Chapter 4

Seismicity and Faulting Characteristics

4.1 Seismicity

Indonesia is one of the most seismically active zones of the earth. Sumatra Island as a part of Indonesia experienced very large earthquakes in the past and this high seismic activity has been still continuing. Seismic events with a magnitude greater than 8 took place in the Sumatran section of the Sunda subduction zone before the 26, December 2004 earthquake (Figure 3.4). For example, the seismic events with a magnitude of 8.5 and 9.0 in 1861 and 1833, respectively, resulted in the uplifts of corals ranging between 70cm to 230cm. However, the tsunamis caused by these earthquakes were limited to the south of the location of the 26 December 2004 event. Figure 4.1 shows the plots of the seismic event having a magnitude greater than 6.5 since 1900. Furthermore inland earthquakes also took place along the Sumatran fault system as shown in Figure 3.4.

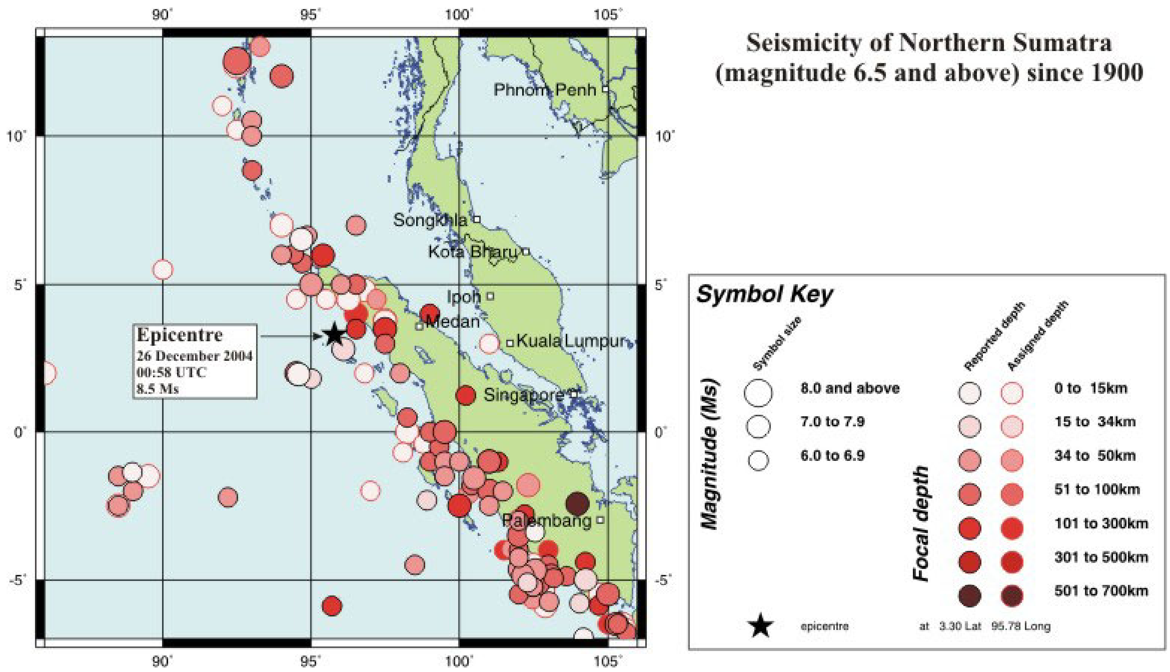
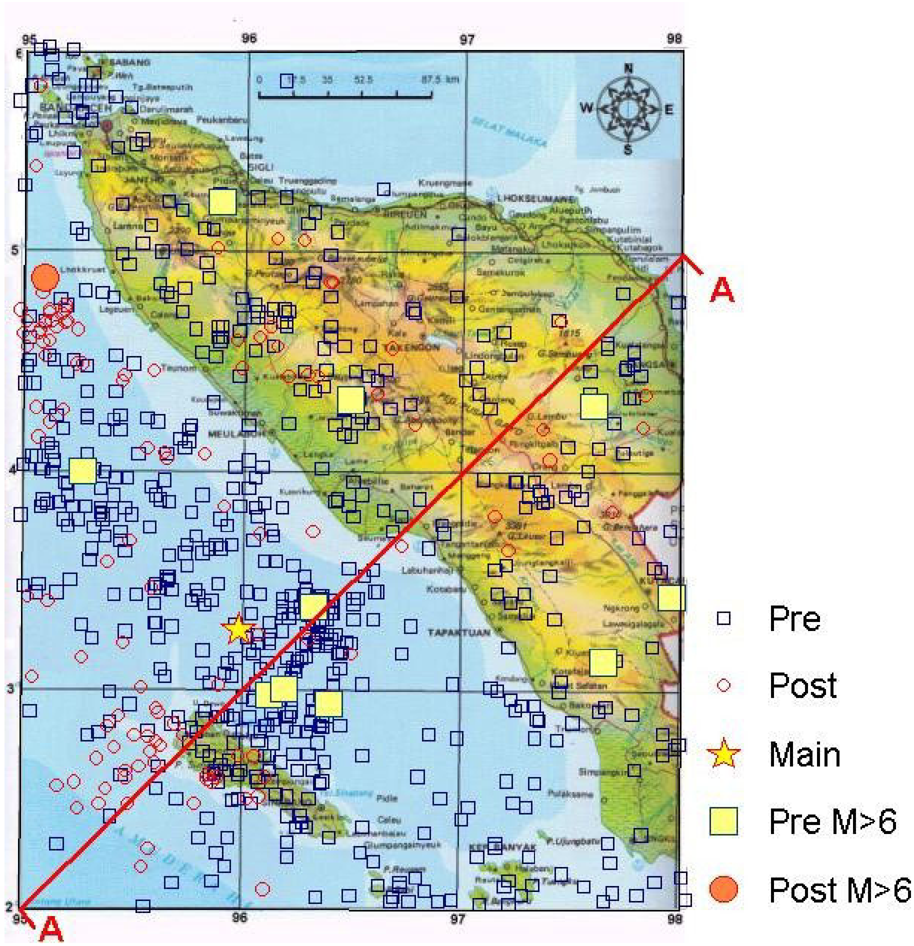


Figure 4.1 Historical seismicity of the area since 1900 (British Geological Survey)

Most of earthquakes occur along the subduction zone and they extend as far as Malacca strait. The pre-post seismicity of a region bounded between Latitudes 2°N to 6°N and Longitudes 95°E and 98°E is shown in Figure 4.2(a). The earthquake catalog of NEIC is used for this purpose and the magnitude of the earthquakes is set to be greater than 3. Figure 4.2(b) shows the seismicity projected onto a cross-section along the direction A-A shown in Figure 4.2(a), which is perpendicular to the strike of the subduction zone in the region of the earthquake. The pre-shocks occurred over a wide area. However, the distributions clearly indicate the existence of a subducting plate. Aftershocks are shallow and distributed along a gently inclined plane.

(a)



(b)

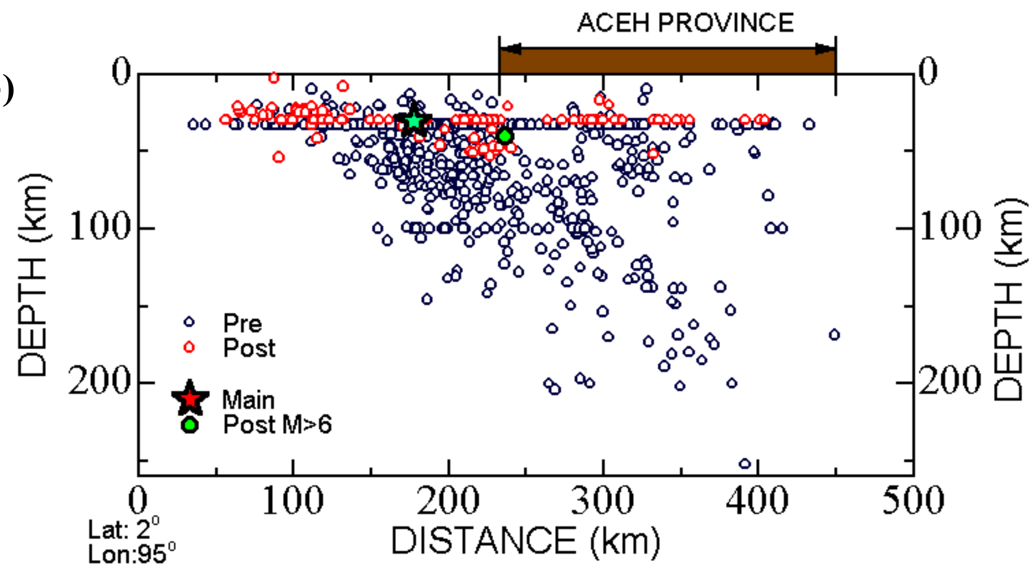


Figure 4.2 Pre-post seismicity of the region of the 26, December 2004 earthquake

(Prepared by Aydan using NEIC data and base map of Indo Prima Saran)

Figure 4.3 shows the seismic activity since 1973. The cumulative magnitude of the earthquakes since 1973 is computed and plotted in the figure. The cumulative magnitude variation seems to fit the following relation:

$$\sum M = 1.81(t - 1965)^2$$

This variation indicates an accelerating seismic activity in the region of the earthquake before the main event.

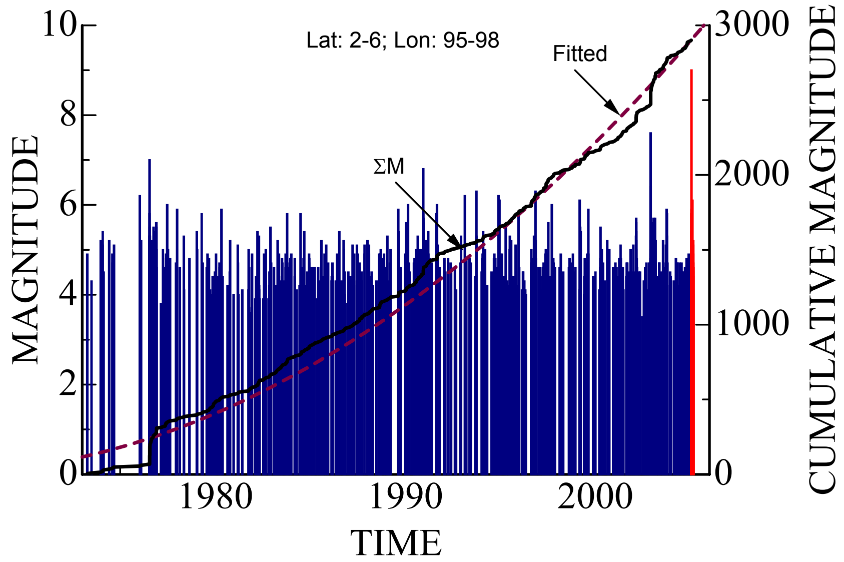


Figure 4.3 Variation of magnitude and cumulative magnitude with time
(Prepared by Aydan using NEIC data)

4.2 Faulting Characteristics

Following the earthquake, several institutes analyzed the data measured at various seismograph stations all over the world. These analyses yielded some important characteristics of this mega-size earthquake.

4.2.1 Fault Plane Solutions for Pre-shocks

The fault plane solutions (HARVARD) of the events before the main shock are shown in Figure 4.4. Most of the fault plane solutions indicate the dominant faulting mode is thrust type with a slight dextral or sinistral lateral strike-slip sense in the area of the earthquake. Nevertheless, between the northern tip of Sumatra Island and Nicobar Island, dominant strike-slip faulting is also observed. The fault plate solutions indicate dextral strike-slip sense of deformation for faults trending NW-SE. The fault plane solutions for folding and striations observed at Lhonga are shown in Figure 4.5. It is of great interest that the geological traces observed on rock formations also yield some information on the likely faulting mechanisms of the earthquakes in the region.

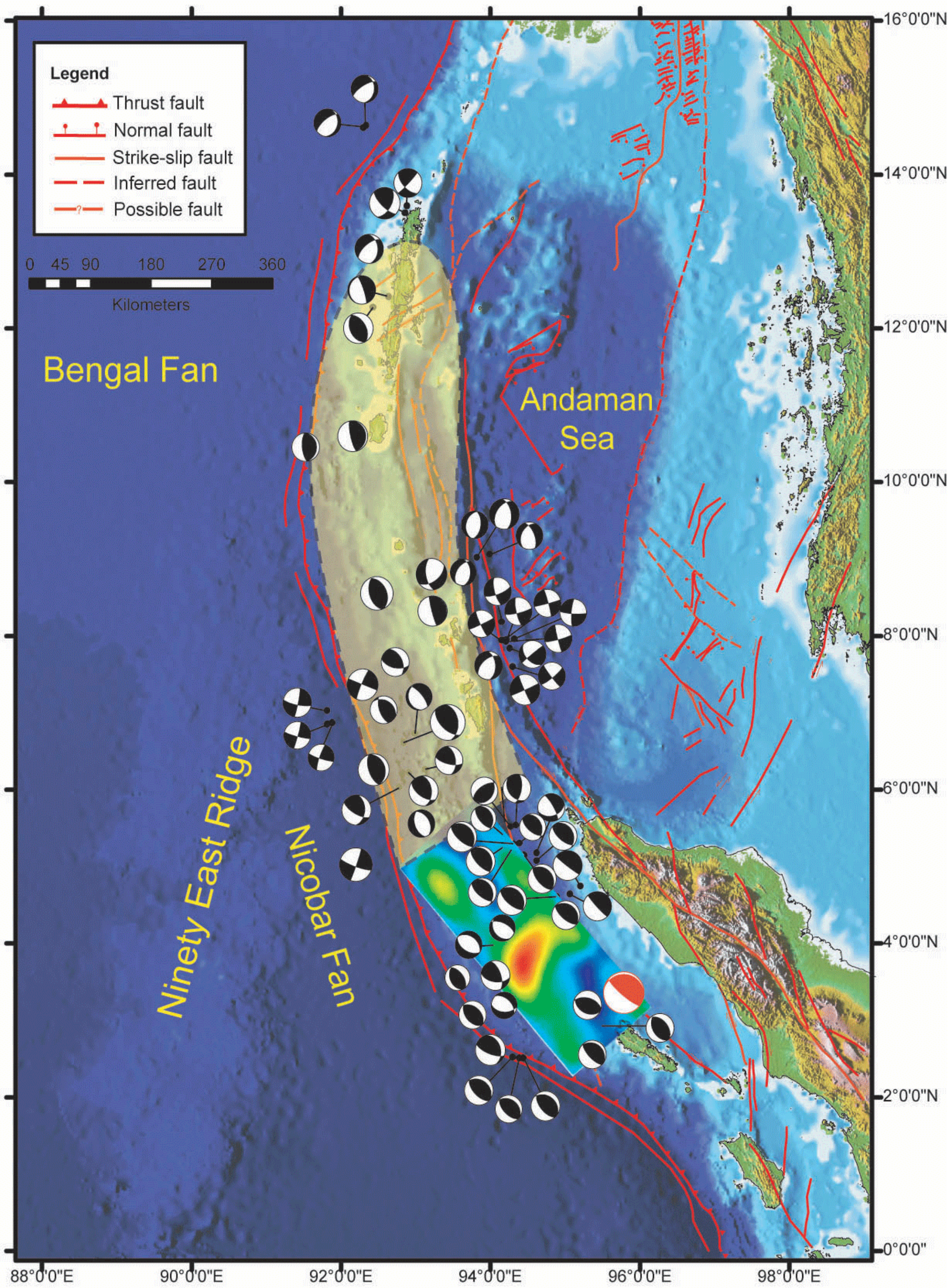


Figure 4.4 Fault plane solutions for the events before the main shock (http://www.coas.oregonstate.edu/)

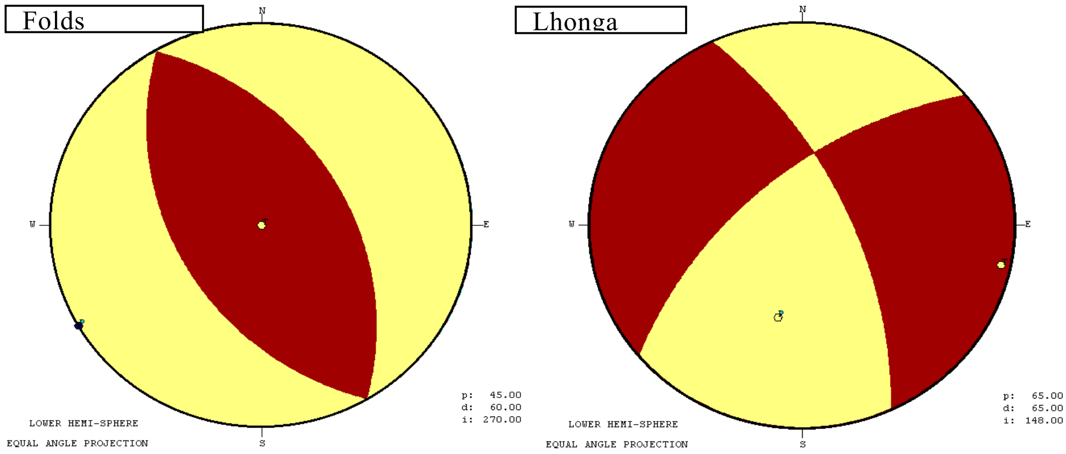


Figure 4.5 Inferred focal plane solutions for folds and striations on bedding planes
(Drawn on the measured data in Lhonga using Aydan's method (Aydan et al. 2002, JSCE))

4.2.2 Parameters and Mechanism of Faulting of Main Event

The magnitude, location and fault plane parameters of the earthquake are listed in Table 4.1. Fault plane solutions computed by various institutes listed in Table 4.1 are illustrated in Figure 4.6. The earthquake magnitude was estimated to be ranging between 8.7 and 9, and the fundamental faulting mode was thrust-type with a dextral sense. However, the solution obtained by the USGS indicated that strike-slip component of the faulting was sinistral, which is contrary to those of the solutions reported by other institutes. The inclination of the causative fault was gently inclined. Furthermore, the depth of the earthquake was shallow and it seems that it took place along the upper surface of the Indo-Australian plate in contact with Euro-Asian plate. The faulting mechanism of this earthquake has the characteristics of a subducting plate-boundary earthquake as illustrated in Figure 4.7.

Table 4.1 Main characteristics of the earthquake inferred by various Institutes

Institute	M	Mw	LAT (N)	LON (E)	DEP (km)	NP1 strike/dip/rake	NP2 strike/dip/rake
USGS	9.0	8.2	3.32	95.85	30	274/13/55	130/79/98
HARVARD		9.0	3.09	94.26	29	329/8/110	129/83/87
ERI(Japan)	9.0	9.0	3.25	95.80	10	340/8/112	
BRI(Japan)		8.7	-	-		329/10/110	
ITU(Turkey)		9.0	-	-	25	320/15/95	135/75/89
CPPT		8.9	3.00	96.00	27	350/5/112	138/86/87

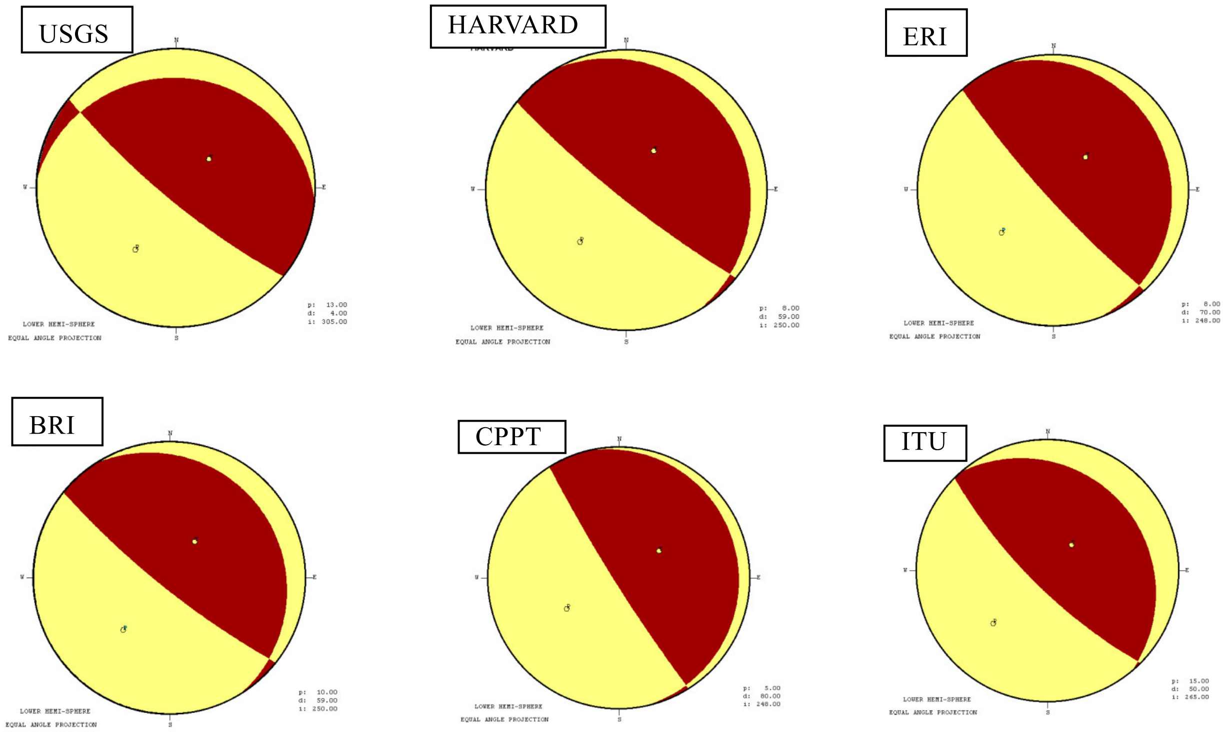


Figure 4.6 Fault plane solutions by various institutes for the main shock

(Re-dawn using the computed data by various institutes on an equal angle stereo projection net.)

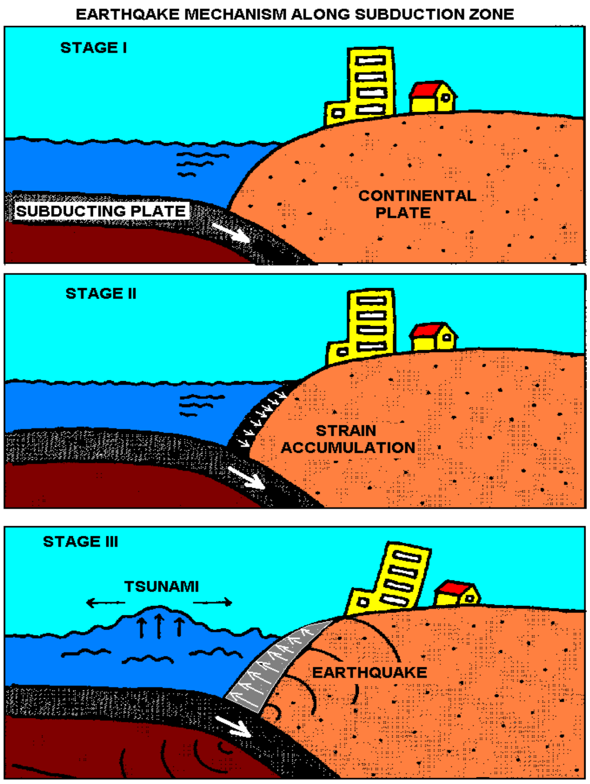


Figure 4.7 An illustration of the subducting plate-boundary earthquake

(Re-arrangement of a figure from a Japanese newspaper source)

4.2.3 Rupture propagation and slip characteristics

The rupture and slip characteristics estimated by several researchers are given in Table 4.2. Assuming that the inclination of the fault plane is about 10^o, the vertical component of the relative displacement should range between 1.5 and 3.5m. The measurements of the coastal line in Simeulue Island nearby the earthquake epicenter by Sieh confirmed these estimations.

Table 4.2 Rupture and slip characteristics of the earthquake fault

Reference	Magnitude	Length	Slip(m)	Area(km^2)
Yamanaka(ERI)	9.0	850(3segments)	8.9	850x200
Yagi (BRI)	8.7	700	18.6	700x140
Ji(Caltech)	9.0	400(1st)	20.0	400x50
Borges et al.	9.0	1000	9.0	1000x150
Taymaz(ITU)	9.0	450	9.5	450x200
Dasgupta(India)	9.0	1000	15.0	1000x100
Aydan	8.6(Ms)	975	9.75	975x45

Several researchers estimated the rupture propagation of the causative fault, and their results are shown in Figure 4.8 to 4.11. It seems that the causative fault was segmented. Depending upon the solutions, the segment number ranges from 2 to 5. The solutions released by ERI, BRI and ITU are all based on Kikuchi's method. The longest segment was very close the Banda Aceh and the distance between highest energy release point and Banda Aceh is about 80-100km. Since there could not be any direct observations on the causative fault plane, the computed results and observed aftershock activity could only give a rough idea about the faulting process and its dimensions. It should also be noted that the slip distributions inferred from those solutions should rather correspond to high-energy release locations rather than the actual relative slip, which may involve both elastic and inelastic components.

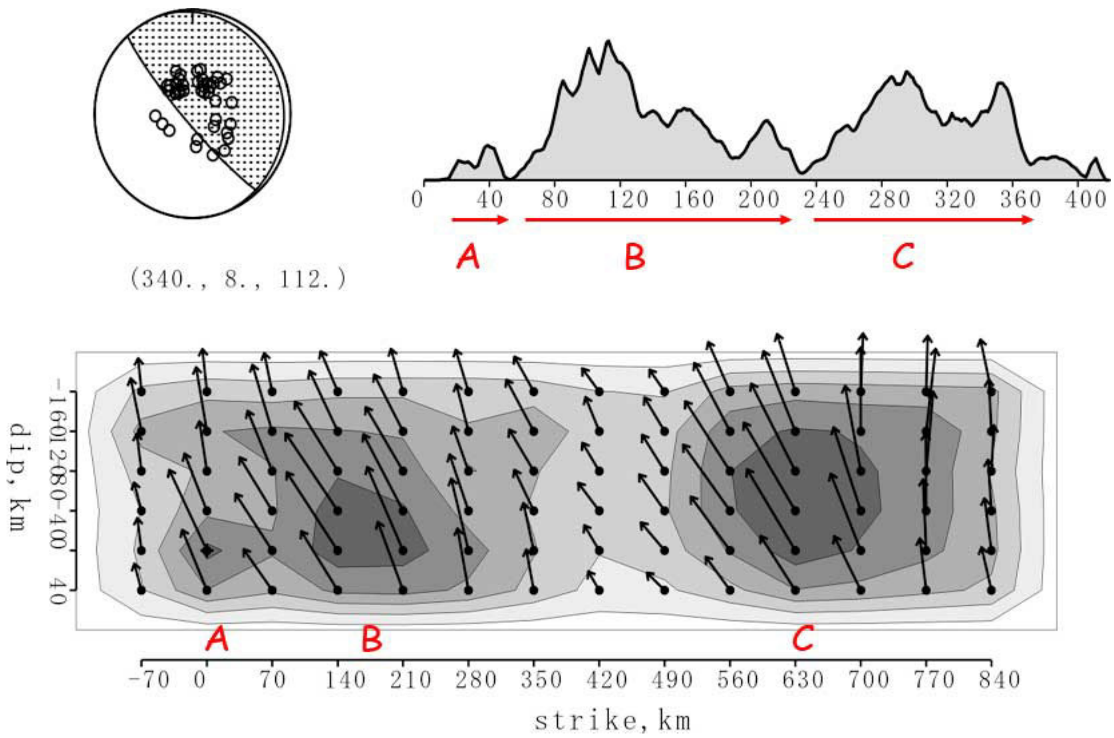


Figure 4.8 Inferred fault mechanism and slip distributions by Yamanaka (ERI)

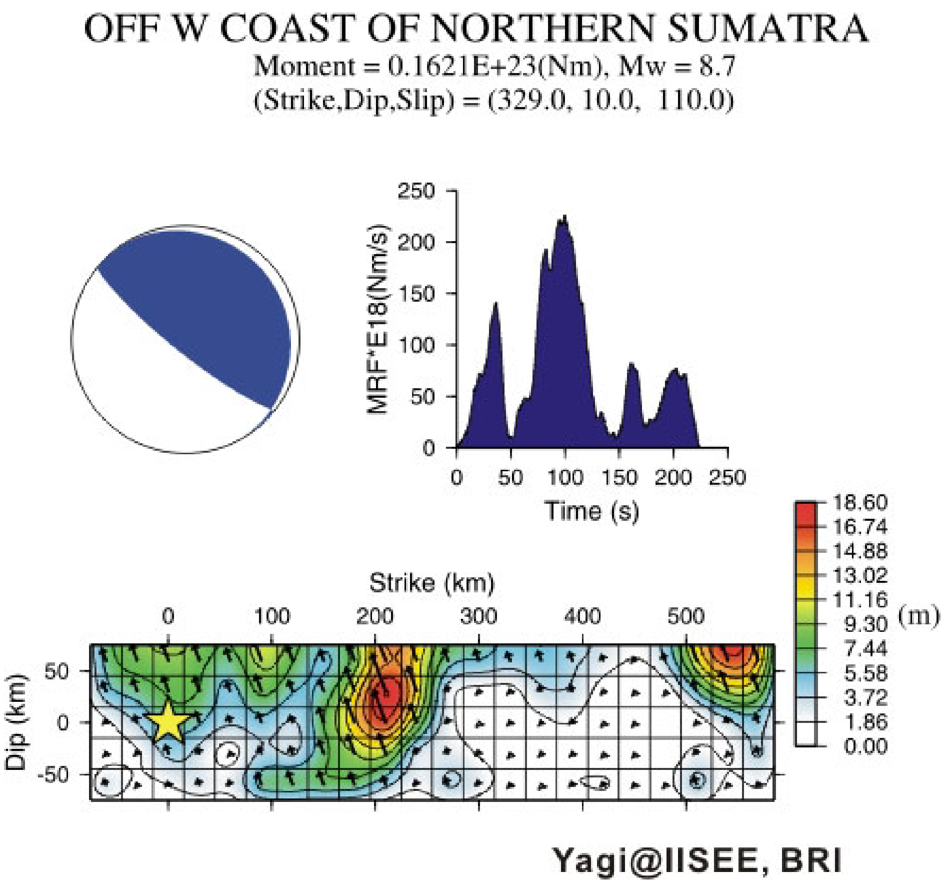


Figure 4.9 Inferred fault mechanism and slip distributions for first event by Yagi (BRI)

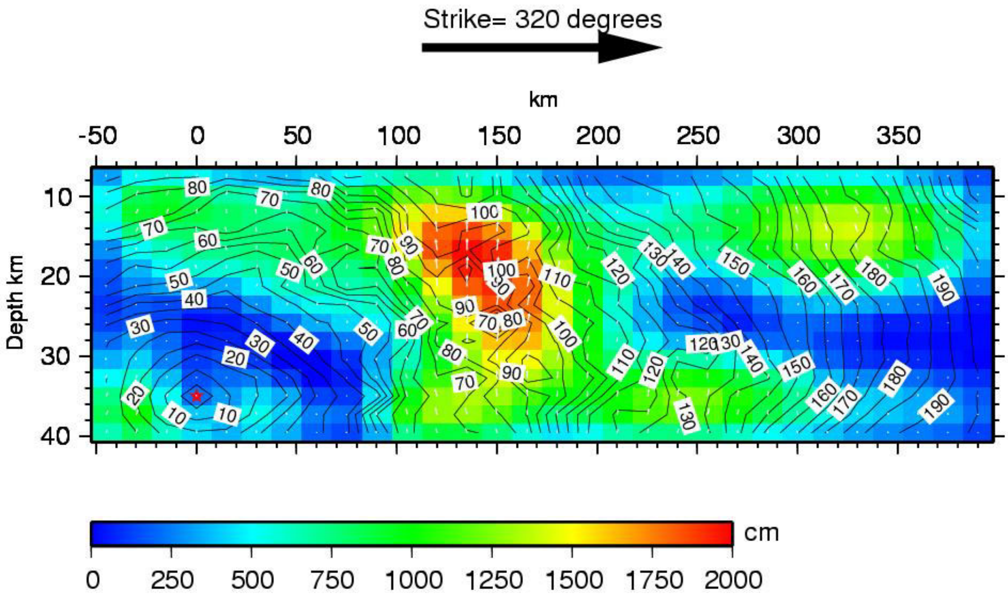


Figure 4.10 Inferred slip distributions for first event by C. Ji (Caltech)

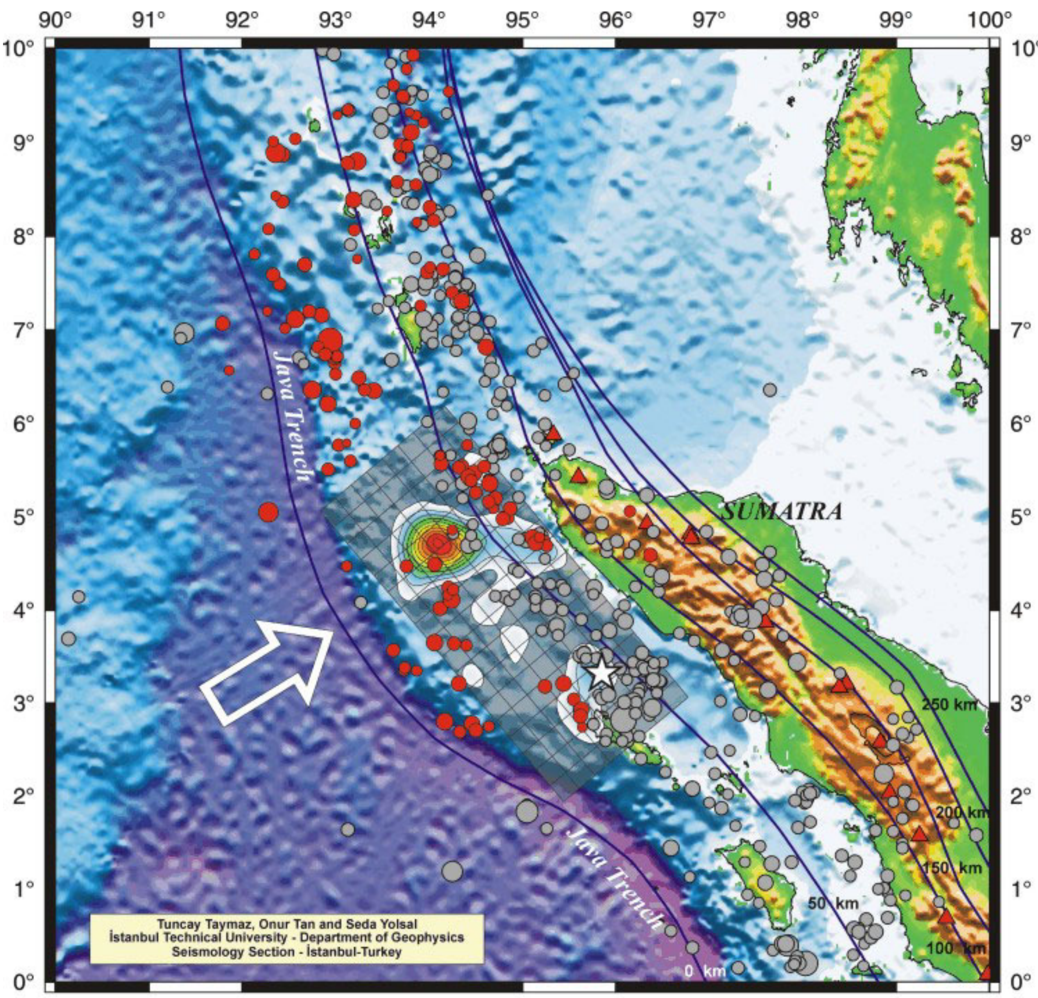


Figure 4.11 Inferred slip distributions by Taymaz et al. (ITU)

4.2.4 Fault Plane Solutions of Aftershocks

The aftershock activity was distributed over 1300km long and 200km wide area as seen in Figure 4.12. The fault plane solutions indicated that the aftershocks had basically the similar characteristics to those of the main event. Nevertheless, some strike-slip events also took place. In addition, some normal faulting events took place on the eastern side of the Sunda trench in Andaman Sea. The largest aftershock event had a magnitude of 7.3 and occurred near Nicobar Island of India on the same day.

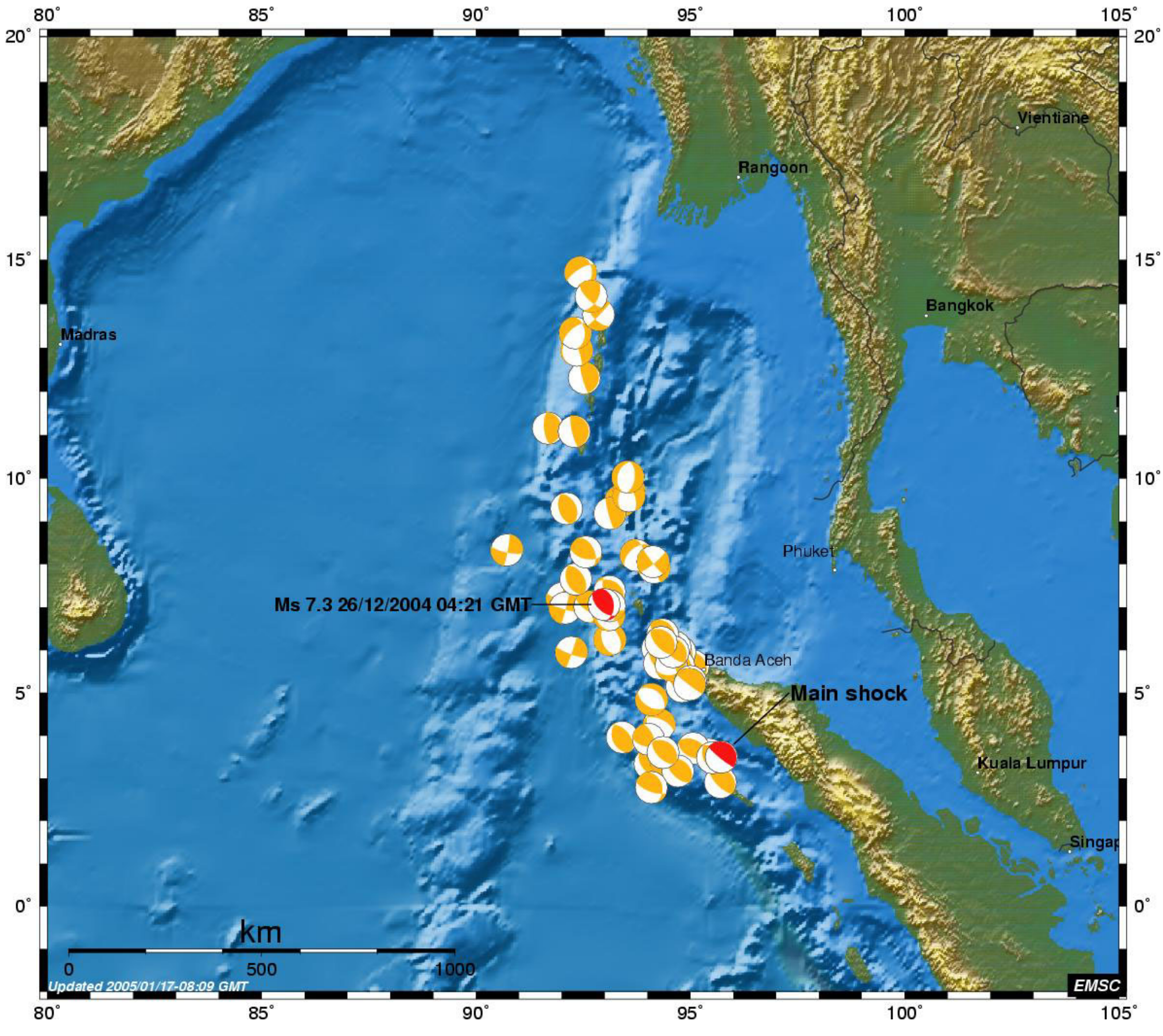


Figure 4.12 Fault plane solutions of the main event and aftershocks (EMSC)

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