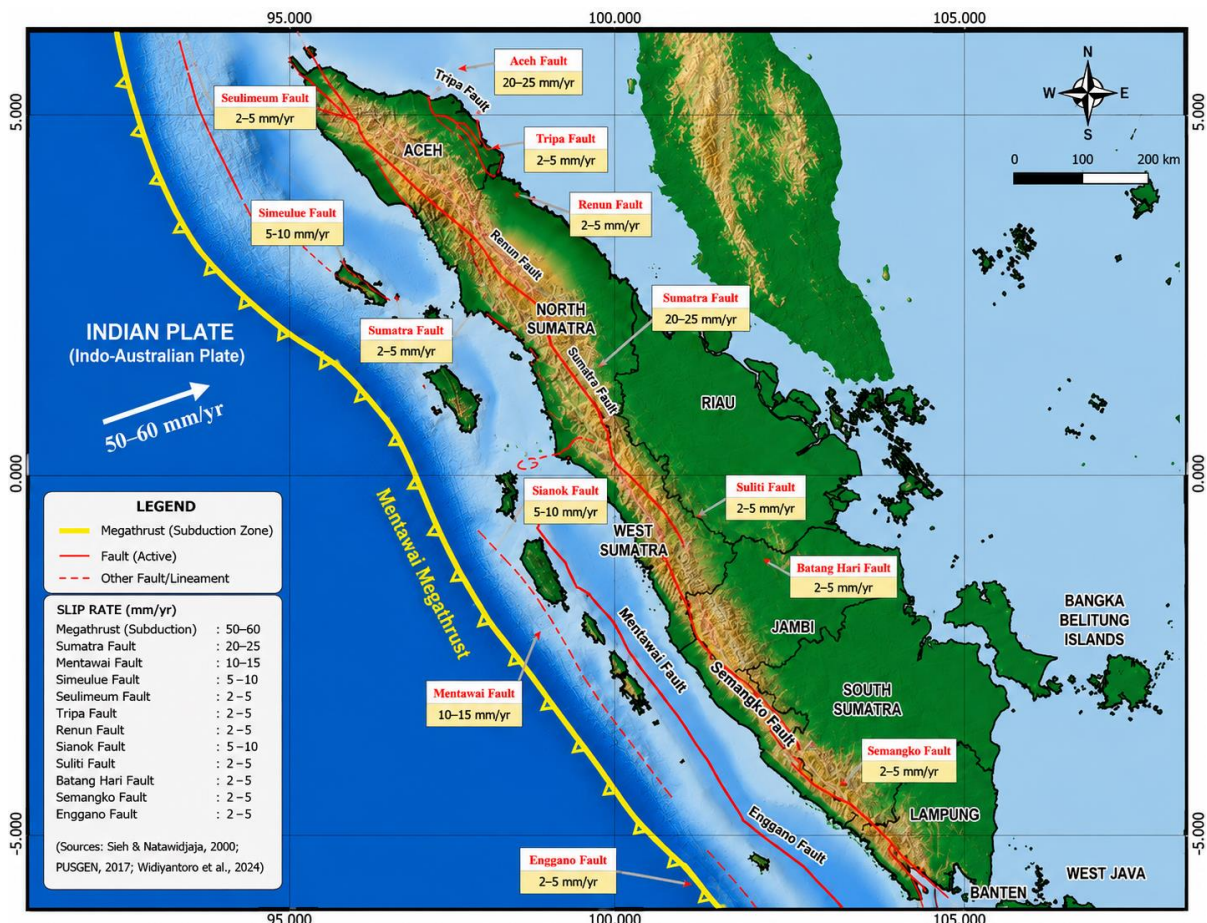


Figure 1. Regional tectonic framework of Indonesia showing major plate boundaries and relative plate motion vectors between the Indo-Australian, Indian, Pacific, Philippine, and Eurasian plates. The Sunda subduction zone along western Sumatra represents the primary convergent margin (Widiyantoro et al., 2024).

earthquake events, often causing stress transfer between adjacent fault segments. As a result, the western margin of Sumatra has repeatedly experienced large-magnitude earthquakes, highlighting both its high seismic hazard and the importance of understanding stress transfer mechanisms within this active subduction system.

Figure 1 shows the tectonic setting of northern Sumatra, where the oblique convergence between the Indo-Australian Plate and the Eurasian Plate is accommodated by the Sunda subduction zone offshore western Sumatra and the Great Sumatran Fault system on land. In the Aceh region, active fault segments such as the Aceh, Seulimeum, and Tripa faults accommodate part of the regional deformation through strike-slip motion (Widiyantoro et al., 2024). The Sunda subduction zone acts as the primary source of large megathrust earthquakes, while the active fault segments contribute to crustal

deformation and shallow seismicity. The interaction between these tectonic structures produces a complex stress regime and frequent seismic activity, making northern Sumatra one of the most seismically active regions in Indonesia.

In 2010, the Aceh and western Sumatra regions experienced two major earthquakes within a short period: the Sinabang earthquake (Mw 7.8) in April 2010 and the Meulaboh earthquake (Mw 7.2) in May 2010, approximately one month later. Both earthquakes occurred in adjacent subduction segments and on the same tectonic structure, the northern part of the Sumatra megathrust, which is known for its history of recurring large earthquakes, such as those in 2004, 2005, and 2007 (Sukrungsri et al., 2024). Given the proximity in both location and time of occurrence, this raises an important question regarding the mechanical relationship between these two events, particularly whether the

Sinabang earthquake contributed to the occurrence of the Meulaboh earthquake through the process of static stress transfer. In the context of earthquake physics, the relationship between earthquake events is often understood through the concept of static stress transfer (Toda et al., 2005). When a large earthquake occurs, the deformation produced by slip on a fault plane alters the stress in the surrounding area, either increasing or decreasing the stress on nearby faults. The Δ CFS approach has become one of the most widely used methods for assessing the potential triggering of earthquakes due to these stress perturbations (Asmaniar et al., 2019; Ishibe et al., 2017). The Δ CFS is defined as the combination of shear and normal stress changes acting on a fault plane, where positive values enhance failure potential and negative values suppress it (Ishibe et al., 2017). Theoretically, an increase in Δ CFS indicates that a fault is closer to failure, making it more likely to rupture. Several studies have shown that stress changes as small as 0.01–0.1 bar can influence earthquake occurrence, particularly for faults that are already in a critically stressed condition (Toda et al., 2011; Sinaga et al., 2022).

More recent studies have demonstrated that aftershock distributions are strongly controlled by coseismic stress redistribution, which can both enhance and suppress seismicity in surrounding regions (Sukrungsri et al., 2024; Kusumawati et al., 2021). Furthermore, earthquake triggering is commonly explained using rate-and-state friction theory, in which stress perturbations modify the timing of failure rather than causing instantaneous rupture (Kame et al., 2013). In this framework, static stress changes may accelerate fault instability, resulting in delayed triggering over timescales ranging from days to weeks (Toda et al., 2011).

The 2010 Sinabang Mw 7.8 earthquake significantly altered stress along the northern Sumatra megathrust. The subsequent Meulaboh earthquake may have been influenced by stress transfer from the Sinabang event, highlighting the importance of studying

earthquake interactions in subduction zones, where events often occur sequentially and influence one another (Schäfer & Wenzel, 2019; Toda et al., 2011).

Previous studies have investigated Coulomb stress changes in the Sumatra subduction zone and the Aceh region. Sukrungsri et al. (2024) analyzed coseismic stress changes and aftershock patterns along the Sumatra–Andaman subduction zone and showed that aftershocks tend to concentrate in areas experiencing positive Δ CFS. This finding provides a basis for understanding stress transfer following major earthquakes using a homogeneous elastic model. In addition, Kusumawati et al. (2019) examined Coulomb stress changes caused by major earthquakes in Aceh and found that increased stress on surrounding fault structures is associated with elevated seismic activity after the mainshock. These results support the concept that large earthquakes can trigger spatially distributed aftershocks through stress redistribution.

Recent studies in subduction zones, including Indonesia, have further emphasized that stress transfer plays a critical role in fault interaction and seismic hazard evolution (Kusumawati et al., 2021). These studies highlight that earthquake triggering is a probabilistic process influenced by stress changes, fault properties, and time-dependent deformation. Despite extensive studies on Coulomb stress transfer, the extent to which stress redistribution from a major earthquake may influence the occurrence of subsequent large earthquakes in the Sumatra subduction system remains uncertain. Therefore, this study evaluates whether the stress changes generated by the Mw 7.8 Sinabang earthquake may have increased the failure potential of the Mw 7.2 Meulaboh earthquake through static Coulomb stress transfer.

This study aims to investigate how the Mw 7.8 Sinabang earthquake modified the stress distribution along the Aceh segment of the Sumatra–Andaman Subduction Zone and to evaluate whether this stress perturbation contributed to increasing the failure potential

of the Mw 7.2 Meulaboh fault segment. The Δ CFS approach is employed to quantify static stress transfer from the Sinabang earthquake and to assess its relationship with the subsequent occurrence of the Meulaboh earthquake. To address these objectives, the study integrates Coulomb stress modeling, focal mechanism analysis, cross-sectional stress distribution, receiver-fault evaluation, and aftershock validation through spatial correlations between Δ CFS and seismicity. Alternative Nodal Plane solutions are also examined to identify the fault geometry that best represents the regional tectonic setting and observed aftershock distribution. Through this approach, the study explores the mechanical interaction between the two major earthquakes that occurred in 2010 and provides insights into stress redistribution and fault interaction within the Sumatra megathrust system. The findings contribute to a better understanding of earthquake interactions in active subduction environments and have implications for regional seismic hazard assessment.

METHODS

This study examines the Δ CFS generated by two major earthquakes that occurred in Aceh in 2010: the 6 April 2010 Sinabang earthquake (Mw 7.8) and the 9 May 2010 Meulaboh earthquake (Mw 7.2). Both events took place along the Sumatra–Andaman Subduction Zone (SASZ), one of the most seismically active and structurally complex subduction systems in the world. The SASZ is formed by the subduction of the Indo-Australian Plate beneath the Eurasian Plate, producing frequent large earthquakes and significant stress interactions along the plate boundary.

Because the Meulaboh earthquake occurred approximately one month after the Sinabang event, it is important to evaluate whether stress redistribution from the Mw 7.8 earthquake contributed to the occurrence of the Mw 7.2 earthquake and the surrounding seismicity. To address this, the study combines

seismic data analysis, fault geometry estimation, focal mechanism interpretation, and Coulomb stress modeling. Earthquake source parameters were obtained from the United States Geological Survey (USGS) catalog, including hypocenter location, focal depth, and focal mechanism solutions (strike, dip, and rake), which define the geometry and orientation of the rupture planes (USGS, 2026).

The seismic activity following the Sinabang mainshock was characterized by selecting events based on spatial and temporal parameters derived from the declustering methodology of Gardner & Knopoff (1974). These windows were utilized to isolate earthquakes within the sequence's immediate influence for subsequent comparison with the modeled static stress distribution. Notably, the Mw 7.2 Meulaboh event was considered an independent target for analysis rather than being pre-defined as a standard aftershock. This approach allowed for an objective evaluation of the mechanical interaction and potential triggering relationship between the two major events through direct Δ CFS quantification.

All modeling assumed a homogeneous elastic half-space, a common simplification in static stress transfer studies (Toda et al., 2008). This approach allows coseismic stress changes from the Sinabang and Meulaboh earthquakes to be resolved onto surrounding fault planes. The resulting Δ CFS patterns were compared with aftershock distribution to assess whether positive stress changes correlate with increased seismicity, providing insight into stress interaction along the SASZ.

The Sinabang earthquake (green star) occurred about one month before the Meulaboh event (blue star) along the active Aceh megathrust (Figure 2). Both earthquakes exhibit thrust faulting, with aftershock concentrated near the rupture zones, suggesting that stress transfer from the Mw 7.8 Sinabang event may have increased Coulomb stress and influenced the Mw 7.2 Meulaboh earthquake.

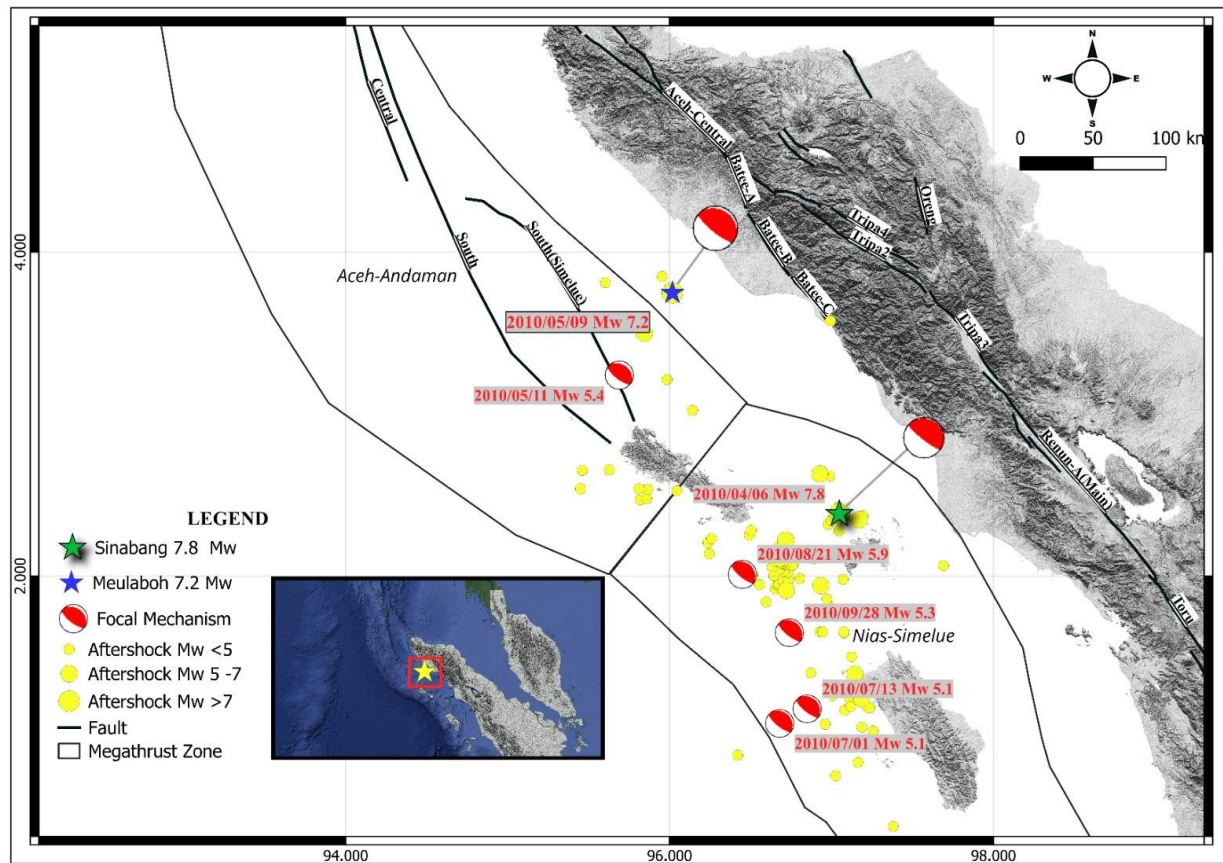


Figure 2. The Spatial Relationship Between the 6 April 2010 Sinabang Earthquake (Mw 7.8) and the 9 May 2010 Meulaboh Earthquake (Mw 7.2) along the Sumatra Andaman Subduction Zone.

Data on the mainshock and aftershocks were obtained from the USGS catalog, including information on the time of occurrence, epicenter location, depth, moment magnitude (Mw), and focal mechanism parameters including strike, dip, and rake (USGS, 2026). To separate the main earthquake from the aftershocks, the Gardner and Knopoff (1974) declustering algorithm was used, which determines the distance window (S) and time window (T) based on the magnitude of the main earthquake (Gardner & Knopoff, 1974). Although the declustering procedure yielded a broader temporal window, this study focused

on 107 aftershocks recorded during the first seven months after the 6 April 2010 Sinabang earthquake, as these events represent the period of intensified postseismic activity used to validate the modeled Coulomb stress distribution. The maximum distance window was calculated using the equation:

$$S = 10^{0.1238M+0.983} \quad (1)$$

while the maximum time window is determined through:

$$T = 10^{0.032M+2.7389} \quad (2)$$

This formula ensures that only earthquakes with a smaller magnitude occurring within a distance of S (km) and

Table 1. Nodal Planes Parameters of Sinabang and Meulaboh earthquakes.

Date	Long (E)	Lat (N)	Depth (km)	Mw	Strike	Dip	Rake	Focal Mechanism
2010/04/06 Sinabang	97.048	2.383	31	7.8	307	7	88	
					129	83	90	
2010/05/09 Meulaboh	96.018	3.748	38	7.2	320	15	90	
					140	75	90	

within a period interval of T (days) after the mainshock are classified as aftershocks. This approach is effectively used in SASZ seismicity studies by Sukrungsri et al. (2024) and provides consistent results in separating the Sinabang Mw 7.8 and Meulaboh Mw 7.2 earthquake clusters. In this case, the Sinabang earthquake with its focal mechanism can produce aftershocks up to a radius of ± 89 km for ± 2.7 years, while the Meulaboh earthquake produced aftershocks up to ± 75 km for ± 2.5 years.

The determination of fault geometry was based on the focal mechanisms from the USGS catalog, which provides two alternative Nodal Planes for each earthquake. Aftershocks that have focal mechanisms, as shown in **Table 2**, exhibit identical orientations and patterns. This indicates a similarity to the focal mechanism of the Sinabang earthquake. Accurate determination of fault geometry is important because the distribution pattern and magnitude of stress changes are highly dependent on the orientation of the fault plane, the direction of slip, and the distribution of energy along the source plane.

To define the fault geometry required for Coulomb stress modeling, rupture dimensions were estimated using the empirical scaling relationships proposed by Wells & Coppersmith (1994). These relationships relate earthquake magnitude to rupture length and rupture width and are commonly used when detailed finite-fault rupture models are unavailable. Based on the focal mechanism solutions obtained from the USGS catalog, both the 2010 Sinabang (Mw 7.8) and Meulaboh (Mw 7.2) earthquakes were

classified as reverse-fault events. Therefore, the scaling equations for reverse faulting were applied:

$$\text{Log } L = -2.42 + 0.58 \text{ Mw} \quad (3)$$

$$\text{Log } W = -1.61 + 0.41 \text{ Mw} \quad (4)$$

where L is the rupture length (km), W is the rupture width (km), and M_w is the moment magnitude of the earthquake (Wells & Coppersmith, 1994). Based on these equations, the Sinabang earthquake (Mw 7.8) yielded an estimated rupture length of approximately 127 km and a rupture width of approximately 39 km, while the Meulaboh earthquake (Mw 7.2) yielded an estimated rupture length of approximately 57 km and a rupture width of approximately 22 km. These fault geometry parameters were subsequently used as input for the Coulomb stress calculations. Although the scaling relationships of Wells & Coppersmith, (1994) were developed primarily from a global dataset dominated by continental crustal earthquakes, they provide a practical first-order approximation of rupture dimensions and are widely used in static stress transfer studies when detailed source models are unavailable.

The calculation of static stress changes was performed using Coulomb 3.3 software (Toda et al., 2008) assuming a homogeneous elastic half-space. The elastic parameters used include a Young's modulus of 8×10^5 bar, shear modulus of 3.2×10^5 bar, and Poisson's ratio of 0.25. An effective friction coefficient ($\mu' = 0.4$) was adopted based on commonly used values in subduction zone studies, representing typical fault frictional behavior under crustal conditions. This assumption is widely applied in Coulomb stress modeling to simplify stress

Table 2. Aftershock data of the 2010 Sinabang earthquake with Mw = 4.0.

Date	Long (E)	Lat (N)	Mw	Depth	Focal Mechanism
2010/05/11 Mw 5.4	95.69	3.24	5.4	42	
2010/07/01 Mw 5.1	96.68	1.09	5.1	35	
2010/07/13 Mw 5.1	96.85	1.18	5.1	23	
2010/08/21 Mw 5.9	96.45	2.01	5.9	24	
2010/09/28 Mw 5.3	96.74	1.65	5.3	16.9	

calculations. Stress changes were calculated using Coulomb's criterion, where the total stress change on the receiver fault followed the equation:

$$\Delta CFS = \Delta \tau + \mu' \Delta \sigma_n \quad (5)$$

Positive shear stress change occurs when the resolved shear stress acts in the direction of fault slip. In contrast, a reduction in normal stress (unclamping) decreases the effective normal stress acting on the fault plane, thereby facilitating slip. Consequently, a positive ΔCFS promotes failure, while a negative ΔCFS inhibits failure and is associated with stress shadow regions (Toda et al., 2008). This evaluation was performed on several orientations of the receiver fault: (1) planes with the same mechanism as the main earthquake, (2) planes optimal for strike-slip, and (3) planes optimal for normal or thrust. This multi-fault approach provides a comprehensive understanding of how each earthquake affects the surrounding structure and how stress is transferred along the SASZ.

After the ΔCFS modeling was completed, the aftershock locations were plotted on the stress map to evaluate the correspondence between the stress increase zone and the distribution of aftershock activity. This evaluation was used to assess the role of stress transfer in determining the seismicity pattern after the two earthquakes. Based on Coulomb trigger theory, aftershocks tend to occur in areas with positive ΔCFS .

RESULTS AND DISCUSSION

Co-Seismic Static Stress Transfer from the Mainshock (Finite Fault Approach)

The co-seismic static stress changes generated by the Mw 7.8 Sinabang earthquake were analyzed using a finite-fault approach, which provides a more realistic representation of fault geometry and rupture characteristics. The Coulomb stress results (Figure 3) reveal a heterogeneous redistribution of stress characterized by alternating positive and negative ΔCFS lobes along the Sunda

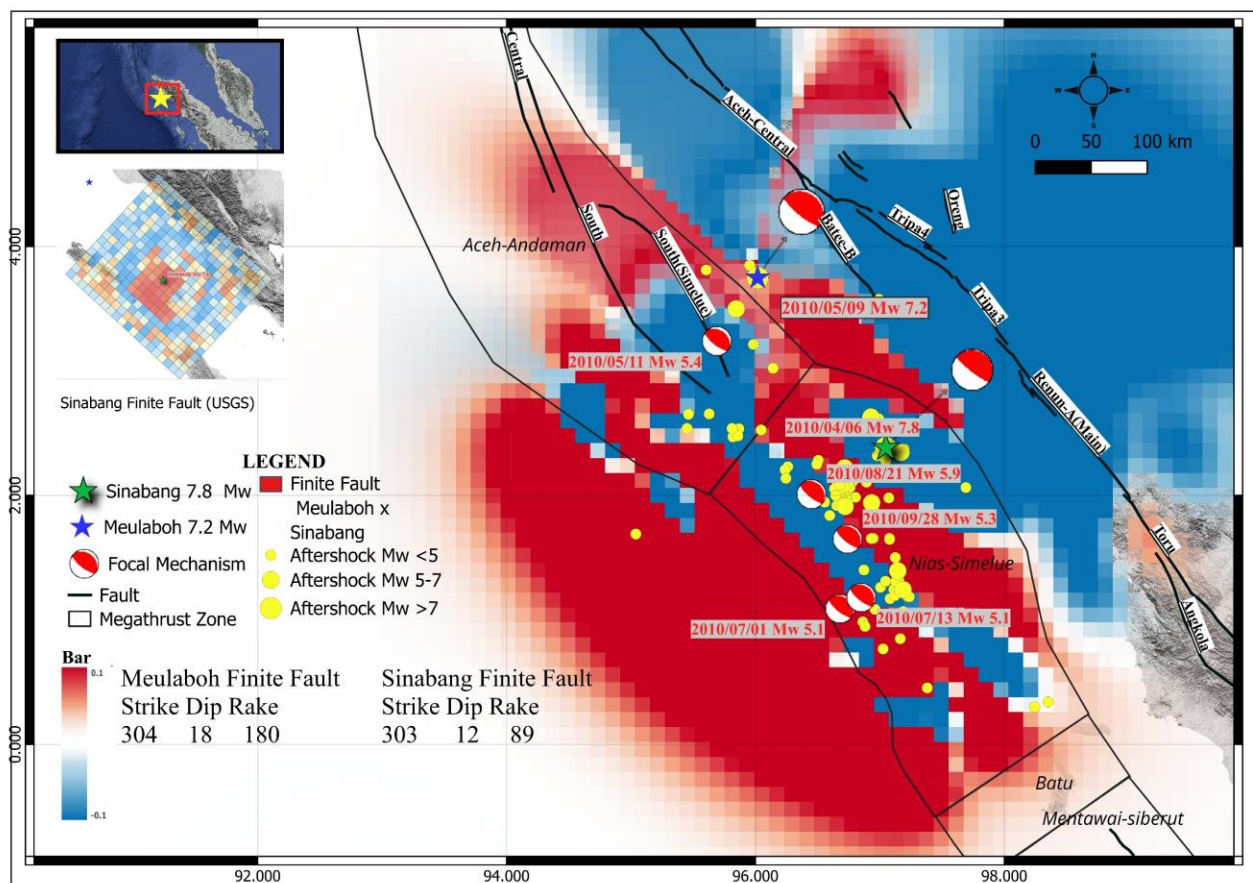


Figure 3. Coulomb Stress Distribution Map of the Sinabang and Meulaboh Earthquakes Using Finite Fault Model.

megathrust. Positive ΔCFS lobes predominantly extend toward the southeast direction, following the geometry of the subduction interface and indicating the influence of fault orientation and slip distribution on the resulting stress field. Areas associated with larger slip contributions appear to play a significant role in promoting stress enhancement.

To further investigate the vertical

distribution of stress changes, a cross-sectional analysis was constructed based on Nodal Plane 1 (NP1) of the Sinabang earthquake (Figure 4). The results show that stress enhancement predominantly occurs within depths of approximately 20–40 km, corresponding to the active seismogenic zone. Most earthquake hypocenters are spatially associated with regions of positive ΔCFS , particularly in the down-dip direction of the fault plane. This

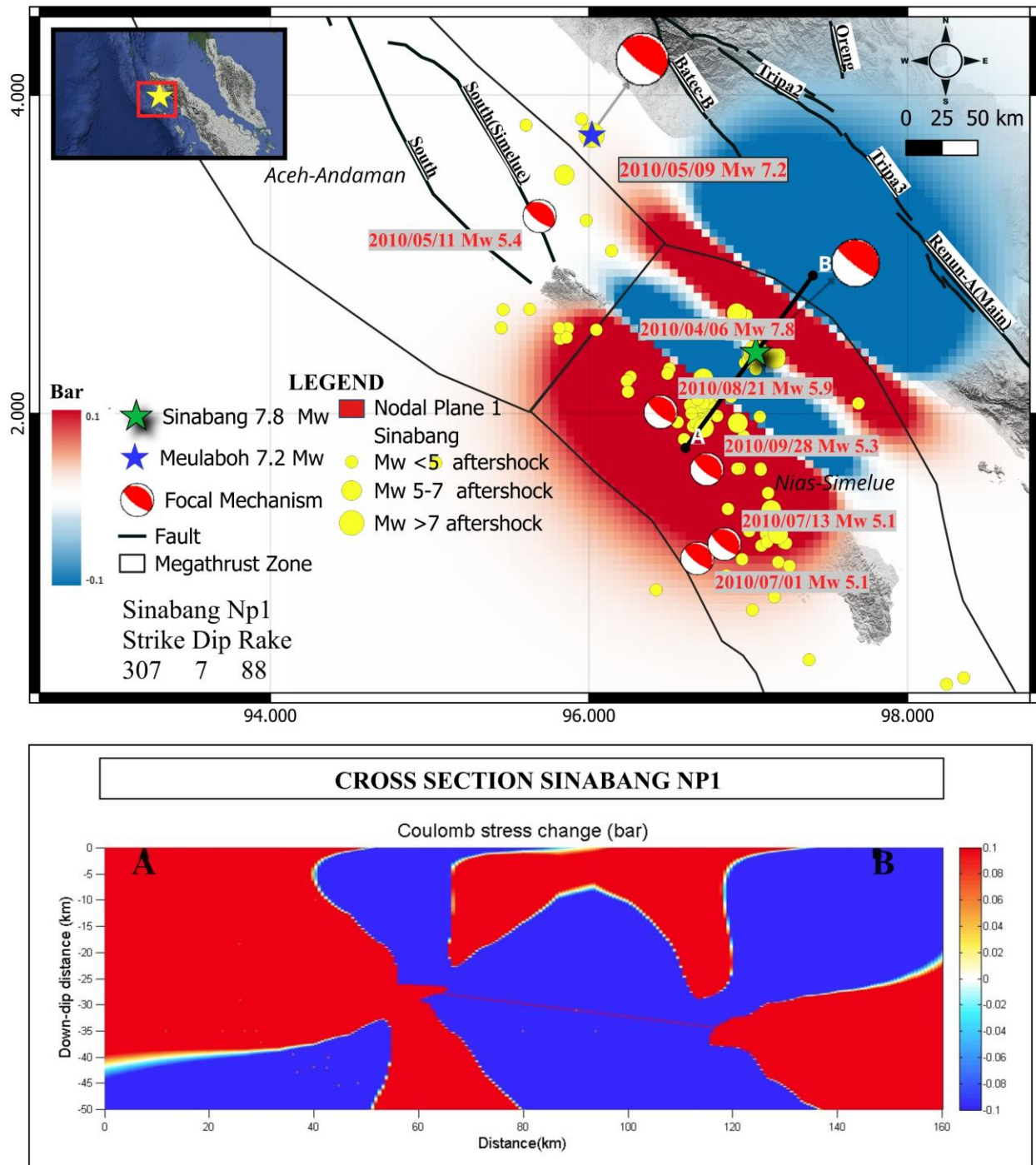


Figure 4. Cross-section of Nodal Plane 1 of the Sinabang earthquake showing the distribution of Coulomb stress based on depth.

Table 3. Shear Stress Change ($\Delta\tau$), Normal Stress Change ($\Delta\sigma_n$), and Coulomb Stress Change (ΔCFS) Resolved into the Two Nodal-Plane Solutions of the Mw 7.2 Meulaboh Earthquake.

Receiver Fault Plane	$\Delta\tau$ (bar)	$\Delta\sigma_n$ (bar)	ΔCFS (bar)
Meulaboh NP1	0.021	0.002	0.022
Meulaboh NP2	0.021	-0.025	0.011

correspondence suggests that stress redistribution following the Sinabang earthquake contributed to increasing the failure potential of surrounding fault segments.

The hypocenter of the Meulaboh earthquake (Mw 7.2) is located within a region of increased stress (positive ΔCFS) induced by the Sinabang earthquake, suggesting a spatial relationship between the two events. This suggests that the stress increase resulting from the Sinabang earthquake may have promoted failure on nearby megathrust segments. As noted by Toda et al. (2011), static stress transfer can enhance the likelihood of earthquake occurrence on surrounding faults. Likewise, Sukrungsri et al. (2024)

demonstrated that aftershocks in subduction environments tend to concentrate within stress-enhanced regions. These findings support the interpretation that stress redistribution associated with the Sinabang earthquake may have contributed to increasing the failure potential of adjacent megathrust segments.

Evaluating Epistemic Uncertainty and Model Robustness in Coulomb Stress Change Analysis

The finite-fault model reveals that the resulting ΔCFS patterns are sensitive to assumptions regarding fault geometry and rupture parameters. To evaluate the robustness of the stress-transfer relationship, Coulomb stress changes were resolved onto

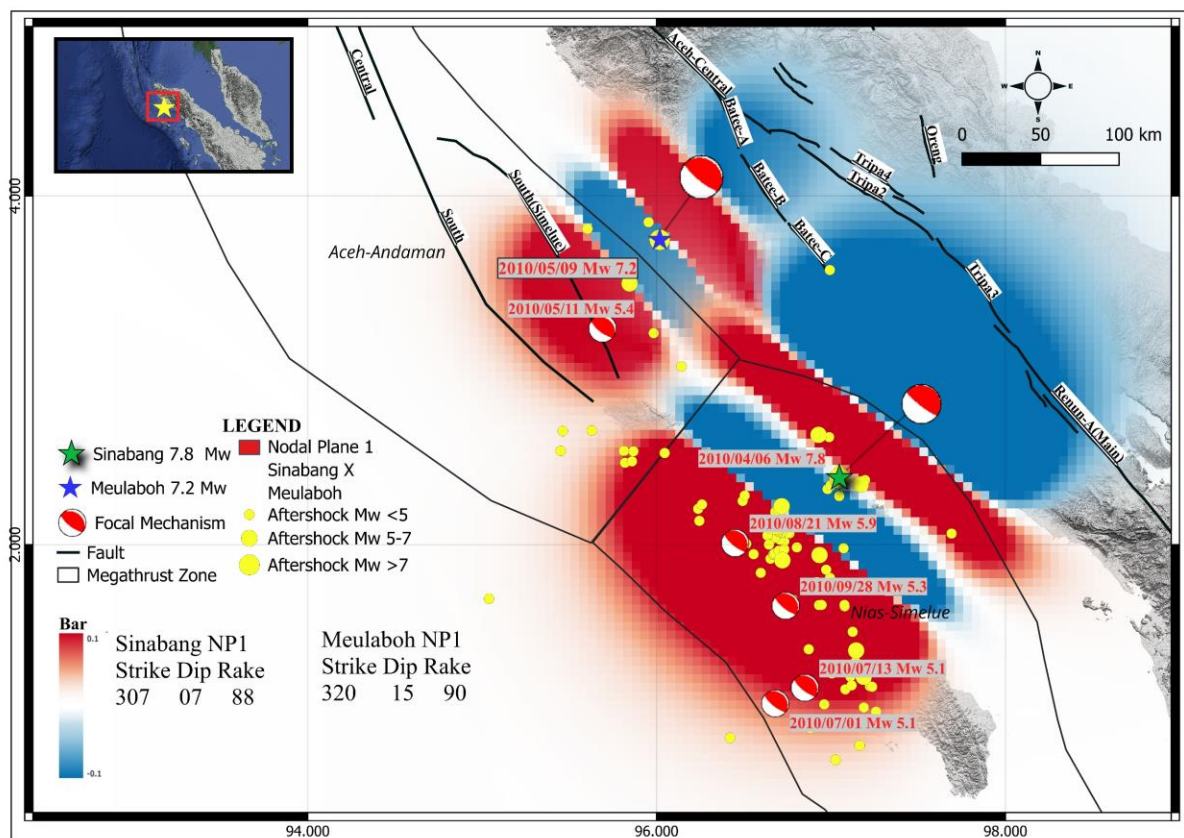


Figure 5. Coulomb Stress Distribution Map of the Sinabang and Meulaboh Earthquakes Using Nodal Plane 1.

both Nodal-Plane solutions of the Meulaboh focal mechanism (Table 3).

Receiver-fault analysis yielded positive ΔCFS values for both nodal planes, indicating that the Meulaboh fault experienced stress enhancement following the Sinabang earthquake. NP1 produced a shear stress change ($\Delta\tau$) of 0.021 bar, a normal stress change ($\Delta\sigma_n$) of 0.002 bar, and a resulting ΔCFS value of 0.022 bar. In contrast, NP2 yielded the same shear stress change ($\Delta\tau = 0.021$ bar), but with a normal stress change of -0.025 bar and a lower ΔCFS value of 0.011 bar.

Although both nodal planes indicate positive stress perturbations, NP1 appears to be more consistent with the regional tectonic setting. The Aceh segment of the Sumatra–Andaman Subduction Zone is characterized by low-angle reverse faulting associated with the subduction of the Indo-Australian Plate beneath the Eurasian Plate (McCaffrey, 2009; Sieh & Natawidjaja, 2000). The geometry of NP1 (strike 320° , dip 15° , rake 90°) closely resembles this tectonic framework, whereas NP2 (strike 140° , dip 75° , rake 90°) represents a steeply dipping auxiliary plane.

Furthermore, the aftershock distribution exhibits better spatial agreement with the positive stress lobes predicted by NP1. Similar observations were reported by Wulandari et al. (2023), who emphasized that the interpretation of Coulomb stress transfer should be constrained by fault geometry, focal mechanism characteristics, and regional tectonic structures. Therefore, although both nodal-plane solutions are mathematically valid, the combined evidence from regional tectonics, hypocentral location, and aftershock distribution suggests that NP1 more plausibly represents the actual fault plane involved in the stress-transfer process between the 2010 Sinabang and Meulaboh earthquakes.

Empirical Validation Based on Aftershock Seismicity

To evaluate the relationship between Coulomb stress changes and seismic activity, the spatial distribution of 107 aftershocks was analyzed with respect to the modeled ΔCFS

values (Figure 6). The results indicate that 63 events (58.88%) occurred within regions of positive ΔCFS , whereas 44 events (41.12%) were located within regions of negative stress change for NP1. This distribution suggests a moderate tendency for aftershocks to cluster within areas experiencing stress enhancement.

These findings are consistent with the stress-triggering hypothesis proposed by King et al. (1994) and further developed by Toda et al. (2011), which states that positive Coulomb stress perturbations increase the likelihood of fault failure. Similar spatial relationships between aftershock occurrence and positive ΔCFS have also been documented in subduction environments by Sukrungsri et al. (2024).

However, the proportion of aftershocks occurring within positive stress regions is not overwhelmingly dominant. A considerable number of events remain distributed within stress-shadow regions, suggesting that Coulomb stress transfer alone cannot fully explain the observed aftershock pattern. Other factors, including long-term tectonic loading, fault heterogeneity, and pre-existing stress conditions, likely contribute to the evolution of postseismic seismicity (Freed, 2005a; Stein, 1999).

Table 4. Distribution of Aftershocks in Positive and Negative ΔCFS Regions for NP1 and NP2.

Stress Status	Nodal Plane 1	Nodal Plane 2
Positive	63(58.88%)	44(41.12%)
Negative	44(41.12%)	63(58.88%)
Total	107(100%)	

Interestingly, the results obtained from NP2 show the opposite tendency, with 63 events (58.88%) occurring within negative ΔCFS regions. This contrast highlights the sensitivity of Coulomb stress analysis to fault-plane selection and reflects the presence of epistemic uncertainty in the modeling process. Consequently, Coulomb stress transfer should be interpreted as a probabilistic rather than deterministic mechanism in earthquake interaction studies.

Mechanisms of Delayed Earthquake Triggering and Fault Interaction

The Sinabang (Mw 7.8) and Meulaboh (Mw 7.2) earthquakes were separated by an interval of approximately 33 days, indicating that fault failure on the Meulaboh segment did

not occur immediately following the Sinabang event. Coulomb stress modeling results show that the Meulaboh hypocenter is located within a region of positive ΔCFS , and receiver-fault analysis yielded positive ΔCFS values of 0.022 bar for NP1 and 0.011 bar for NP2. These

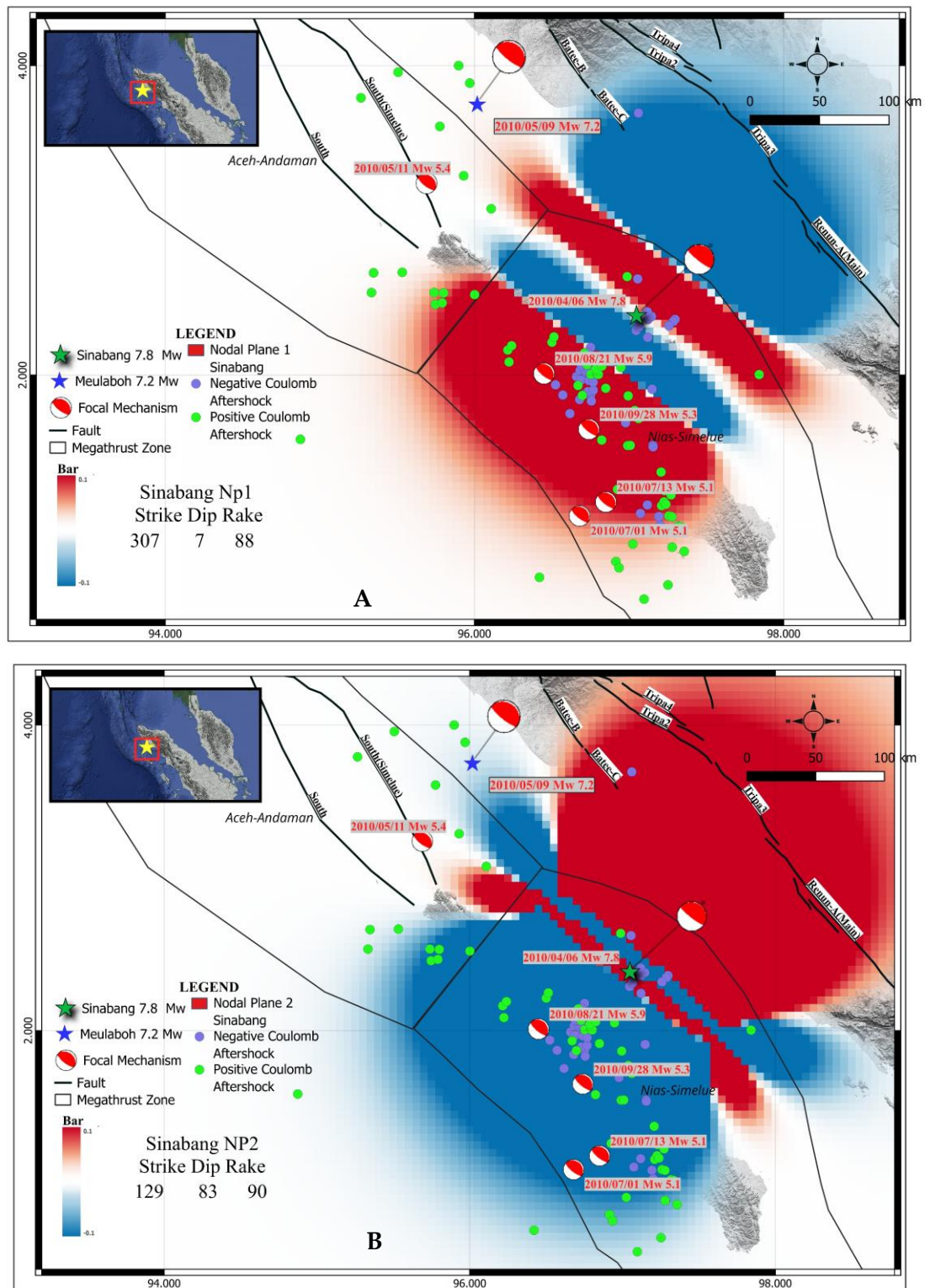


Figure 6. a) Distribution of Coulomb Stress Transfer and Aftershock Distribution in the Sinabang Area Based on Nodal Plane 1; b) Distribution of Coulomb Stress Transfer and Aftershock Distribution in the Sinabang Area Based on Nodal Plane 2.

results suggest that the Sinabang earthquake increased the failure potential of the adjacent megathrust segment, although the calculated stress perturbations remain below the commonly adopted static triggering threshold of 0.1 bar (0.01 MPa) (Stein, 1999).

Nevertheless, previous studies have suggested that stress perturbations as small as approximately 0.01 bar may still influence faults that are already close to failure (King et al., 1994; Ma et al., 2005). Therefore, the positive ΔCFS values identified at the Meulaboh hypocenter may have contributed to increasing the failure potential of the adjacent megathrust segment, even though they do not provide conclusive evidence that static stress transfer alone triggered the Mw 7.2 earthquake.

Previous studies have further demonstrated that positive Coulomb stress perturbations do not necessarily result in immediate fault failure but may instead modify the timing of subsequent earthquakes faults (Dieterich, 1994; King et al., 1994). In addition, fault interactions within subduction systems can generate complex stress-transfer patterns that influence the spatial and temporal evolution of seismicity (Toda et al., 2011). Time-dependent postseismic processes, such as afterslip and viscoelastic relaxation, have also been proposed as mechanisms capable of progressively redistributing stress following major earthquakes (Freed, 2005). by advancing the failure of critically stressed

Because the present study employed static Coulomb stress modeling and did not explicitly incorporate rate-and-state friction, afterslip, or viscoelastic relaxation, the approximately 33-day delay between the Sinabang and Meulaboh earthquakes cannot be directly attributed to any specific postseismic mechanism. Nevertheless, the combination of positive ΔCFS values at the Meulaboh hypocenter, the concentration of aftershocks within stress-enhanced regions, and the relatively short temporal separation between the two events suggests that static stress redistribution may have contributed to

increasing the probability of fault failure.

Overall, these findings indicate that earthquake interactions within the Sumatra–Andaman Subduction Zone are inherently probabilistic and influenced by multiple processes operating over different temporal scales. While static Coulomb stress transfer provides a valuable framework for evaluating fault interactions and potential triggering relationships, its interpretation should consider fault geometry, model uncertainty, and the contribution of time-dependent postseismic processes. Such an integrated perspective is essential for improving the understanding of earthquake interactions and refining regional seismic hazard assessments.

CONCLUSION

The results indicate that the Mw 7.2 Meulaboh earthquake occurred within a region of positive Coulomb stress change generated by the Mw 7.8 Sinabang earthquake. The spatial correspondence between positive ΔCFS values and the distribution of aftershocks suggests that static stress transfer contributed to modifying the regional postseismic stress field and increasing the likelihood of fault failure in the Meulaboh segment. Receiver-fault analysis yielded positive ΔCFS values of 0.022 bar and 0.011 bar for Nodal Plane 1 (NP1) and Nodal Plane 2 (NP2), respectively. Although these stress perturbations remain below the commonly adopted static triggering threshold of 0.1 bar (0.01 MPa), they indicate that the Meulaboh fault experienced stress enhancement following the Sinabang earthquake.

The approximately 33-day interval between the Sinabang and Meulaboh earthquakes suggests that fault failure was not immediate and may have involved additional postseismic processes beyond coseismic stress redistribution. However, because this study employed static Coulomb stress modeling and did not explicitly simulate rate-and-state friction, afterslip, or viscoelastic relaxation, the contribution of these time-dependent mechanisms remains hypothetical. Therefore,

the present results support the interpretation that static stress transfer may have acted as a contributing factor that increased the failure potential of the Meulaboh segment, rather than providing conclusive evidence that static stress transfer alone triggered the Mw 7.2 earthquake. These findings emphasize the probabilistic nature of earthquake interactions within subduction systems and highlight the importance of integrating static stress analyses with time-dependent processes in future studies aimed at improving the understanding of delayed earthquake triggering and seismic hazard assessment.

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