

Focal Mechanism Analysis of the Earthquakes Beneath the Sunda-Banda Arc Transition, Indonesia, Using the BMKG Data

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Abstract. Structural complexity in the Sunda-Banda arc transition is a topic of much debate amongst Earth scientists. We have processed focal mechanism study using moment tensor inversion for 20 events in the region using the Agency for Meteorology, Climatology, and Geophysics (BMKG) data from 2014-2016 for earthquakes of magnitude $M_w \geq 5.0$. Our result shows different solutions that depend on the source region of the earthquakes that include subduction zones and collision zones, which host active faults and the back-arc thrusts. Earthquakes that occurred in the subduction zone appear to rupture on thrust faults for shallow and intermediate events, while the deep events have normal fault mechanisms. The shallow events in the collision zone occur on thrust faults with differing strike directions, but generally, there are largely parallel to the Timor trough. We also found normal fault mechanisms at play for deep events below the collision zone. The occurrence of deep earthquakes in this area is consistent with remnant slab activity that persists to the present day. Focal mechanism solutions for shallow events in the north of Sumbawa island indicate a thrust fault with a strike direction that is almost parallel to the back-arc thrust in this area. We also found evidence of strike-slip motion along local-scale active faults in the area.

Keywords: Focal mechanism, earthquakes, Sunda-Banda Arc.

1. Introduction

The Sunda-Banda arc transition lies at the confluence of the eastern end of the Australian plate subduction margin, defined by the Sunda arc, and the western section of the collision between the Australian plate and the Banda arc. Based on the Agency for Meteorology, Climatology, and Geophysics (BMKG) earthquakes catalog from 1975 to 2018 that spans the Sunda-Banda arc transition, there have been 40 destructive earthquakes that resulted in fatalities, three of which were followed by a tsunami:



The 1977 Mw 8.3 Sumba earthquake and tsunami, the 1992 Mw 7.5 Flores earthquake and tsunami, and the 1995 Mw 6.5 Timor earthquake and tsunami [1]. Earthquakes in the region are a consequence of subduction, collision, back-arc thrust faults, and faults located on land. The structural complexity of the region and its importance in understanding fundamental plate tectonic processes has resulted in intensive discussions and disagreements amongst scientists, and more high-quality data is needed to achieve consensus. Since 9-10 Ma, the Australian continent has been effectively colliding with the western section of the Banda arc [2], along the islands of Timor, Sumba, and Flores [3]. Recent seismic tomography and earthquake relocation results suggest that the Indo-Australian slab is dipping at 10-30° from trench to the arc, before dipping more steeply down to the transition zone [4]. The slab dip along the Sunda arc is ~55–60°, while along the Banda arc it is ~75–80° [5]. In this study, we have conducted focal mechanism analysis to reveal fault types of shallow, intermediate, and deep earthquakes using moment tensor inversion for 20 events (magnitude $M_w \geq 5.0$) in the region using the BMKG station network from 2014-2016.

2. Data and Method

We used waveforms from 21 BMKG stations (Fig. 2) from March 2014 to March 2016. We used the ISOLA package [6] to perform moment tensor inversion. We used displacement data from at least three BMKG stations at a narrow epicentral location to invert for full moment tensors. The observed data were pre-processed using a low pass filter with a corner frequency of 0.01 Hz to 0.05 Hz and we used the Ak135 seismic velocity model in the inversion [7]. The ground motion recorded by a seismometer can be viewed as a convolution of three processes: The earthquake source, the response of the Earth's crust, and the seismometer response. The source is defined by a tensor (\mathbf{m}) and the Green's function describes the impulse response of the medium through which the waves propagate. The best-fitting between synthetic and observed seismograms (example in Fig. 1) is essential for assessing the achievement of the inversion.

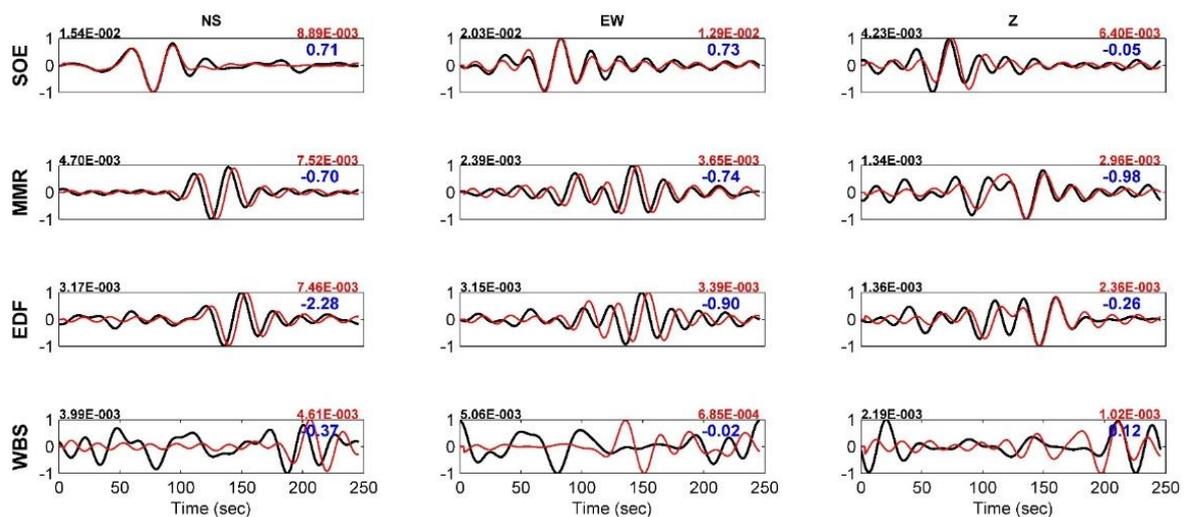


Figure 1. Example of waveform fitting for event number 17 (19 Nov 2014). Black and red waveforms are observation and synthetic waveforms, respectively. Blue numbers depict variance reduction (VR) values for each component.

3. Results and Discussion

We have calculated focal mechanism solutions of 20 events from the subduction zone, collision zone in the south of the islands, and the back-arc thrust fault in the north of islands (Table 1 and Fig. 2). The similarity between the observed and synthetic waveforms can be expressed as a variance reduction (VR), where a VR value close to 1 indicates that our model predictions are close to the actual data predictions. The average VR value for the 20 events is 0.3 (Fig.3).

Table 1. List of the focal mechanism solutions along the Sunda-Banda arc transition.

Date	Time (UTC)	Lat (°)	Long (°)	Depth (km)	Mw	Nodal Plane 1			Nodal Plane 2			Event ID
						strike	dip	rake	strike	dip	rake	
30/05/14	00:56:21	-8.54	119.47	180	5.1	119	52	43	360	58	133	13
07/07/14	09:15:29	-7.27	123.6	561	5.4	150	27	-171	53	86	-63	6
06/08/14	11:45:29	-6.89	127.72	19	6.2	314	70	157	53	68	22	11
19/11/14	02:56:27	-10.47	123.92	27	5.1	71	60	84	263	31	100	17
31/01/15	17:30:10	-7.31	126.51	352	5.5	289	48	-37	46	63	-132	10
27/02/15	13:45:09	-7.85	122.61	483	7.0	41	22	-77	207	69	-95	4
10/06/15	22:01:34	-10.35	120.99	61	5.1	341	86	-177	251	87	-4	15
15/06/15	17:41:00	-9.67	125.13	23	5.8	170	20	36	46	78	106	19
15/06/15	22:09:50	-8.03	118.16	21	5.0	304	69	100	97	23	65	1
19/06/15	09:14:00	-9.03	127.32	49	5.0	127	48	137	249	59	51	20
02/07/15	07:04:31	-7.25	120.18	430	5.2	56	49	-18	158	77	-138	3
31/07/15	22:26:09	-7.68	118.24	23	5.0	77	59	74	286	35	115	2
17/08/15	23:39:32	-7.88	123.08	19	5.0	100	42	123	239	56	64	5
31/10/15	04:43:57	-9.13	124.12	65	5.0	287	53	99	92	38	78	18
03/11/15	21:25:04	-7.89	125.28	26	5.6	55	83	21	322	70	172	8
04/11/15	03:44:21	-8.2	124.95	12	6.5	47	62	-16	145	76	-151	7
15/12/15	19:01:47	-7.13	127.8	246	5.0	204	19	-147	82	80	-74	12
03/02/16	20:27:31	-9.99	123.46	20	5.1	70	80	121	176	32	18	16
12/02/16	10:02:30	-9.87	119.35	38	6.2	63	50	56	288	51	123	14
12/03/16	04:26:00	-7.66	125.87	16	5.2	32	63	62	261	38	132	9

The focal mechanisms of several events in the Sunda-Banda arc transition reveal different solutions that depend on the source of the earthquakes, which include subduction zones, collision zones, active faults on land, and back-arc thrust faults. Event 13 (180 km depth) and 14 (38 km depth) occurred in the subduction zone and are thrust faults with different strikes. The strike direction for event 14, located in the south of Sumba island is roughly trench parallel, while event 13 is more trench-perpendicular. The northern boundary of the Scott Plateau now lies below the Sumba Ridge, this condition has resulted in the young thrusting north of Savu and Rote [8]. A deep earthquake that occurred beneath this area at 430 km depth (event 3) is a normal fault earthquake. This event may have been caused by a gravitational slab pull force that was more dominant than the buoyancy force at this depth. Event 15 is a shallow earthquake that occurred in the southeast of Sumba island on a strike-slip fault.

Event numbers 16, 17, 18, 19, and 20 are close to the collision zone between the Australian plate and the Banda arc and occur at depths of less than 100 km. They are all thrust fault mechanisms but with various strikes, though they are all roughly, parallel to the Timor trough. Event 4 (483 km depth) occurs on a normal fault with a strike almost parallel to the collision zone, and may be caused by the ongoing sinking of remnant slab material from the Australian plate that followed the collision millions of years ago. The presence of remnant slabs in the area has previously been shown by [4]. Furthermore, event 6 (561 km depth), event 10 (352 km depth) and event 12 (246 km depth) all have normal fault mechanisms that strike parallel to the collision zone.

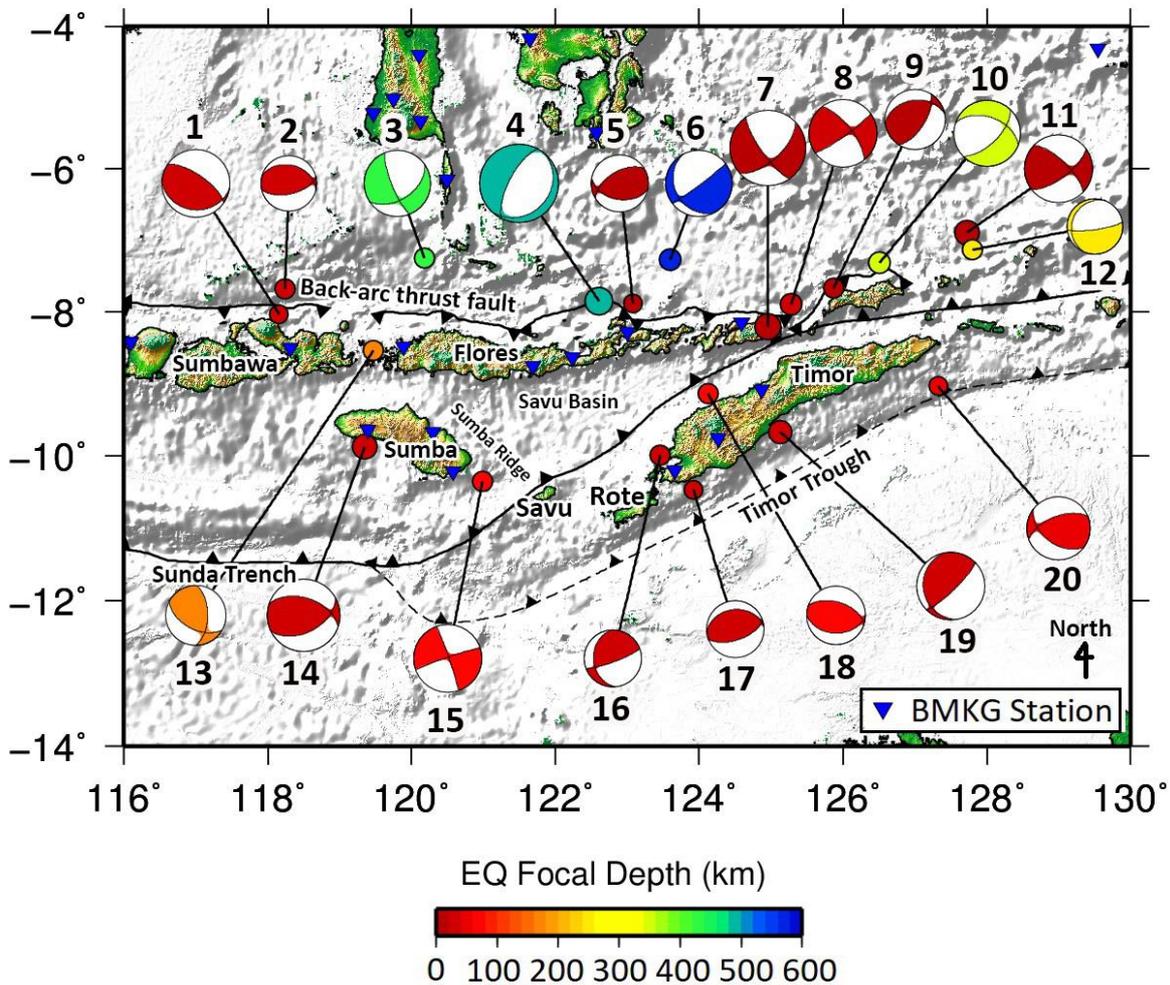


Figure 2. Map view of focal mechanism solutions along the Sunda-Banda arc transition. The black-arc thrust fault locations are taken from [9], while trench (solid line) and trough (dashed line) data are taken from [10]. The epicenters of earthquakes are represented by coloured circles as a feature of focal depth.

The occurrence of deep events in this area indicates that the remnant slab material is still capable of producing earthquakes in the present day. Events located along the back-arc thrust fault, i.e., event 1 (21 km depth), event 2 (23 km depth), and event 9 (16 km depth) indicate a thrust fault with a strike that is almost parallel to the back-arc thrust. The continental collision is the primary driving force behind the back-arc thrust in the eastern Sunda Arc [11]. The difference between back-arc thrusting mechanisms has a considerable influence on the development of the convergent margin [12]. Event 7 (12 km depth) and event 8 (26 km depth) are located in the north of Alor island and occurred on a strike-slip fault that trends northeast-southwest.

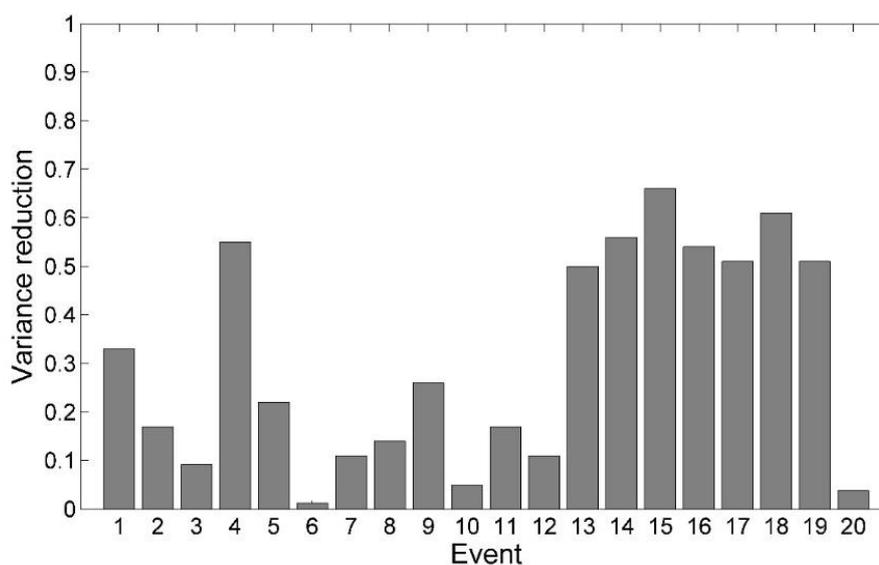


Figure 3. Waveform fitting variance reduction for the 20 events used in this study.

4. Conclusion

The focal mechanisms of shallow earthquakes in the subduction zone, collision zone, and back-arc thrust in the Sulu-Banda arc transition reveal thrust faulting, but the deep earthquakes reveal normal faulting, which may be related to the ongoing sinking of post-collisional slab remnants. Shallow earthquakes are also found to occur on active strike-slip faults with different orientations to the plate margins, and likely accommodate different movements caused by slip along a relatively complex configuration of thrust faults in the region.

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