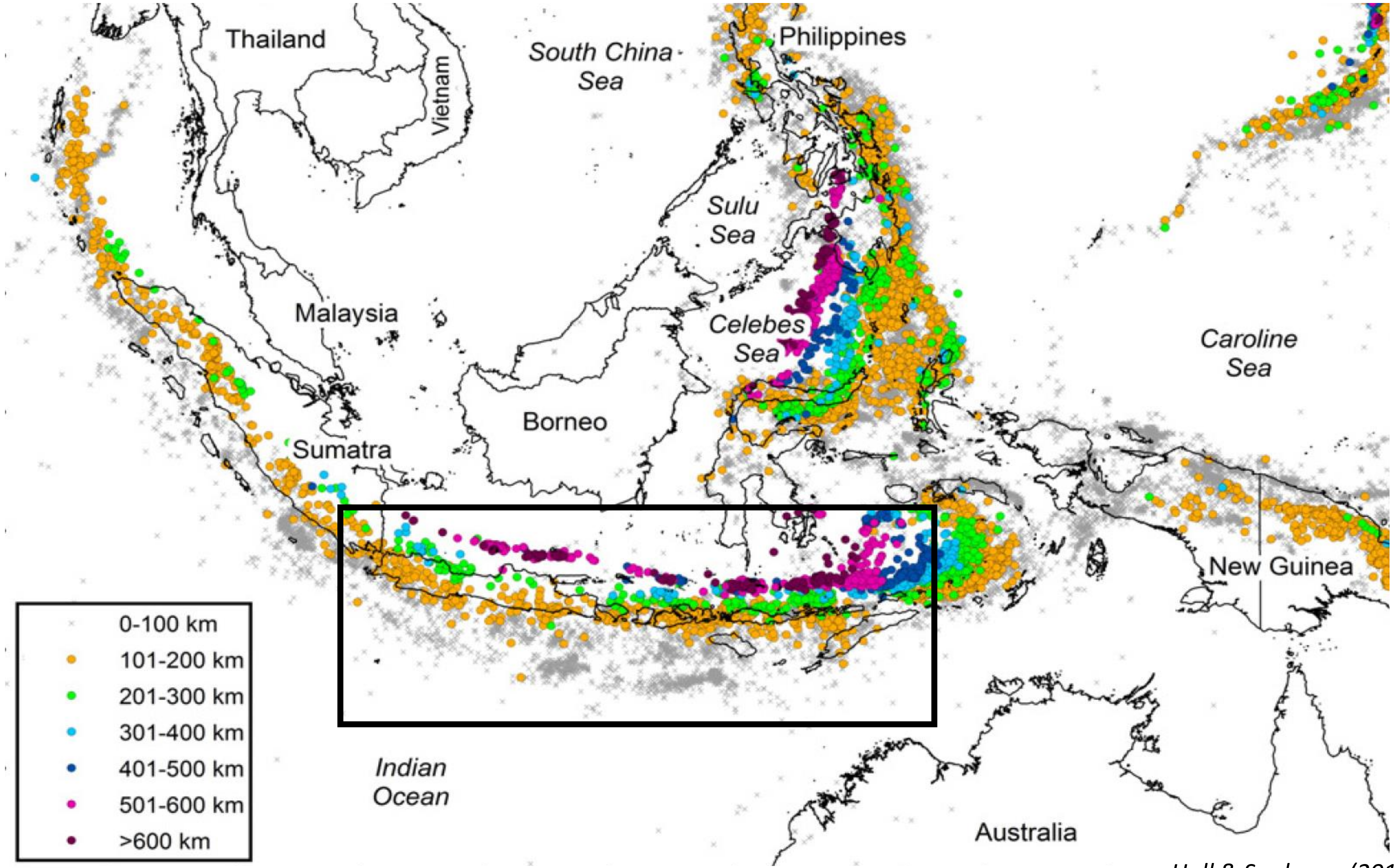
Memahami Geologi Kegempaan Megathrust Jawa – Nusa Tenggara, Intraplate Jawa Timur, dan Back-Arc Thrust Bali – Flores



Hall & Spakman (2015)

INSTITUT TEKNOLOGI SEPULUH NOPEMBER SURABAYA (ITS)
DEPARTEMEN TEKNIK GEOFISIKA

"Exploring the Earth Empowering Society"

Web Seminar # 34 - 21 Maret 2021

Awang Harun Satyana
Geolog Indonesia

Diskusi

1. **Tektonik Busur Sunda-Banda: Sumatra – Flores**
   Karakter geologi dan tektonik yang berbeda
2. **Gempa Megathrust Jawa – Sumbawa**
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   Shallow background earthquake, mungkinkah menghasilkan gempa >M 6+ ?
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   Kerak transisi – samudra Sundaland-Banda yang menekan Busur Sunda-Banda

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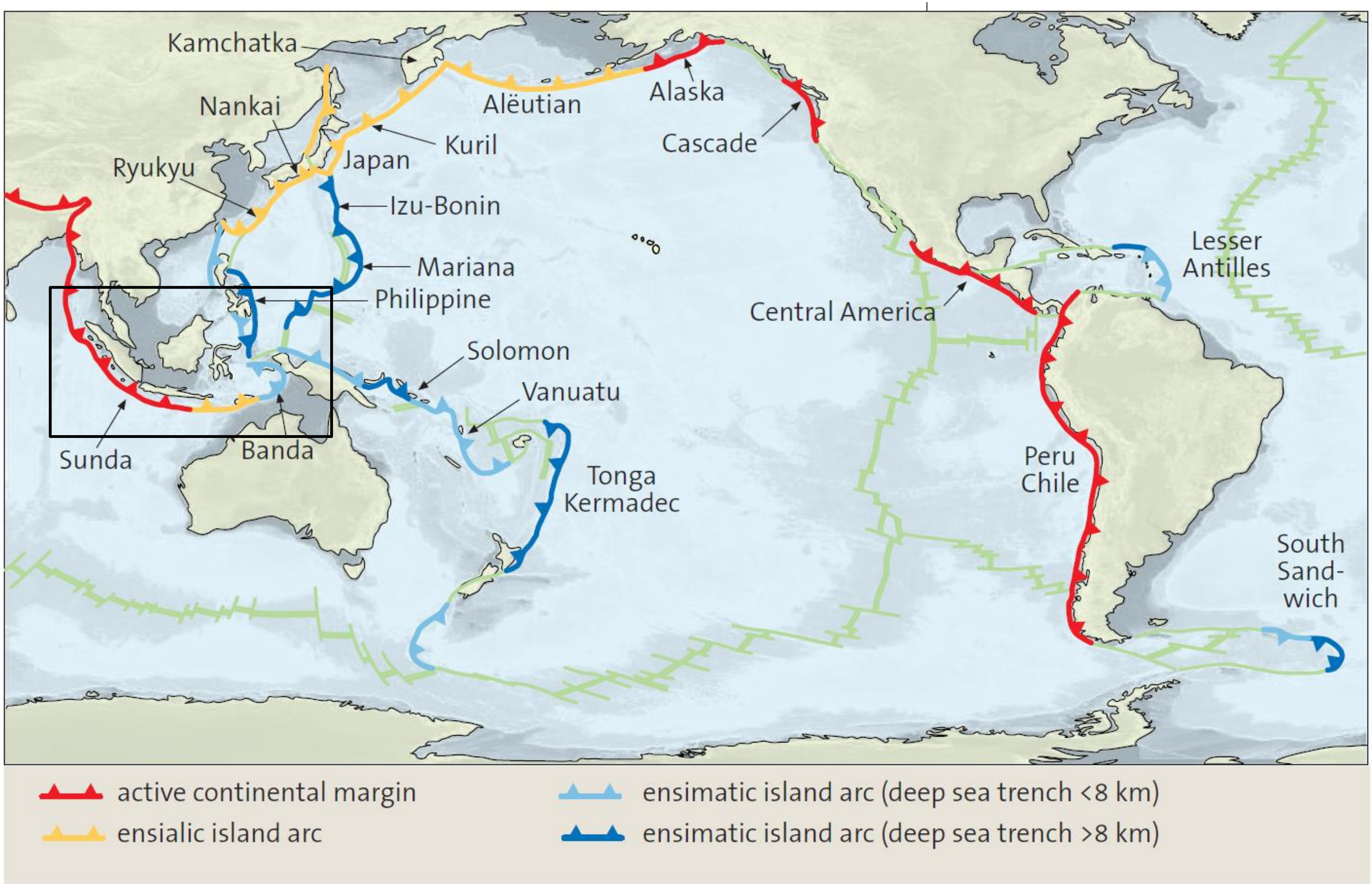
Convergent Plate Margins



Convergent plate margins of the Earth characterized by ensimatic island arcs (underlain by oceanic crust), ensialic island arcs (underlain by continental crust), and active continental margins.

Frisch et al. (2011)

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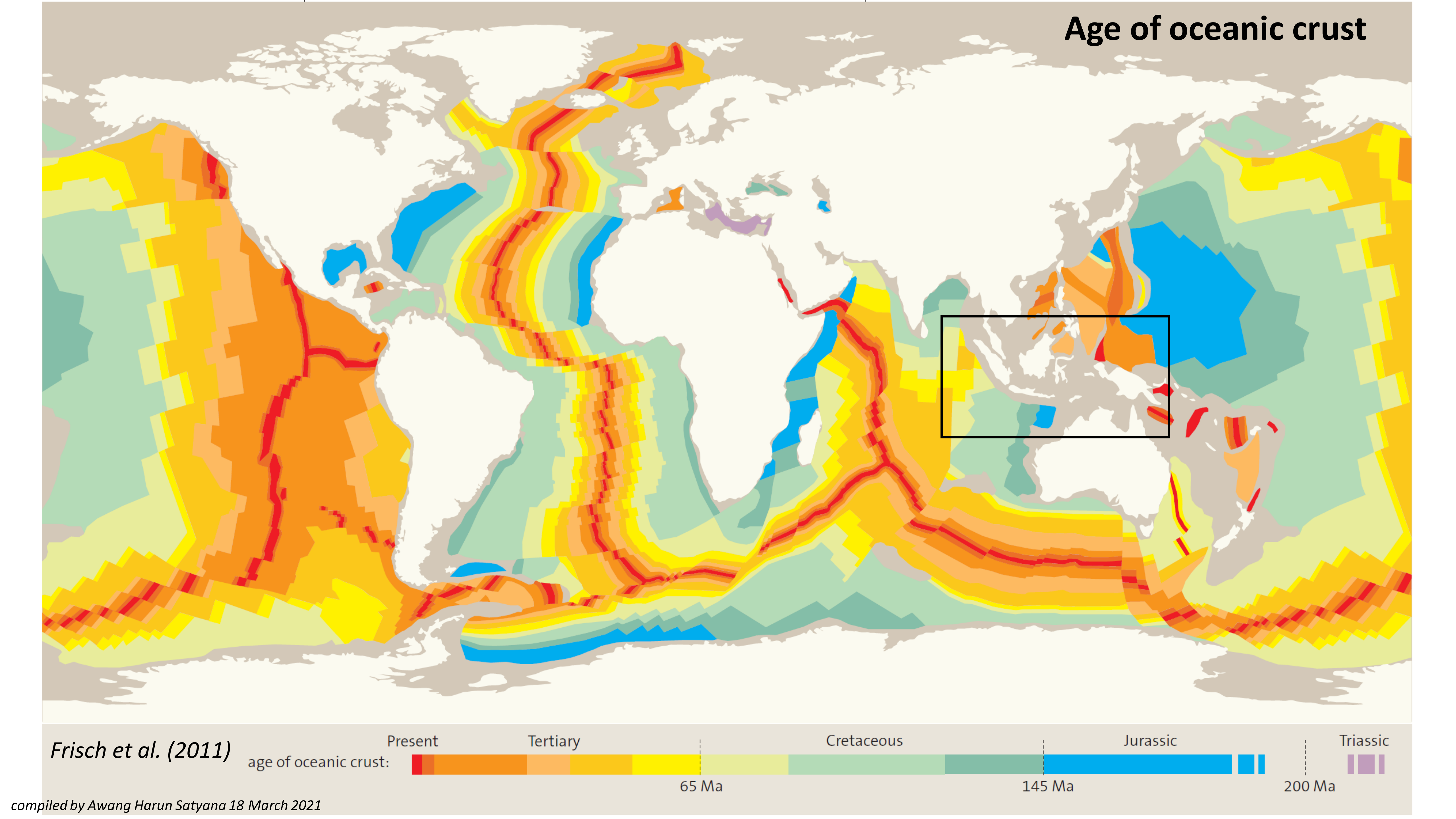
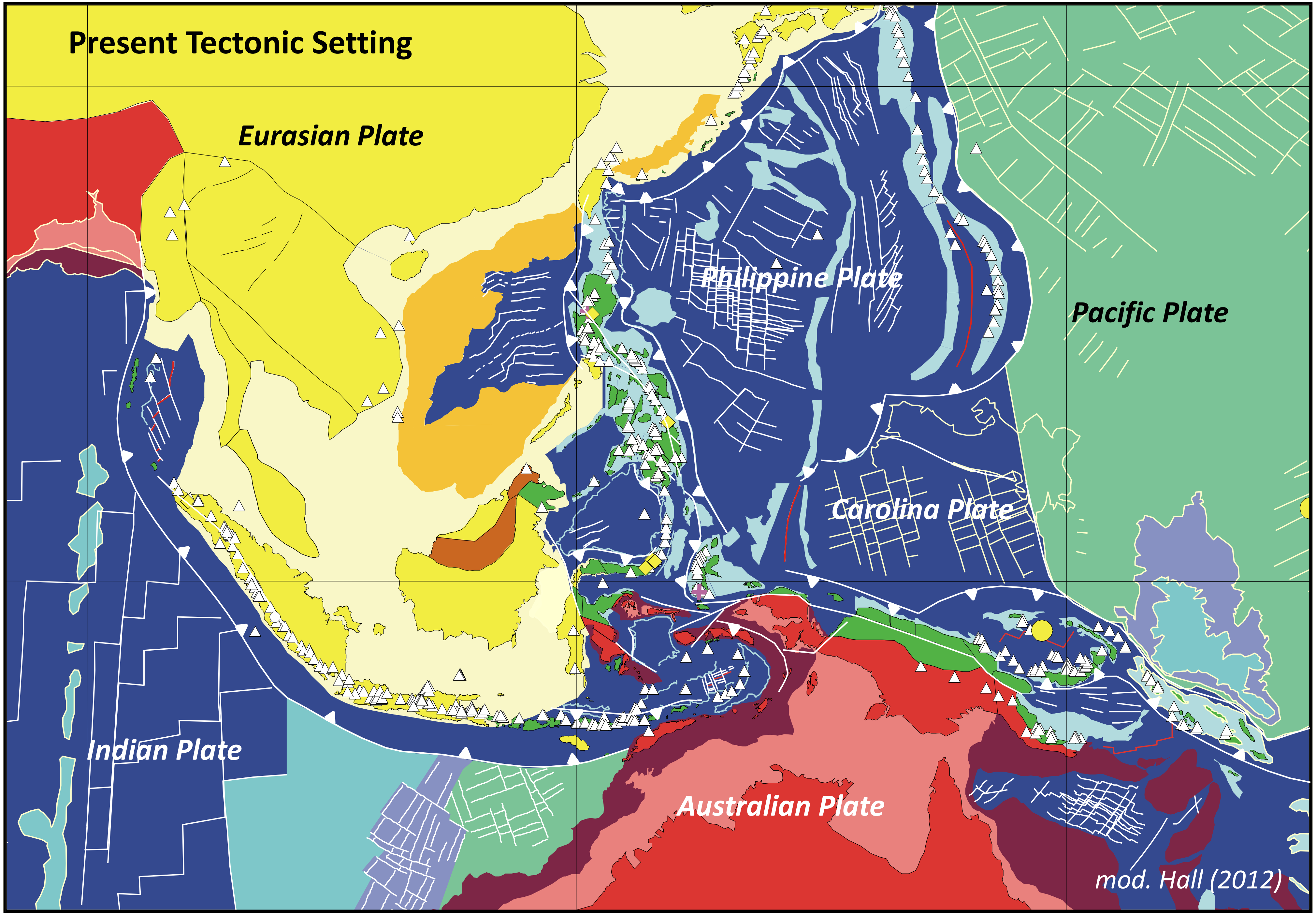

Age of oceanic crust
Frisch et al. (2011)
age of oceanic crust:
Present
Tertiary
Cretaceous
Jurassic
Triassic
65 Ma
145 Ma
200 Ma
compiled by Awang Harun Satyana 18 March 2021



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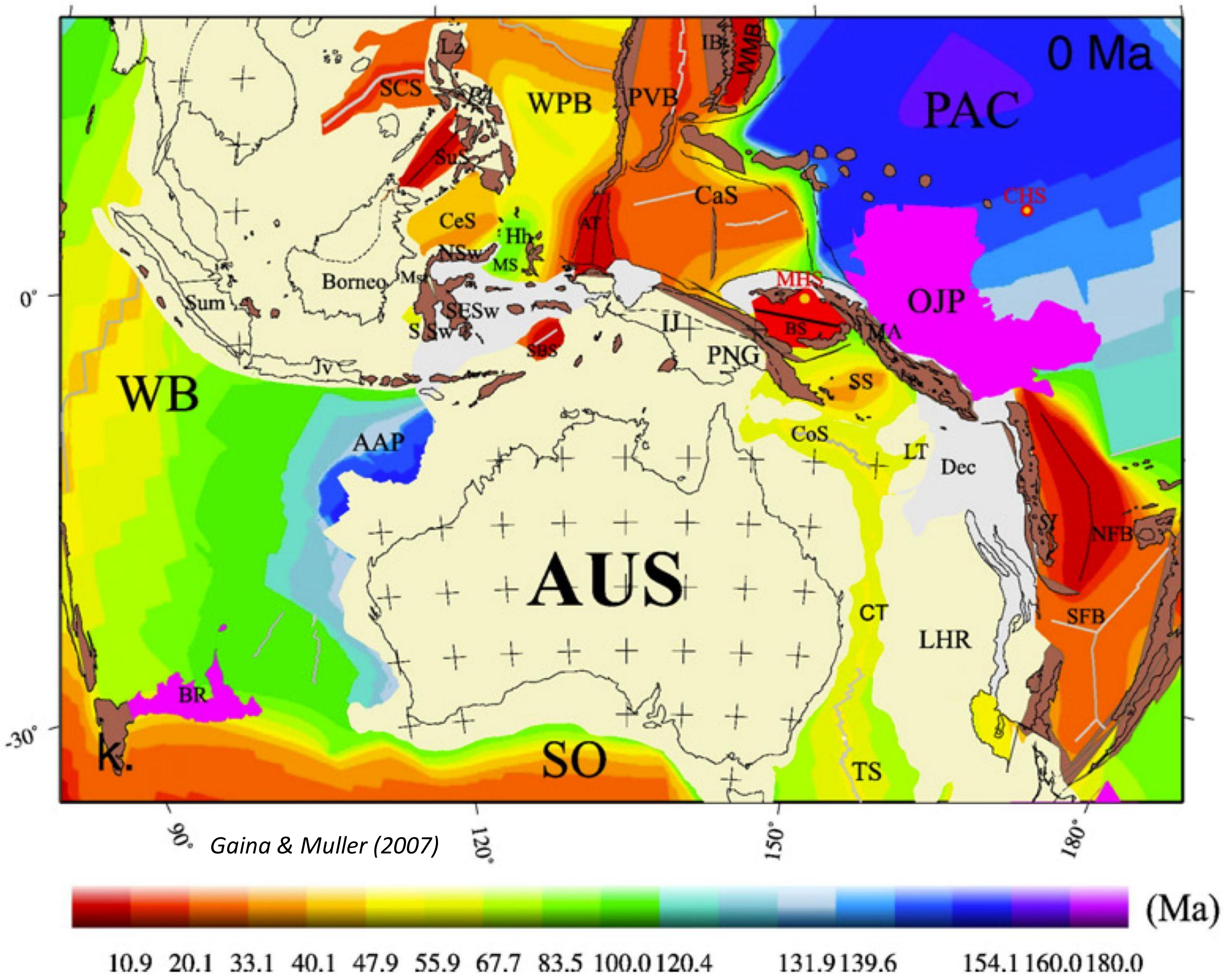
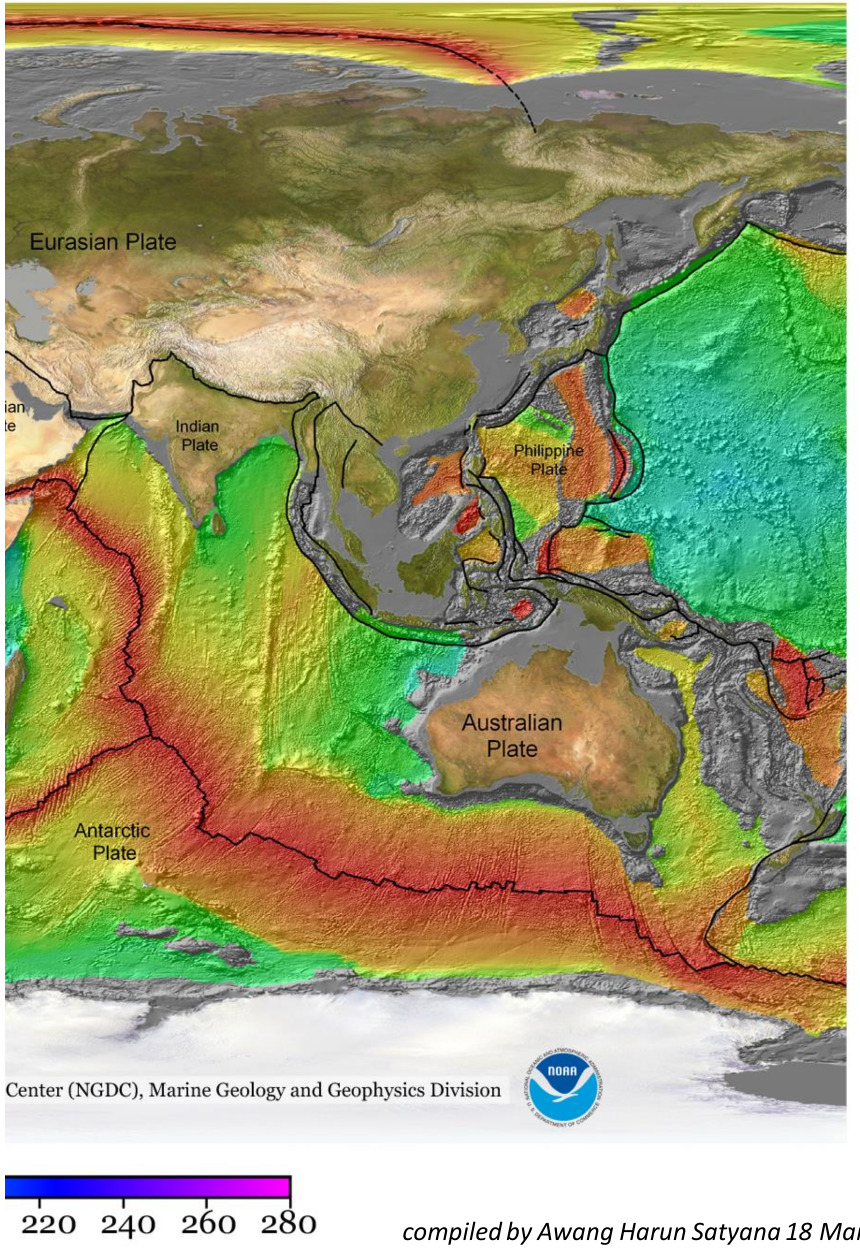
Age of Oceanic Lithosphere (m.y.)

Data source:

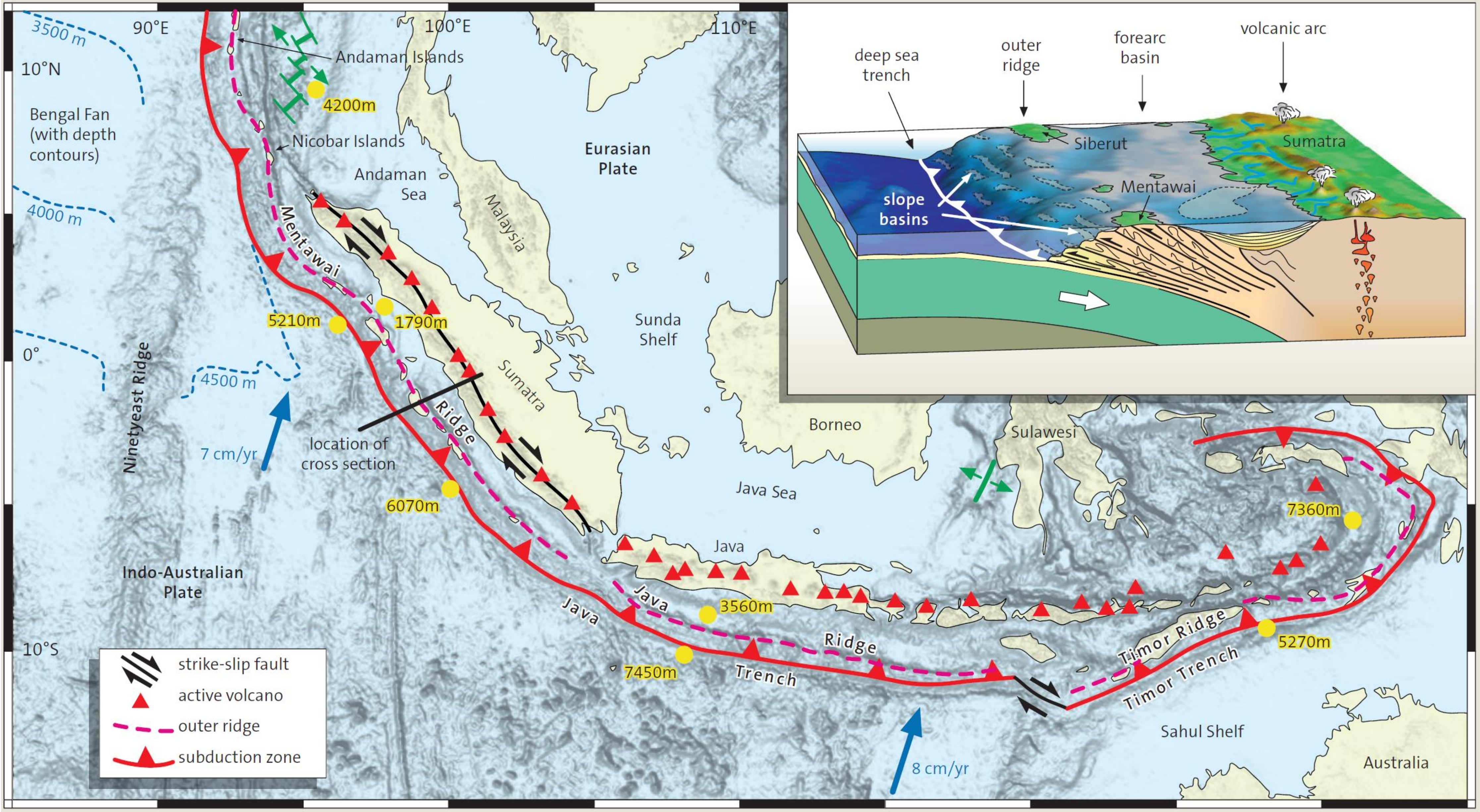
Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust,Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.



Gaina & Muller (2007)



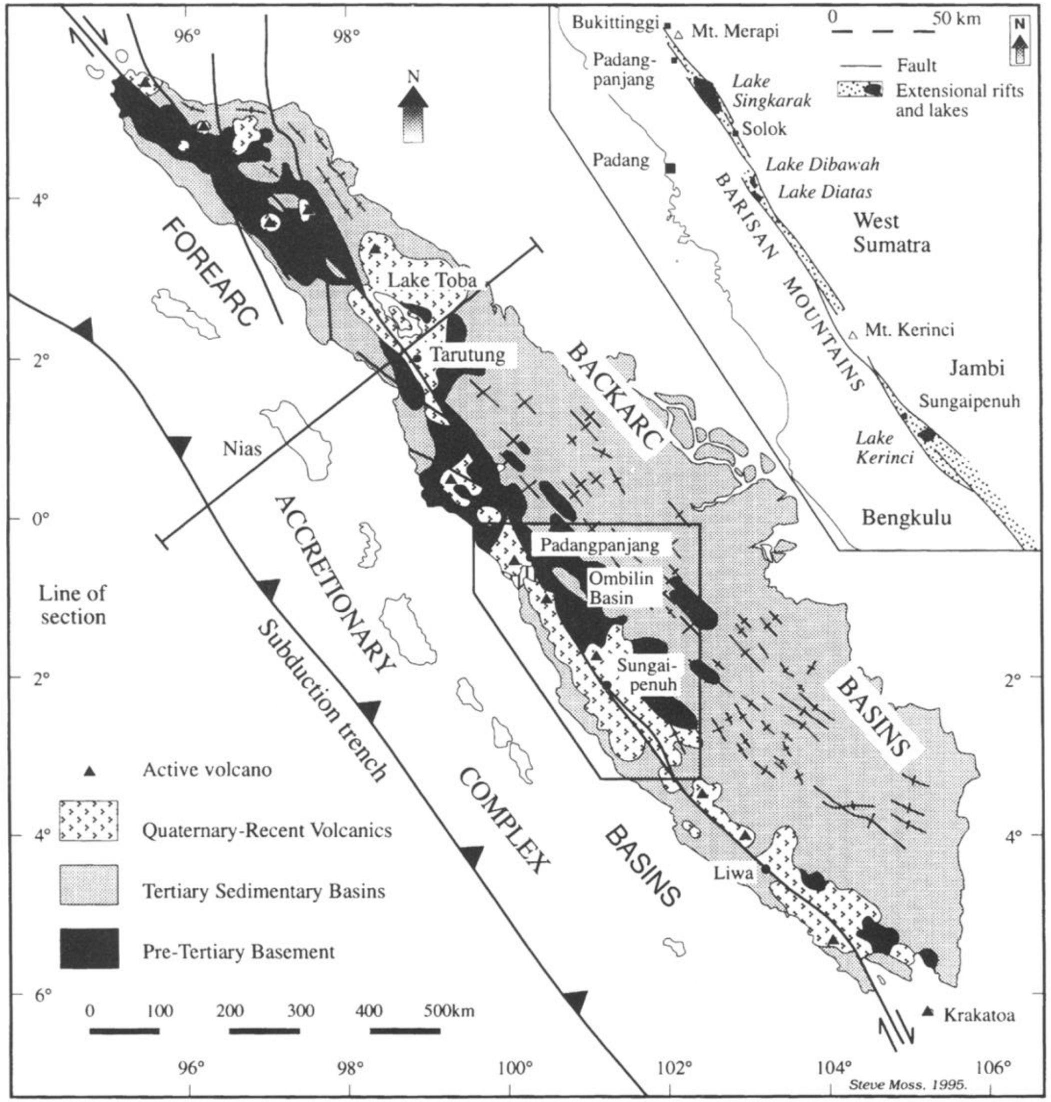
compiled by Awang Harun Satyana 18 March 2021

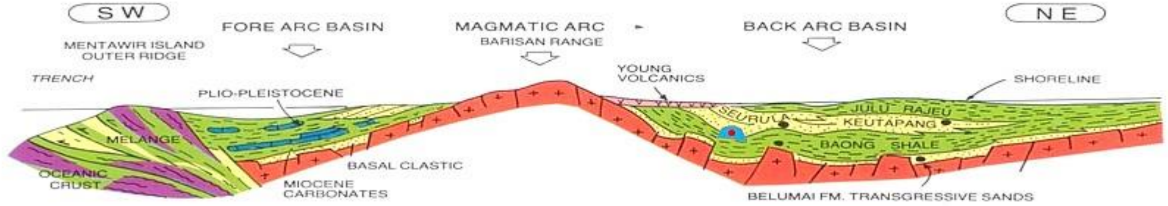


Map showing contrasting plate-tectonic conditions along the Sunda Arc. In front of Sumatra, sediment of the thick Bengal fan are scraped-off and incorporated into the accretionary wedge. This causes the outer ridge to emerge from the sea at this location (Mentawai Ridge – see insert). In front of Java, the deep sea trench and the outer ridge are significantly deeper. In front of Australia, the continental crust of the Sahul shelf is being subducted beneath the Sunda Arc; this causes a particularly strong uplift of the outer ridge (Timor Ridge) and marks the initial stage of orogenesis.

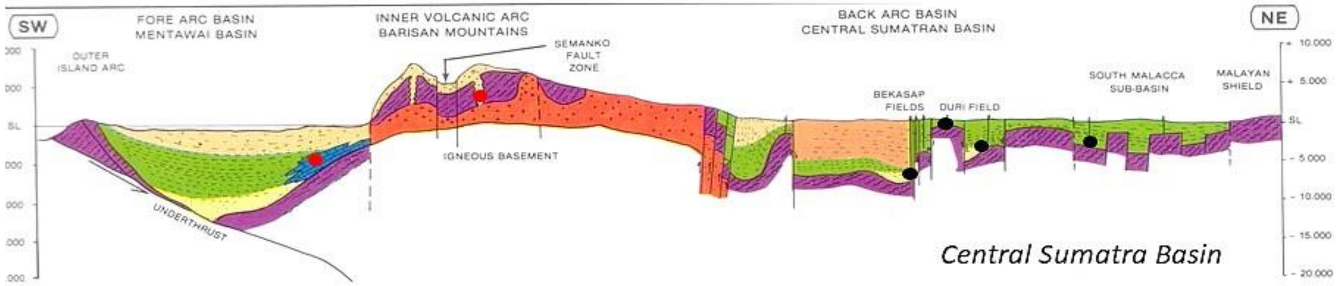
Frisch et al. (2011)

compiled by Awang Harun Satyana 18 March 2021

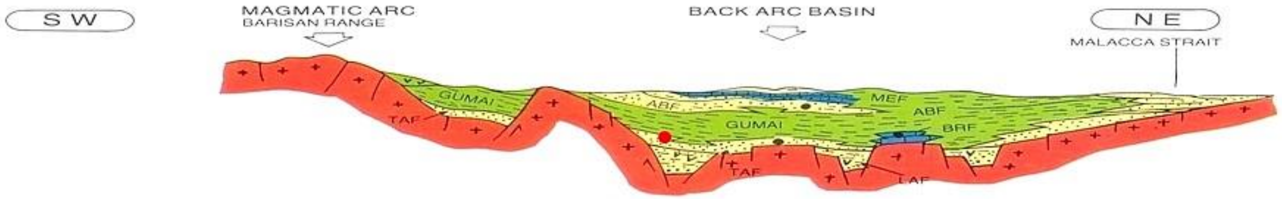




North Sumatra Basin

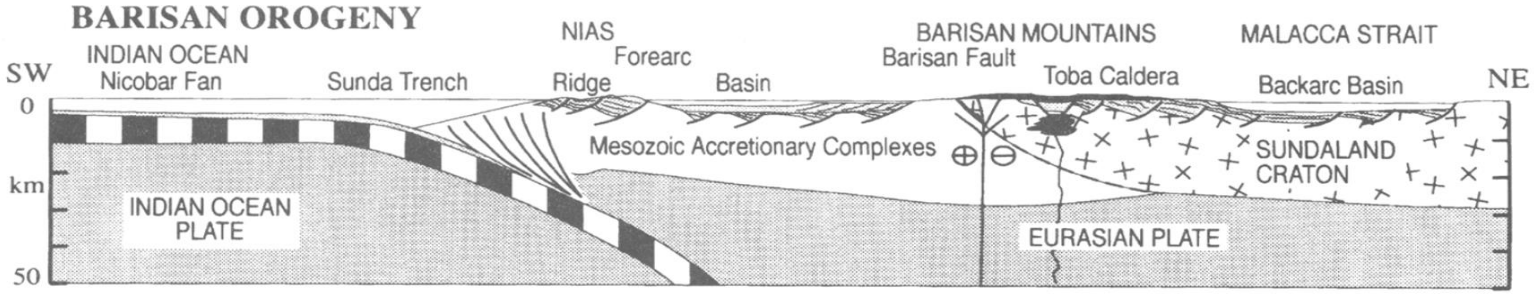


Central Sumatra Basin



Samuel & Gultom (1984)

South Sumatra Basin

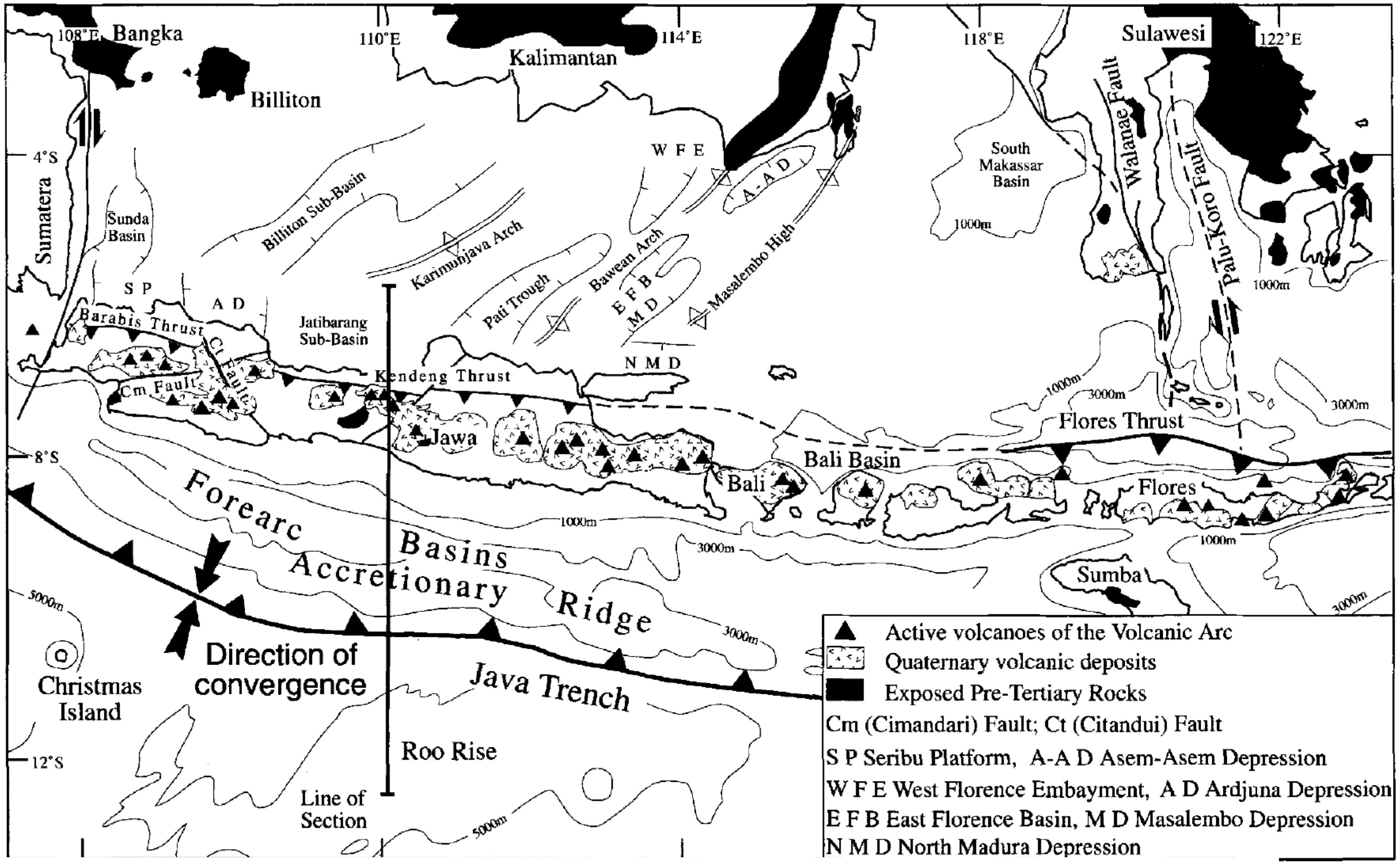


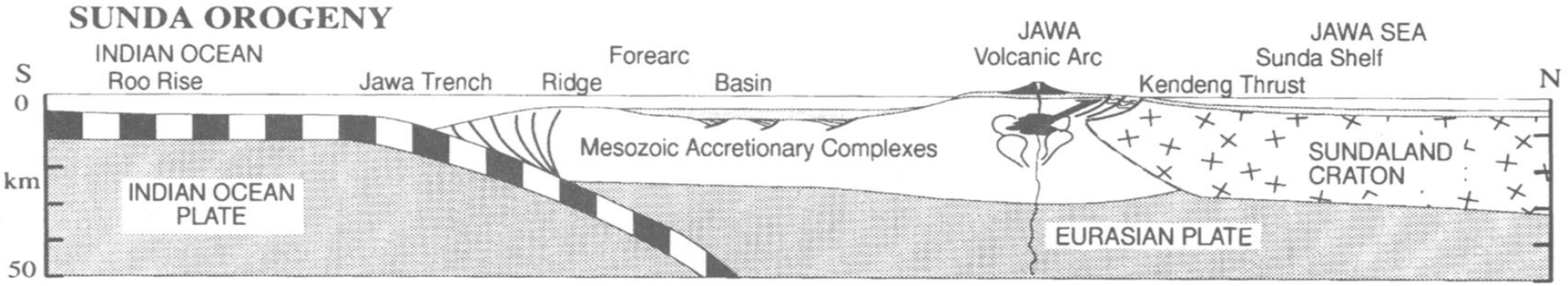
Sumatra tectonic setting

Simandjuntak and Barber (1996)

compiled by Awang Harun Satyana 18 March 2021

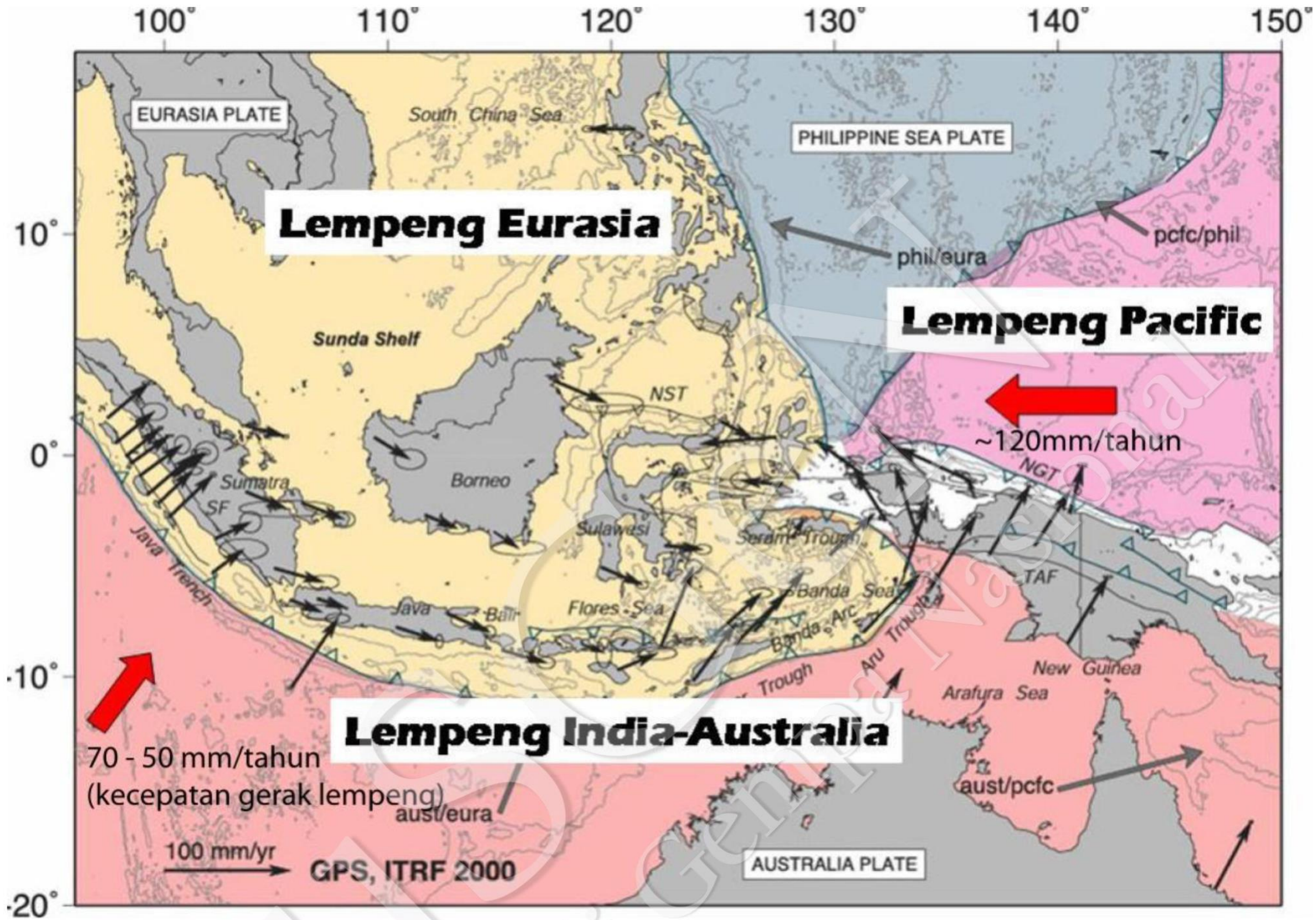
Java and Lesser Sunda tectonic setting





compiled by Awang Harun Satyana 18 March 2021

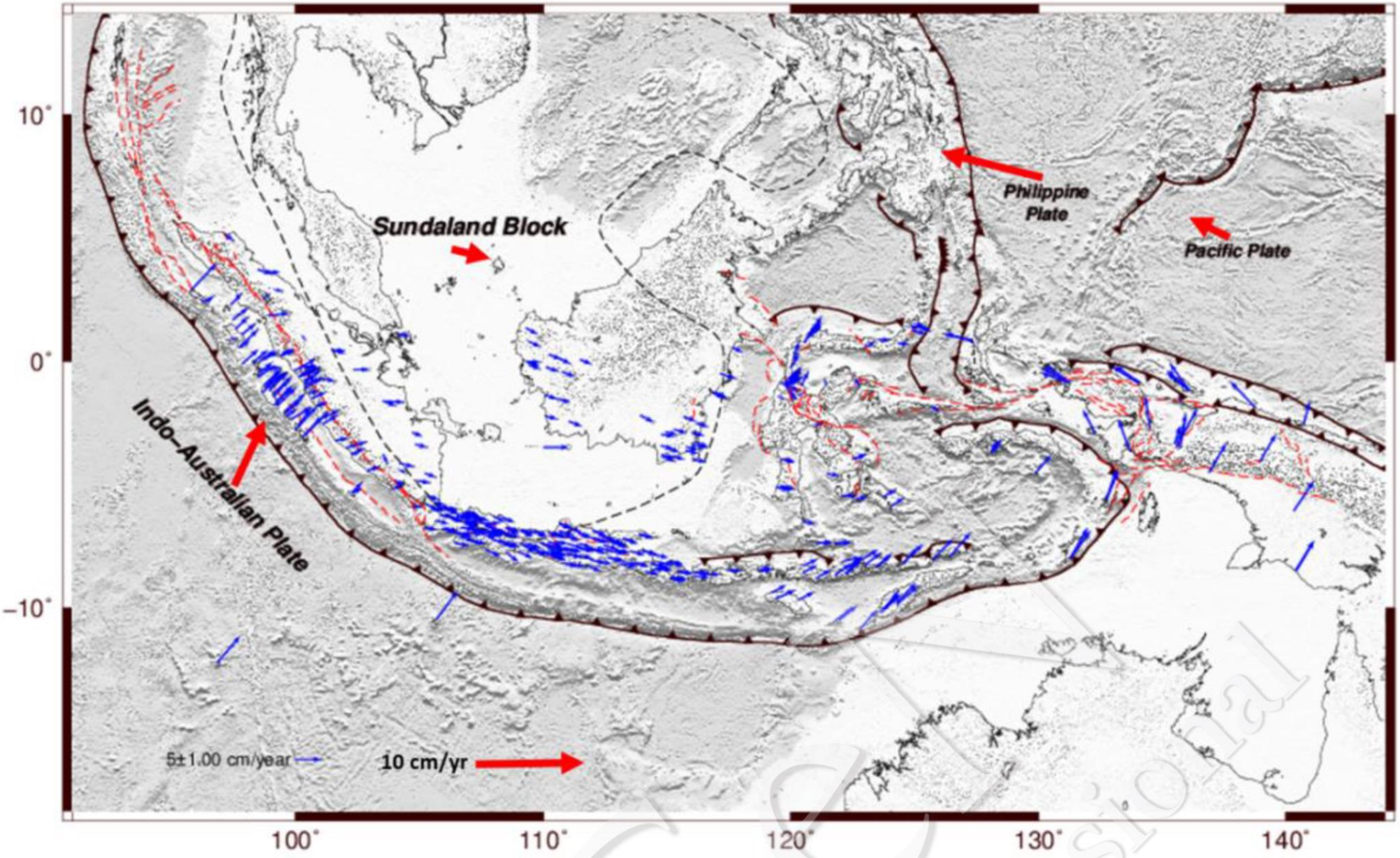
Simandjuntak and Barber (1996)



Tektonik aktif wilayah Indonesia, panah menunjukkan relatif pergerakan berdasarkan GPS (Bock et al., 2003)

Pusgen (2017)

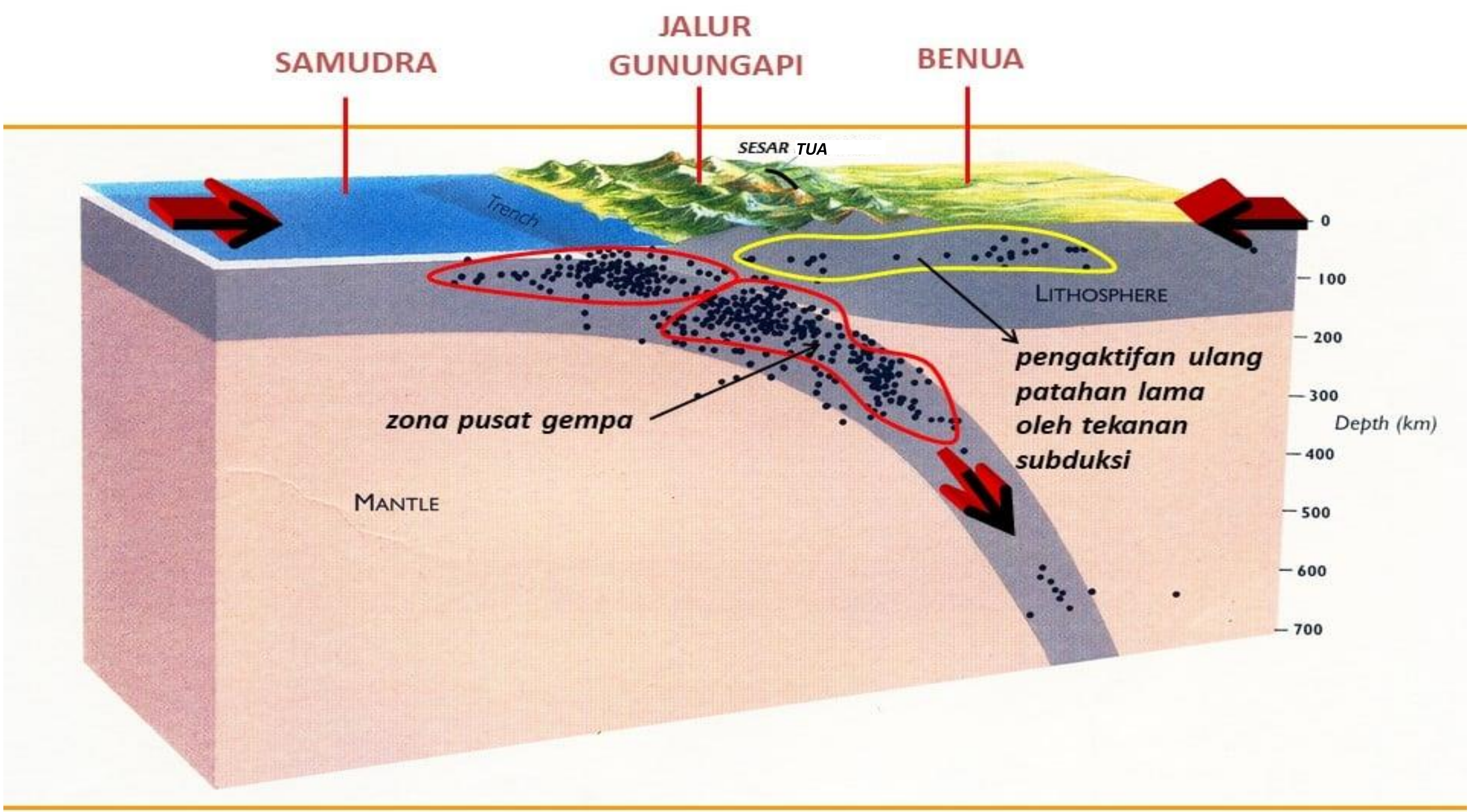
compiled by Awang Harun Satyana 18 March 2021



Kondisi tektonik wilayah Indonesia berdasarkan data geodetik tahun 1995 hingga tahun 2016 (Susilo dkk., 2016)

Pusgen (2017)

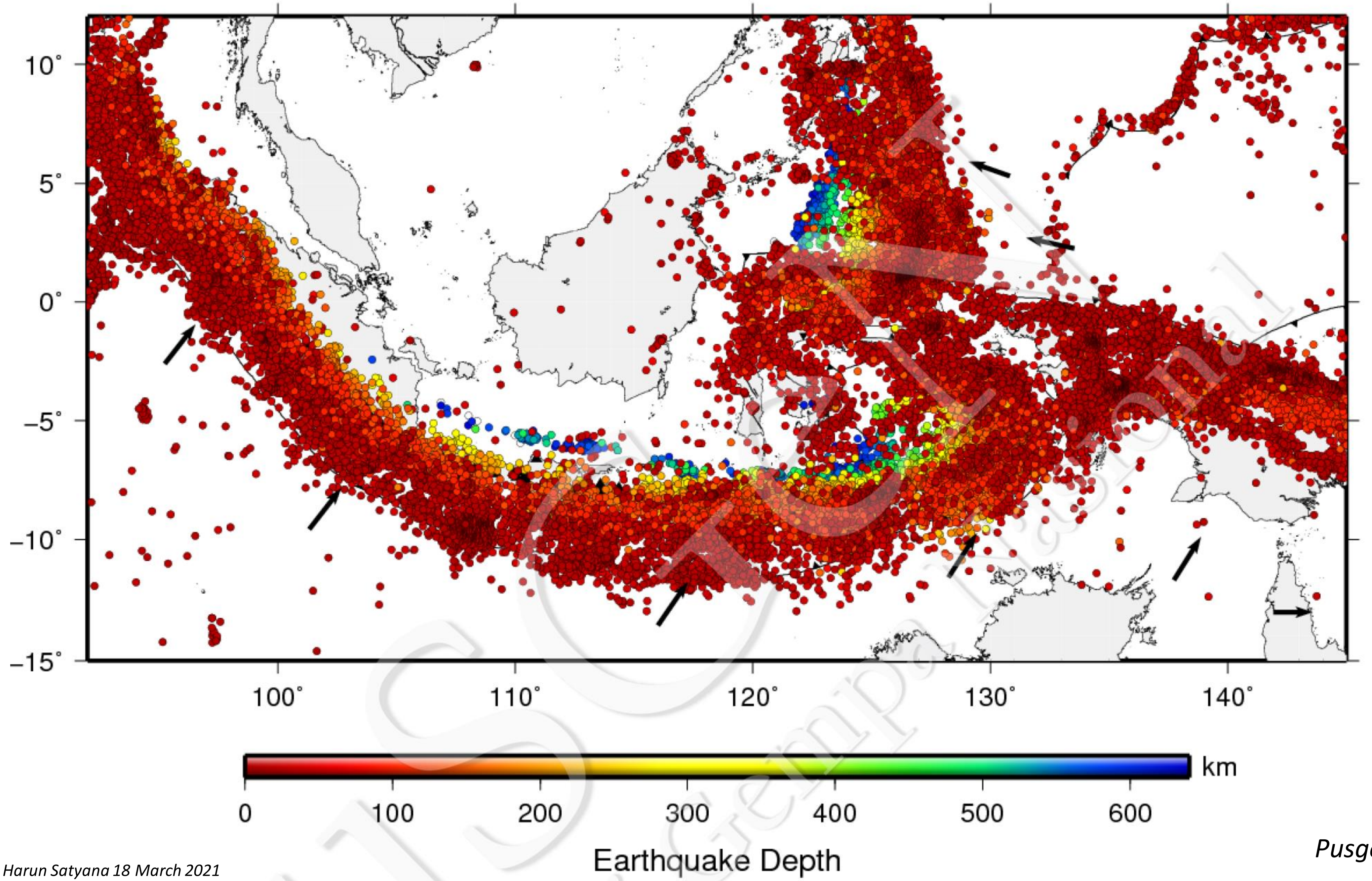
compiled by Awang Harun Satyana 18 March 2021



HUBUNGAN ANTARA GERAKAN LEMPENG DAN DISTRIBUSI PUSAT-PUSAT GEMPA

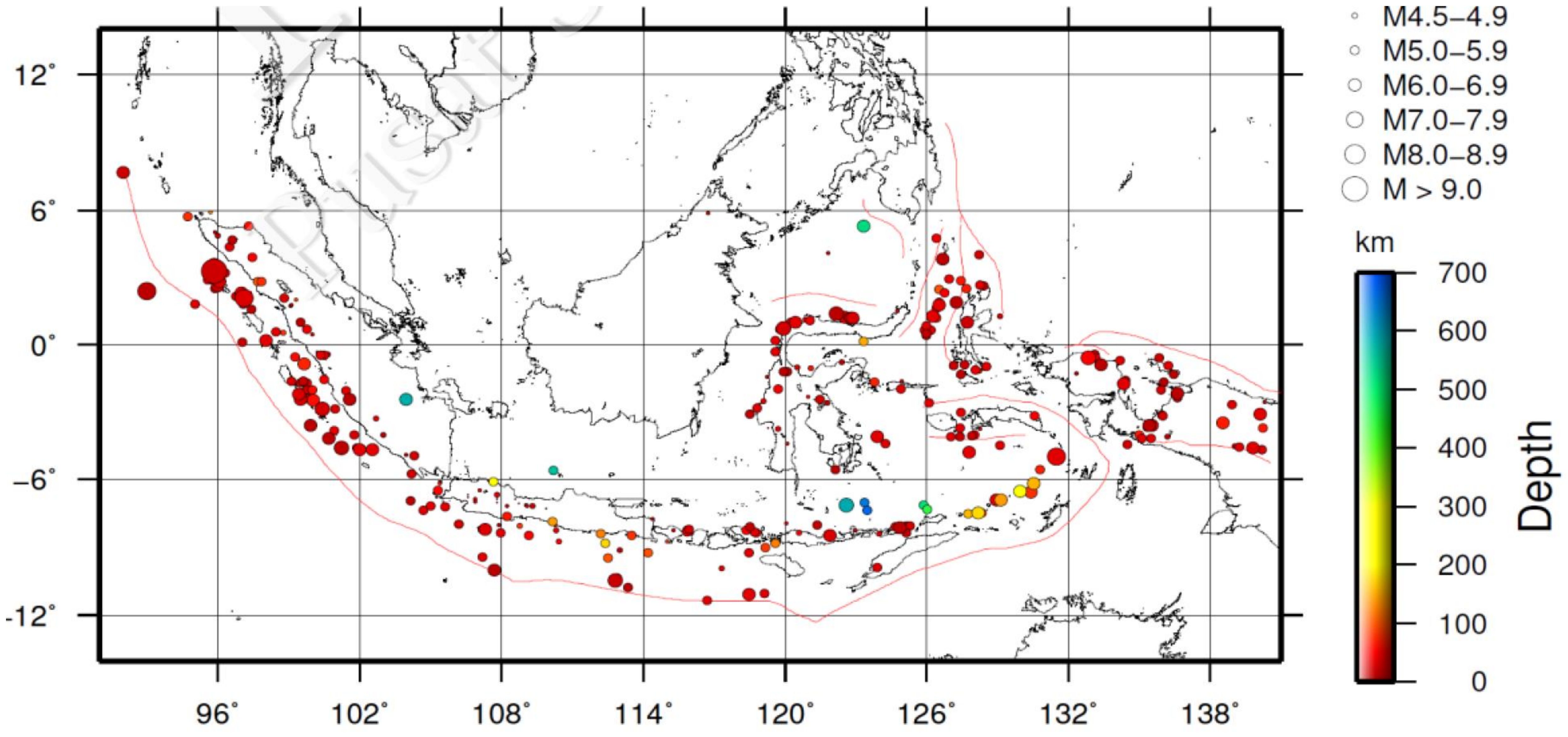
compiled by Awang Harun Satyana 18 March 2021

Gempa di Indonesia hasil relokasi hingga 2016 (Katalog Pusgen, 2016)



Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

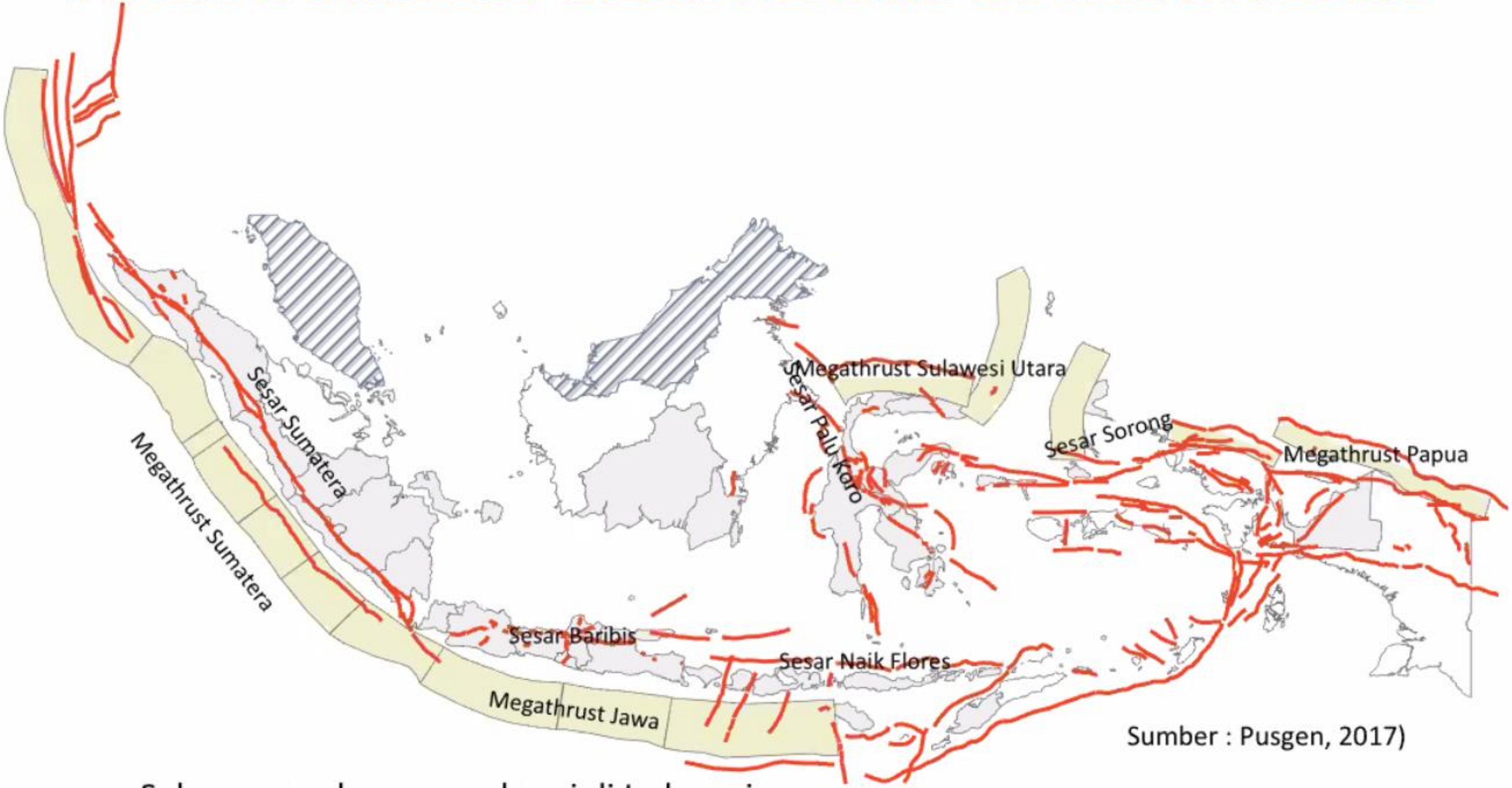


Peta episenter gempa merusak pada periode tahun 1938-2014 (Masturyono dkk., 2015)

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

PETA SUMBER GEMPABUMI DI INDONESIA



Sebaran sumber gempabumi di Indonesia :

- ✓ Zona penunjaman terletak di laut.
- ✓ Zona Benioff/ Interplate bisa di darat.
- ✓ Sesar aktif dominan di darat dan ada beberapa di laut

Faizal –Pusgen (2020)

compiled by Awang Harun Satyana 18 March 2021

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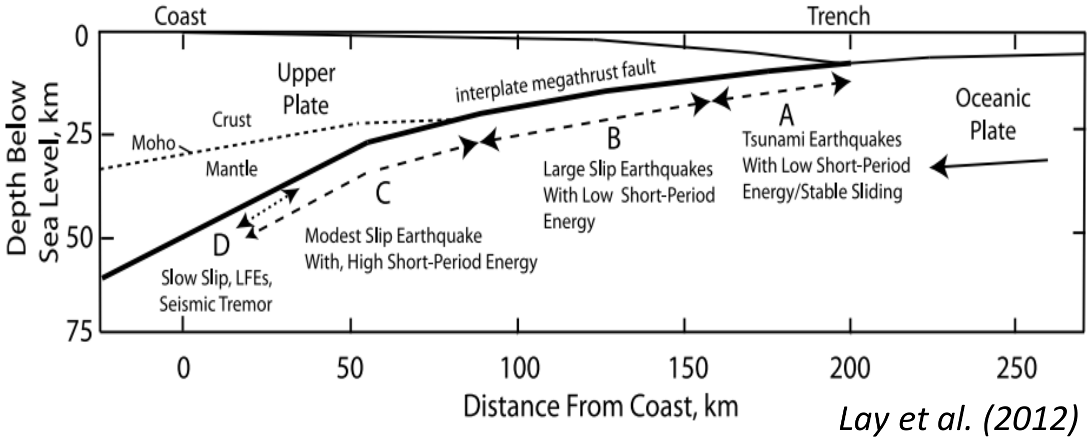
Newsweek (December, 2005)

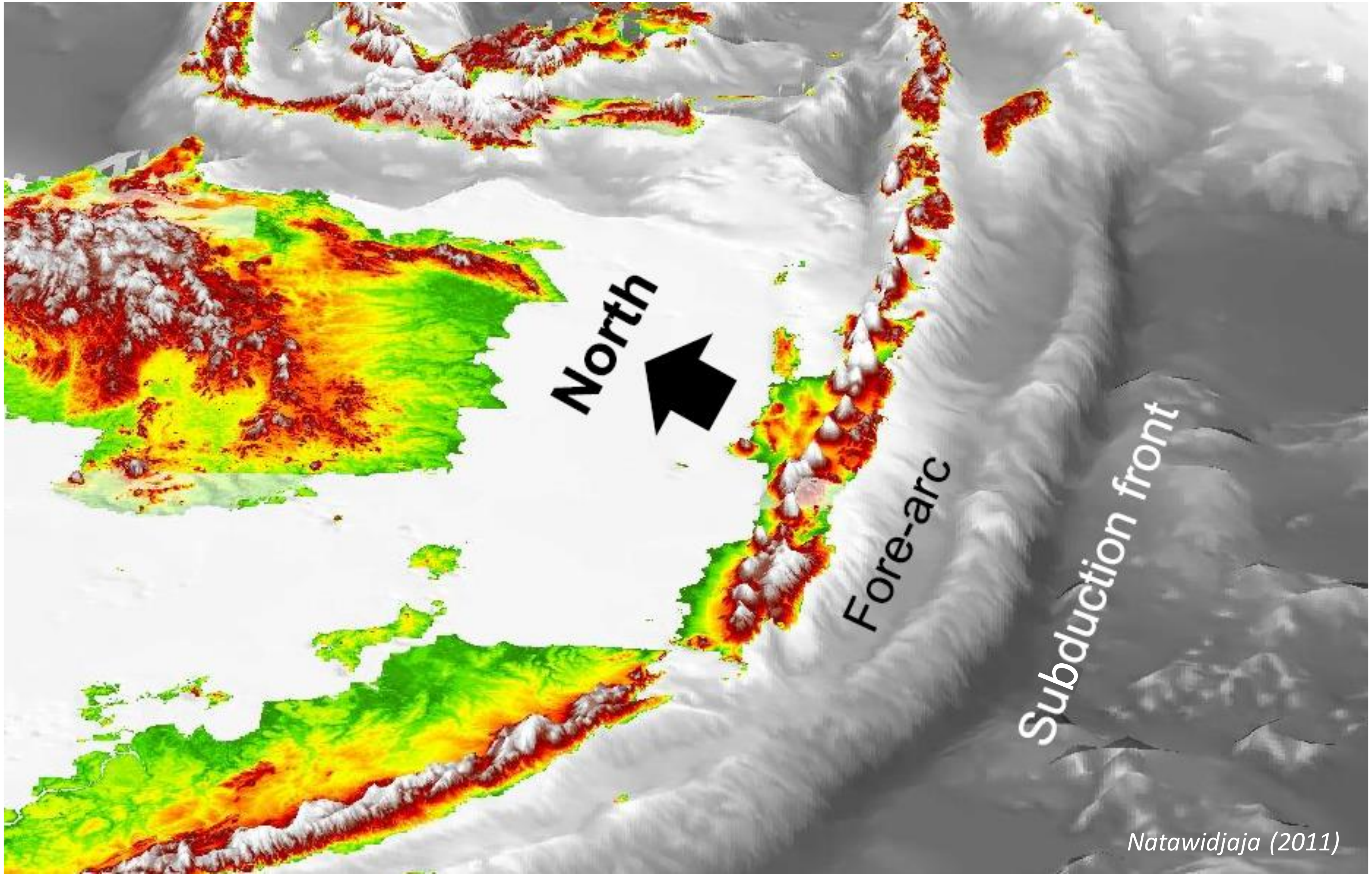
Megathrust Earthquake

The term **megathrust** (Park et al., 2005) is used to refer to an extremely large thrust fault, typically formed at the plate interface along a subduction zone. Megathrust earthquakes occur at subduction zones at destructive convergent plate boundaries, where one tectonic plate is forced underneath another, caused by slip along the thrust fault that forms the contact between them. These interplate earthquakes are the planet's most powerful, with moment magnitudes (Mw) that can exceed 9.0. Since 1900, all earthquakes of magnitude 9.0 or greater have been megathrust earthquakes.



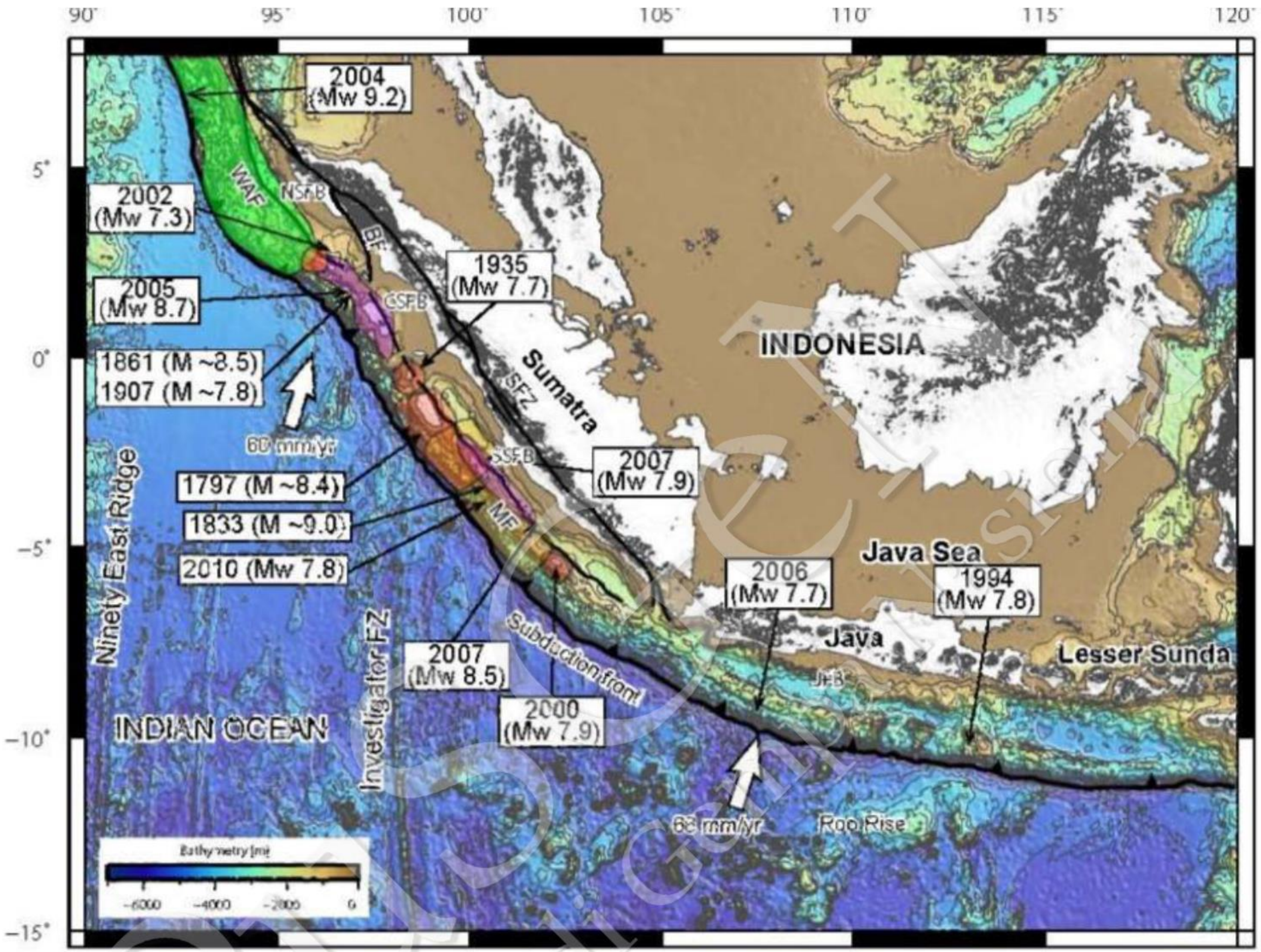
Lay et al. (2012)

compiled by Awang Harun Satyana 18 March 2021



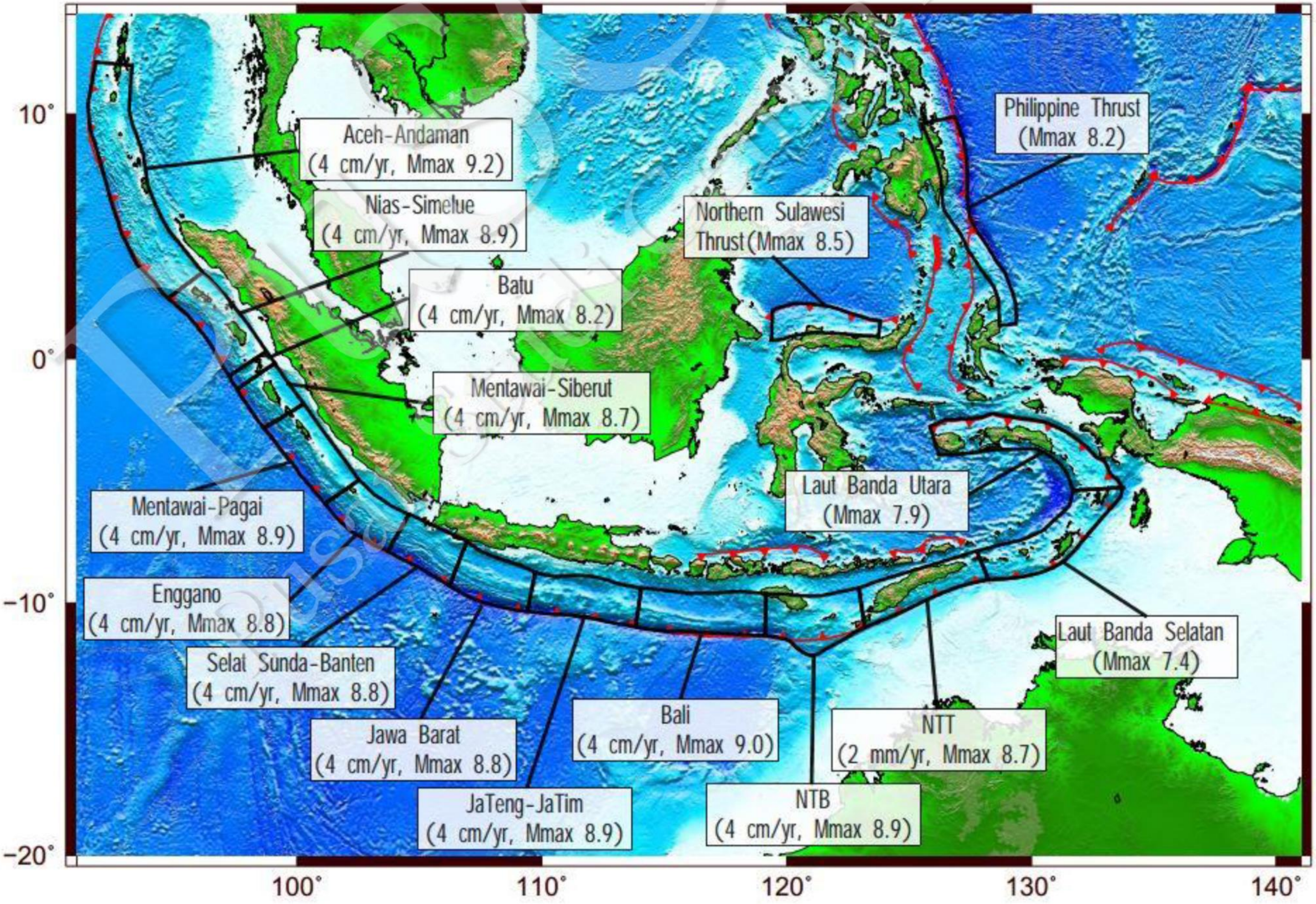
Indian oceanic plate subducts beneath Sumatra, Jawa, Bali, Lesser Sunda

compiled by Awang Harun Satyana 18 March 2021



Peta regional struktur yang berkembang di Sumatra (Diament dkk., 1992; Malod and Kemal, 1996; Samuel and Harbury, 1996), dan daerah rupture gempa besar (Abercrombie dkk., 2001; Ammon dkk., 2006; Briggs dkk., 2006), serta fitur struktur utama di kerak Samudra.

Pusgen (2017)



Pemutakhiran Segmentasi Megathrust Peta Gempa Nasional 2017

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

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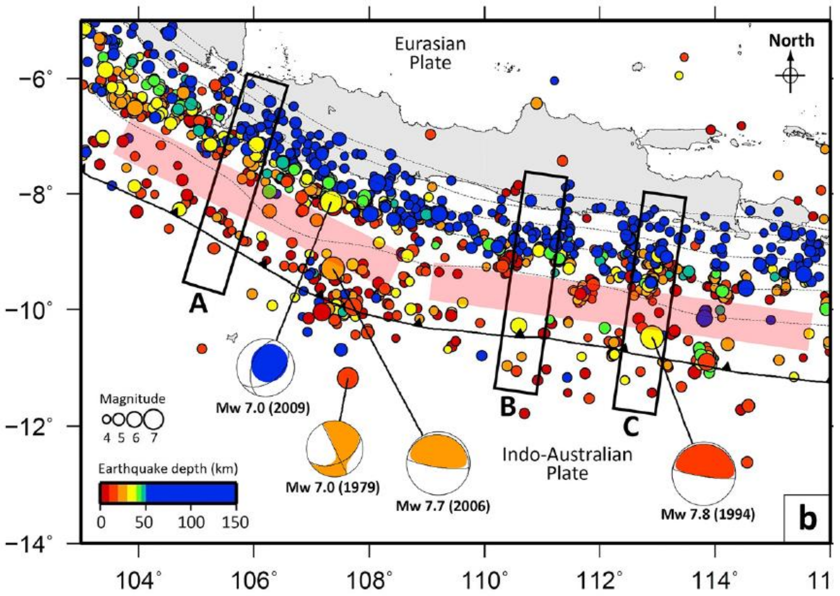
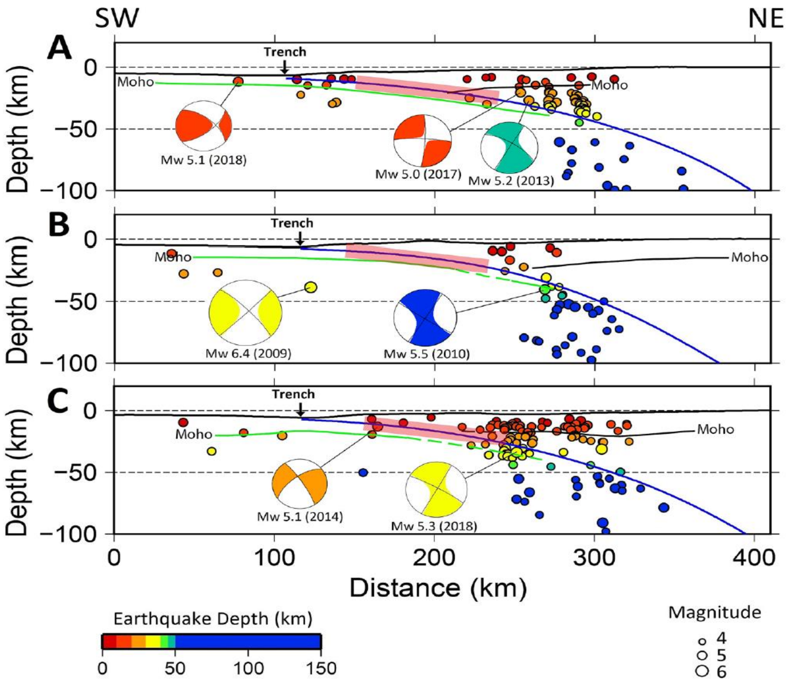
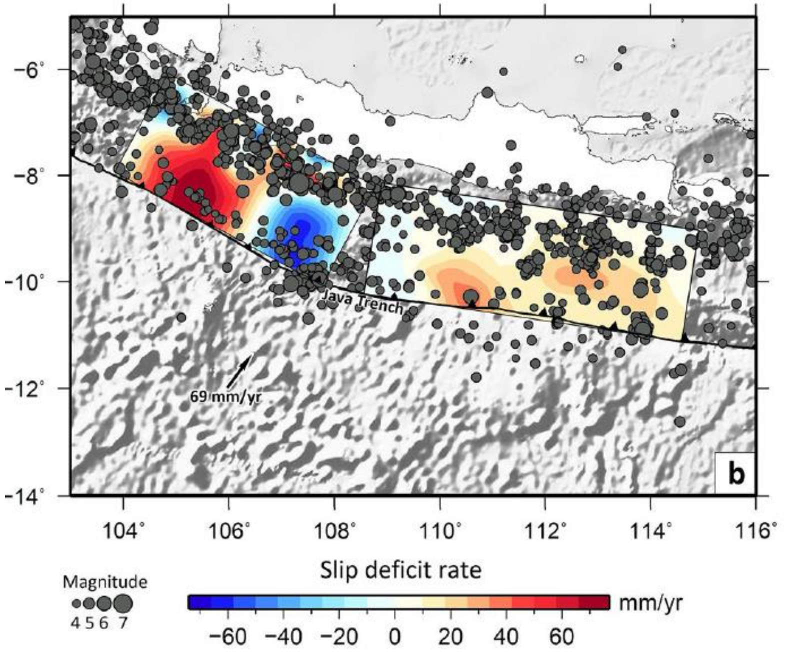
Implications for megathrust earthquakes and tsunamis from seismic gaps south of Java Indonesia

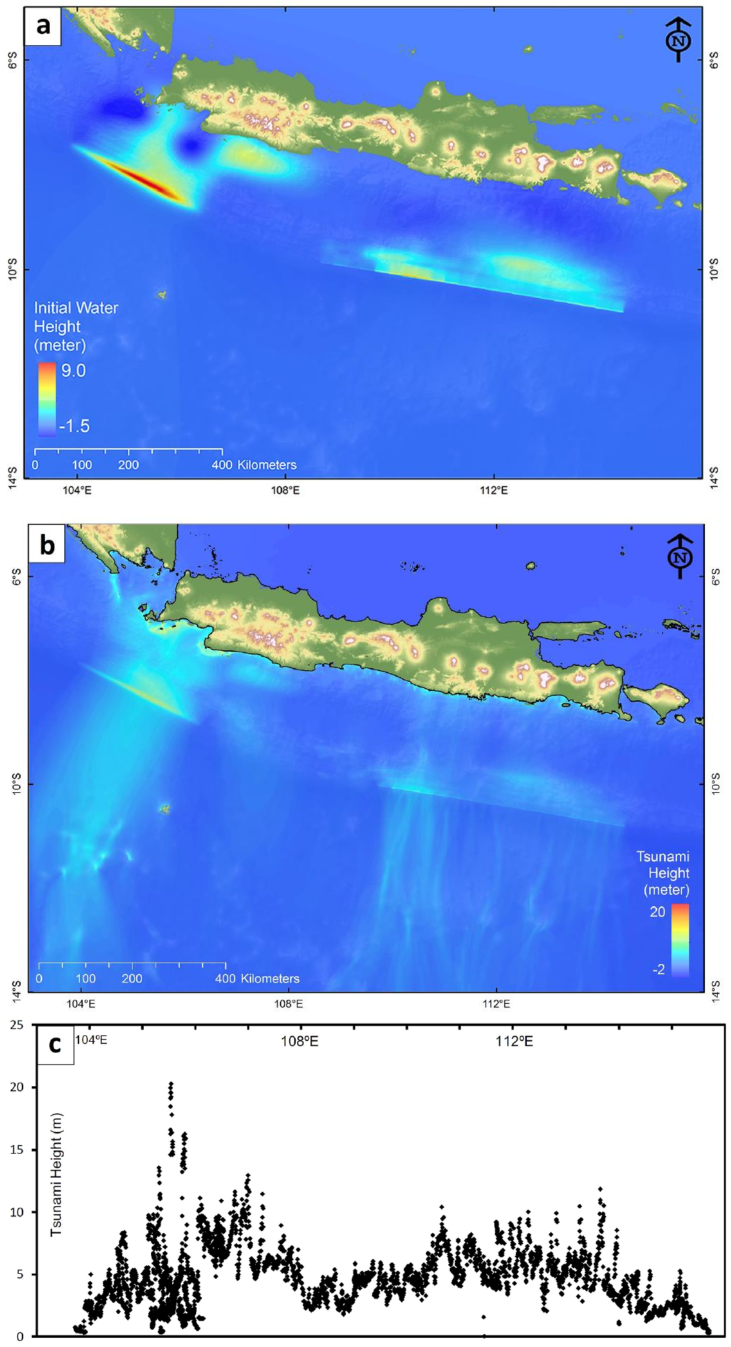
S. Widiyantoro[1,2], E. Gunawan[1], A. Muhari[3], N. Rawlinson[4]✉, J. Mori[5], N. R. Hanifa[6], S. Susilo[7], P. Supendi[8], H. A. Shiddiqi[9], A. D. Nugraha[1] & H. E. Putra[10]

Relocation of earthquakes recorded by the agency for meteorology, climatology and geophysics (BMKG) in Indonesia and inversions of global positioning system (GPS) data reveal clear seismic gaps to the south of the island of Java. These gaps may be related to potential sources of future megathrust earthquakes in the region. To assess the expected inundation hazard, tsunami modeling was conducted based on several scenarios involving large tsunamigenic earthquakes generated by ruptures along segments of the megathrust south of Java. The worst-case scenario, in which the two megathrust segments spanning Java rupture simultaneously, shows that tsunami heights can reach ~ 20 m and ~ 12 m on the south coast of West and East Java, respectively, with an average maximum height of 4.5 m along the entire south coast of Java. These results support recent calls for a strengthening of the existing Indonesian Tsunami Early Warning System (InaTEWS), especially in Java, the most densely populated island in Indonesia.









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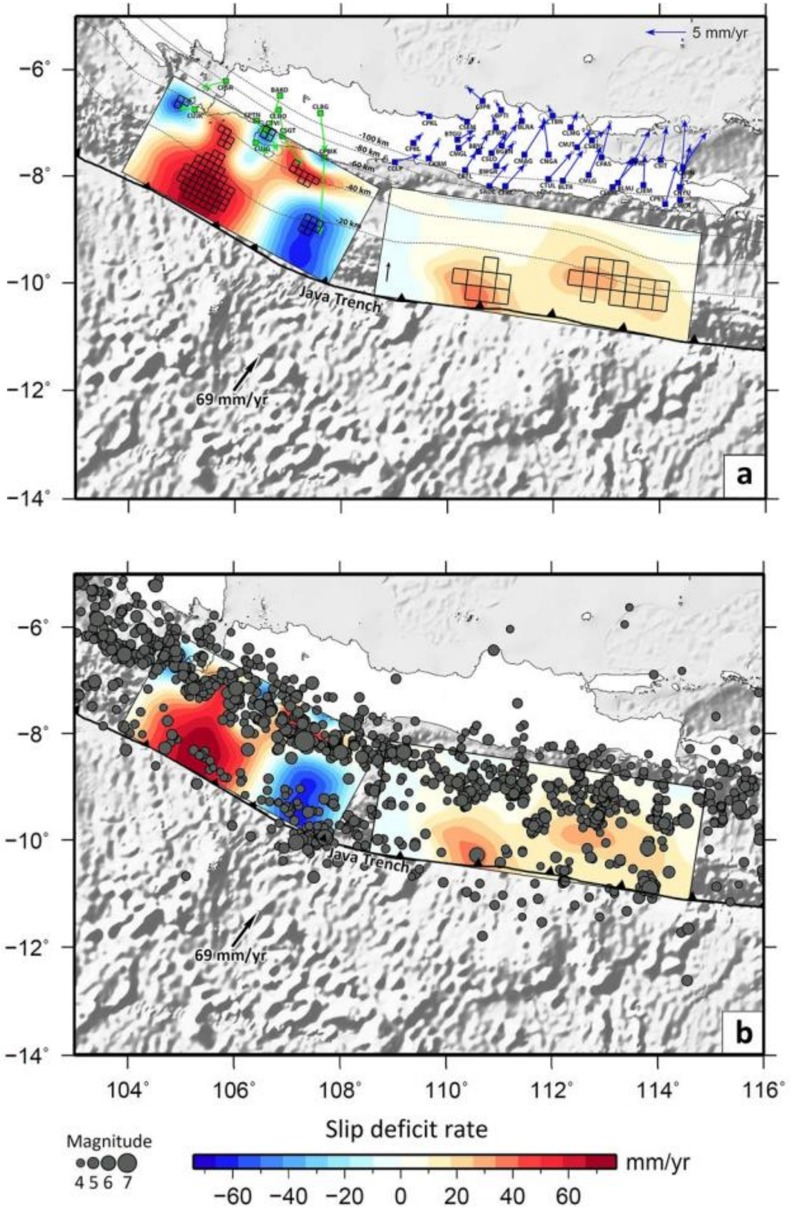
of strain energy (Fig. 3). Where the observed GPS deformation is less than the plate motion (slip deficit), the areas are inferred to be likely sources of future earthquakes. The area of strongest slip deficit is south of West Java (Fig. 3), which may be a potential source for a megathrust earthquake[20]. The inversion of GPS data from Central and East Java undertaken in this study shows similar features, i.e., two zones with slip deficits, albeit of lower magnitude compared to the west, which is unsurprising considering the differences in GPS velocities between the two regions (Fig. 3). The first high-slip deficit zone is located on the shallower part of the fault off the south coast of Central Java. The second high-slip deficit region is in the deeper part of the megathrust seismogenic zone off the south coast of East Java.

The assumption that the areas of large slip deficit will correspond to areas of large seismic slip during future large earthquakes may turn out to be an over-simplification. Examples from other regions reveal a complicated relationship between geodetic measurements and slip during earthquakes[21]. However, we still feel that it is a useful exercise to investigate this scenario, since it does provide a means to estimate potential tsunami heights in the event of a future great earthquake. The approach and assumptions we adopt are similar to those used for the Nankai trough, where areas of strong geodetic coupling are assumed to be areas of large slip during earthquakes[22].

If we adopt the above assumption, then the area of high slip deficit may rupture separately or together during an earthquake. The area of the deficit zone south of West Java is equivalent to a Mw 8.9 earthquake, assuming a return period of 400 years (consistent with Harris et al.[13] and Okal[23]). For the same return period, the area of high slip deficit in Central and East Java is equivalent to a Mw 8.8 earthquake, whereas if both areas rupture in a single earthquake, it would produce a Mw 9.1 event.

To assess the potential tsunami heights along the south coast of Java we conducted tsunami modeling using several different scenarios. Hypothetical megathrust segments are available from the National Center for Earthquake Studies of Indonesia (see Supplementary Fig. 9), but in this study we used megathrust segments from our GPS data inversion, which we regard as more realistic since we estimated the expected amount of slip. Here, we carried out tsunami modeling with three different megathrust scenarios: (1) western Java segment only (Mw 8.9), (2) eastern Java segment, i.e., to the south of Central and East Java, only (Mw 8.8), and (3) western and eastern Java segments (Mw 9.1). The results of Scenarios 1 and 2, along with initial water heights for all three scenarios, are presented in Supplementary Figs. 10–12. The worst-case scenario (Scenario 3) with a return period of 400 years can generate a giant earthquake of Mw 9.1 and a very large tsunami with a maximum height of 20.2 m near the small islands to the south of Banten, the westernmost province of Java, at ~ 105.5°E (Fig. 4). We note that the tsunami heights can be even higher than modeled when slumping occurs, as has been suggested in the case of the 2018 M 7.5 Palu strike-slip earthquake in Sulawesi, East Indonesia, where submarine landslides may have contributed to tsunami generation[24].



Widiyantoro et al. (2020)

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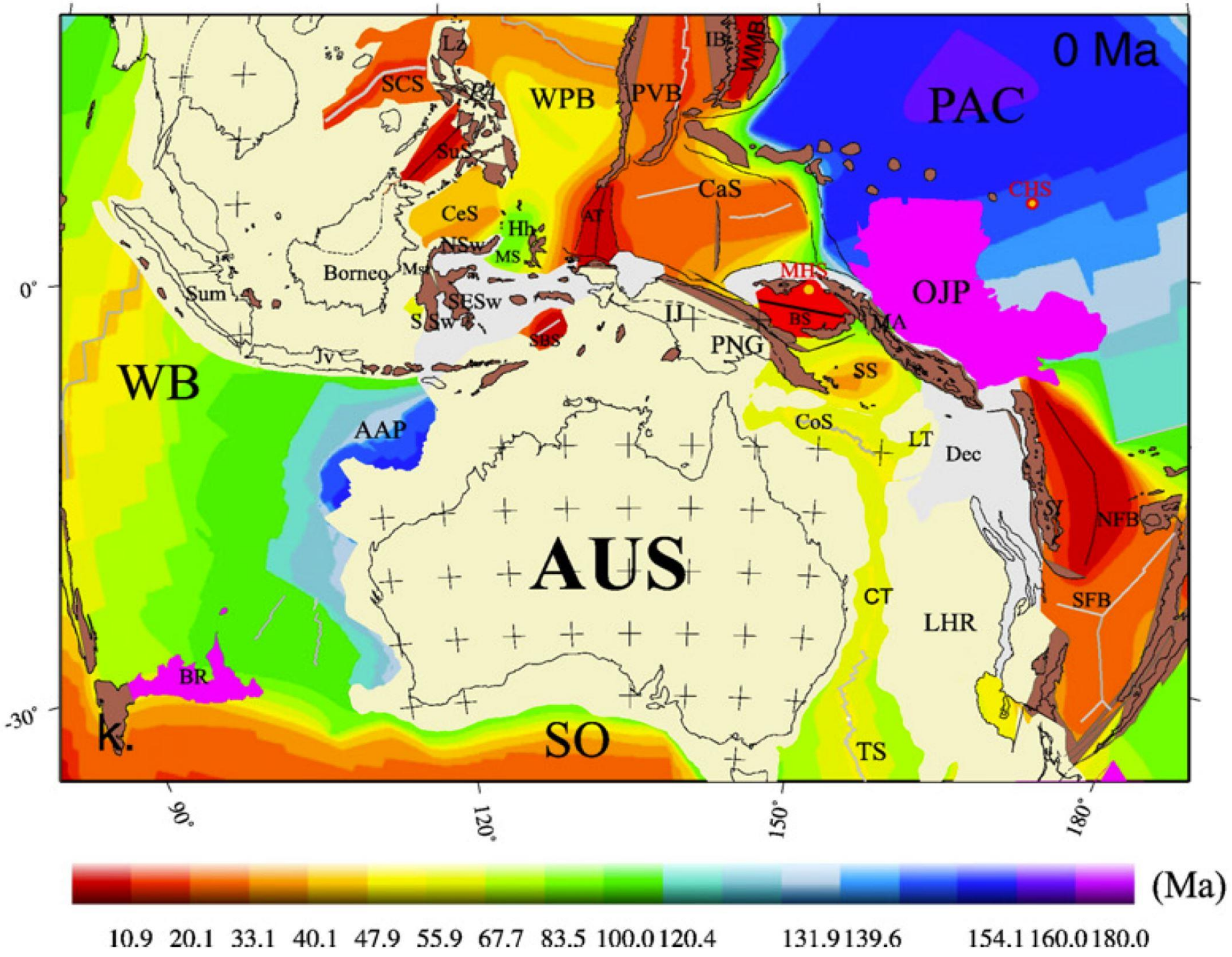
Each of megathrust zone should be characterized based on type of arc (continental or island arc), age of subducted slab, convergence rate

Age of oceanic lithosphere



Gaina & Muller (2007)

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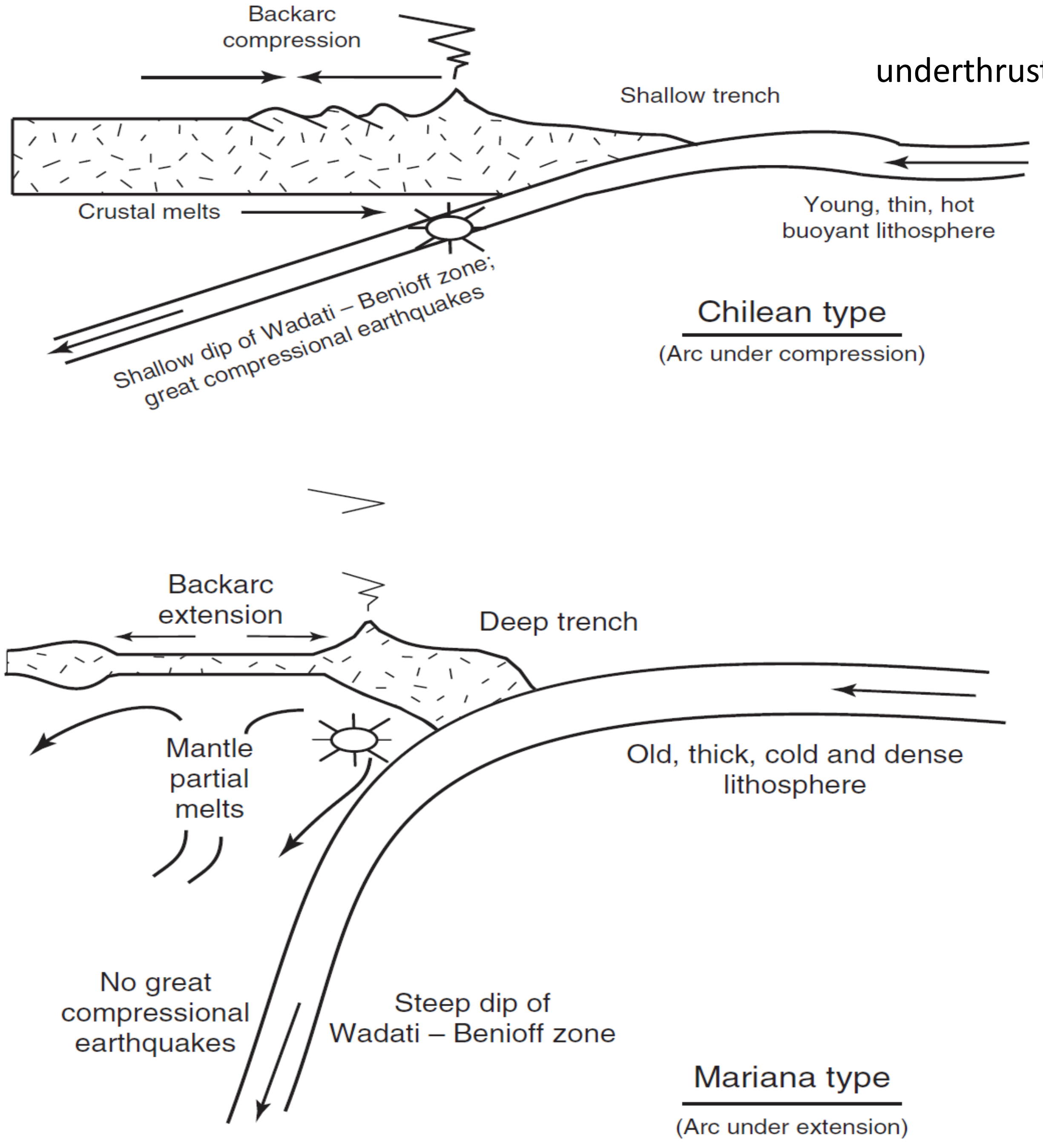
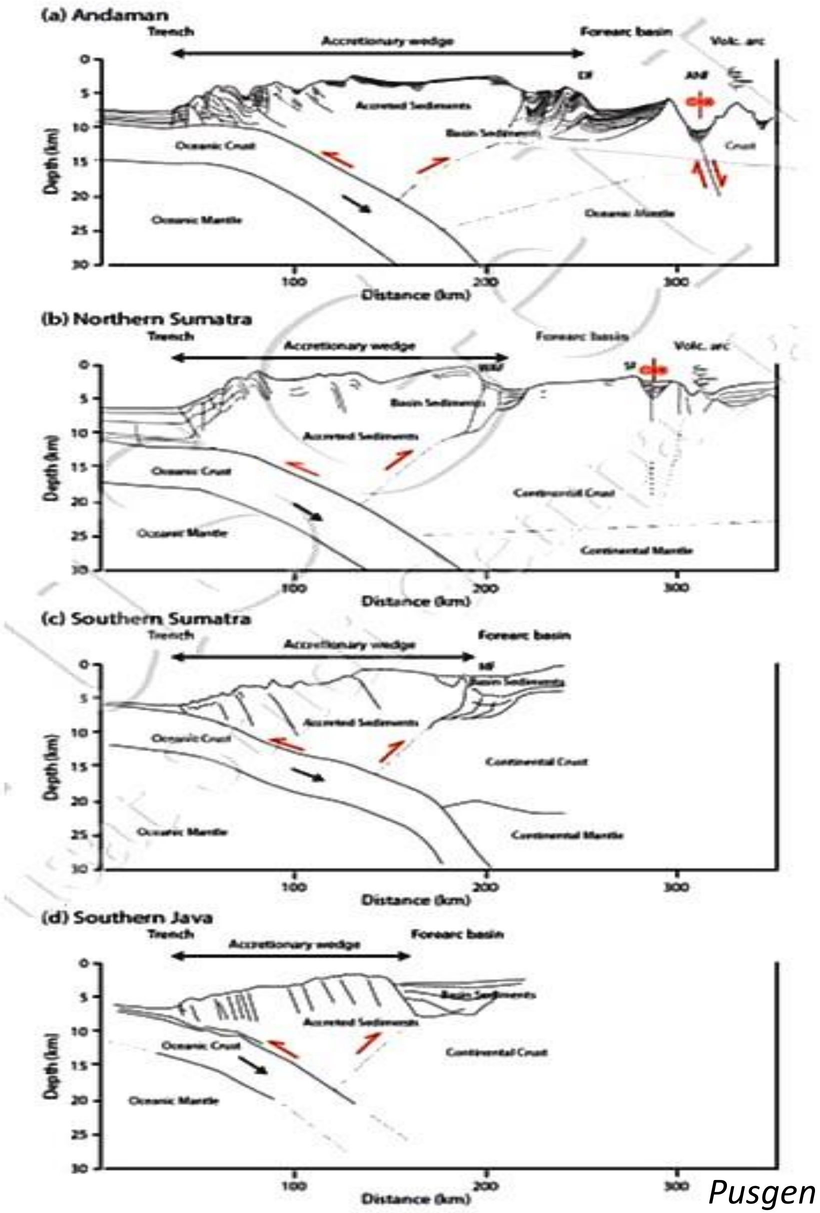
End-member types of subduction zone based on the age of the underthrusting lithosphere and the absolute motion of the overriding plate.



Uyeda & Kanamori, 1979; Stern, 2002; Kearey et al., 2009



Pusgen (2017)

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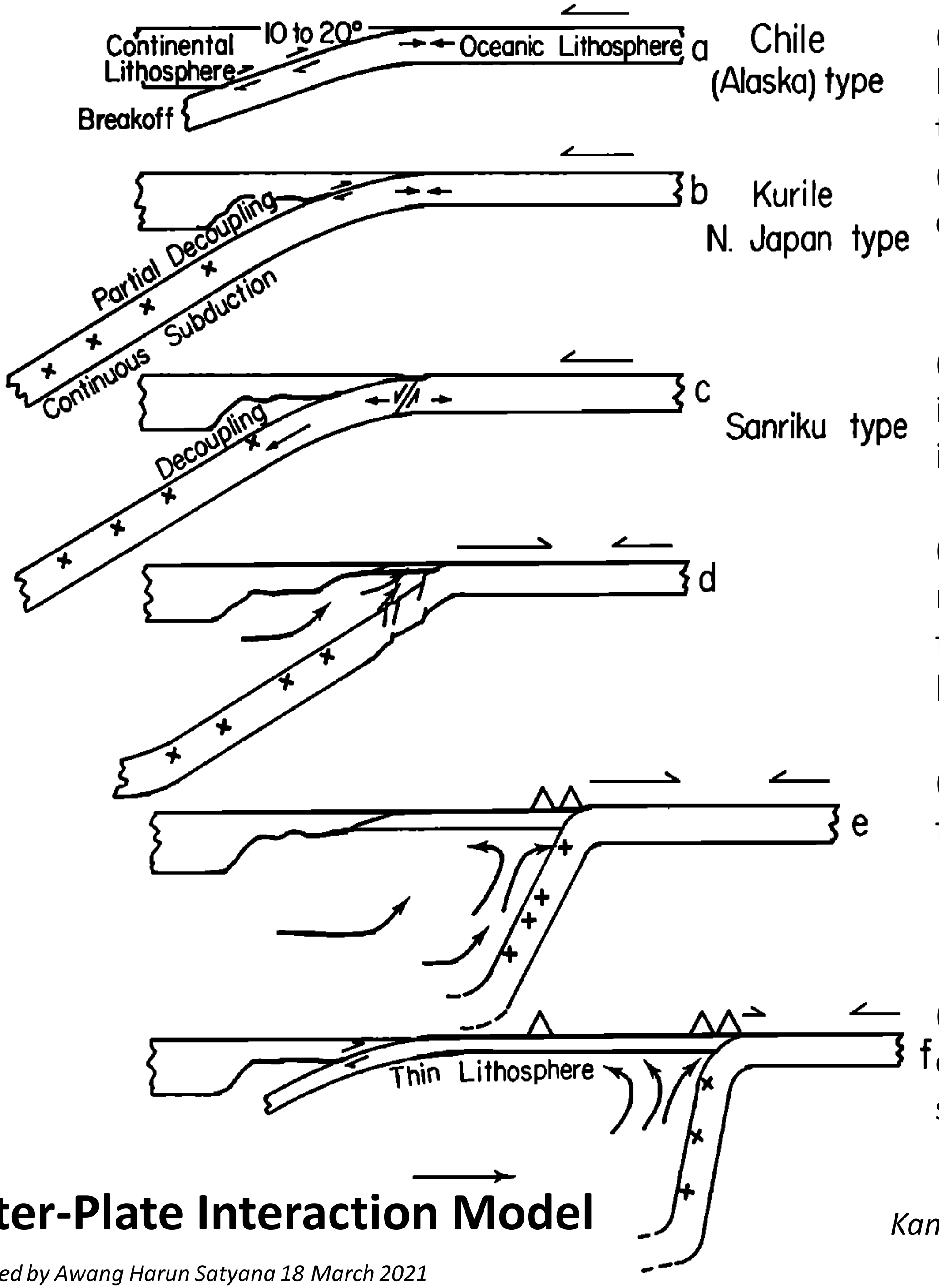


(a) Strong coupling between the oceanic and continental lithospheres results in great earthquakes and break off of the subduction lithosphere at shallow depths.

(b) Partial decoupling results in smaller earthquakes and continuous subduction.

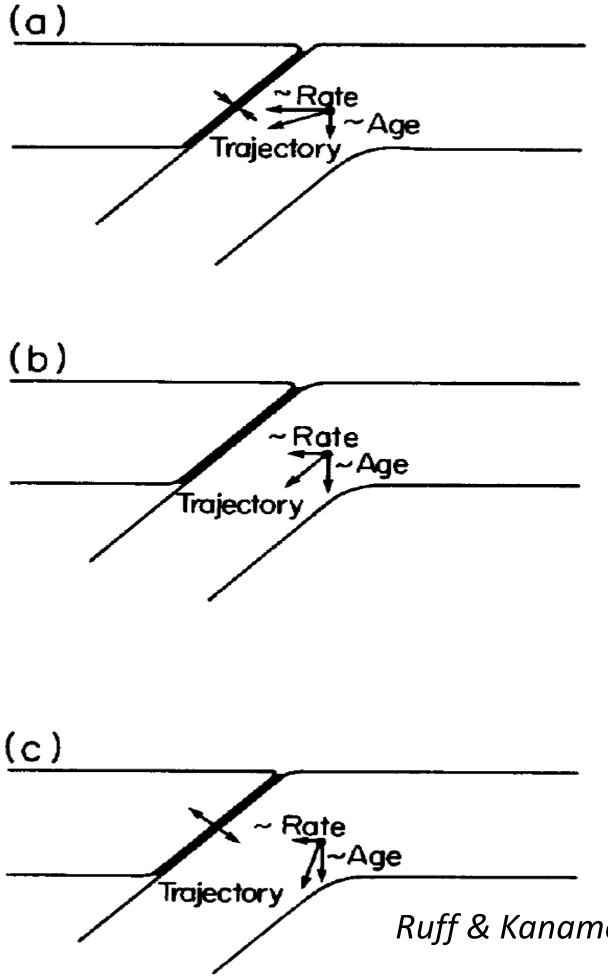
(c) Further decoupling results in aseismic events and intraplate tensional events.

(d) Sinking plate results in retreating subduction and formation of a new thin lithosphere.

(e) Episodic retreat and formation of ridges.

(f) Decelerated retreat and commencemen of new subduction

Kanamori (1977)



Ruff & Kanamori (1980)

Fig. 6. Schematic representation of how particular combinations of lithospheric ages and convergence rates might cause subducting slabs to have preferred trajectories, thereby affecting Benioff zone geometry. The preferred instantaneous trajectory of a slab is most certaintly affected by other influences, such as the global mantle flow.

Inter-Plate Interaction Model

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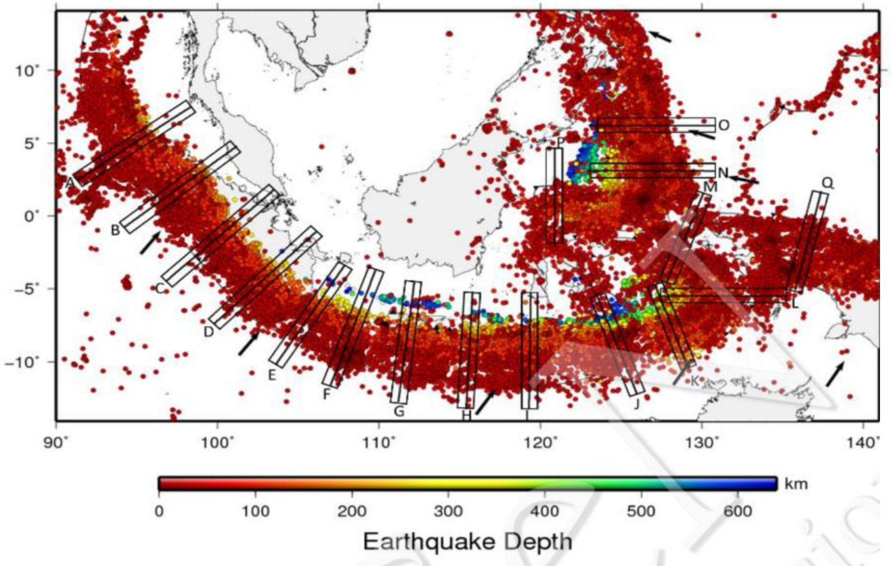
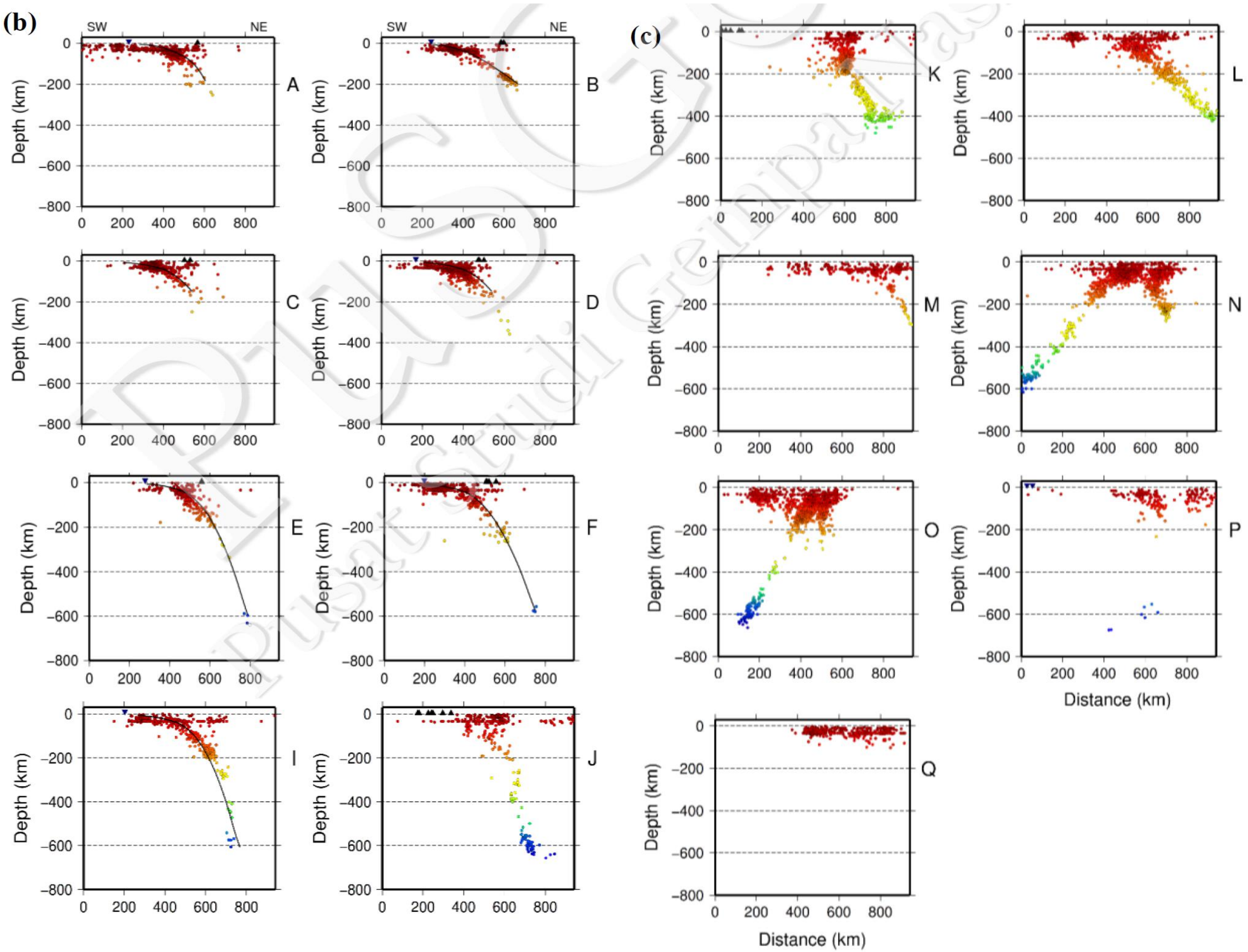




a) Penampang melintang (*cross-section*) gempa untuk beberapa zona di Indonesia.
b,c) Segitiga hitam adalah simbol gunung api dan garis hitam menggambarkan geometri slab subduksi dari model slab 1.0 (Hayes dkk., 2012)

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

Coupled and Un-/Decoupled Subduction

In a **coupled convergent margin,**

- the downgoing plate pushes tightly against the overriding plate, so the plate boundary overall is under compression. As a consequence, large shear stresses develop across the contact, causing efficient offscraping and tectonic underplating, and therefore buildup of a large accretionary wedge.
- This shear stress also triggers devastating earthquakes, and development of a contractional backarc region.
- Perhaps because compression squeezes crustal fractures closed, magma rises slowly, and therefore has time to fractionate and/or cause partial melting of adjacent continental crust produces intermediate to felsic magma.

In an **un-/de-coupled convergent margin,**

- the downgoing plate does not push tightly against the overriding plate, so compression across the margin is not great. As a consequence, shear stresses across the plate boundary are relatively small, and relatively little offscraping and underplating occurs.
- thrust earthquakes at the boundary have smaller magnitude, in uncoupled systems we find extensional backarcs.
- cracks in the overriding plate remain somewhat open, so mantle derived magmas rise directly to the surface before significant fractionation or crustal contamination occurs produces mafic igneous rocks.

compiled by Awang Harun Satyana 18 March 2021

Kanamori (1977), Uyeda & Kanamori (1979), Ruff & Kanamori (1980), Newcomb & Cann (1987), van der Pluijm & Marshak (2004), Stein & Okal (2007), Okal (2012)

Table 2

Subduction Zone Convergence Parameters and Maximum Earthquake Magnitudes Used in This Study

Region	Plate Pair[#]	Convergence Rate mm/yr	Convergence Rate Ref.*	Plate Age Ma	Plate Age Ref.[†]	Maximum Event Date	M_w	Note[‡]	Ref.[§]
South Chile	NZ-SA	70	R	26	M	1960	9.6	S	a
Central Chile	NZ-SA	70	R	40	M	1922	8.3	M/UM	b
North Chile	NZ-SA	68	R	46	M	1877	9.1	I/UM	c
South Peru	NZ-SA	67	R	43	M	1868	9.2	T/UM	d
North Peru	NZ-SA	63	R	29	M	1940	8.2	S	e
Ecuador-Colombia	NZ-SA	55	R	10	M	1906	8.5	M/UM	b
Central America	CO-CA	73	L	18	M	1992	7.6	S	f
Mexico	RI-NA	30	N	4	M	1932	8.1	M	b
Cascadia	JF-NA	42	N	9	M	1700	9.1	T/G	g
Alaska	PA-NA	54	N	42	M	1964	9.3	S	h
East Aleutian	PA-NA	64	N	55	M	1946	8.6	S	i
West Aleutian	PA-NA	73	N	57	M	1965	8.7	S	j
Kamchatka	PA-NA	78	N	84	Q	1952	8.9	S	k
Kuriles	PA-NA	81	N	110	L	1963	8.5	S	l
Northeast Japan	PA-NA	83	N	130	L	1968	8.2	S	m
Nankai	PH-EU	57	R	20	O	1707	8.8	I/UM	n
Ryukyu	PH-EU	65	R	60	L	1920	8.0	O/UM	o
Izu	PA-PH	45	R	150	L	1947	7.2	O/UM	p
Marianas	PA-PH	27	R	148	L	1929	7.2	O/UM	p
Loyalty-Vanuatu	AU-PA	103	C	60	L	1950	7.8	M/UM	b
Tonga	PA-AU	185	B	120	Q	1865	8.3	T/UM	q
Kermadec	PA-AU	63	R	120	Q	1917	8.1	M/UM	b
New Zealand	PA-AU	43	R	120	Q	1931	7.8	O	p
Java	AU-EU	64	CR	127	M	1994	7.7	S	r
South Sumatra	AU-SU	51	CR	61	M	1833	9.2	G	s
North Sumatra	IN-BU	33	TS	72	M	2004	9.3	S	t
Makran	AR-EU	28	R	99	M	1945	8.1	S	u
Lesser Antilles	NA-CA	20	L	82	M	1974	7.5	O/NF	p,v
South Scotia	SA-SS	78	P	40	M	1924	7.0	O/UM	p

*Rate references: R, REVEL (Sella *et al.* 2002); L, López *et al.* (2006); N, NUVEL-la (DeMets *et al.*, 1994); C, Calmant *et al.* (2003); B, Bevis *et al.* (1995); CR, Chamot-Rooke and Le Pichon (1999); TS, this study, see text; P, Pelayo and Wiens (1989).

[†]Age references: M, Müller *et al.* (1997); L, Larson *et al.* (1985); O, Ocean Drilling Program, Leg 190; Q, interpolated in magnetic quiet zone from L.

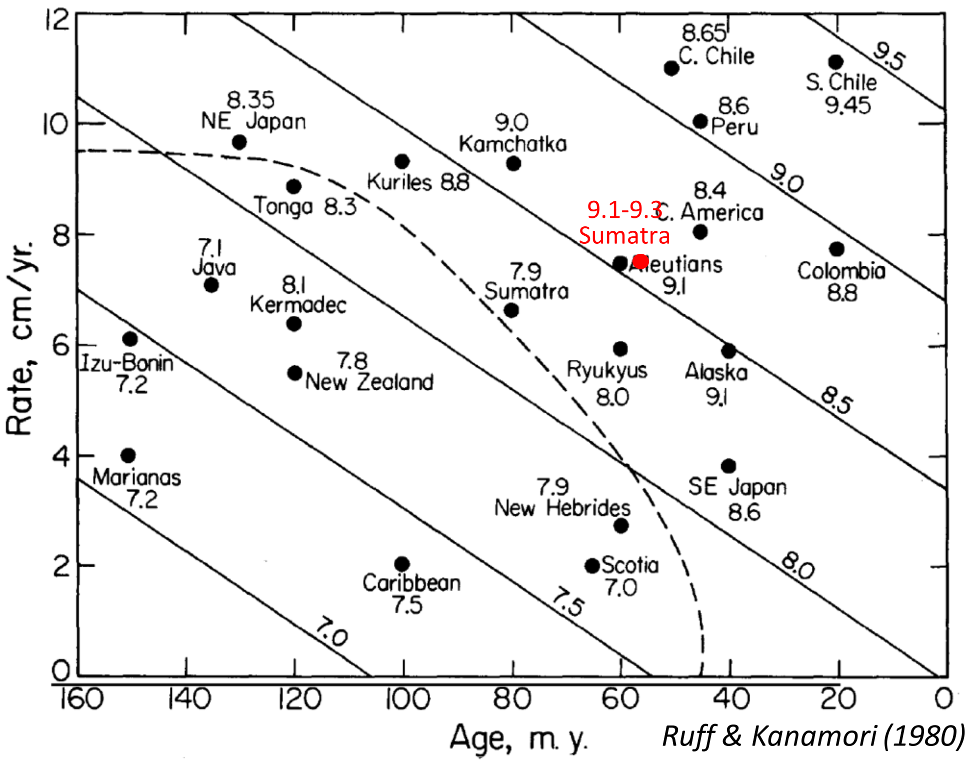
[‡]S, seismological modeling; M, mantle magnitude; I, estimated from macroseismic study; T, tsunami modeling; O, other magnitude (M_s); G, geologic modeling; NF, normal faulting; UM, unknown mechanism.

[§]Seismic moment references: a, Cifuentes and Silver (1989); b, Okal (1992); c, Beck *et al.* (1998); d, Okal *et al.* (2005); e, Beck and Nishenko (1990); f, Dziewonski *et al.* (1993); g, Satake *et al.* (2003); h, Kanamori (1970a); i, López and Okal (2006); j, Wu and Kanamori (1973); k, Kanamori (1976); l, Kanamori (1970b); m, Kanamori (1971b); n, Ando (1974); o, Kanamori (1977b); p, Ruff and Kanamori (1980); q, Okal *et al.* (2004); r, Dziewonski *et al.* (1995); s, Zachariasen *et al.* (1999); t, this study; u, Byrne *et al.* (1992); v, Stein *et al.* (1982).

[#]Plate names: NZ, Nazca; SA, South America; CO, Cocos; CA, Caribbean; RI, Rivera; NA, North America; EU, Eurasia; PA, Pacific; JF, Juan de Fuca; PH, Philippines; AU, Australia; AR, Arabia; IN, India; BU, Burma.

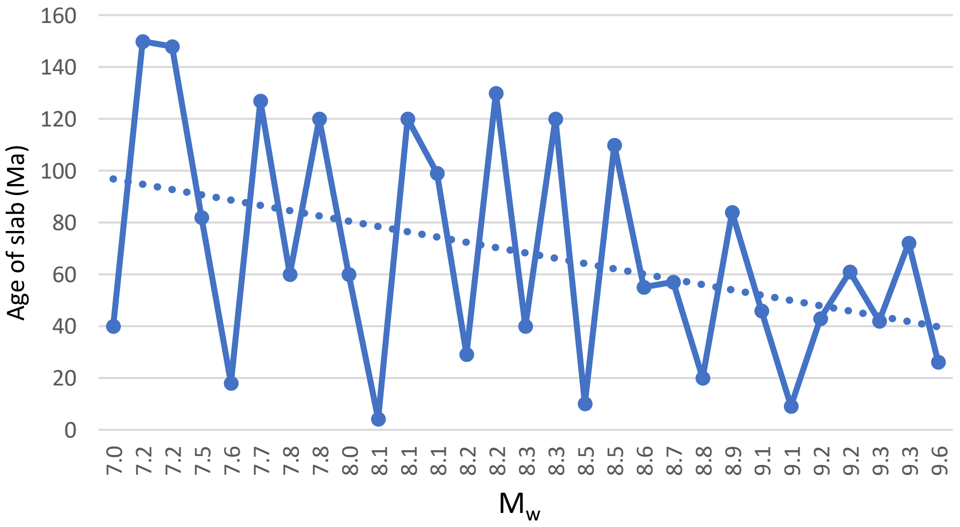
Stein & Okal (2007)

Seismicity, convergence rate, age of subducted slab

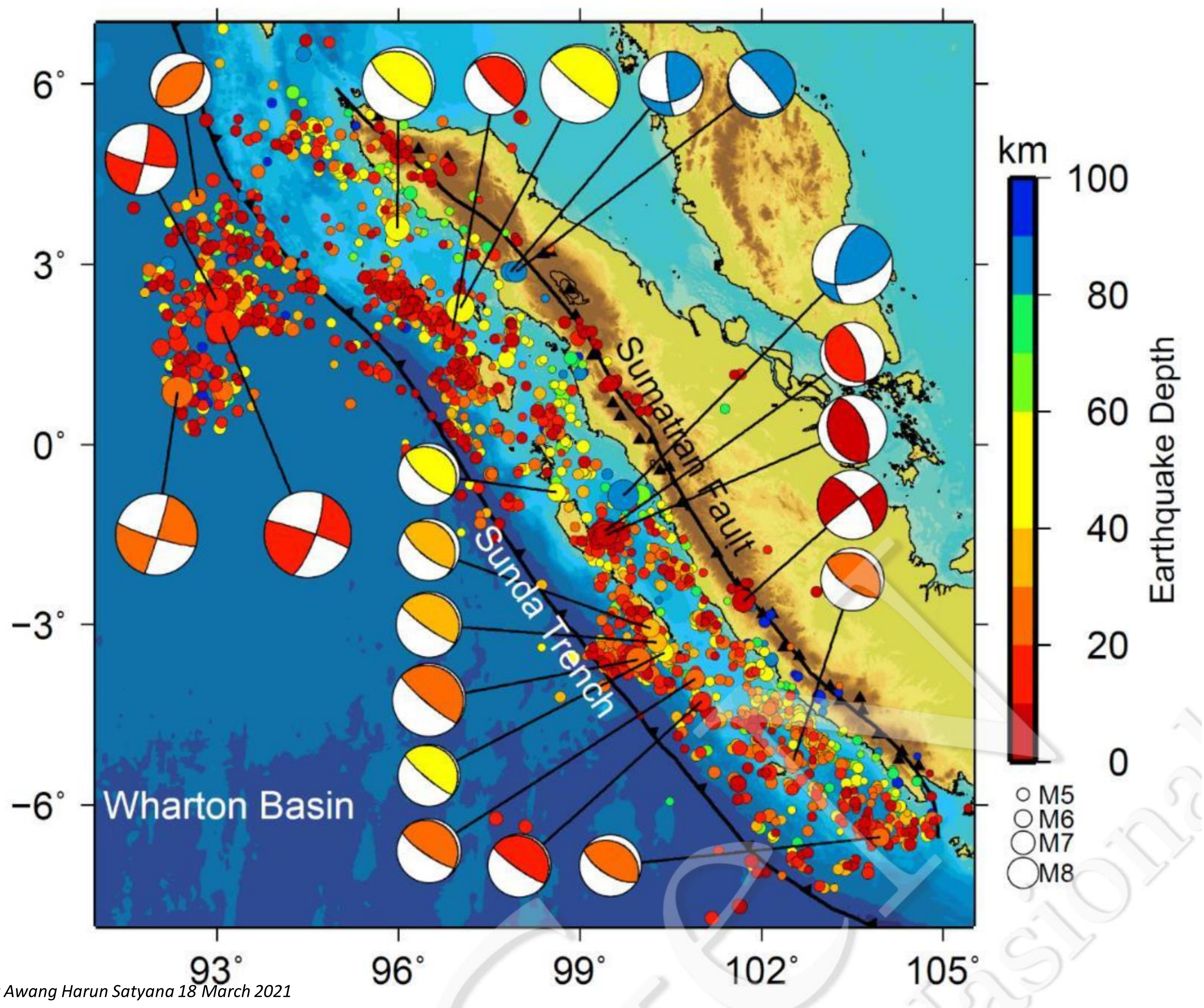


Ruff & Kanamori (1980)

Age of subducted slab & EQ magnitude



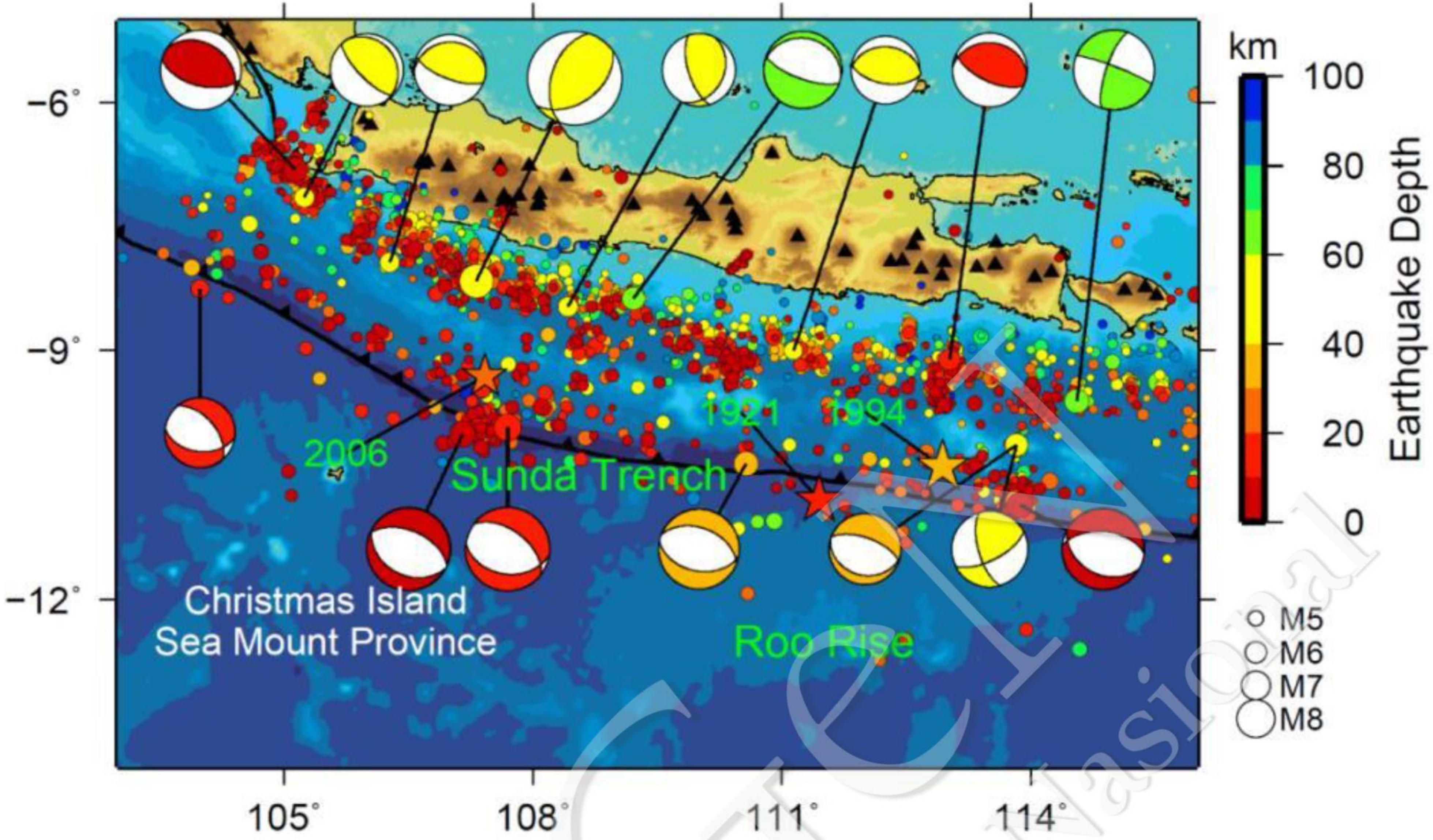
compiled by Awang Harun Satyana 18 March 2021



Seismisitas hasil relokasi gempa-gempa Sumatera dengan magnitudo ≥ 4,0. Mekanisme fokus diambil dari *Global Centroid Moment Tensor* (GCMT) (Dziewonski dkk., 1981; Ekström dkk., 2012) untuk gempa dengan magnitudo ≥ 6,0 (Shiddiqi, 2015)

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021



Episenter gempa hasil relokasi di Pulau Jawa dan sekitarnya untuk *event* dengan kedalaman ≤ 100 km dan magnitudo ≥ 4. Mekanisme fokus merupakan solusi dari GCMT untuk gempa dengan magnitudo ≥ 6 (Shiddiqi, 2015)

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

GEMPA BESAR *(MAJOR EARTHQUAKE) DI* SELATAN JAWA

Gempa besar dengan magnitudo antara 7,0 dan 8,0 yang bersumber di zona megathrust selatan Jawa sudah terjadi lebih dari 12 kali, yaitu:

1. *4 Januari 1840 (~7,5)*
2. *20 Oktober 1859 (~7,5)*
3. *10 Juni 1867 (~7,5)*
4. *28 Maret 1875 (~7,5)*
5. *27 Feb. 1903 (7,9)*
6. *11 Sept. 1921 (7,5)*
7. *27 Sept. 1937 (7,2)*
8. *1 April 1943 (7,1)*
9. *24 Juli 1979 (7,0)*
10. *3 Juni 1994 (7,6)*
11. *17 Juli 2006 (7,8)*
12. *2 Sept. 2009 (7,3)*

Daryono (2020)

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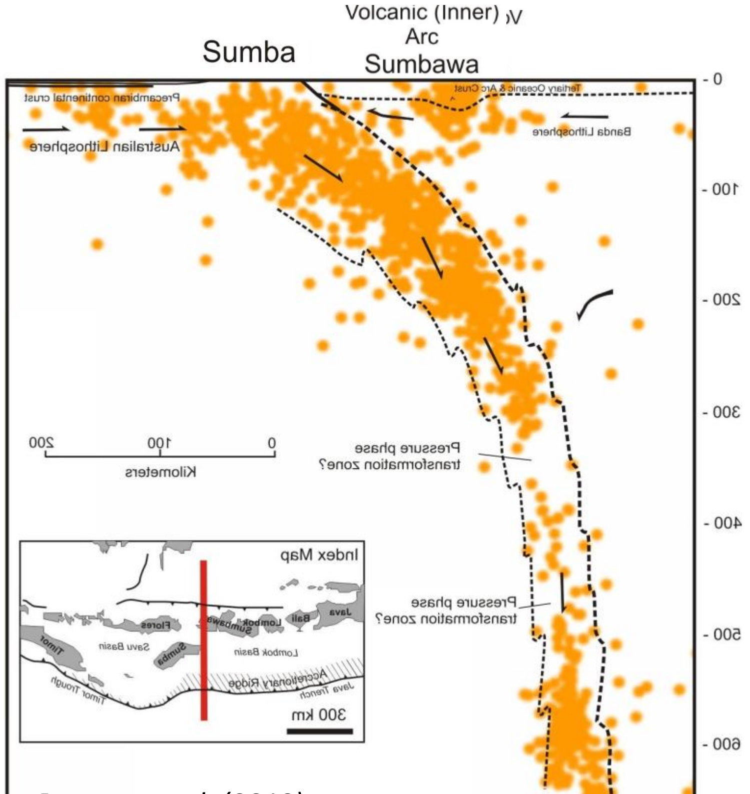
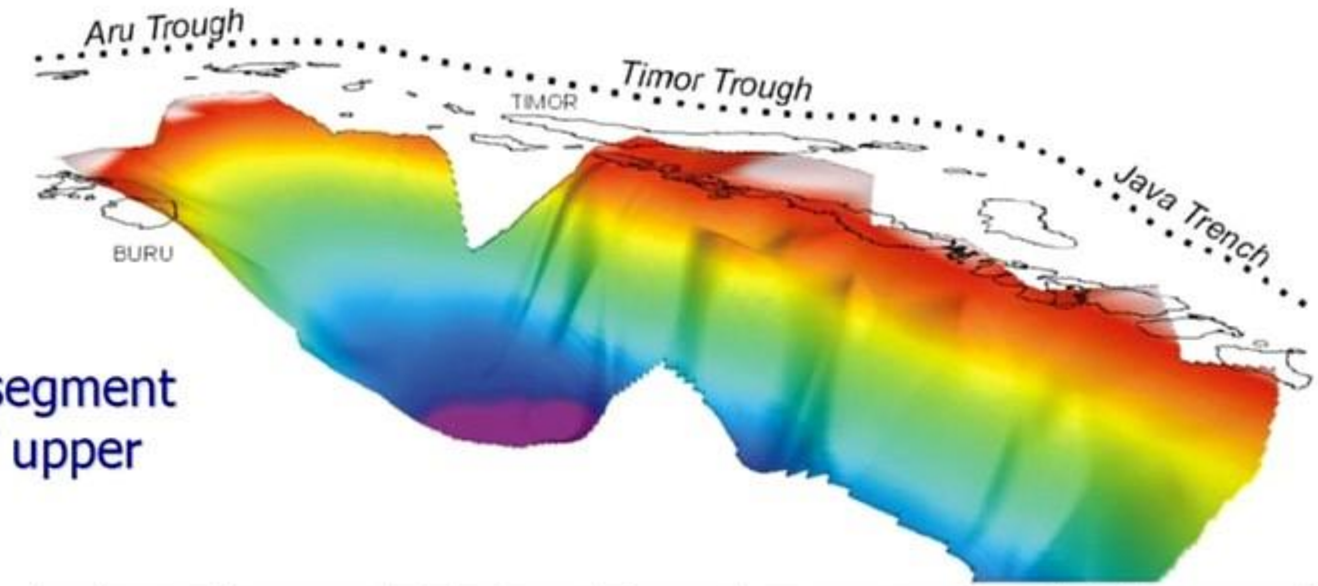


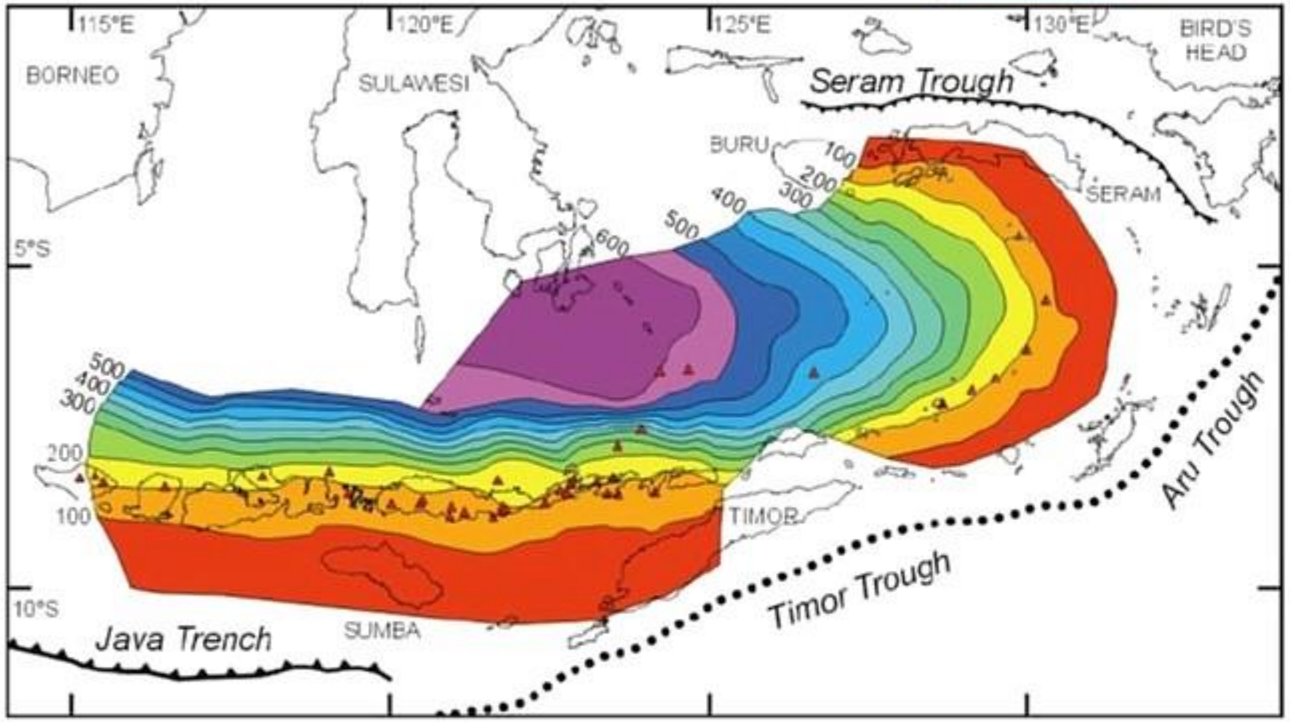
Darman et al. (2012)

In the Sunda Arc, the width of the plate interface, as measured from the trench axis to the 100-km depth contour, indicates a more broad zone of contact at Sumatra, where great interplate earthquakes occur, and a relatively narrower zone at Java, where shallow portions of the Benioff zone dip more steeply (Figure 2). The width of the zone of contact between adjoining plates has been related to the characteristic earthquake size of Pacific subduction zones [Kelleher et al., 1974]. Extremely long rupture zones (> 400 km), and hence great earthquakes, were found to occur at margins with shallowly dipping slabs and wide zones of contact, while moderately large rupture zones (> 150 km) occur in regions that dip more abruptly. These observations are consistent with the concepts of coupling in that younger lithosphere being subducted at a higher convergence rate has a more shallow dip, a greater area of contact, and greater shear traction applied to the plate boundary

Newcomb & Cann (1987)



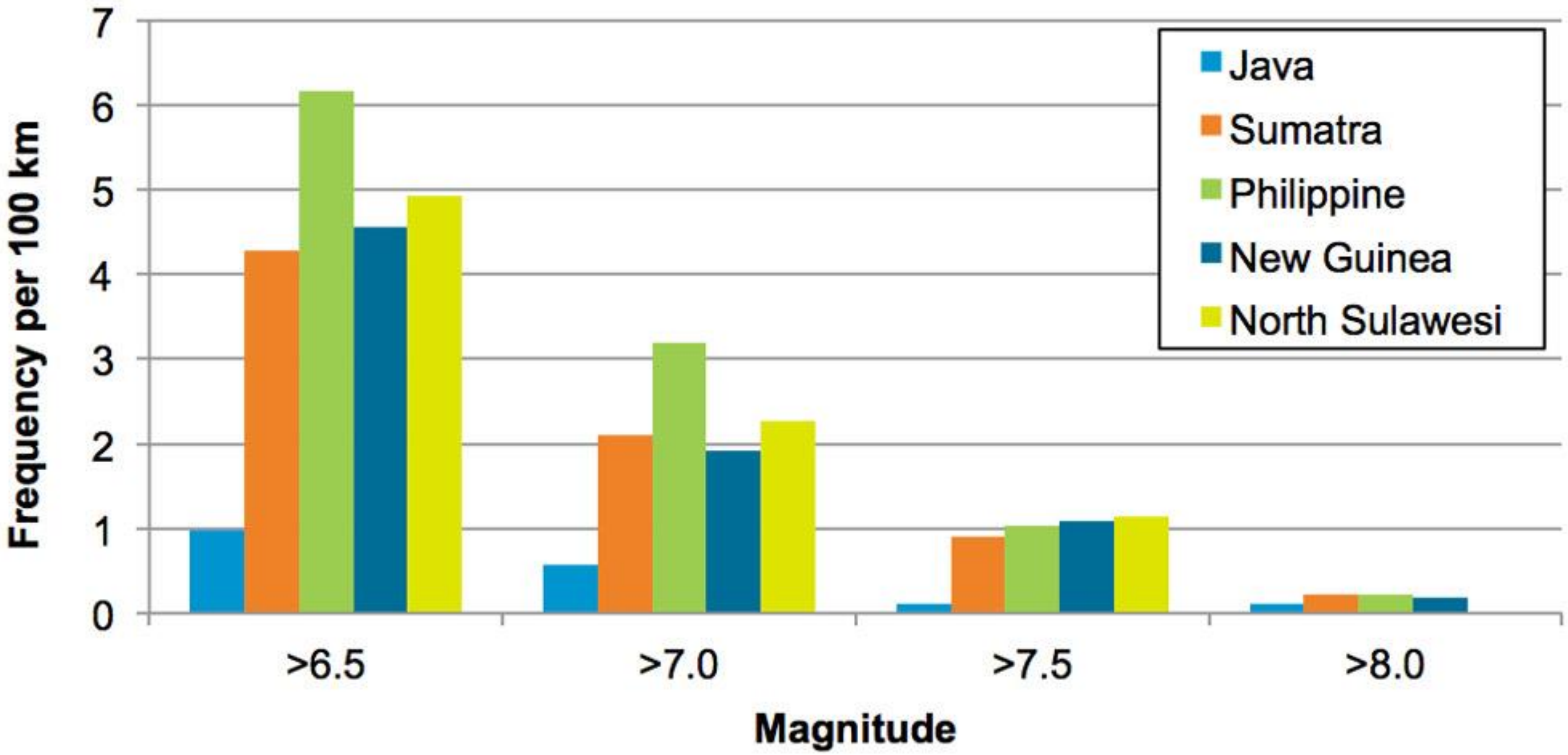
Note flat segment at base of upper mantle



Hall (2014)

compiled by Awang Harun Satyana 18 March 2021

Java Subduction Zone Earthquakes: The Worst Is Yet to Come (?)



Shen-Tu (2016)

Earthquake frequency since 1800 in the main subduction zones in Southeast Asia. The frequency is normalized by trench length (per 100 km) and adjusted by the convergence rate across the subduction zones

the Java Trench subduction zone is seismically least productive among the major subduction zones in the region, with the rate of seismicity of moderate-to-large-magnitude earthquakes lower than other subduction zones by a factor of 5 to 8. The seismic coupling factor (or seismic factor)—the ratio of seismic energy released by an earthquake to the total energy accumulated—of the Java Trench subduction zone is less than 1%. Many scientists have postulated that much of the tectonic energy in the Java Trench may be released aseismically (i.e., by aseismic deformation, such as fault creep) because of this comparatively very low seismic coupling factor and the absence of large-magnitude earthquakes in the past 100 to 200 years. Aside from an M8.0–8.5 Java Trench earthquake in 1780 (the largest historical earthquake in the Java Trench), the trench has not had any earthquakes larger than M8.0 in the known history (200 to 300 years).

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Overriding plate controls spatial distribution of megathrust earthquakes in the Sunda–Andaman subduction zone

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Available online 18 October 2006
Editor: Scott King

Abstract

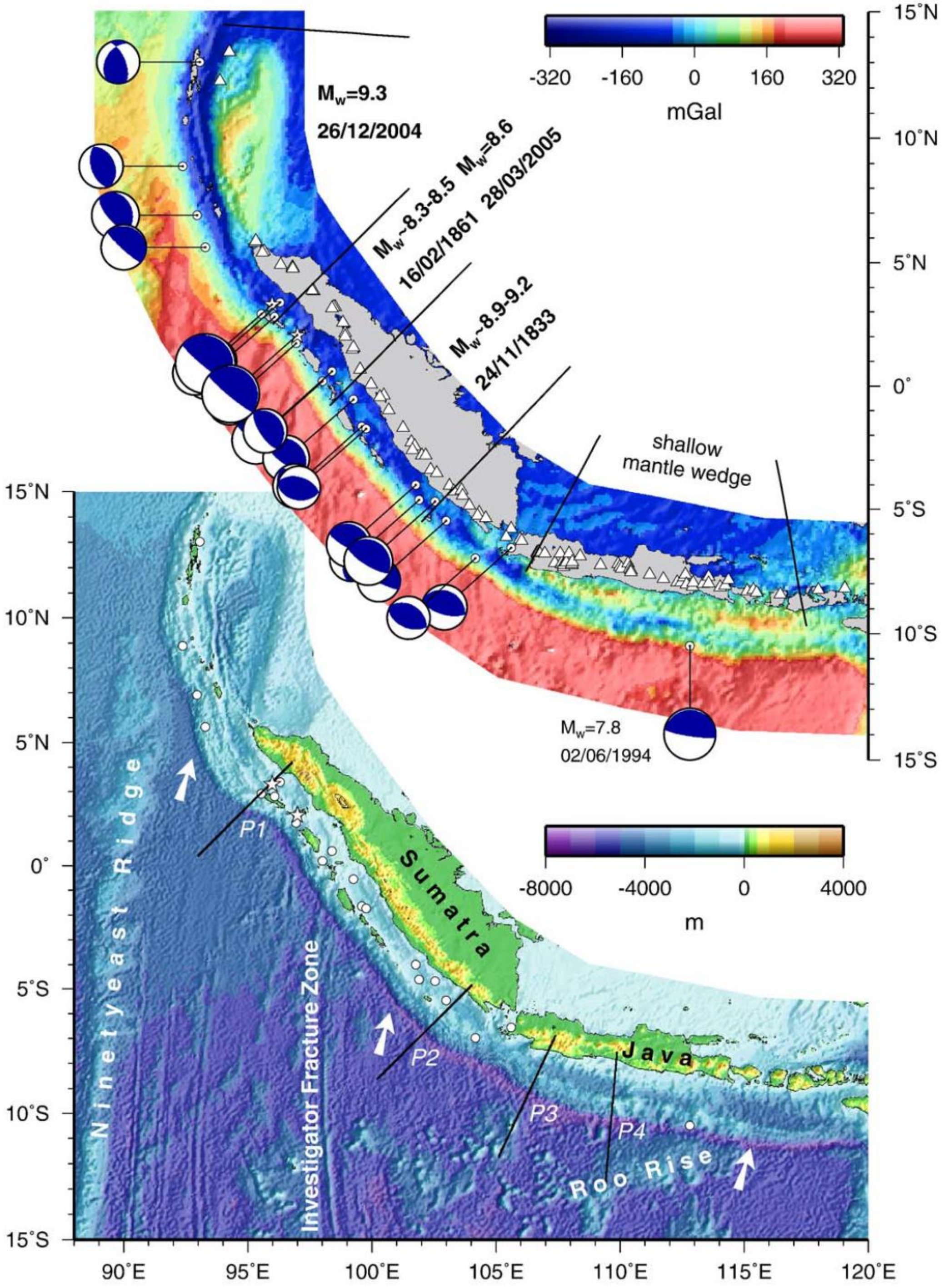
The historic record of large megathrust earthquakes suggests that the potential for great destructive events is much larger for Sumatra than Java. Bouguer gravity anomalies correlate well with the occurrence of large megathrust earthquakes in the Sunda subduction zone; negative anomalies mark segments characterized by larger earthquakes while positive anomalies indicate lower seismic potential. Thermal models and structural constraints derived from seismic and gravity data are used to explain the seismogenic behaviour in the Sunda subduction zone. With respect to Java, oblique subduction of young oceanic crust shifts the seismogenic coupling zone roughly 40 km trenchward offshore of northern Sumatra and increases the width of the locked megathrust. A prominent positive gravity anomaly offshore of Java is caused by a shallow mantle wedge underlying the forearc basin. A serpentinized mantle wedge would limit the width of the coupling zone off Java to only 30–40 km, compared to >120 km offshore of Sumatra. Sumatra remains therefore the most vulnerable site for future megathrust earthquakes, while the shallow mantle wedge may limit the violence of rupture off Java.

Keywords: Subduction; Earthquakes; Seismic hazard; Crustal structure; Mantle wedge; Serpentinization

1. Introduction

The 26 December 2004 Sumatra–Andaman earthquake ruptured a subduction zone megathrust plate boundary, where the oceanic Indo-Australian plate un-

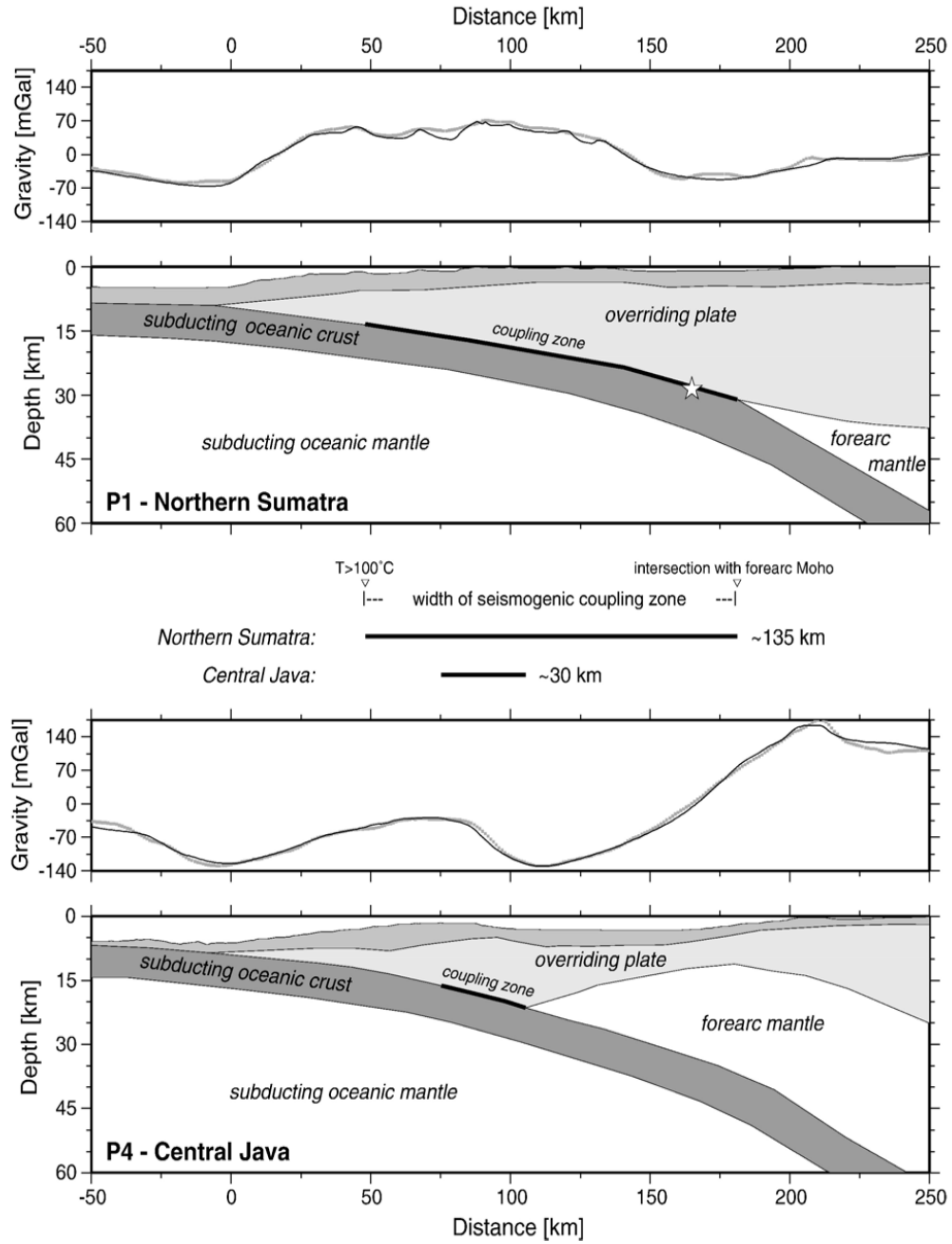
ocean [1,2]. Following the event, the possibility of a triggered earthquake on the contiguous Sunda trench subduction zone was a real concern [3]. And indeed, on 28 March 2005 the adjacent 300-km-long portion of the plate boundary broke, causing a M_w=8.6 earthquake



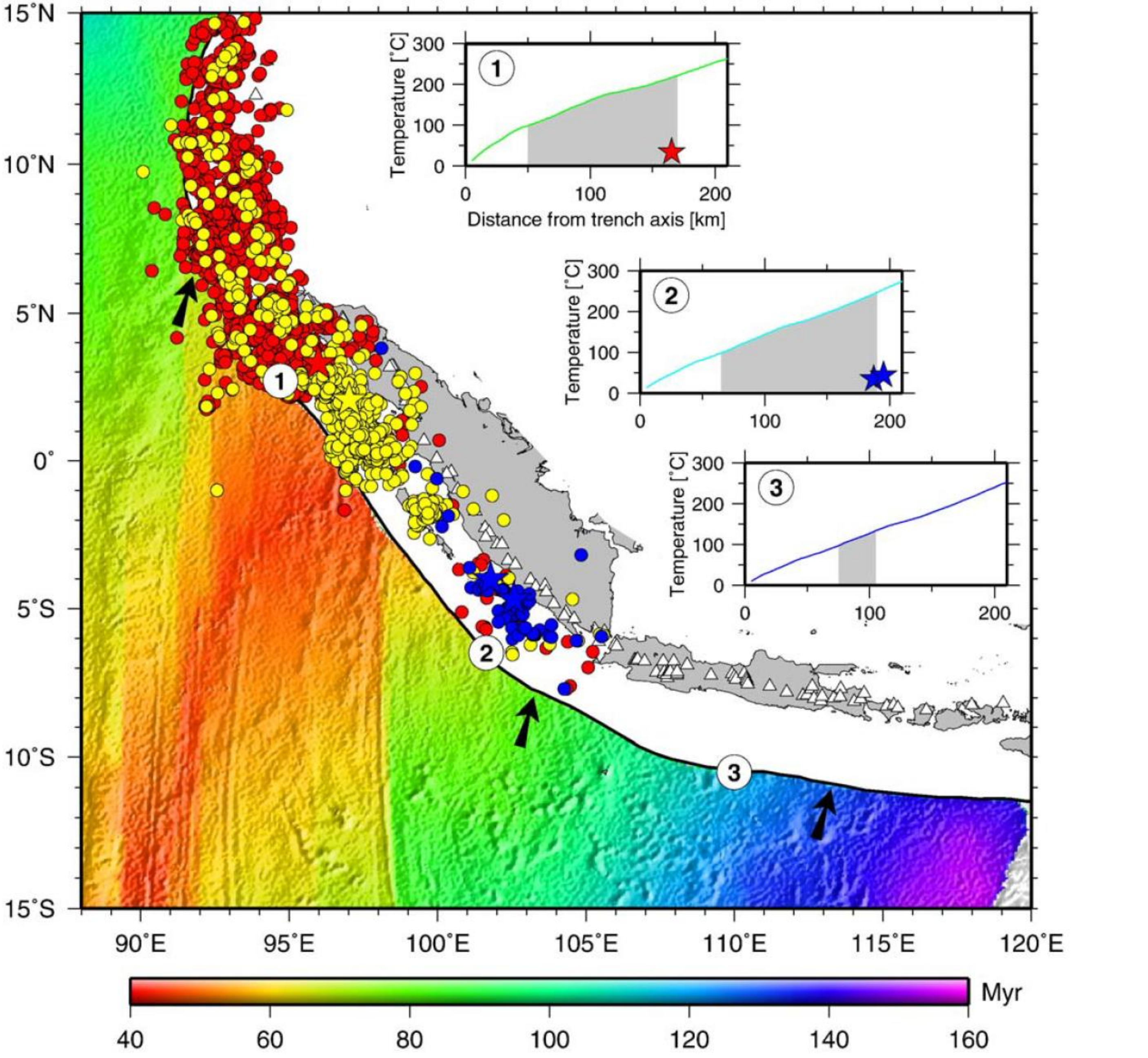
Bouguer gravity map of the Sunda–Andaman trench, fault plain solutions of large thrust earthquakes, topography & bathymetry

compiled by Awang Harun Satyana 18 March 2021

Gravity model



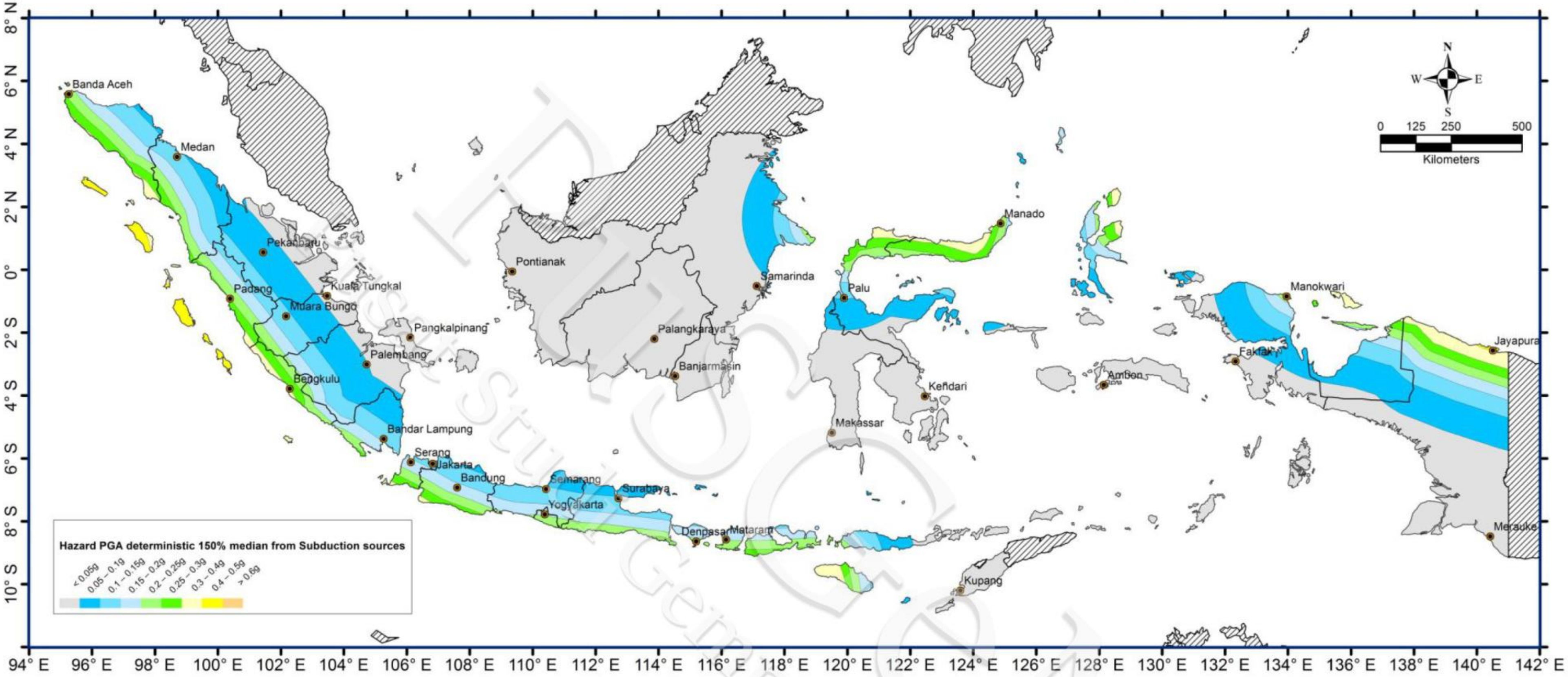
Age of the incoming oceanic lithosphere in million years & thermal model of subduction thrust fault



compiled by Awang Harun Satyana 18 March 2021

Grevemeyer & Tiwari (2006)

D2: Peta percepatan puncak di batuan dasar (SB) deterministik akibat sumber gempa Subduksi dengan 84-percentile (150% Median)



PuSGeN
Pusat Studi Gempabumi Nasional
National Center for Earthquake Studies

TIM PEMUTAKHIRAN PETA SUMBER DAN BAHAYA GEMPABUMI INDONESIA TAHUN 2017

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- Ir. Lutfi Faizal (Wakil Ketua)
- Dr. Danny Hilman Natawidjaja (Ketua Pokja Gelogi)
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- Dr. M. Ridwan
- Prof. Dr. Phil Cumming

PETA SUMBER DAN BAHAYA GEMPABUMI INDONESIA TAHUN 2017

Kementerian Pekerjaan Umum dan Perumahan Rakyat

Jakarta, 4 September 2017
Menteri Pekerjaan Umum dan Perumahan Rakyat

Dr. Ir. M. Basuki Hadimoeljono, M. Sc.

Kerjasama :

AIPI
Australian Government
DMInnovation
USGS
GEM
GLOBAL EARTHQUAKE MODEL
working together to assess risk

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

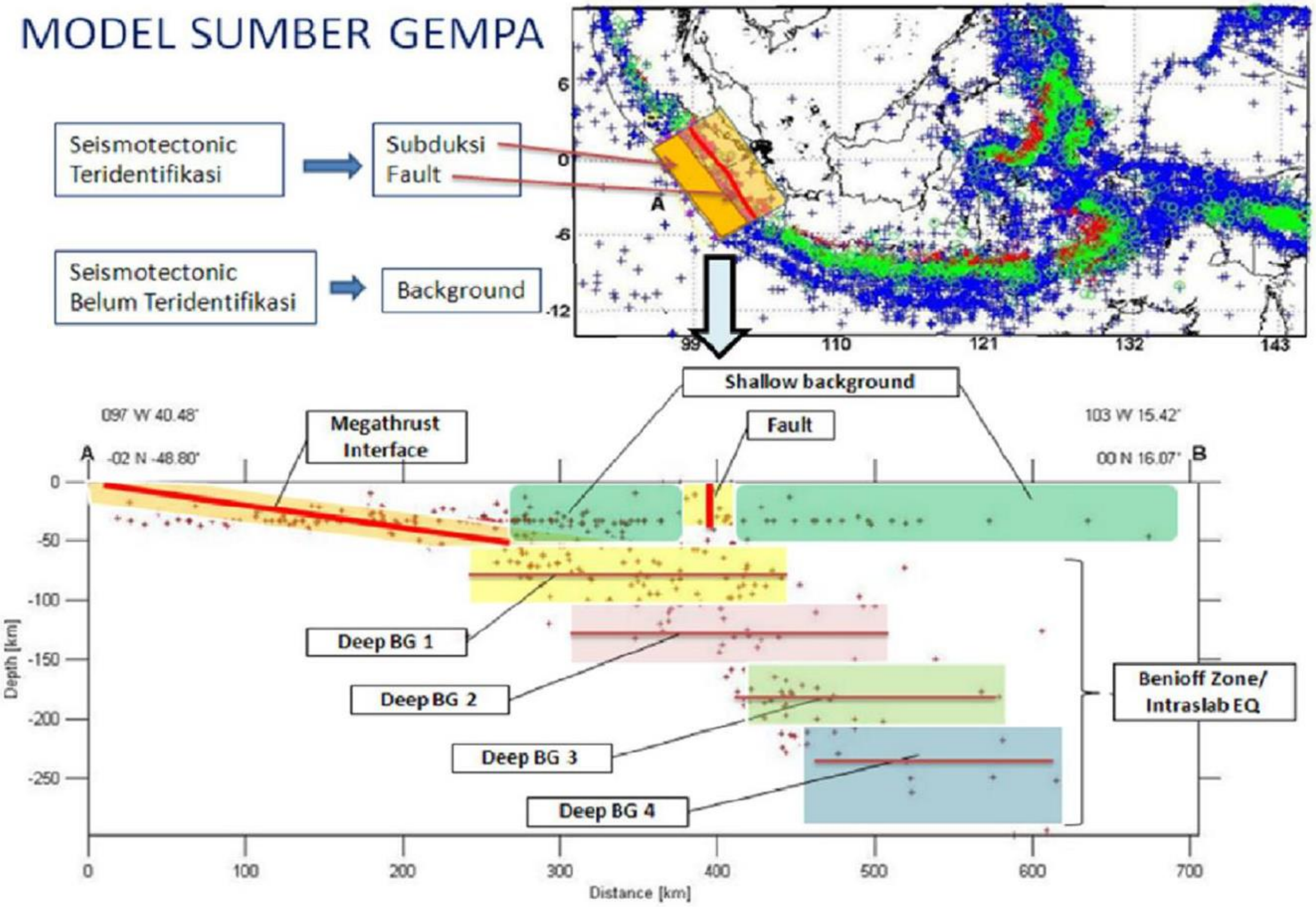
Diskusi

1. Tektonik Busur Sunda-Banda: Sumatra – Flores
   Karakter geologi dan tektonik yang berbeda
2. Gempa Megathrust Jawa – Sumbawa
   Mungkinkah menghasilkan gempa megathrust >M 8+ ?
3. **Gempa Intra-Plate Jawa Timur**
   Shallow background earthquake, mungkinkah menghasilkan gempa >M 6+ ?
4. Gempa Back-Arc Thrust Bali – Flores
   Kerak transisi – samudra Sundaland-Banda yang menekan Busur Sunda-Banda

MODEL SUMBER GEMPA

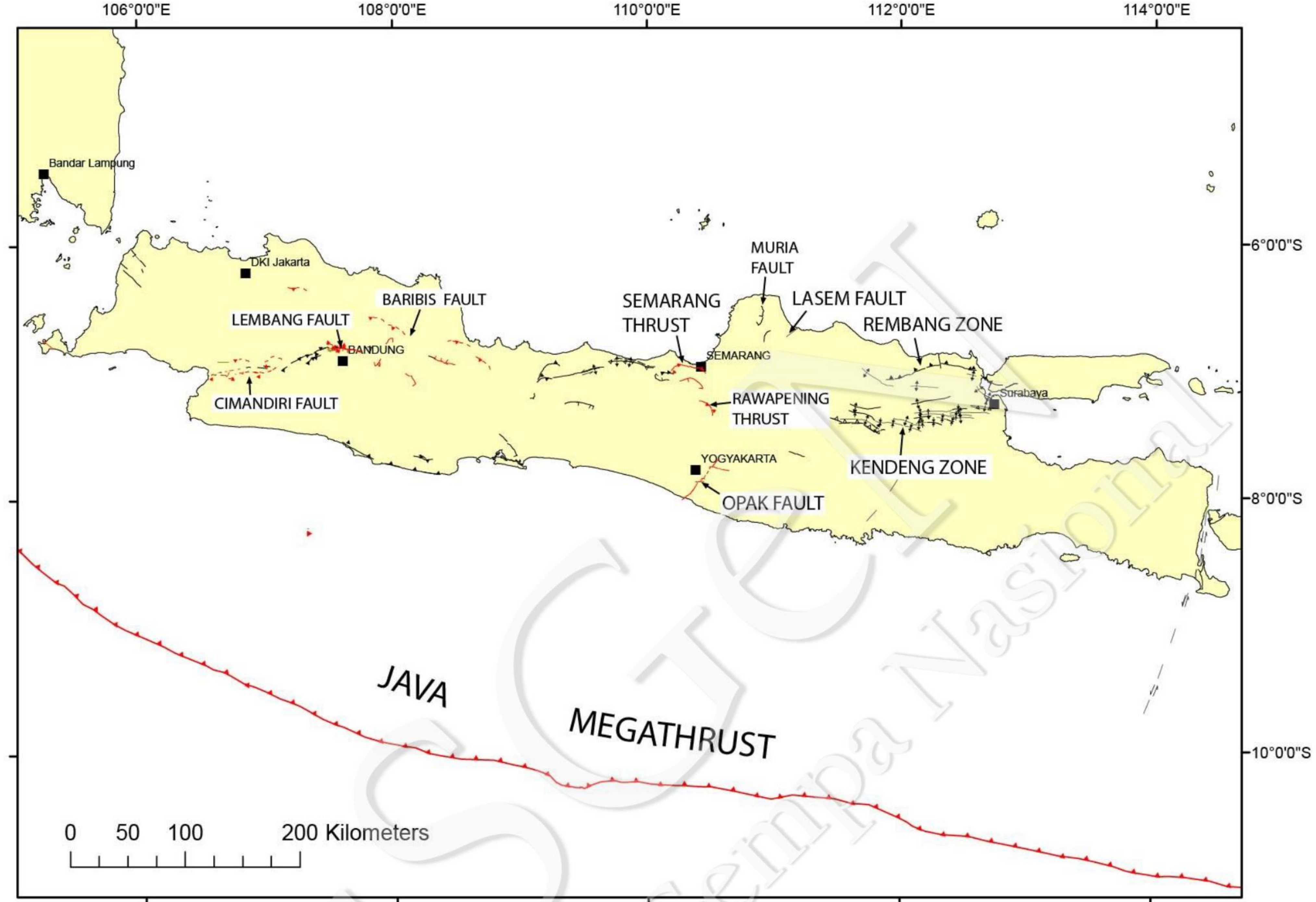
Peta respons Spektra Indonesia Untuk Perencanaan Bangunan Tahan Gempa Berdasarkan Sumber Gempa 3-Dimensi Dalam Analisis Probabilitas

Disertasi Doktor Jurusan Teknik Sipil, Institut Teknologi Bandung



Gambar III.31. Ilustrasi model sumber gempa fault, subduksi dan background.

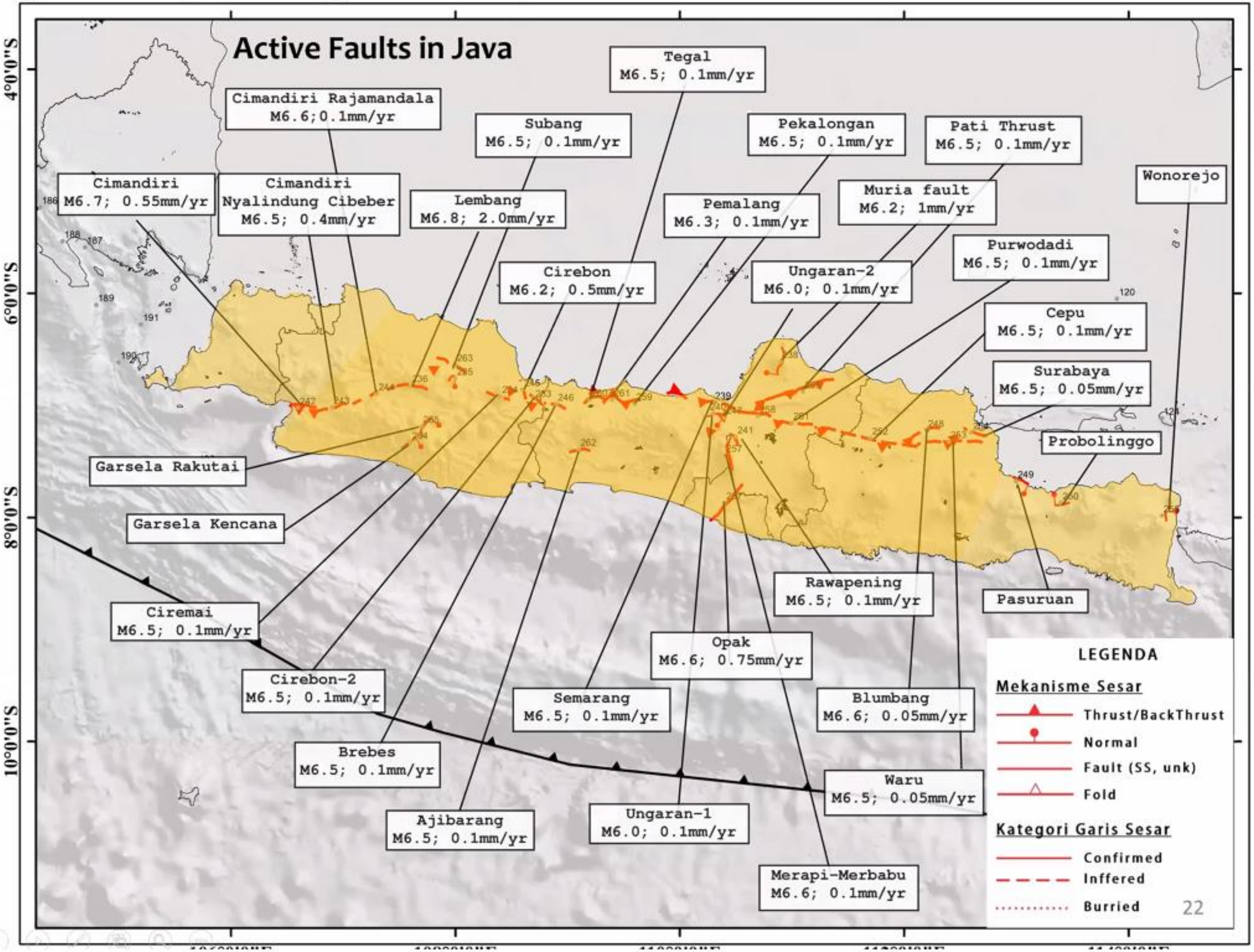
M Asrurifak, 2010

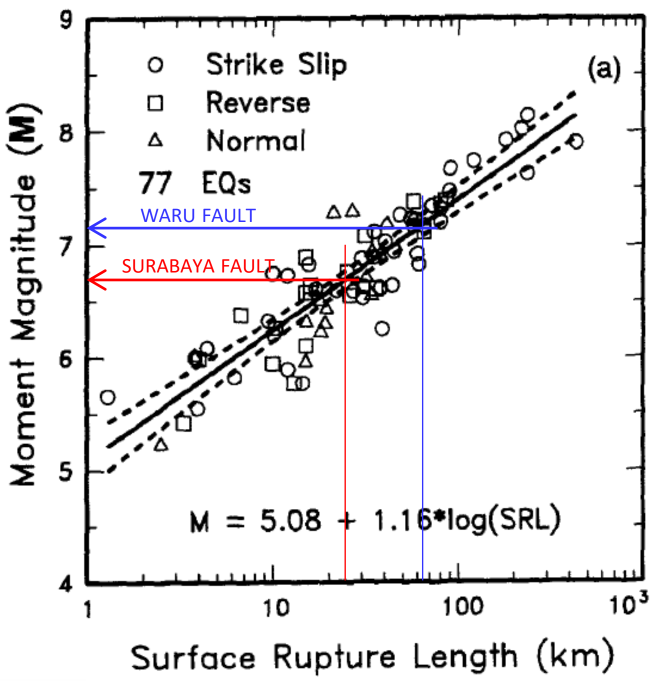


Peta sesar aktif di Jawa yang teridentifikasi sampai saat ini yang terangkum dalam Peta Gempa Nasional 2017

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021





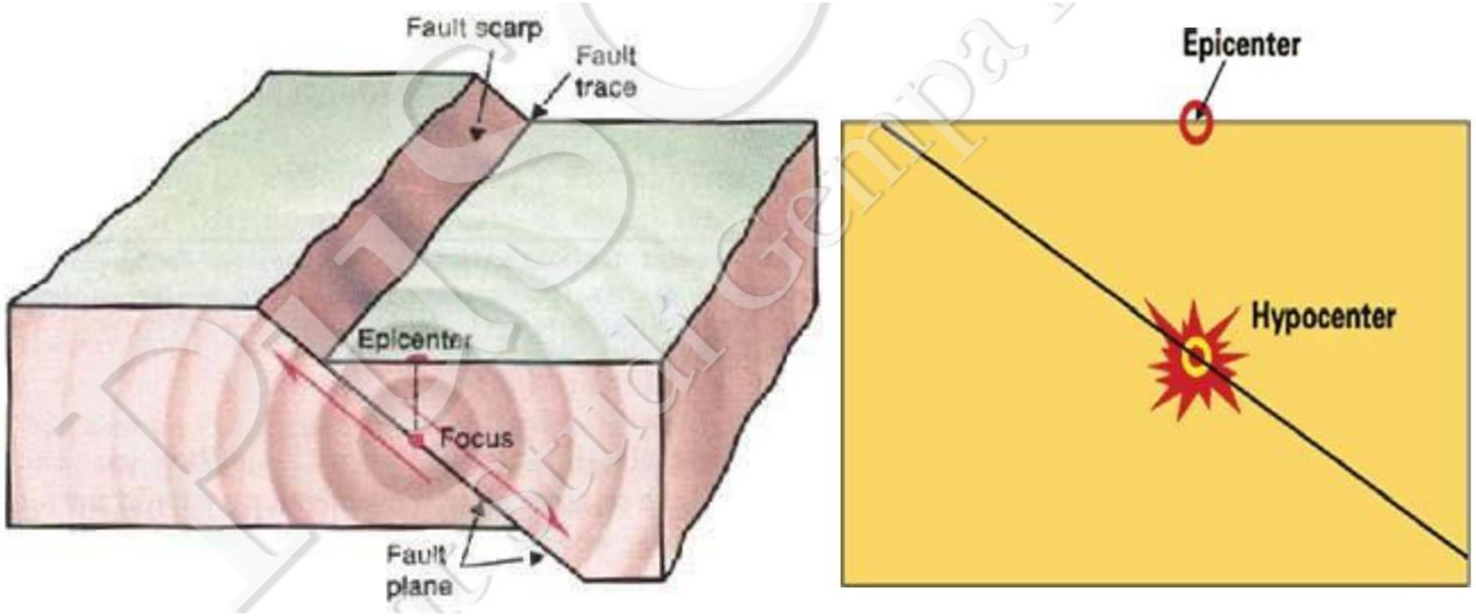
Wells & Coppersmith (1994)

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

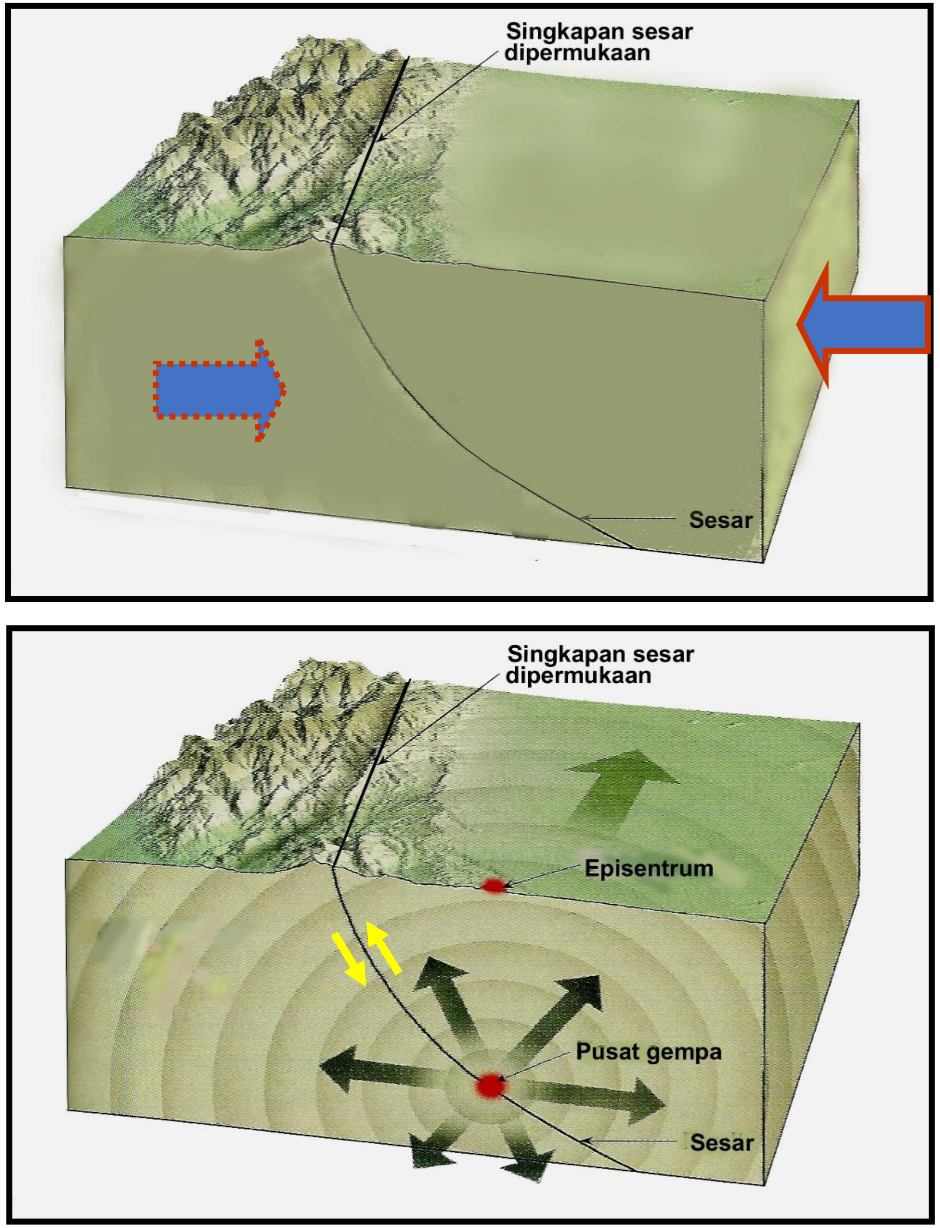
Sumber Gempa

REAKTIVASI PATAHAN/SESAR LAMA

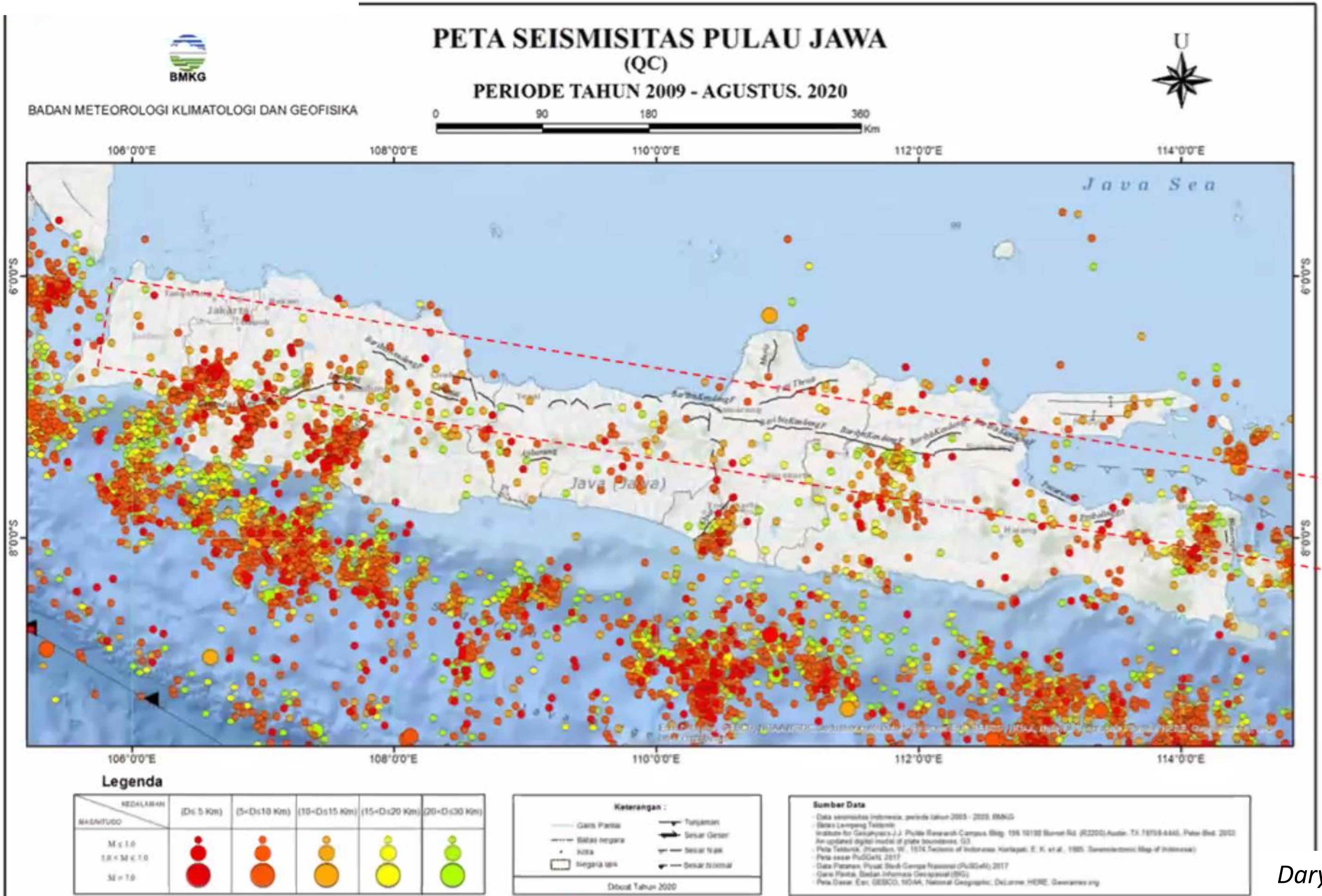


Ilustrasi model sumber gempa sesar/fault (http://earthquake.usgs.gov/learn/glossary/)

Pusgen (2017)

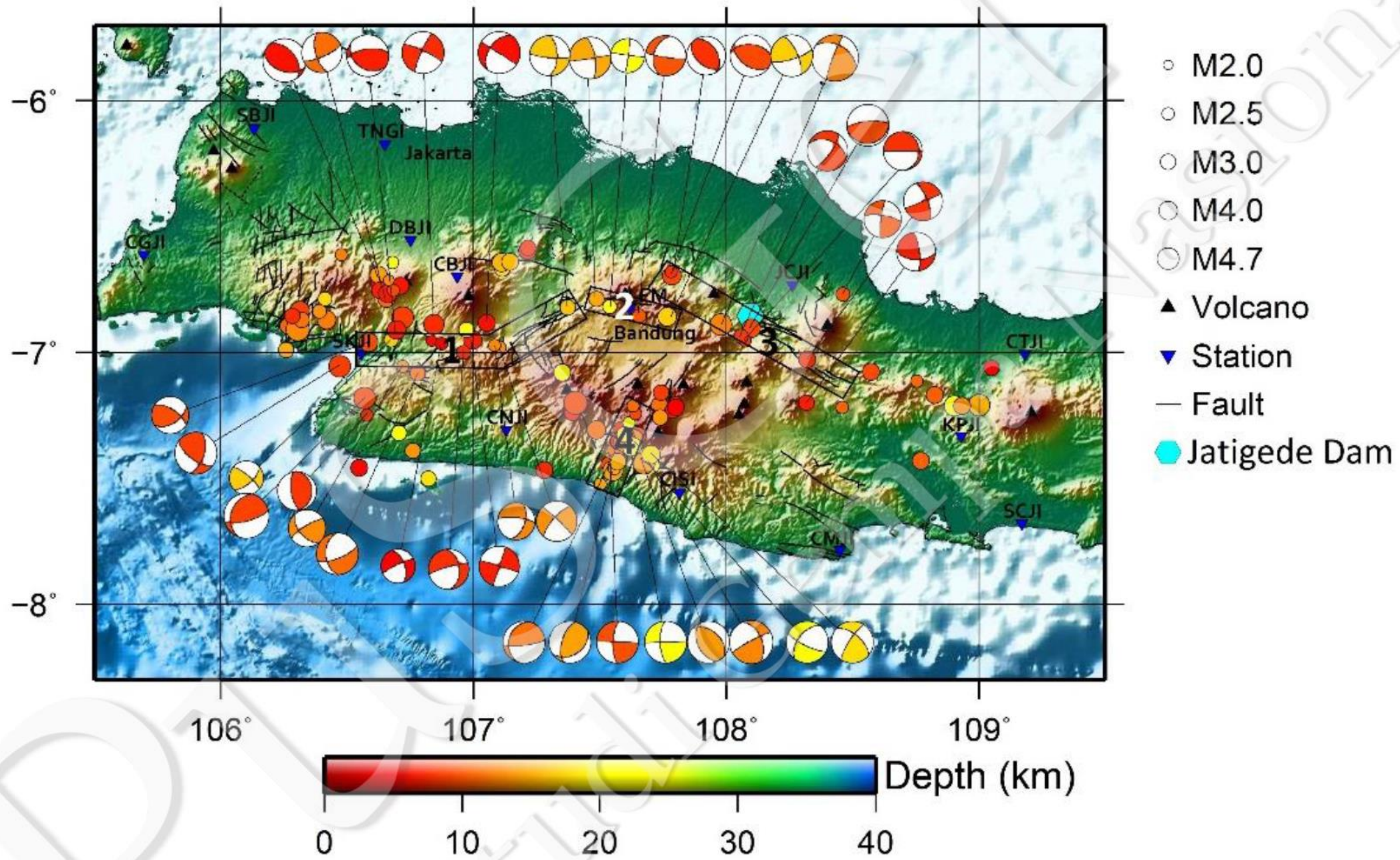


Geologi UGM



Daryono (2020)

compiled by Awang Harun Satyana 18 March 2021



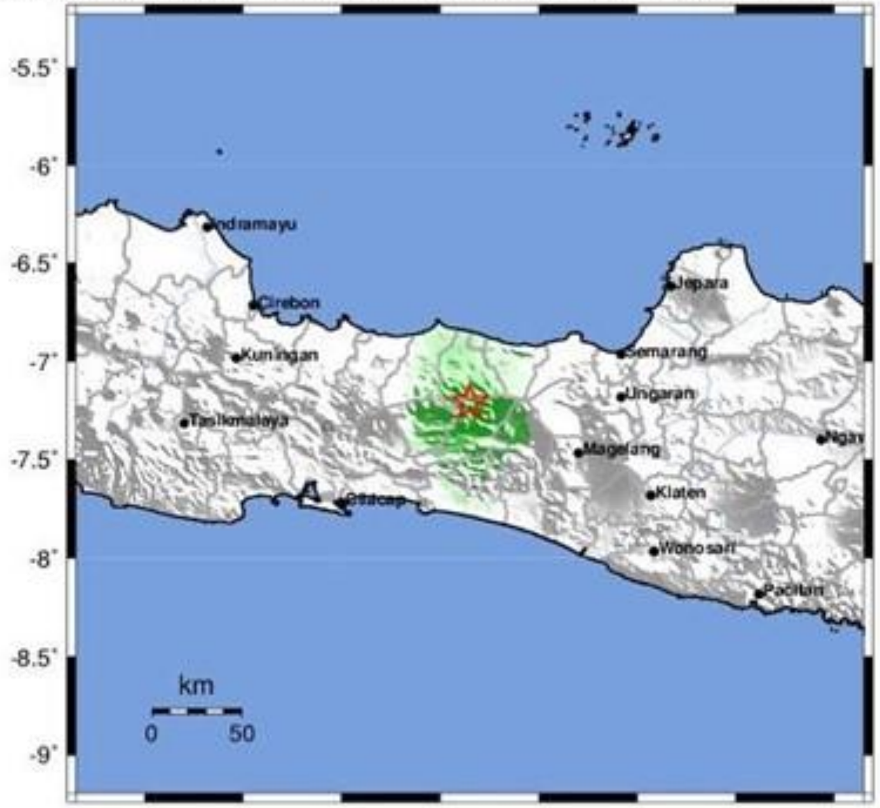
Peta episenter dan mekanisme fokus gempa di Jawa Barat. Perbedaan warna menunjukkan kedalaman yang berbeda. Kotak nomor satu sampai empat adalah klaster gempa yang kemungkinan berasosiasi dengan sesar di Jawa Barat (Supendi dkk., 2016)

Pusgen (2017)

MAGNITUDO GEMPA 4 KEDALAMAN 4 KM

BMKG ShakeMap : Java Region, Indonesia

8, 2018 13:28:35 WIB, M:4.4, 7.21LS 109.65BT, Kedlmn:4km, ID:20180418132835_44_-7210_109650_201804



Map Version 1 Processed Wed Apr 18, 2018 14:15:23 WIB

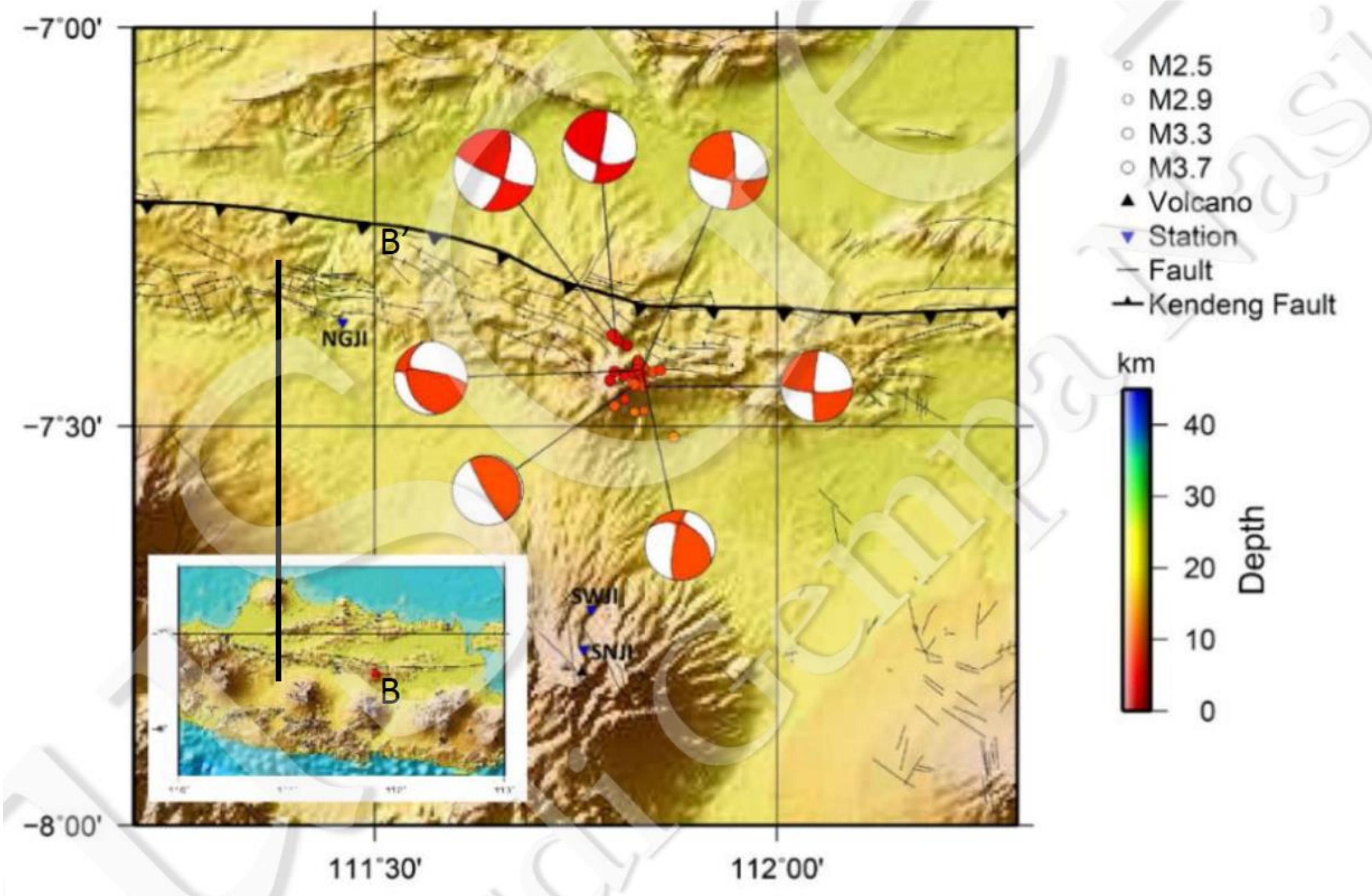
POTENSI KERUSAKAN	Tidak dirasakan	Dirasakan	Rusak ringan	Rusak sedang	Rusak berat
PERCEPATAN TANAH MAKS. (gal)	<2.9	2.9-88	89-167	168-564	>564
KECEPATAN TANAH MAKS. (cm/s)	<0.1	0.1-7.2	7.3-14.8	14.9-63.5	>63.5
SKALA INTENSITAS GEMPABUMI BMKG (SIG-BMKG)	I	II	III	IV	V

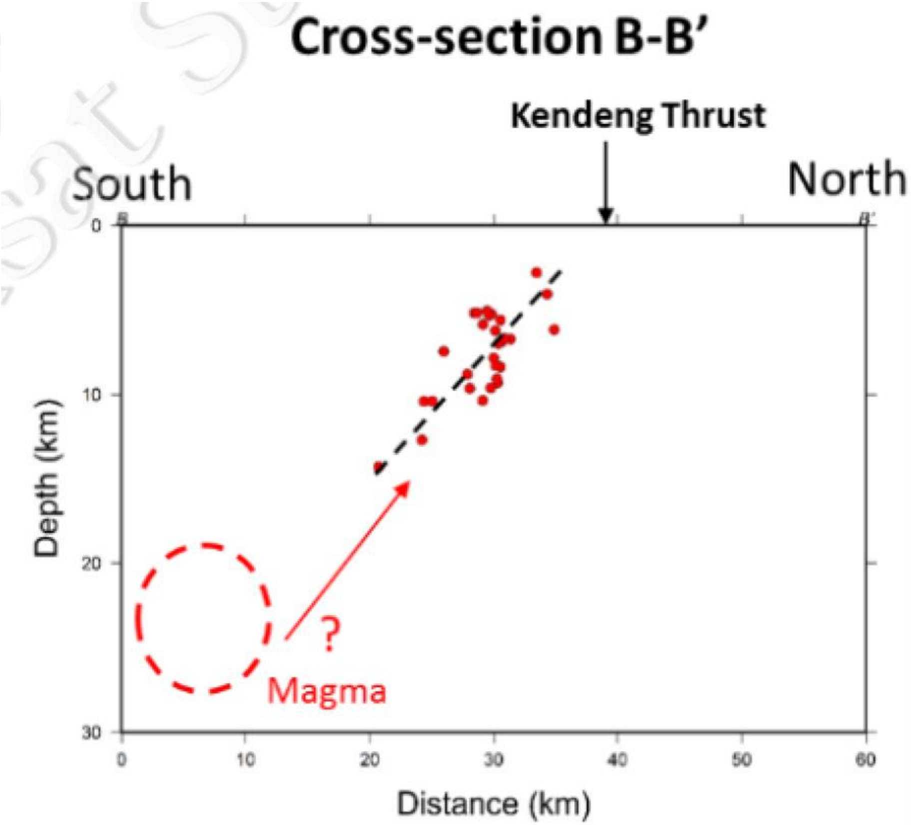
SIG-BMKG scale refered and modified from Worden et al. (2011)

Gempa Banjarnegara 4.4 SR
Kedalaman 4 km 18 April 2018

Widodo (2020)

compiled by Awang Harun Satyana 18 March 2021

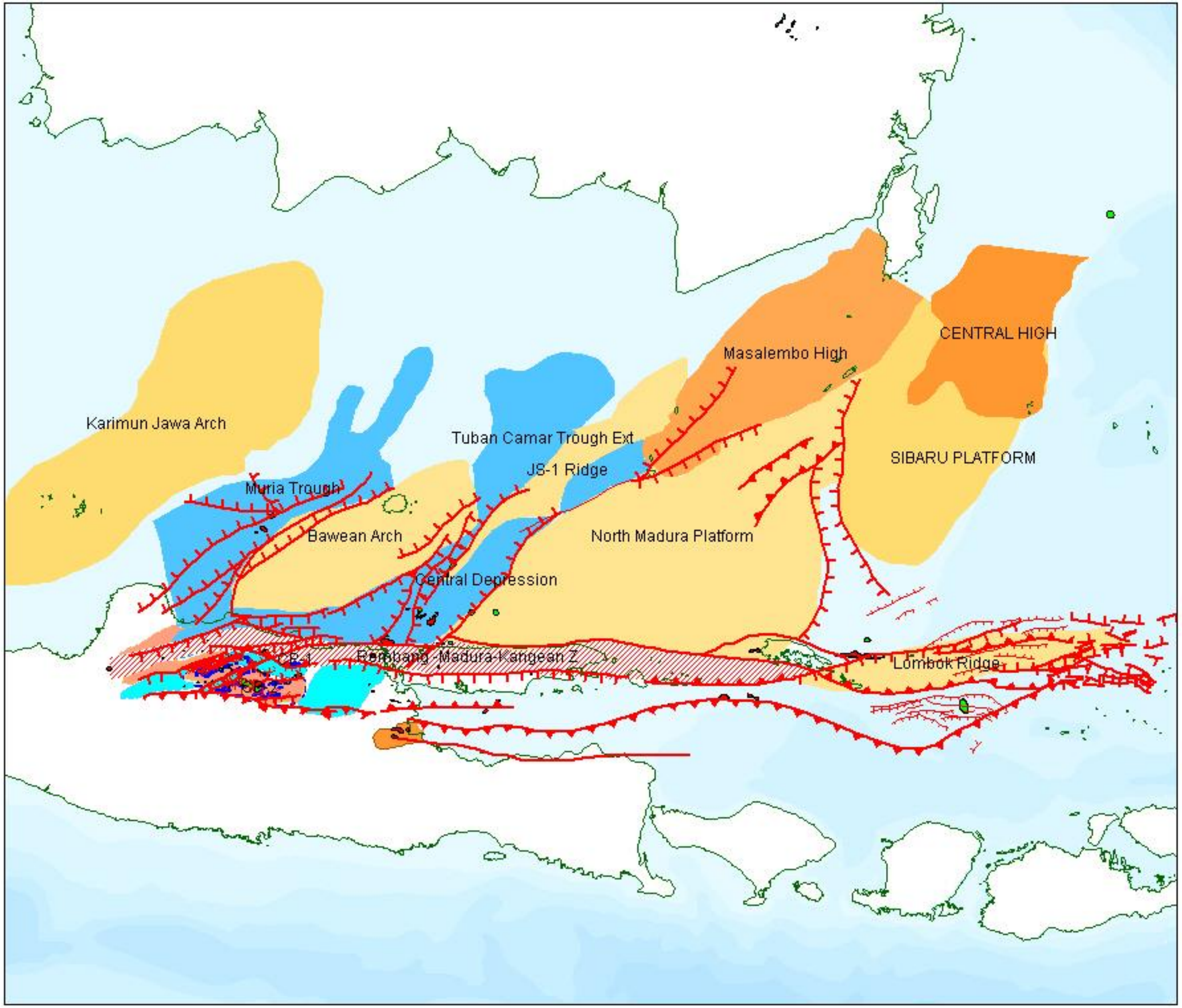




a) Peta episenter dan mekanisme fokus gempa hasil relokasi di Madiun selama bulan Februari 2016 dengan kedalaman dangkal ≤ 30 km. Lingkaran merah sampai kuning adalah hiposenter gempa berdasarkan kedalaman. Segitiga terbalik warna biru adalah stasiun seismik BMKG yang digunakan b) Penampang vertikal B-B' dari gempa-gempa di Madiun (Nugraha dkk., 2017)

Pusgen (2017)

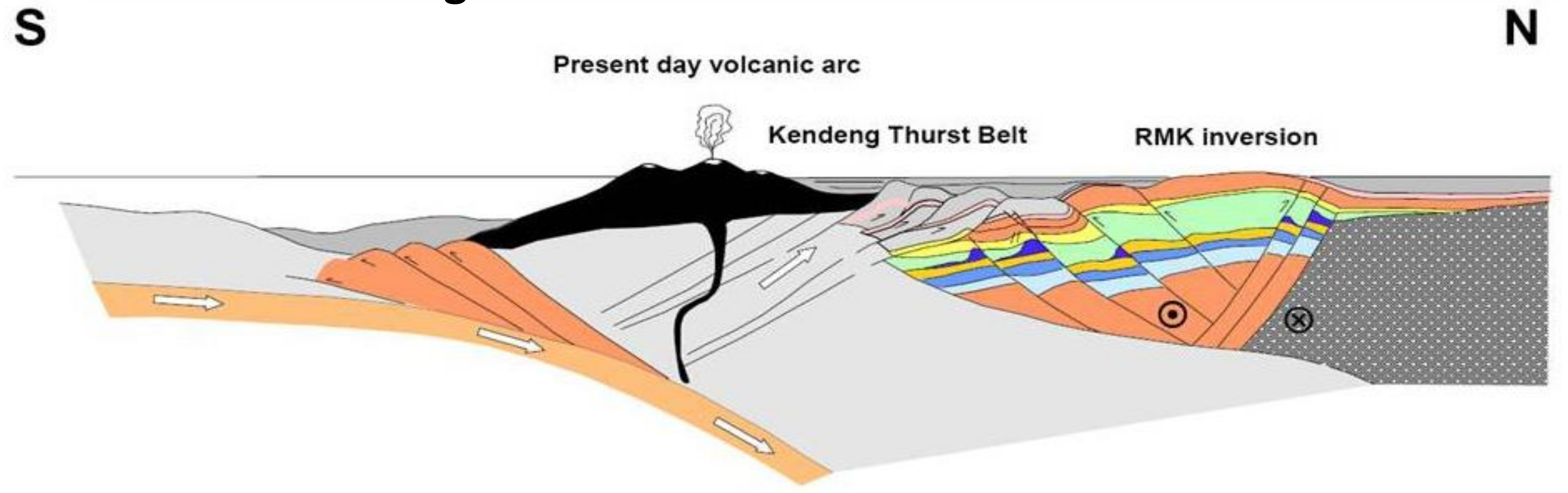
Deformation of East Java Basin



- *Rembang-Madura-Kangean-Sakala (RMKS) Fault Zone - strike-slip faulting, inverted zone, simple shear deformation*
- *Kendeng Fault Zone – thrust and reverse faults, pure shear deformation*

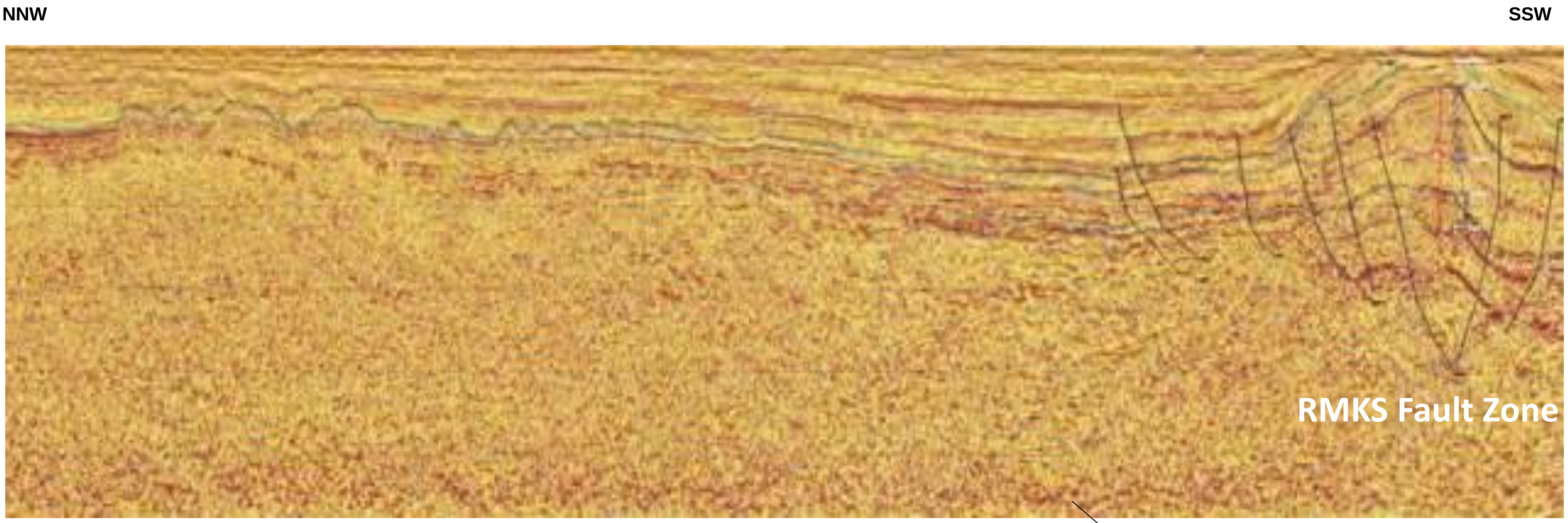
compiled by Awang Harun Satyana 18 March 2021

Neogene Deformation of East Java Basin

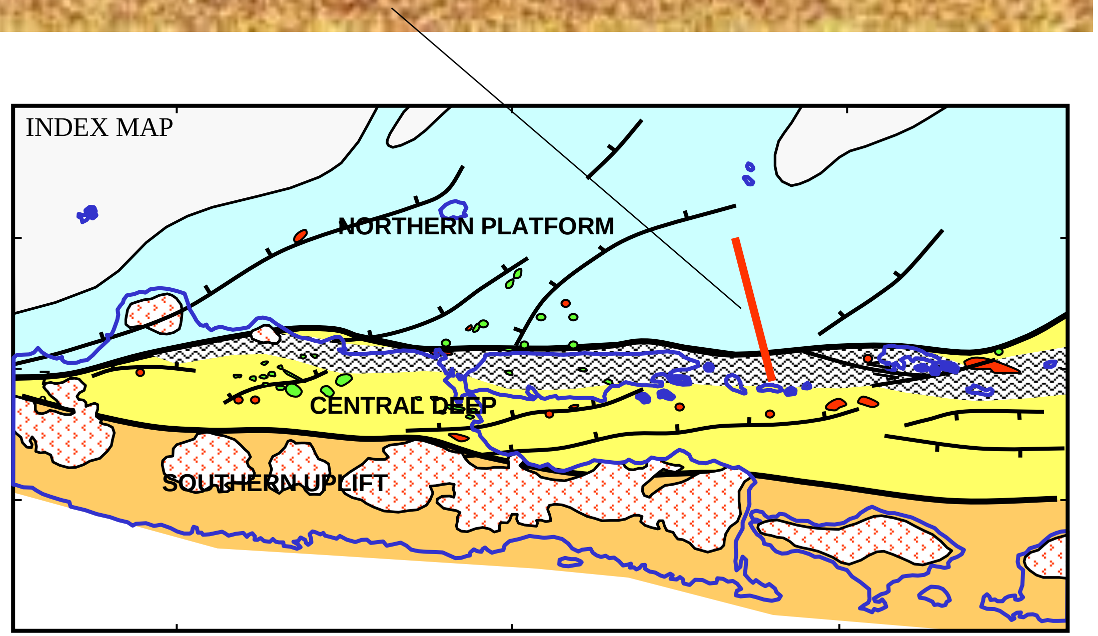


- Back-arc basin bounded to the south by Quaternary volcanic arc and to the north by SE Sundaland platform
- Back-thrusting along the north of the arc develops Kendeng thrust belt along the southern margin of the basin
- Left-lateral transpression along the RMKS (Rembang-Madura-Kangean-Sakala) fault zone resulted in inversion of the basin deep and uplift along this trend

Bransden & Matthews (1992); Santos (2004)

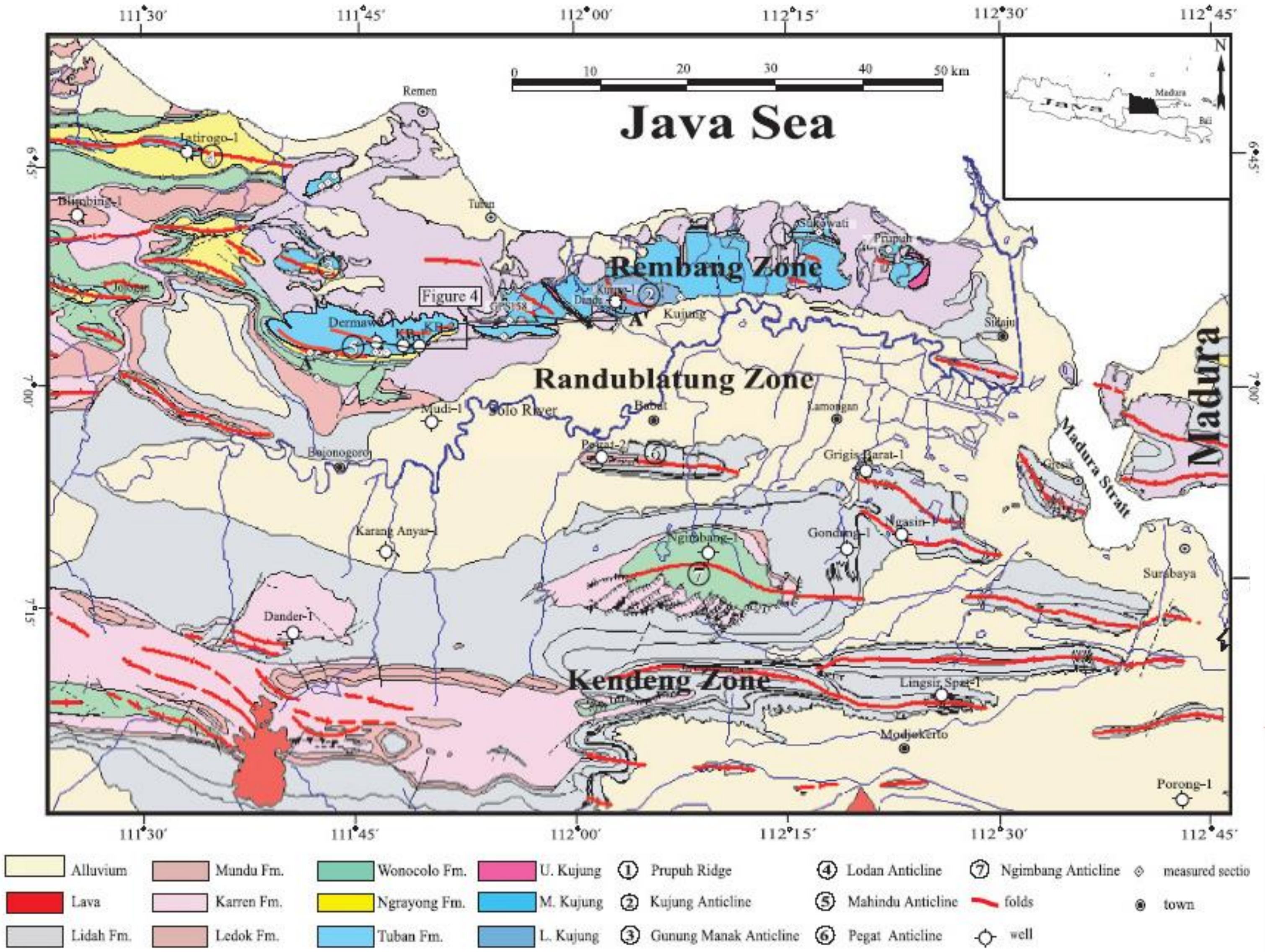


Flower structure of the RMKS fault zone in the Kangean area

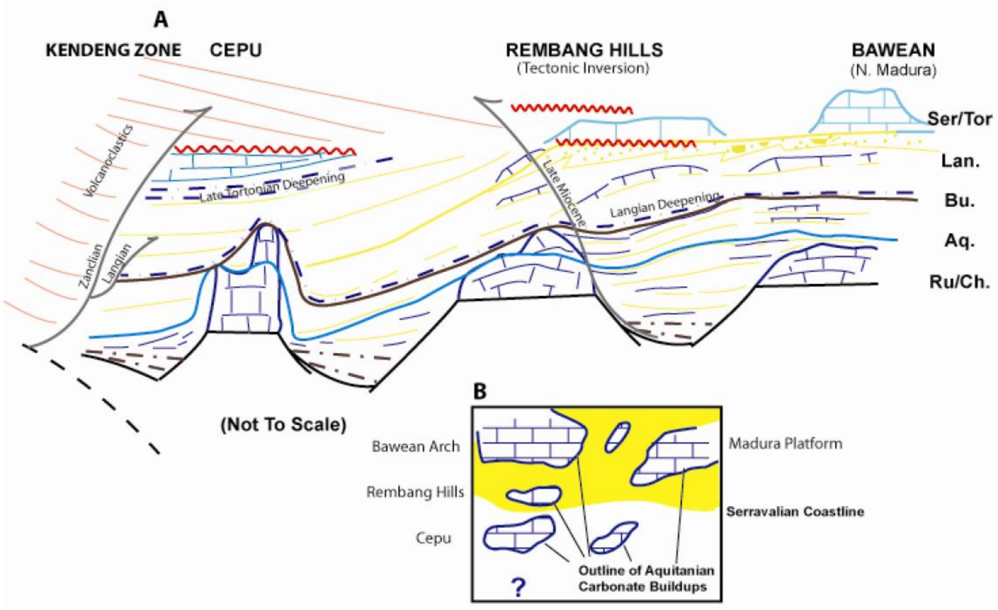


Satyana et al. (2004)

Northeast Java Geologic Map



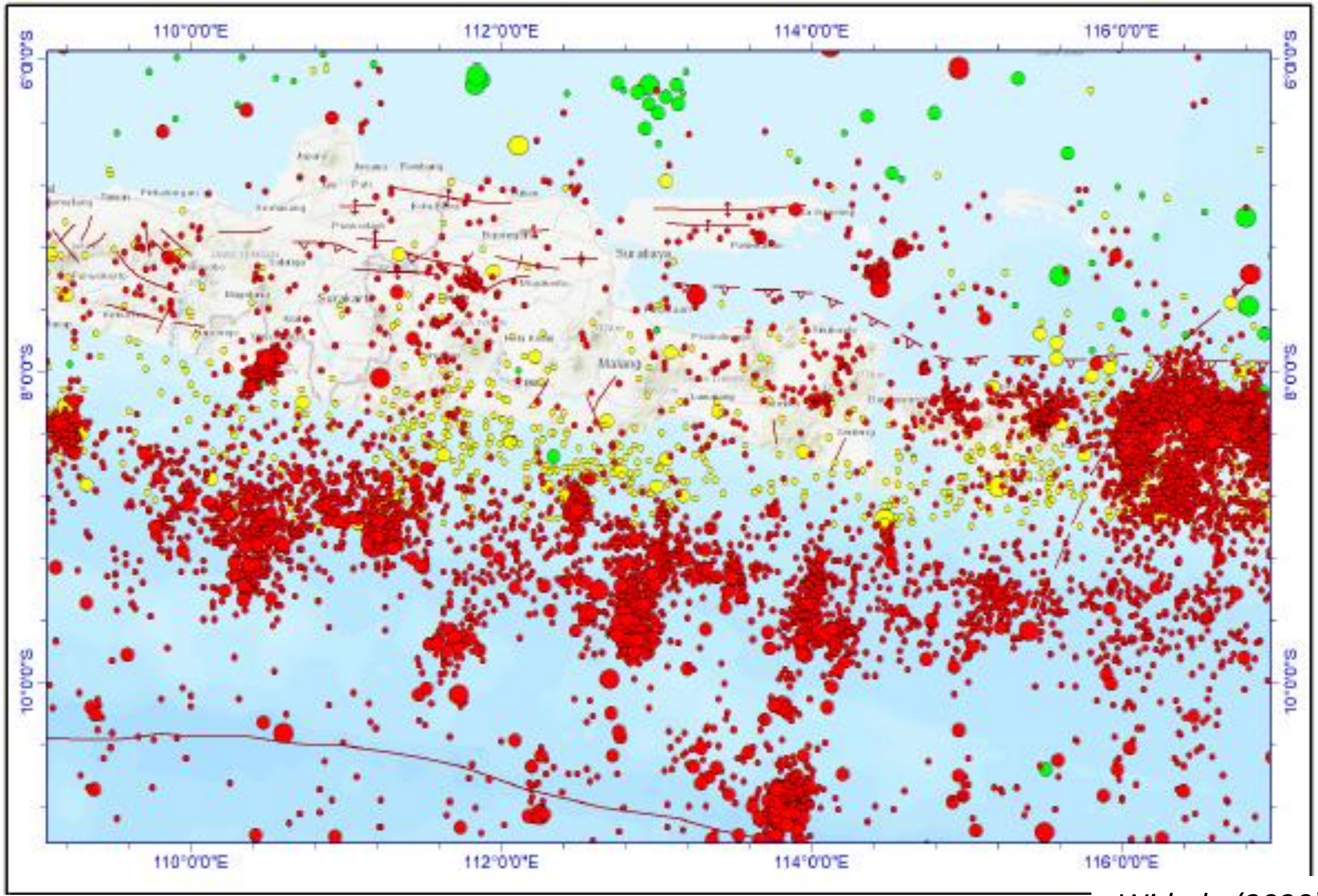
Lundin (2000)



Simo et al. (2011)

compiled by Awang Harun Satyana 18 March 2021

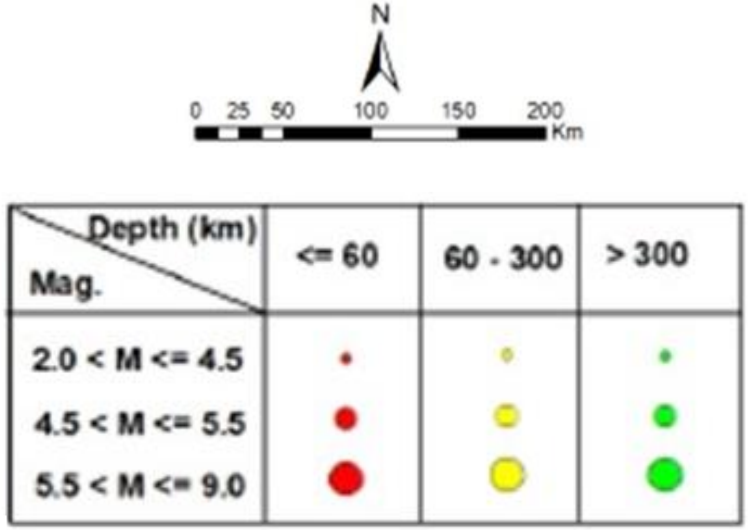
SEISMISITAS JAWA TIMUR



BMKG

Sumber Data : Katalog Gempabumi BMKG

Seismisitas Jawa Timur

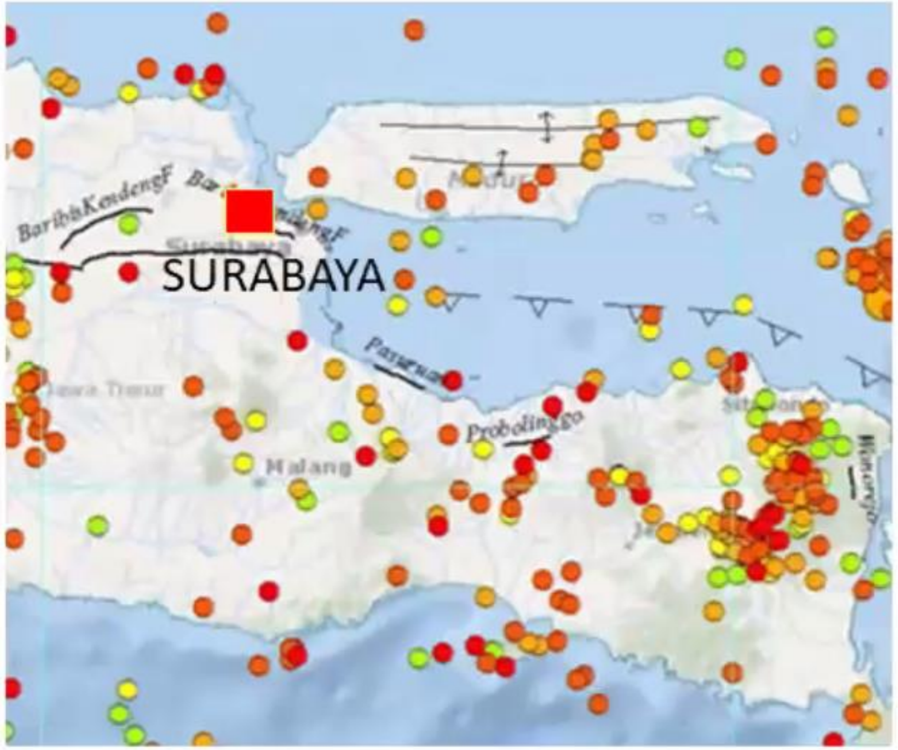


compiled by Awang Harun Satyana 18 March 2021

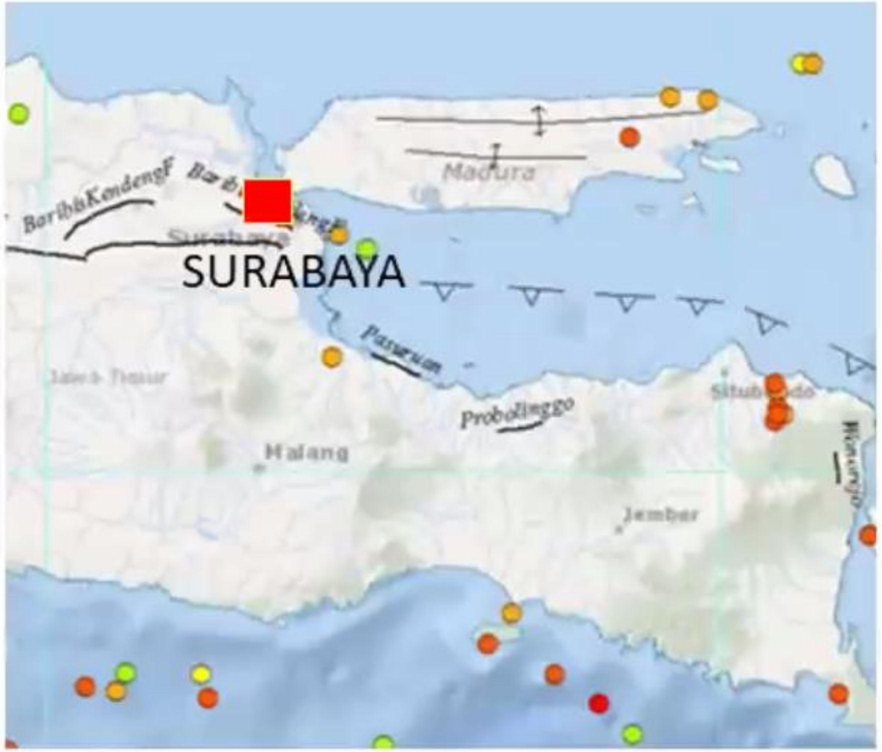
Widodo (2020)

SEISMISITAS KOTA SURABAYA 2008-2019

- *Sesar Kendeng terbukt masih aktif*
- *BMKG masih mencatat banyak pusat gempa dangkal dekat Kota Surabaya*



2009 – AGUST 2020

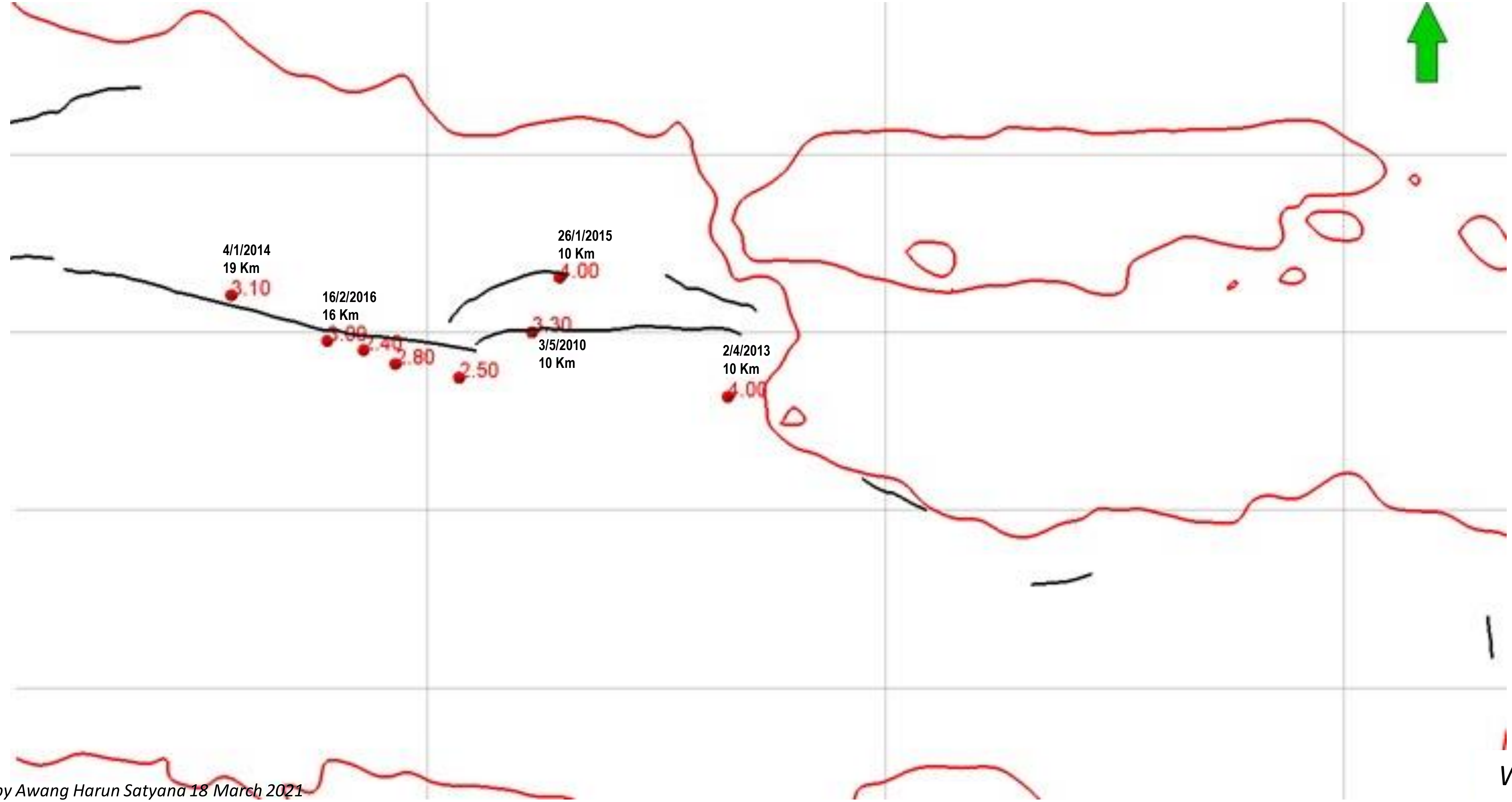


MARET – OKTOBER 2020

Daryono (2020)

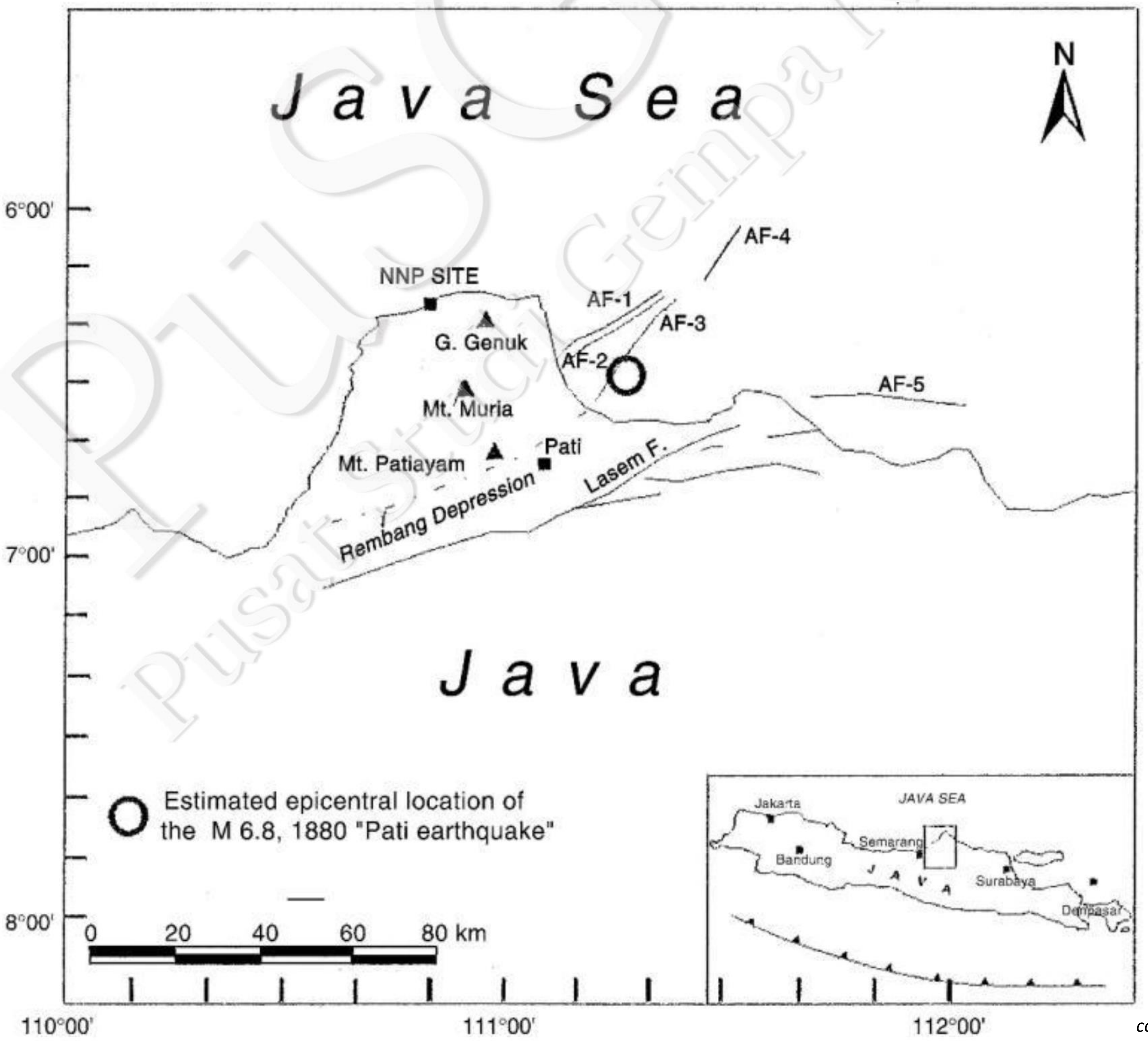
compiled by Awang Harun Satyana 18 March 2021

GEMPA DI SEPANJANG SESAR AKTIF



compiled by Awang Harun Satyana 18 March 2021

Widodo (2020)



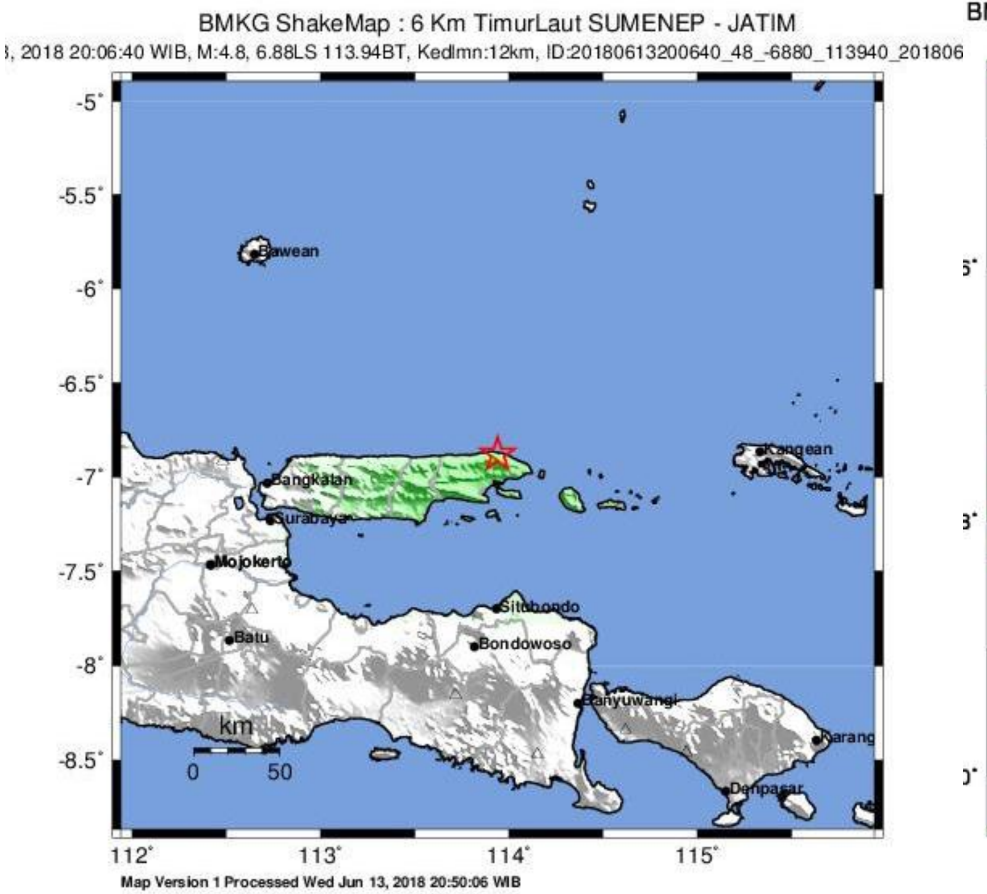
Delineasi Sesar Lasem
Menurut McBirney dkk. (2003)
Relatif Terhadap Episenter
Gempa M6.8 Pada Tahun 1880

M 6.8 (?)

Pusgen (2017)

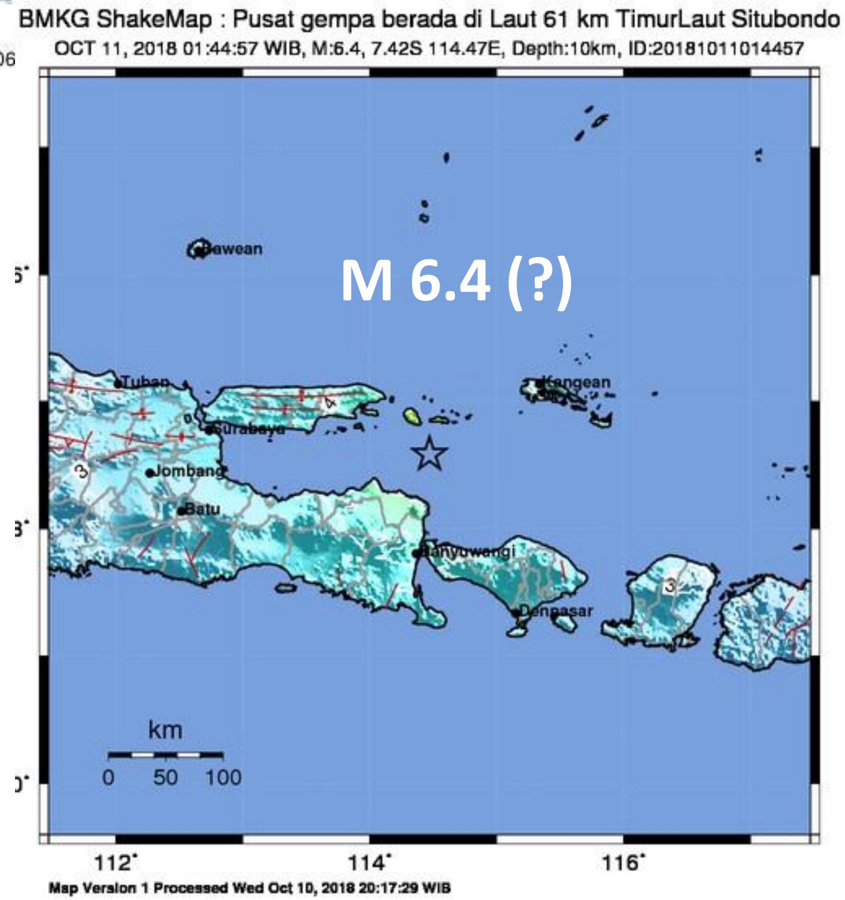
compiled by Awang Harun Satyana 18 March 2021

Gempa tahun 2018



POTENSI KERUSAKAN	Tidak dirasakan	Dirasakan	Rusak ringan	Rusak sedang	Rusak berat
PERCEPATAN TANAH MAKS. (gal)	<2.9	2.9-88	89-167	168-564	>564
KECEPATAN TANAH MAKS. (cm/s)	<0.1	0.1-7.2	7.3-14.8	14.9-63.5	>63.5
SKALA INTENSITAS GEMPABUMI BMKG (SIG-BMKG)	I	II	III	IV	V

SIG-BMKG scale refered and modified from Worden et al. (2011)



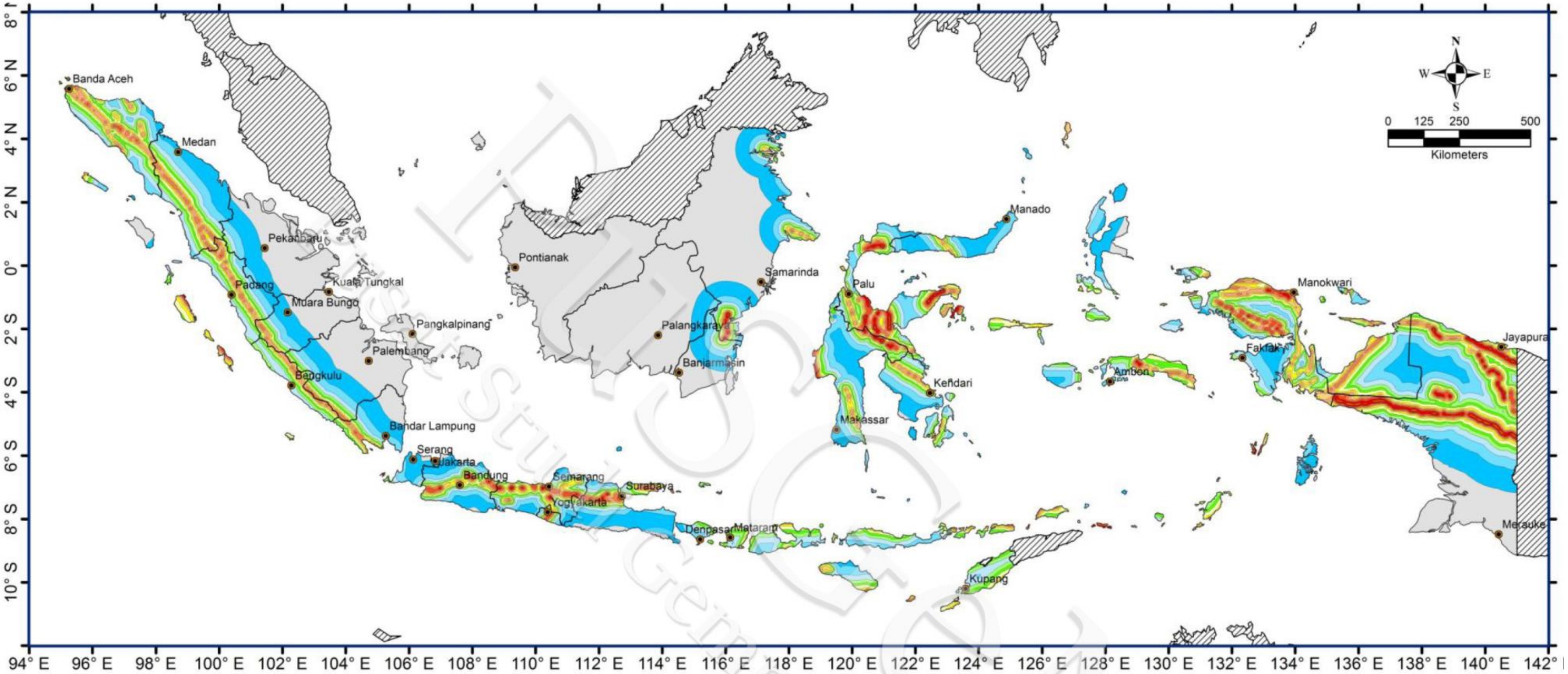
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very heavy
MMI	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2011)

compiled by Awang Harun Satyana 18 March 2021

Widodo (2020)

D1: Peta percepatan puncak di batuan dasar (SB) deterministik akibat sumber gempa sesar dangkal dengan 84-percentile (150% Median)



PuSGeN
Pusat Studi Gempabumi Nasional
National Center for Earthquake Studies

TIM PEMUTAKHIRAN PETA SUMBER DAN BAHAYA GEMPABUMI INDONESIA TAHUN 2017

- Prof. Dr. Masyhur Irsyam (Ketua)
- Ir. Lutfi Faizal (Wakil Ketua)
- Dr. Danny Hilman Natawidjaja (Ketua Pokja Gelogi)
- Dr. Irwan Meilano (Ketua Pokja Geodesi)
- Prof. Dr. Sri Widiyantoro (Ketua Pokja Seismologi)
- Dr. Wahyu Triyoso (Ketua Pokja Katalog)
- Ariska Rudyanto, M.Phil. (Ketua Pokja GMPE)
- Dr. Sri Hidayati (Ketua Pokja SHA)
- Dr. M. Asrurifak
- Dr. M. Ridwan
- Prof. Dr. Phil Cumming

PETA SUMBER DAN BAHAYA GEMPABUMI INDONESIA TAHUN 2017

Kementerian Pekerjaan Umum dan Perumahan Rakyat

Jakarta, 4 September 2017
Menteri Pekerjaan Umum dan Perumahan Rakyat

Dr. Ir. M. Basuki Hadimoeljono, M. Sc.

Kerjasama :

Australian Government

USGS

GEM GLOBAL EARTHQUAKE MODEL working together to assess risk

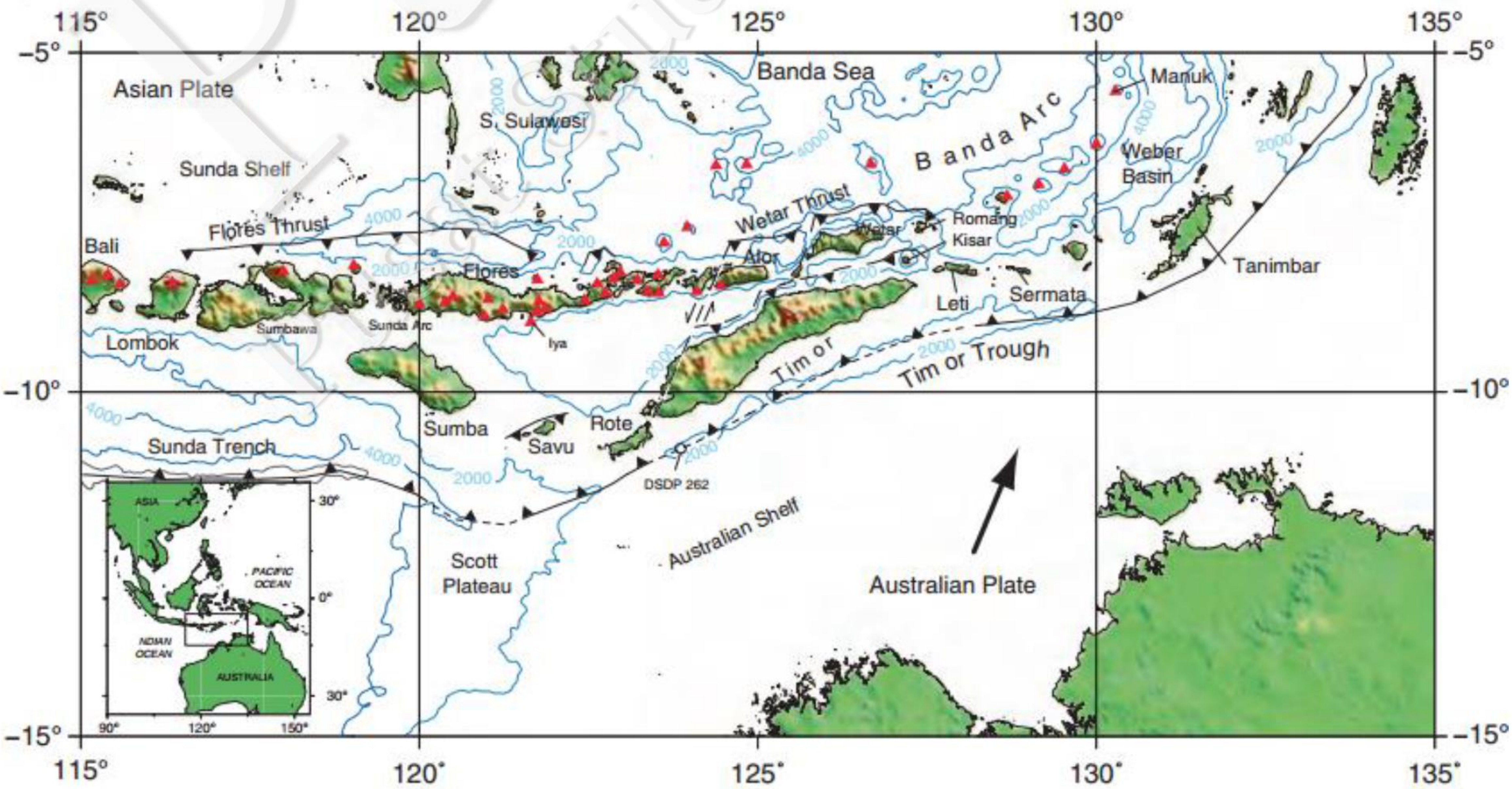
Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

Diskusi

1. Tektonik Busur Sunda-Banda: Sumatra – Flores
   Karakter geologi dan tektonik yang berbeda
2. Gempa Megathrust Jawa – Sumbawa
   Mungkinkah menghasilkan gempa megathrust >M 8+ ?
3. Gempa Intra-Plate Jawa Timur
   Shallow background earthquake, mungkinkah menghasilkan gempa >M 6+ ?
4. **Gempa Back-Arc Thrust Bali – Flores**
   Kerak transisi – samudra Sundaland-Banda yang menekan Busur Sunda-Banda


FLORES BACKARC THRUST
compiled by Awang Harun Satyana 18 March 2021

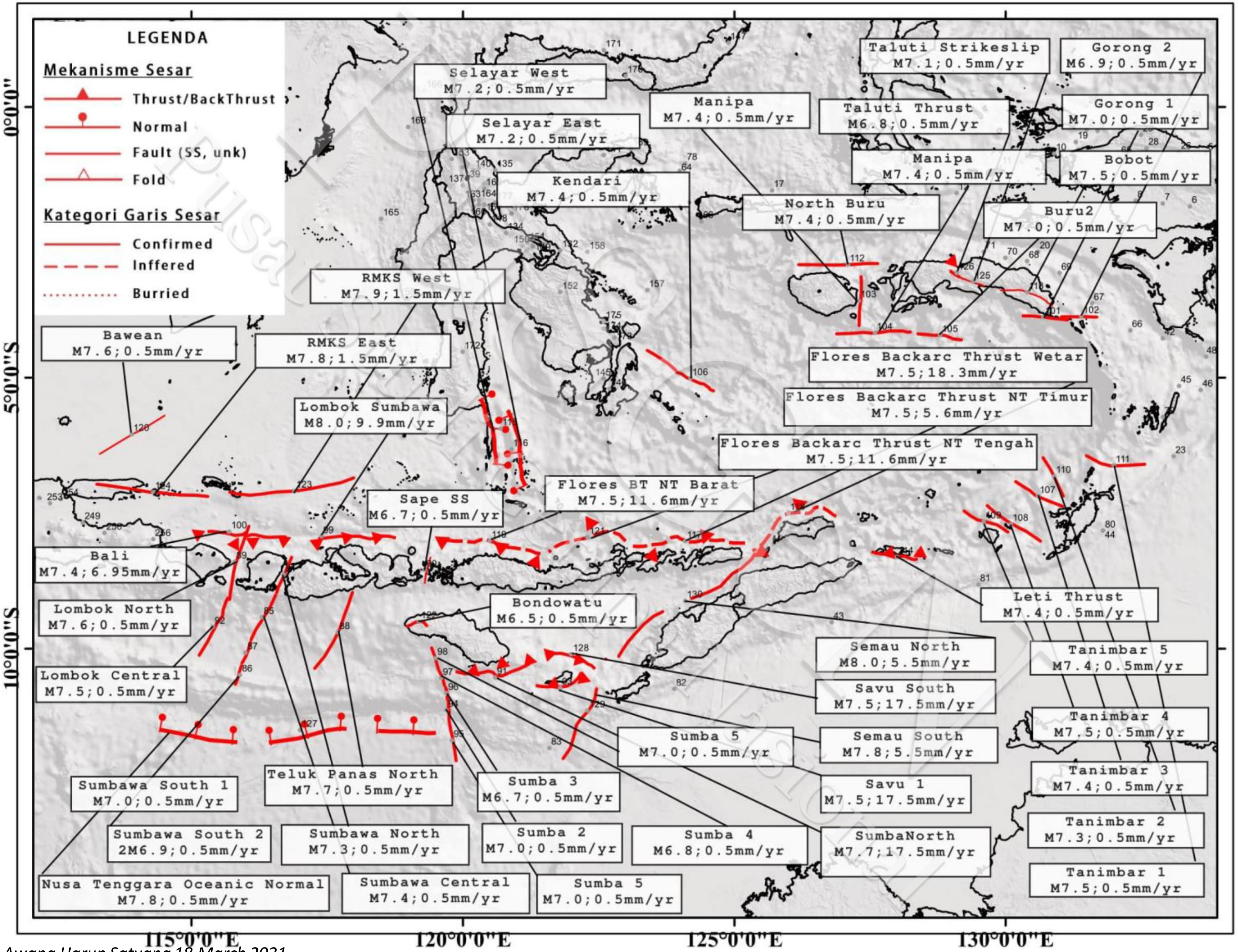


Konfigurasi daerah Bali - Nusa Tenggara dan Banda (Harris, 2011)

Pusgen (2017)

compiled by Awang Harun Satyana 18 March 2021

Sumber gempa di Nusa Tenggara (Busur Sunda Timur dan Busur Banda)



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Pusgen (2017)

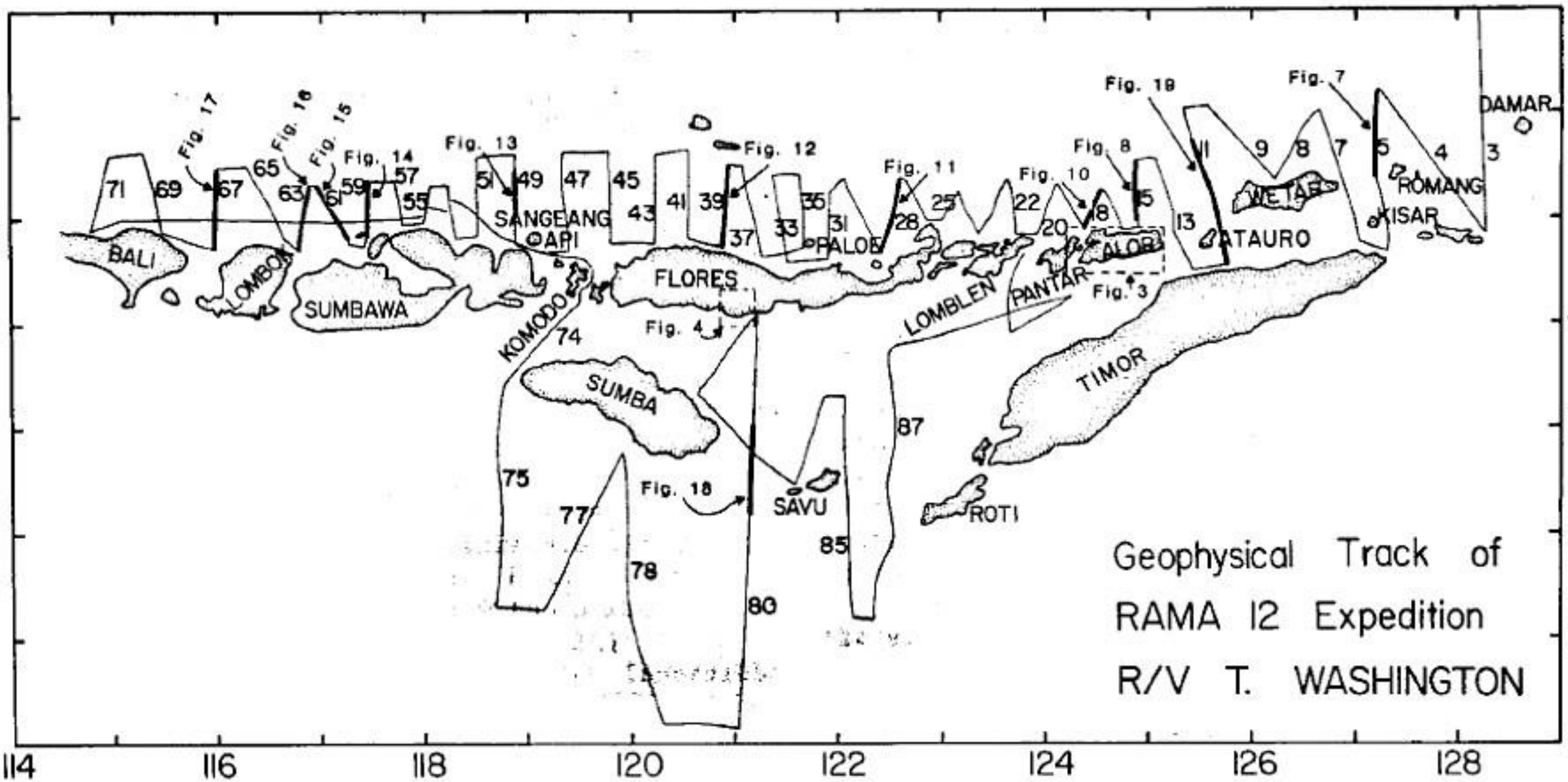
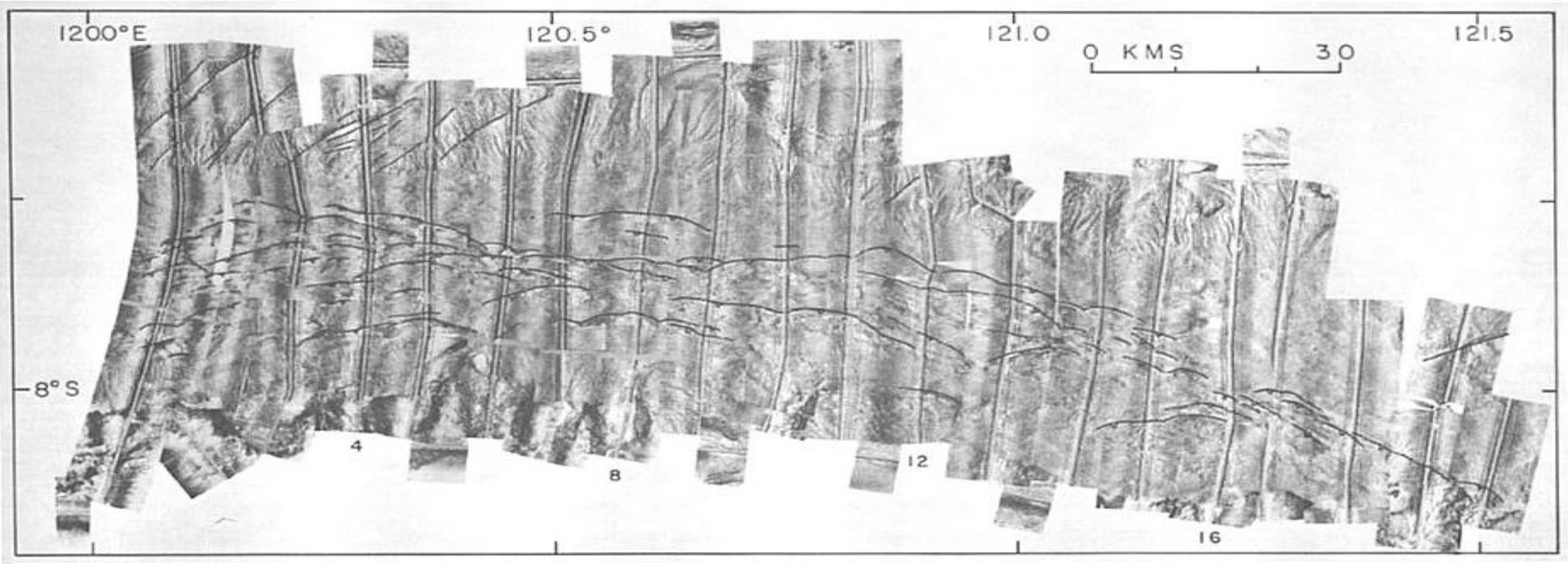
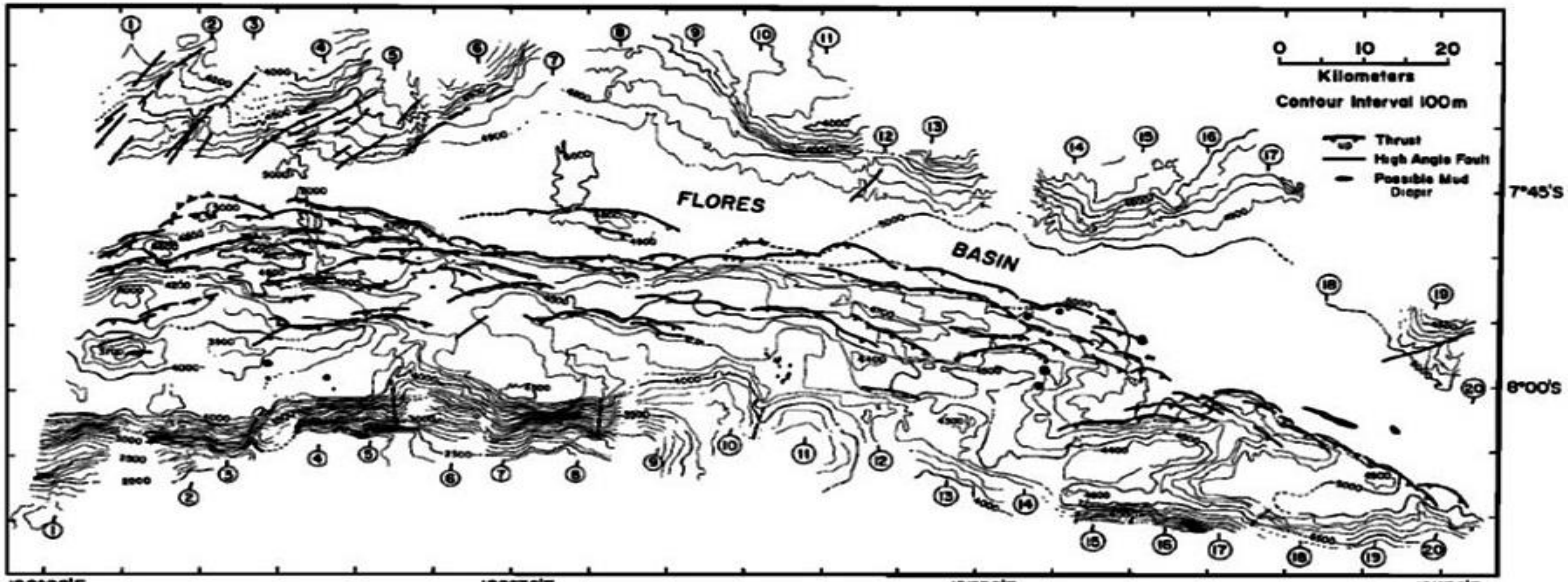


Fig. 6. Track of the R/V Thomas Washington during RAMA 12 expedition in the eastern Sunda arc, showing location of seismic profiles and control on gravity, bathymetry and magnetics. Map also indicates locations of Figures 3, 4, 7, 8 and 10-19. Navigation was by satellite, doppler sonar, and radar ranges and bearings near islands.

Silver et al. (1983)

compiled by Awang Harun Satyana 18 March 2021





Flores back-arc thrust

Silver et al. (1986)

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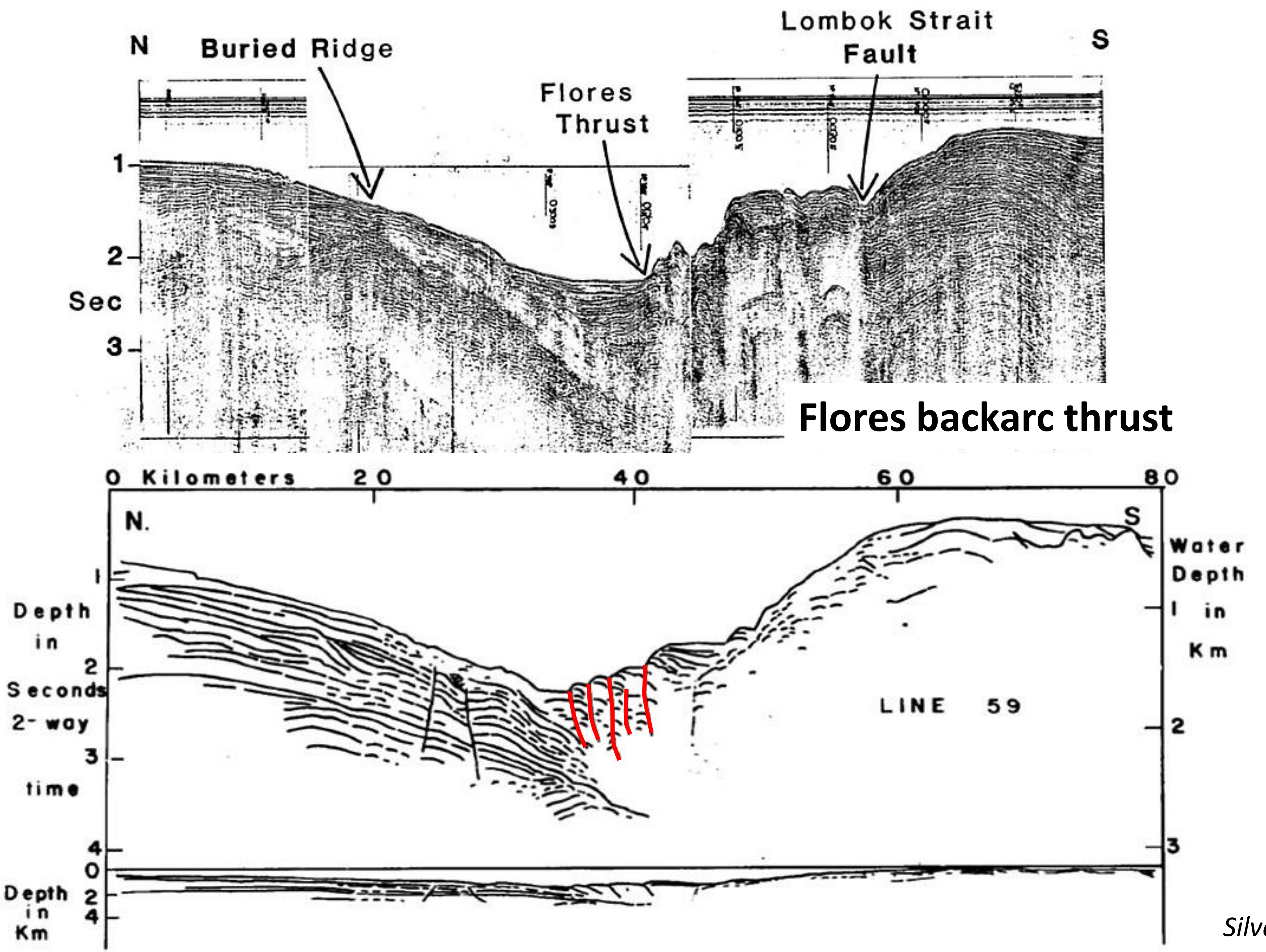

Silver et al. (1983)

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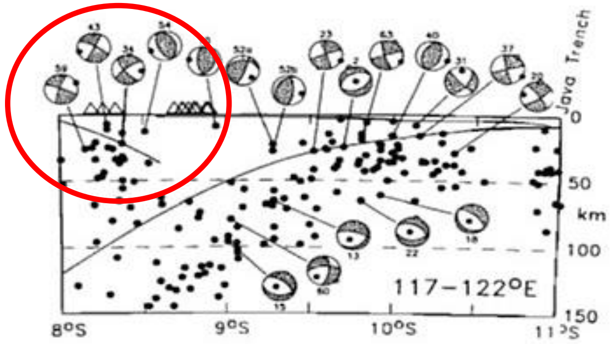
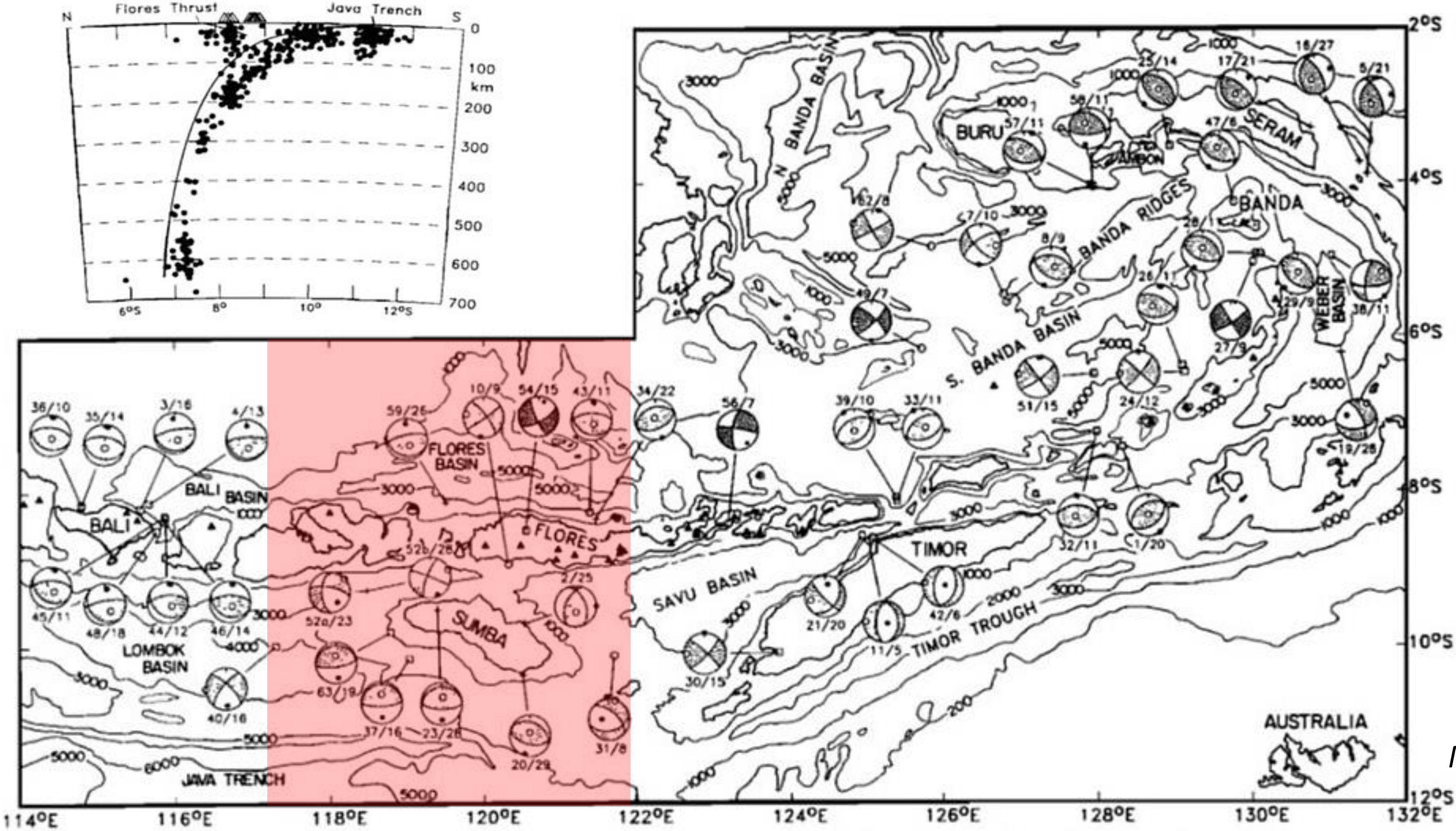


N-S cross sections of earthquake hypocenters and fault plane solutions

Fault plane solutions for shallow earthquakes



McCaffrey (1988)

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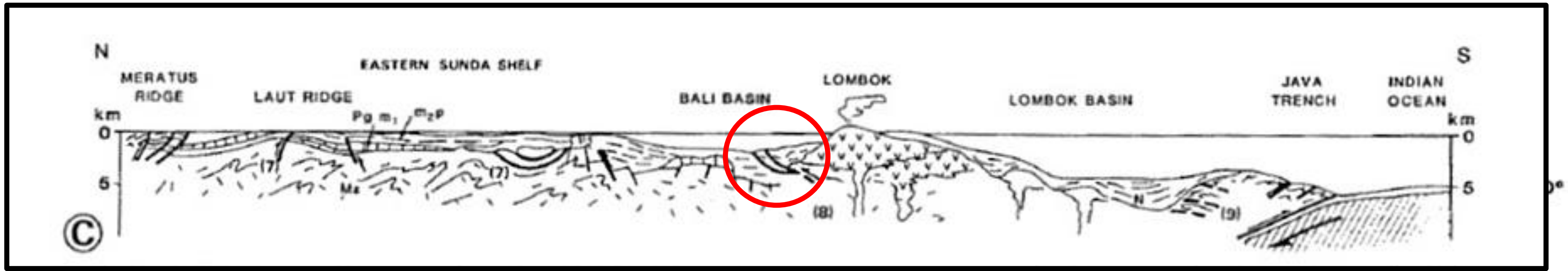

Fig. 1. Location map of the regional cross sections (Fig. 2), showing regional structural framework. Arrows show the convergence at the edges of the plates.

Letouzey et al. (1990)

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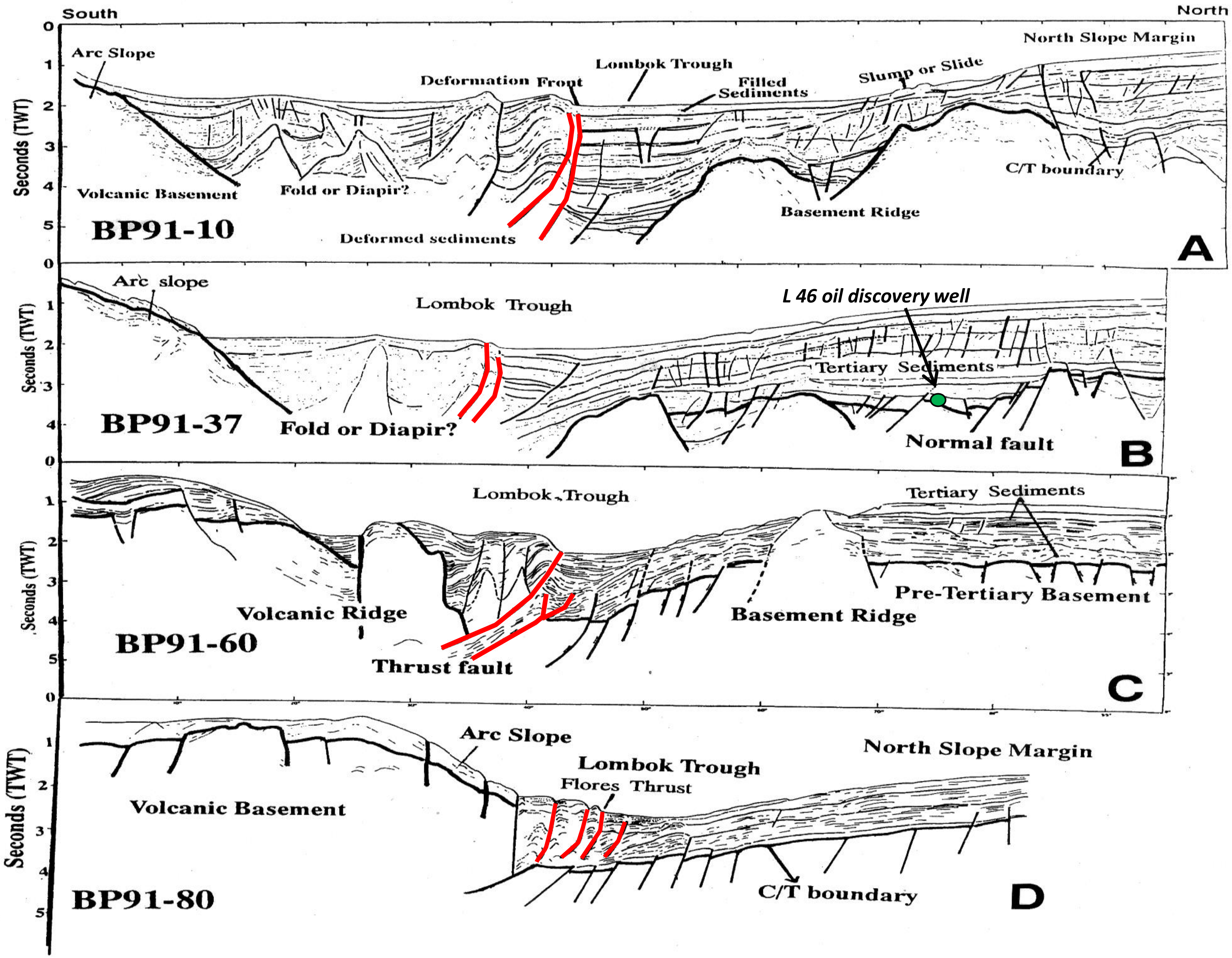
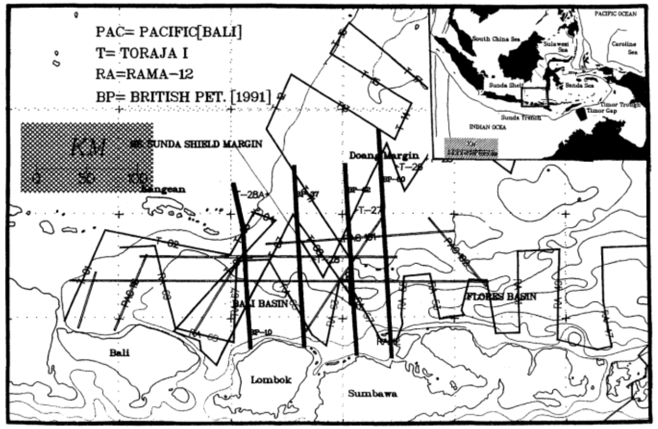
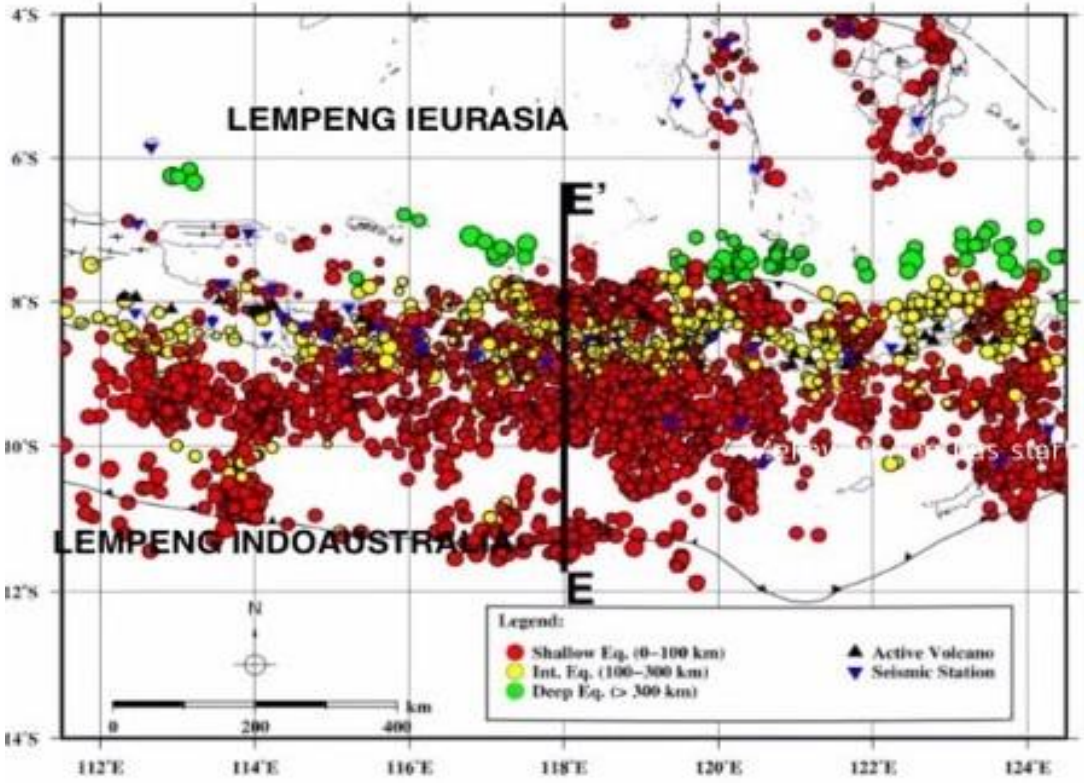
Structures to the north of Lombok and Sumbawa: Flores Back-Arc Thrust

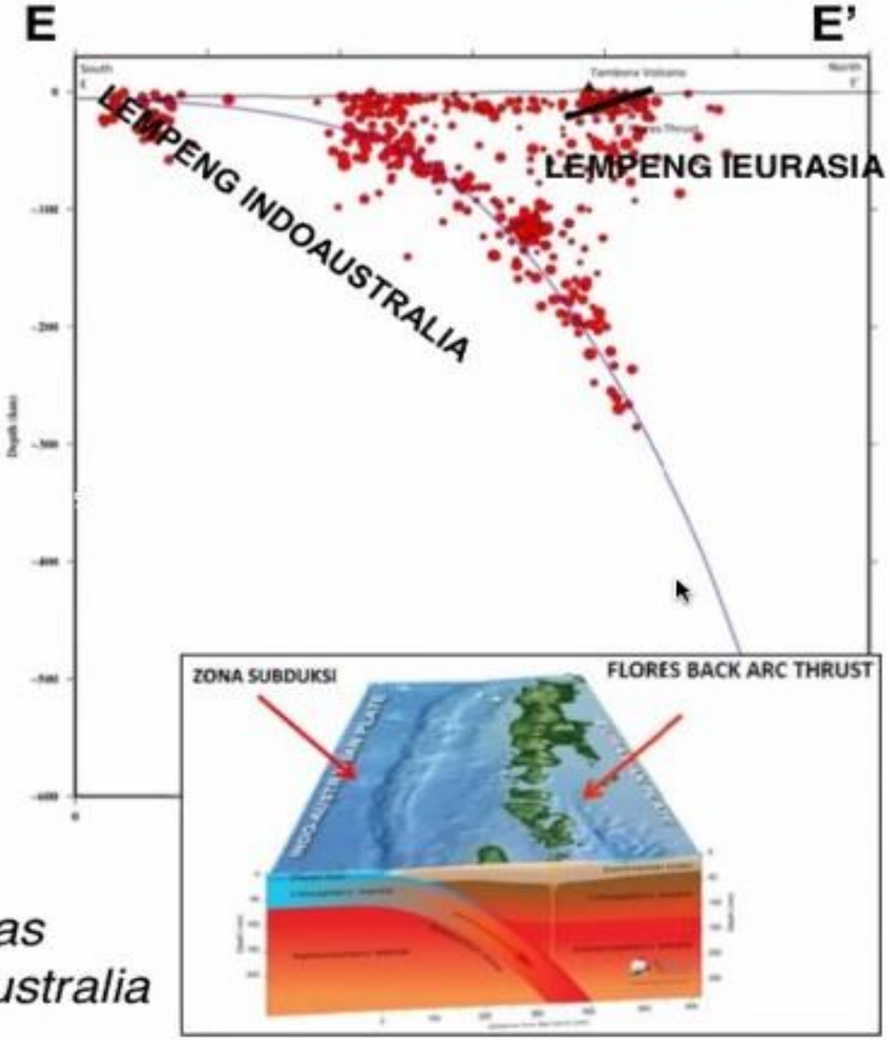


Prasetyo (1992)



AKTIVITAS DI BALI DAN NUSA TENGGARA



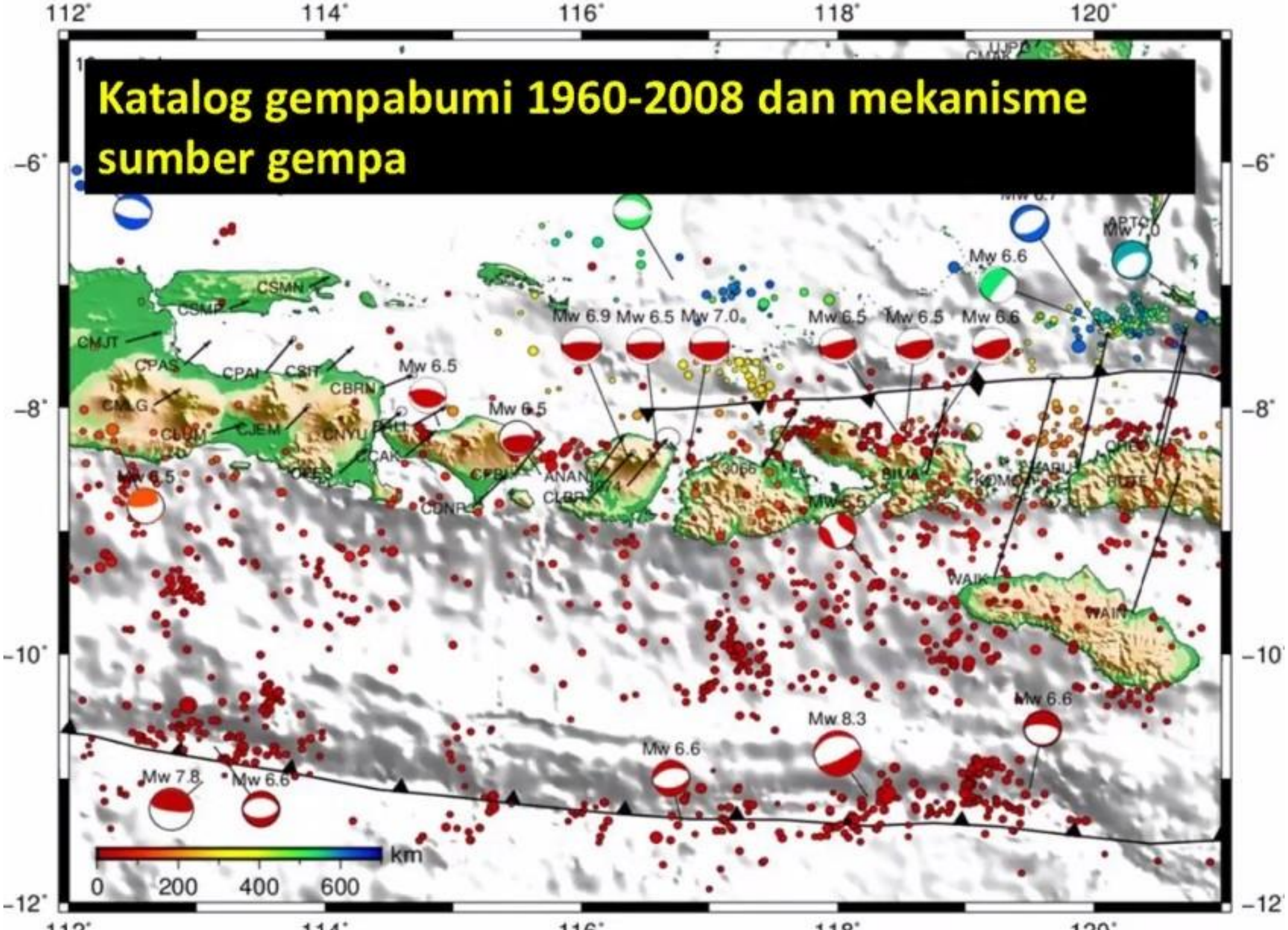


kegempaan di bali nusra dipengaruhi oleh aktivitas subduksi (penunjaman lempeng lempeng indo australia kebawah lempeng eurasia juga aktivitas busur belakang flores dan wetar

compiled by Awang Harun Satyana 18 March 2021

Daryono (2020)

Katalog gempabumi 1960-2008 dan mekanisme sumber gempa



Daryono (2020)

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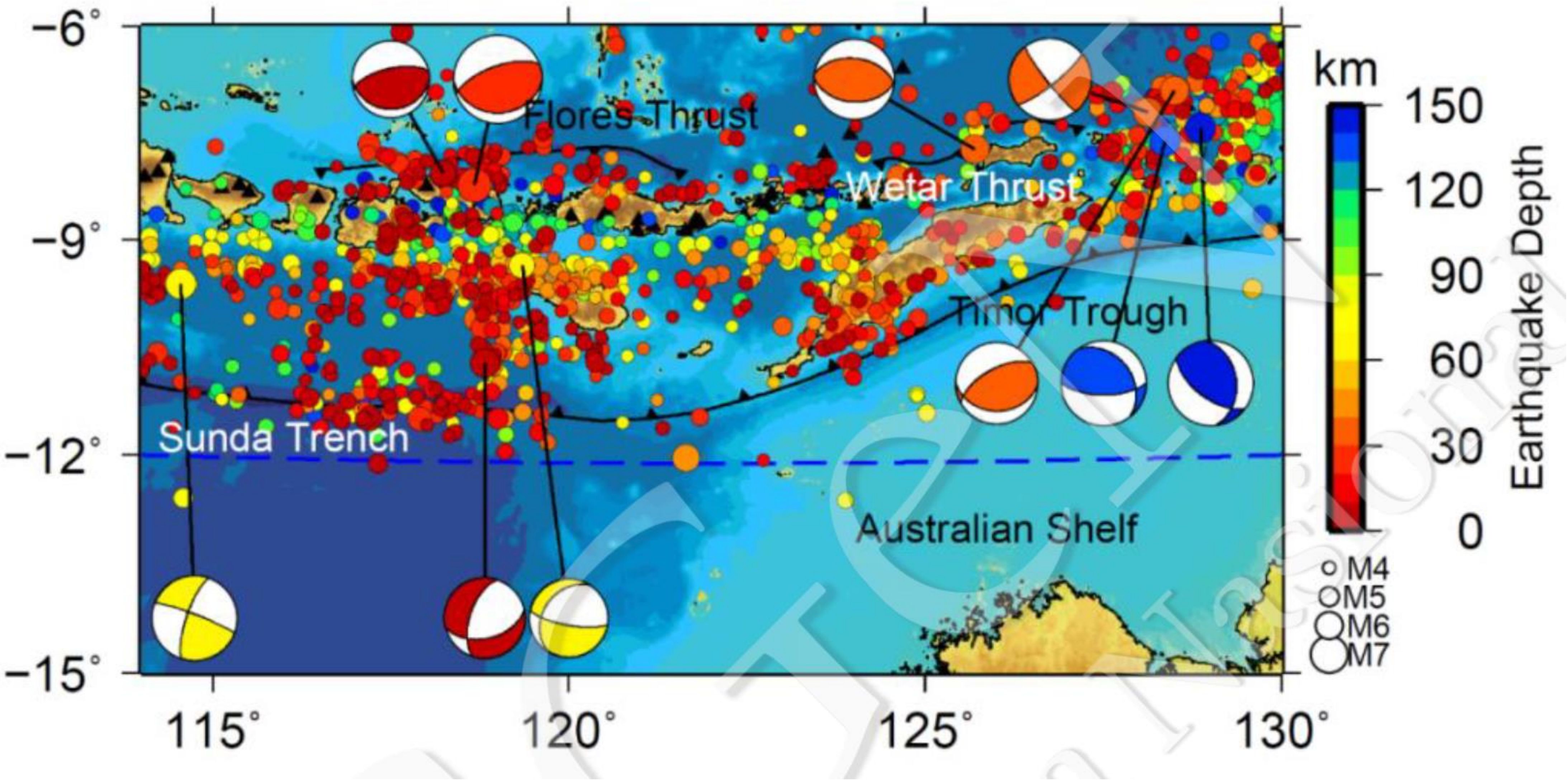
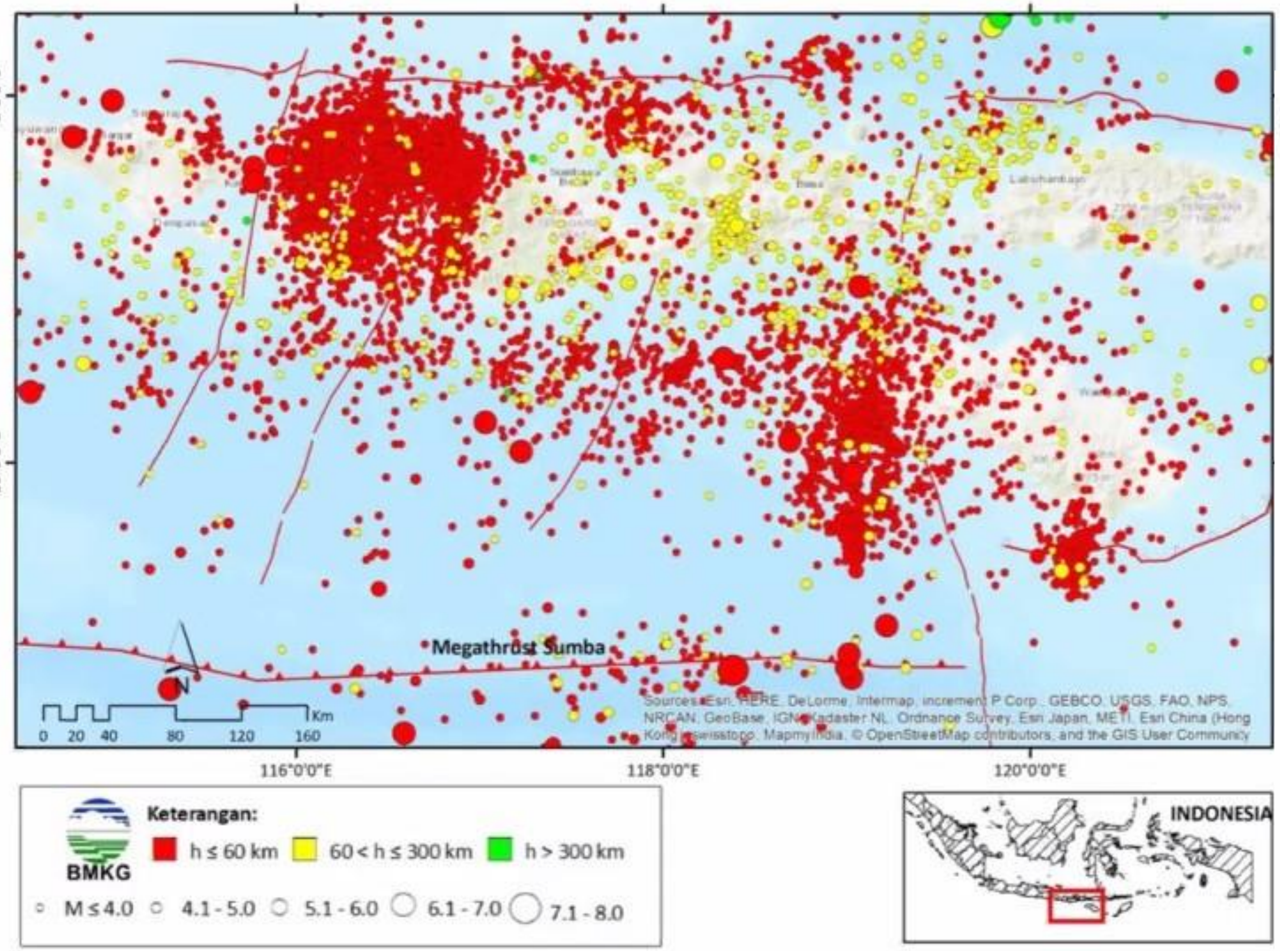


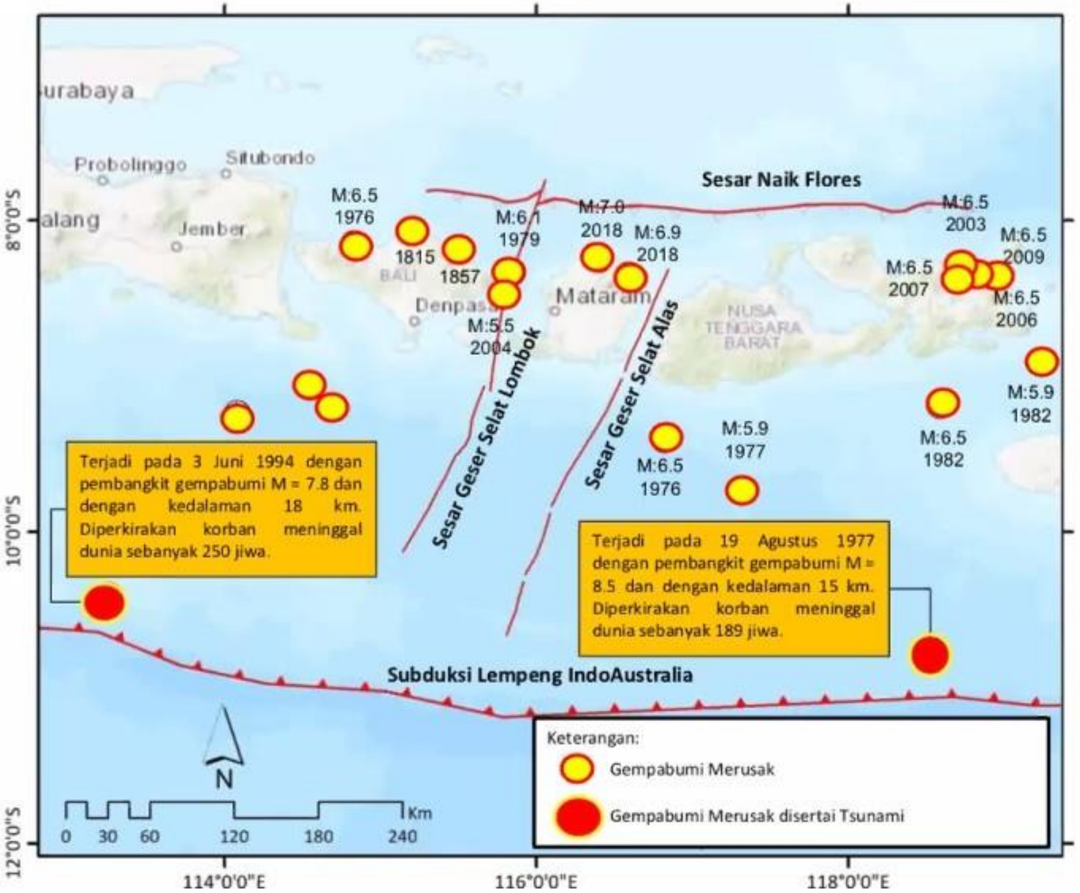
Episenter gempa hasil relokasi di zona transisi Sunda-Banda dan sekitarnya untuk *event* dengan kedalaman ≤ 150 km dan magnitudo ≥ 4. Mekanisme fokus merupakan solusi dari GCMT untuk gempa dengan magnitudo ≥ 6. Garis biru putus-putus adalah posisi penampang data batimetri permukaan laut.

Pusgen (2017)

KEGEMPAAN DAERAH SUMBAWA DAN SEKITARNYA PERIODE 1964-2019



SEJARAH GEMPA MERUSAK DI BALI DAN NUSA TENGGARA



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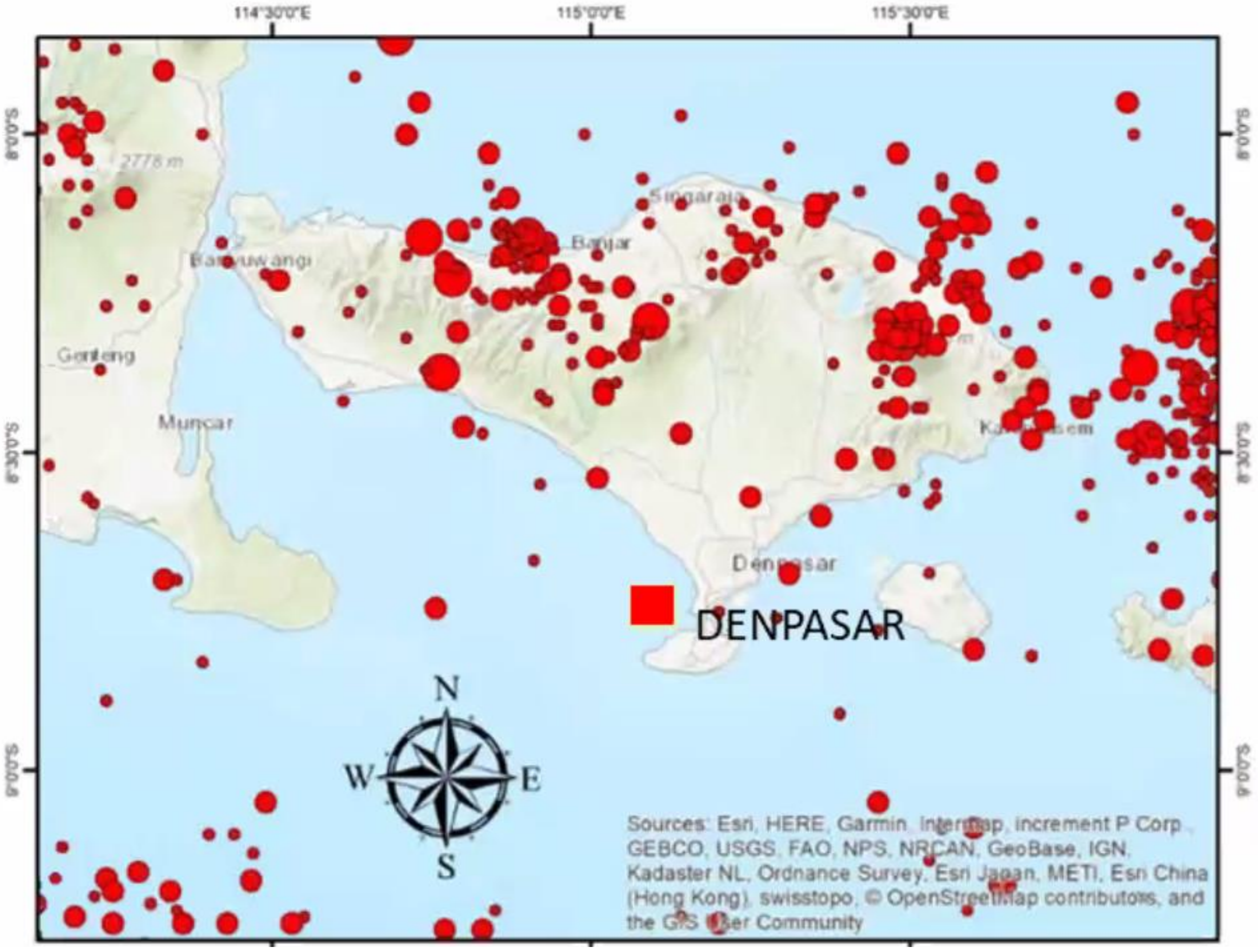
Daryono (2020)

BMKG

SEISMISITAS KOTA DENPASAR 2008-20019

- ***Aktifitas gempa dangkal lebih aktif di wilayah Bali Utara***
- ***Semakin ke selatan aktivitas gempa semakin jarang untuk shallow crustal earthquake***

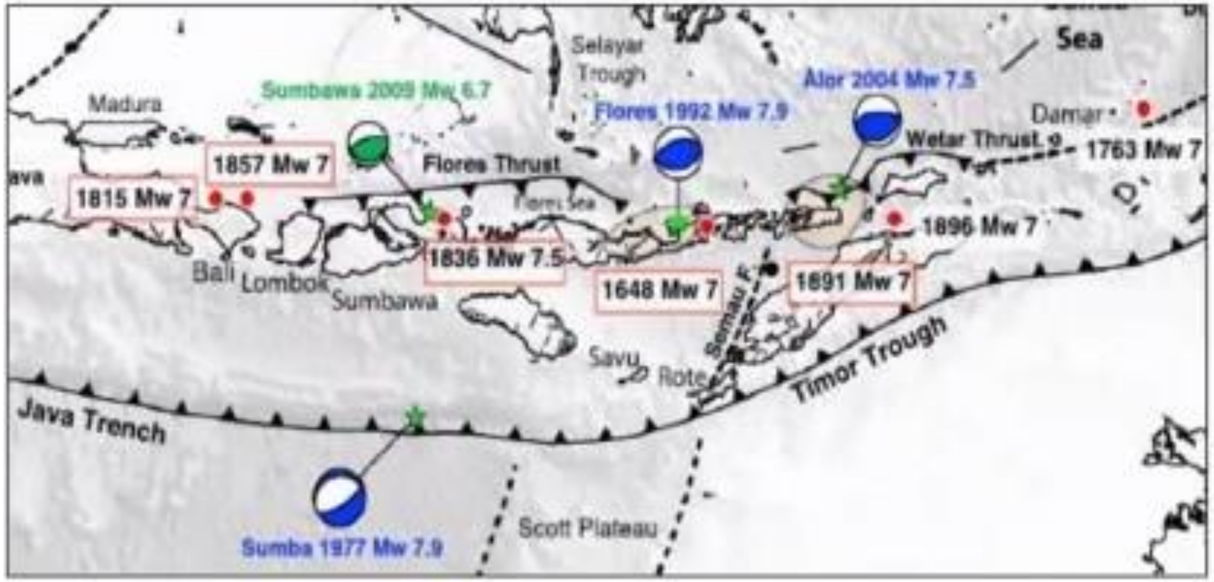


Daryono (2020)

Mengapa di NTB Sesar Naik Flores lebih aktif dibanding zona megathrust?

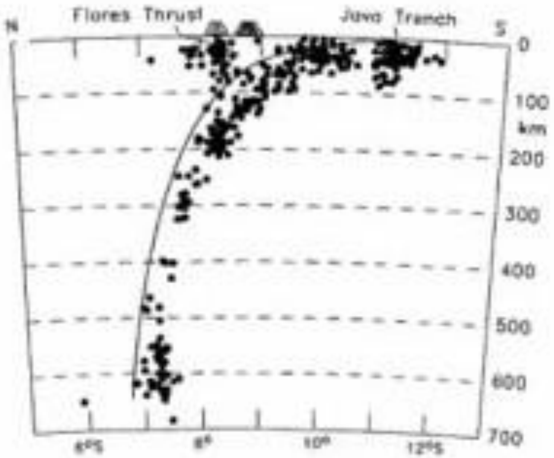
- *Tekanan* ***Sesar Naik Flores*** *terhadap Bali dan Nusa Tenggara* ***sangat kuat*** *→ sehingga memicu terjadinya banyak gempa kuat.*

- *Tekanan* ***subduksi*** *Lempeng Indo-Australia yang menukik* ***lebih lemah*** *→ sehingga gempa kuat di zona megathrust sangat jarang bahkan tidak ada.*



Koulali et al. (2016)

Subduksi lempeng Indo-Australia ke bawah NTB



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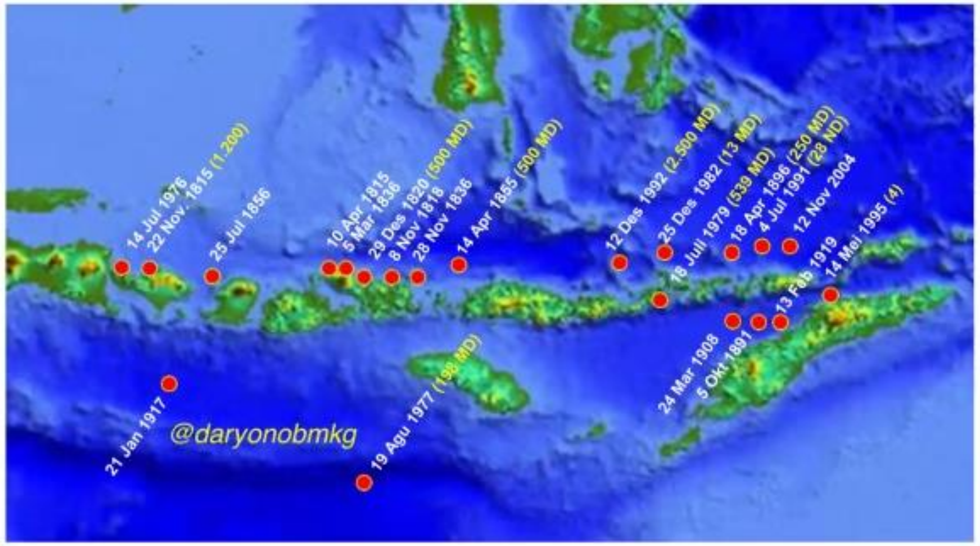
Daryono (2020)

TSUNAMI DI BALI DAN NUSA TENGGARA

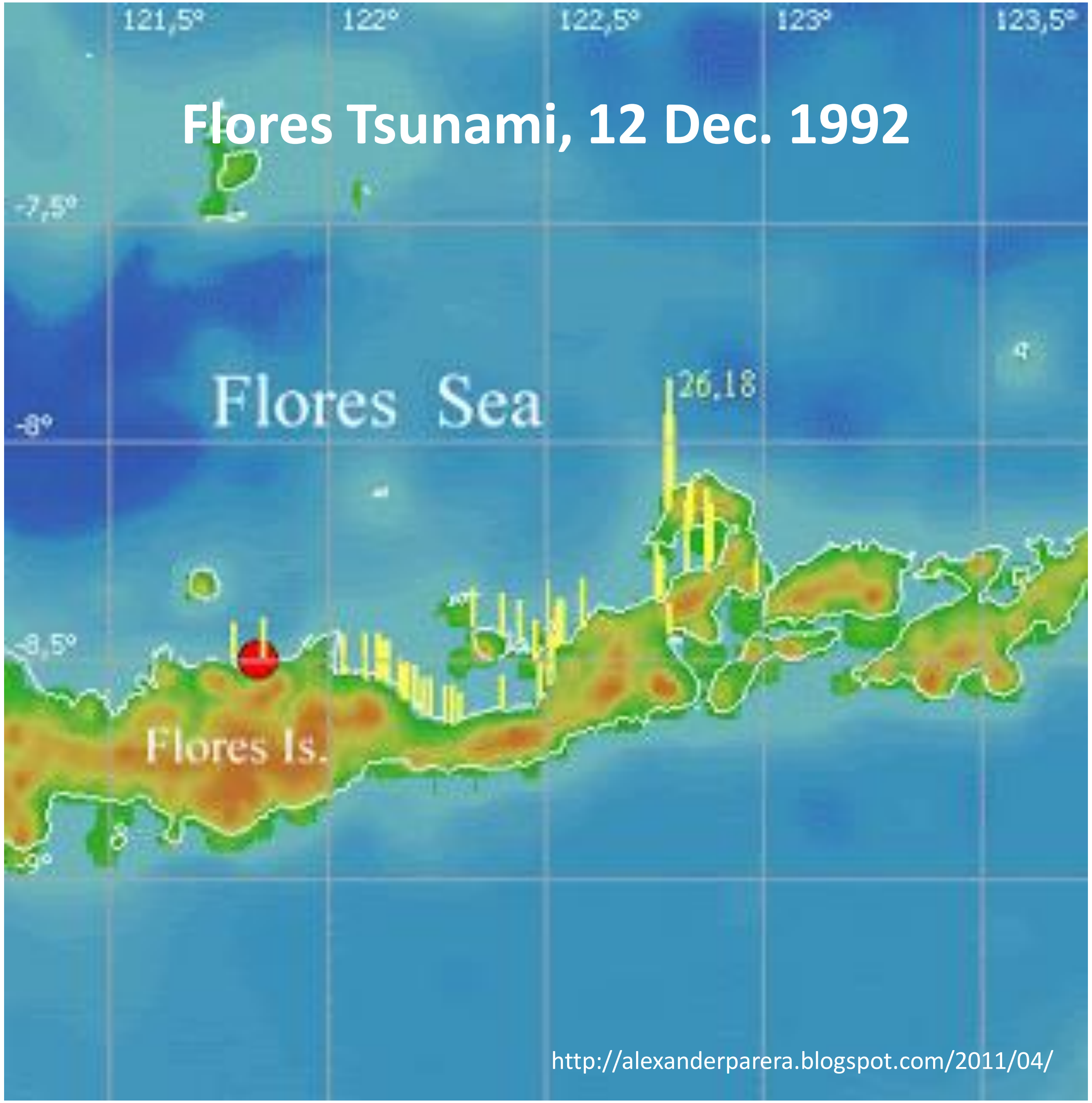
Tsunami sudah terjadi lebih dari 21 kali



TSUNAMI DI SELATAN SUMBAWA 19 AGUSTUS 1977

- *Pada 19 Agustus 1977 pukul 13.00 waktu setempat terjadi gempa dengan magnitudo M 8,3 yang mengguncang Bali, NTB, dan NTT.*
- *Gempa ini memicu tsunami di sepanjang pantai selatan Sumba, Sumbawa, Lombok, dan Bali.*
- *Di Lunyuk, Pantai Selatan Sumbawa, tinggi tsunami mencapai 5,8 m dengan landaan sejauh 500 m dari pantai menyebabkan 65 orang MD dan 37 orang hilang.*
- *Di pantai selatan Lombok tinggi tsunami bervariasi 3 - 4 m dengan landaan sejauh 200 m, menyebabkan 22 orang MD.*
- *Jumlah total korban 198 orang MD dan hilang.*

Daryono (2020)



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Kesimpulan

1. **Tektonik Busur Sunda-Banda: Sumatra – Flores**
   - Karakter geologi dan tektonik yang berbeda, umur lempeng samudra yang subduksi makin tua dari Tersier ke Kapur Bawah, dari 40 ke 125 juta tahun, zona Benioff makin curam, kopling makin lemah, dari kompresi ke tension.
2. **Gempa Megathrust Jawa – Sumbawa**
   - Mungkinkah menghasilkan gempa megathrust >M 8+ (?), sulit meskipun bukan tidak mungkin dikarenakan faktor subduksi yang berbeda dengan Sumatra.
3. **Gempa Intra-Plate Jawa Timur**
   - Shallow background earthquake, mungkinkah menghasilkan gempa >M 6+ (?), sulit meskipun bukan tidak mungkin sebab energi stress sekunder, propagasi gaya, dan sesar di bagian lebih ke tengah lempeng.
4. **Gempa Back-Arc Thrust Bali – Flores**
   - Kerak transisi – samudra Sundaland-Banda yang menekan Busur Sunda-Banda, lebih aktif menggenerasikan gempa-gempa di sebelah utara Bali sampai Flores dibandingkan gempa megathrust di sisi selatan yang dekopling.

Terima kasih atas perhatian Anda.
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