Gempa Nusantara: A database of 7,380 macroseismic observations for 1,200 historical earthquakes in Indonesia from 1546 until 1950

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Supplementary Material

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Contents

Supplementary Material 1 – Gempa Nusantara (Tables S1 – S3)

The entire database i.e., Tables S1, S2 and S3 can be found in file titled "**Gempa_Nusantara_v1.xlsx**" accompanying this BSSA paper. This file (including any future updates) can also be found at https://github.com/7point1/GempaNusantara

Supplementary Material 2 – Approach to Intensity Assessment

We use the 1998 European Macroseismic Scale (EMS-98; *Grünthal*, 1998) to evaluate macroseismic intensity (**Table S2**) displayed as colour-coded filled circles in **Figure 1**. Our approach to assigning macroseismic intensities with the EMS-98, to distinguish between building types and damage grades, and to assess uncertainty (**Table S4** *at the end of this Supplementary Section*) is detailed here. Critically, we note, that our approach and inferences detailed here are ***not to be misinterpreted*** as a revision or an update to the EMS-98 but merely outlines how we adapt to the recommendations and terminology from *Grünthal* (1998) to assign intensities in this study. In many instances, EMS-98 guidelines cannot be used without adaptation because the local building stock was more vulnerable or employed different traditional or indigenous construction types and/or materials than the European construction on which the EMS was based.

Choice of Intensity/Macroseismic Scale

Our choice of the EMS-98 intensity scale marks a shift from the Modified Mercalli Intensity scale in Indonesia (MMI; *Wood & Neumann*, 1931; *Richter*, 1958). The MMI scale was meant to replace both the Batavia Intensity Scale (**Supplementary Material 3**) and the Rossi-Forel scales that were used in Indonesia prior to 1956 (*Anonymous*, 1957). Both the MMI and the EMS-98 scales are successors to older intensity scales such as the Mercalli-Cancani-Sieberg scales (MCS; *Sieberg*, 1912) developed with European conditions in mind. *Taverne* (1925) recognised the MCS as being inadequate with which to characterise damage to the local indigenous building stock on Java. Many modern users outside Europe, especially those in nations formerly colonised by Europe, opt for the seemingly less controversial MMI scale unaware of the MMI scale's common European origins. Nonetheless, the EMS-98 stands apart in its revised form (*Grünthal*, 1998) in that it stipulates non-region-specific diagnostic indicators and recommended guidelines with which to assess intensity. Compared to the MMI, the ability to incorporate non-European construction materials and styles before estimating the quantities and types (referred to as "grades") of damage ensures thorough use of as much of the original observations at hand as possible. This leads to more robust intensity assignments at higher levels of shaking (≥ 6 EMS) especially where data on indigenous, traditional, and non-European building typology are meagre or missing, and when modern fragility curves are unavailable.

General Intensity Diagnostics

At non-damaging levels of shaking (< 5 EMS) we consider diagnostic indicators, that is, definitions or guidelines for each level of intensity (*Grünthal*, 1998) with adjective and adverb modifiers such as “not heavy” (nl: *niet hevig*) or “heavy” (nl: *hevig*), “moderate” (nl: *middlematig*), “more or less” (nl: *meer op minder*), “quite” (nl: *vrij*; nl: *tamelijk*), “repeated” (nl: *herhaalde*) and “very” (nl: *zeer*). We also used percentage counts from *Medvedev et al.* (1965) to distinguish between “few” (≤ 5%), “many” (up to 50%), and “most” (up to and greater than 75%). Adverb distinctions such as “few” (nl: *een paar*; nl: *weinig*), “many” (nl: *veel*), and “most” (nl: *meest*) are necessary in keeping with the statistical nature of EMS-98 (*Grünthal*, 1998; *Tertulliani et al.*, 2016), but we reiterate *Martin & Hough’s* (2016) observation that both modern and historical documentary sources can often be devoid of these.

At damaging intensities (≥ 5 EMS) the adaptability of the EMS-98 allows it to be confidently used to determine intensities when building construction was discussed (*also see subsequent section*) in some detail (e.g., *Abendenanon*, 1915; *Stehn*, 1925) and/or the percentages of buildings destroyed or damaged were recorded (e.g., *Taverne*, 1925; *Berlage*, 1934). In such cases, we determine an EMS-98 intensity based on a combination of diagnostic indicators which also include a combination of damage grades, building vulnerability, and the quantity of damage (*Grünthal*, 1998). Damage grades 1 to 5 (*Grünthal*, 1998) were associated with descriptions indicating “insignificant” (nl: *niet belangrijk*) or “minor damage” (nl: *licht*; grades 1 to 2), “partial” (nl: *gedeeltelijk)* collapse or “no longer inhabitable” (nl: *niet meer bewoonbaar*; grades 3 to 4), or “complete” collapse or collapsed to the ground (nl: *totaal*; grade ≥ 4).

In an ideal scenario, the quantities and grades of damage to different types of buildings are best determined by ground-based surveys (*Ambraseys & Bilham*, 2003; *Musson & Cecić,* 2012). But this is unfeasible when studying historical earthquakes (*Martin & Hough*, 2016). Building on the previous point, we also acknowledge the observation made by *Ambraseys & Bilham* (2003) that the distinction between “damaged” (nl: *beschadigd*), “collapsed” (nl: *storten in*) and “destroyed” (nl: *verneild*; nl: *zerstort*) is rarely preserved in written or published historical documentation. For example, the distinction between the complete collapse of walls from the loss of gables or masonry veneers alone is rarely made. To address these unknowns, we cautiously associate explicit reports of insignificant damage,

damage to walls without collapse, and the collapse of houses (unknown, partial, or complete) with a gradual increase in intensity values from 5 EMS to 8 EMS.

The highest intensities (10 EMS) were assigned in very rare instances when accounts categorically described exceptionally violent ground motions (e.g., Ambon earthquake on 6 January 1898). These assignments were based on eyewitness accounts that recalled the inability to stand or walk and being forcibly thrown to the ground. Whenever possible, these assignments were also supported by documented damage to buildings (many or most of grade ≥ 4) and/or if heavy objects were bodily moved or thrown around.

Estimation of Building Types and Vulnerability Classes

Variations in local construction can be accommodated when using the EMS-98 by adjusting the vulnerability class. Documentary accounts often only recorded rudimentary building types, namely, masonry (nl: *steenen*), or wooden (nl: *houten*) structures. Therefore, extracting damage grades from historical data will be subjective. To account for this uncertainty, all of our intensities ≥ 5 EMS are appropriately assigned lower qualities ("B" to "H"; **Table S4**). Unable to irrefutably identify most individual buildings or to decipher their health or state of preservation (or lack thereof) at the time of a given seismic event we broadly categorise these buildings into vulnerability classes A and B respectively (*Grünthal*, 1998; pp. 14). In these, and all subsequent cases discussed in this section we acknowledge the uncertainties in our values by adding a range of ±1 unit of intensity wherever appropriate in **Table S2**.

The term "*inlandsche woningen*" was often invoked to describe traditional "native" structures known colloquially in Indonesia as the *rumah adat* (bh) or *rumah tradisional* (bh). The Dutch term fails to account for the widespread diversity in architectural and construction styles across Indonesia (e.g., *Sumintardja*, 1978; *Dawson & Gillow*, 1994). In rural Sumatra (including Nias) and Sulawesi, these buildings have a mortised post-and-lintel structure with wooden or bamboo walls and a thatched roof (*Dawson & Gillow*, 1994) and are built on posts or stilts that rest on, but are not attached to, flat stones (nl: *neuten*). In the literature at hand, we also encountered other wooden or bamboo structures in parts of north Maluku and Sulawesi, some of which were built above water on poles (nl: *paalwoningen*), particularly in communities by the sea (bh: *perkampungan laut*).

The wooden structures in Sumatra and Sulawesi are flexible when subjected to lateral seismic loads but can be compromised during very strong ground motions that cause the timber posts to move off the "*neuten*" or to fail from age or neglect resulting in some form of structural failure. Historical descriptions (e.g., *Abendenanon*, 1915) often used the words "shifted" (nl: *verschoven*) or "toppled over" (nl: *omgevallen*) instead of the more common "caved in" (nl: *storten in*) without elaborating further whether these buildings bodily fell over, or completely collapsed. Assuming vulnerability class B (see *Grünthal*, 1998) we used these to infer a damage Grades of 4 to 5 if the account said a building "toppled over" or "caved in", to infer a minimum intensity of 8 EMS; higher values were assigned depending on the number of structures affected (many = 9 EMS; most/all = 10 EMS).

Traditional rural homes in Java were simple square structures on a raised base with a thatched or tiled roof supported by wooden posts and walls of woven bamboo or brick reflecting the affluence of the owner (*Dawson & Gillow*, 1994; *Nas*, 2007). The structures described on Java and, north Maluku, and those in *perkampungan laut*, were easily shaken out of plumb (nl: *scheefstaan*) or collapsed. Assuming vulnerability class A-B (see *Grünthal*, 1998) and inferring Grades 3 to 4 (for out of plumb) and Grades 4 to 5 (for collapsed), we infer a minimum intensity of 7 EMS and 8 EMS respectively, and higher values depending on the number of structures sustaining Grades 4 to 5 (most = 9 EMS; all = 10 EMS).

In urban settings, masonry structures incorporated Chinese, Hindu-Buddhist, Islamic or European influences in architecture (see *Nas*, 2007). Structures built during the VOC period and in the early 19th century were largely masonry with influences (and sometimes material) from the Netherlands (*Nas*, 2007). In colonial enclaves, masonry construction either exactly mimicked designs and layouts from Europe (*Nas*, 2007) or were of a unique tropical colonial *Indische* style; the latter incorporated architectural features such as better ventilation, larger verandas, and larger pyramidal and steeply pitched roofs to adapt to the hot, humid, and wet tropical climate (e.g., *Nas*, 2007). These enclaves were surrounded by additional masonry buildings in the Chinese and Arab quarters (e.g., *Nas*, 2006). We assessed these structures as vulnerability class B (*Grünthal*, 1998). A few reports from western New Guinea were also forthcoming from observers in bivouacs (nl: *bivaak*) but we do not use these to assign intensity.

In records prior to the 19th century from eastern Indonesia, the only damage often recorded was to monumental buildings that included defensive structures such as VOC redouts (bh: *benteng*). The

EMS-98 scale cautions against the singular use of "*monumental structures*" for intensity evaluation (*Grünthal*, 1998). These are structures of societal, economic, symbolic or cultural significance that tend to be sturdier than the prevalent building stock or are structures that are more likely to be damaged owing to their structural or non-structural complexity (*Grünthal*, 1998, p. 53). Reiterating *Grünthal* (1998), we note that, even when available, it was impossible for us to account for any possible exaggeration of damage to elicit higher financial compensation by VOC officials, or to gauge damage to other structures in the vicinity, in particular traditional dwellings whose survival (or lack thereof) might not have been deemed of any importance to the VOC. However, we are also of the opinion that to ignore these reports would severely handicap the long-term record of damaging shaking in eastern Indonesia. The wide diversity in construction styles and materials used in these structures, and the small number of descriptive observations, prevented us from classifying damage grades separately as has been done by previous studies, for example, in Iran (e.g., *Ambraseys and Melville*, 1983) and in Myanmar (*Aung et al.*, 2019). The 17th and 18th century descriptions of damage to these defensive structures in particular, sometimes indicated whether the bastions or the battlements of these buildings were cracked (grade ≤ 3) or destroyed (grade ≥ 4). To these we tentatively assigned 6 EMS or 7 EMS, respectively, with what we deemed an appropriate uncertainty (±1 unit of intensity). Some redouts in the region also had non-masonry canopies (see illustrations in *Valentijn*, 1724). We record a lower intensity (6 EMS) to reports of unspecified damage to redoubts considering the difficulty in determining what part of the structure was damaged or the health of the structure in general. All intensity values derived from these and other descriptions of impacts to monumental buildings have an "M" appended to their respective quality indicator in **Table S2** to clearly distinguish them from the rest of the dataset. This provides future studies the opportunity to either include or exclude these points of observation in case of differing points of view.

Non-Integer and Other Intensity Diagnostics

Accounts that were devoid of descriptive diagnostics are marked as "felt" (F). These include instances when an earthquake was "felt" (nl: *gevoeld*) or was "observable" (nl: *waarneembare*), where only "vibrations" (nl: *trillingen*) or "shocks" (nl: *schuddingen*) were reported, and when vague anecdotal evidence was forthcoming, for example, a "serious earthquake" (nl: *erg aardbeving*) had occurred. Maritime reports (e.g., *Rudolph.,* 1887; 1895) of "seaquakes" felt onboard ships in the open ocean (nl:

zeebevingen; nl: *zeeschuddingen*) are also duly flagged (S). As advised by *Vogt et al.* (1994), these were not assessed for intensity.

We did not assess secondary effects such as ground failure, liquefaction, landslides, and damage to paddy fields (nl: *sawahs*) as these can occur at a wide range of intensity (*Grünthal*, 1993). Their independent usage to determine intensity, particularly in the absence of other diagnostics of intensity, is to be strongly avoided (*Vogt et al.*, 1994; *Musson et al.*, 2010). We also do not include intensity values from published isoseismal maps or other previous studies in our database (*Ambraseys et al.*, 1983); the only two exceptions are *Martin et al.* (2019) and *Martin et al.* (2020), led by the lead author of this present study and which followed the same approach as in this study. Intensities were also not converted between intensity scales (*Ambraseys et al.*, 1983) but we are conscious of the congruence between MMI and EMS-98 (*Musson et al.*, 2010).

Intensity Ranges and Uncertainties

Lastly, quantitative minimum and maximum intensity ranges are recorded for each IDP in **Table S2** in the columns titled “EMS-lower” and “EMS-upper”. The only exceptions (NA) in these columns are in the case of non-integer flags, that is, “felt” (F), “damage” (D), “seaquake” (S), and “tsunami” (T). IDP’s are also alphabetically (“A” to “H”) weighted for quality (*Musson*, 1998); “A” represents a high or good quality while “H” indicates a poorer quality assessment (see **Table S4)**.

Uncertainty	Reason for Uncertainty	This study
0	None	A
1	Reliability of Intensity Value (R)	B
2	Location uncertainty (L)	C
3	R + L	D
4	Veracity of Observation (V)	E
5	R + V	F
6	L + V	G
7	R + L + V	H
-	Monumental buildings (M)	+M
-	Multiple Events (X)	+X

Table S4: Qualitative integer uncertainties in IDP values based on the reliability of assigned intensity or location, or the veracity of the available information from *Musson* (1998). We also indicate the letters that we associate with the integer values from *Musson* (1998). We also append two additional criteria to indicate uncertainties due to intensities based on monumental buildings and damage from multiple events.

These qualities are based on i) how reliable the intensity assessment was, ii) the spatial resolution of a given geographic location, iii) the veracity of available data, or different combinations of the preceding three qualitative uncertainties (*Musson*, 1998). For a handful of Dutch reports, locations were vague such as within an island group or in higher order administrative divisions such as regencies (nl: *regentschappen*; bh; *kabupaten*), departments (nl: *afdeelingen*) or subdepartments (nl: *onderafdeeling*), districts, and occasionally in dependencies (nl: *onderhoorigheden*) such as for Aceh or Sulawesi. For all of these a location uncertainty of "C" was assigned or an appropriate letter, when in combination with other qualitative uncertainties. Intensities assigned to multiple, closely spaced earthquakes or those based on damage to "monumental" structures (*discussed previously*) were assigned "X" and "M" flags respectively that are appended to other alphabetical qualities (**Table S4**).

Supplementary Material 3 – The Batavia Intensity Scale

Prior to 1956, the Rossi-Forel Scale (*de Rossi*, 1883) and the Batavia Intensity Scale were used in Indonesia during the colonial period. Early attempts were made by the colonial Dutch administration to standardise the collection of macroseismic diagnostics (*van Dijk*, 1885), particularly, following the 1883 eruption of Krakatau, when specific directives (*van Dijk and Poortman*, 1885; *Figee et al.*, 1886) with detailed advice (*van Dijk*, 1885) were issued.

Intensity	Description	Translation
I	Zwakke trilling, door velen gevoeld	Weak vibrations, felt by many.
II	Matig, door iedereen gevoeld; rinkelen van glaswerk, rammelen van deuren en ramen	Moderate, felt by everyone; glasswork rattles, doors and windows rattle.
III	Vrij sterk, slapenden worden wakker; hangklokken blijven stilstaan; deuren en ramen slaan open en dicht	Quite strong, sleeping people awakened; pendulum clocks stand still; doors and windows open and shut.
IV	Sterk, schilderijen vallen van de wanden, lichte meubels vallen om, licht scheuren van pleisterwerk	Strong, pictures fall from walls, light furniture falls over, light/slight cracks in plasterwork.
V	Zeer sterk, muren scheuren, stukken pleister en pannen vallen naar beneden, kasten slaan om	Very strong, walls crack, pieces of plaster and (roof) tiles fall down, cupboards fall over.
VI	Steenen huizen storten in, houten huizen vallen an de neuten	Masonry houses collapse, wooden houses fall off their staddle stone supports.
VII	Algemeene verwoesting	General destruction

Table S5: Intensity levels of the Batavia State (*Anonymous*, 1920) with its diagnostics in Dutch with a translation into English.

Observers were instructed to include in their reports of seismic disturbances their “locality” (nl: *plaatsbepaling*), “date, time, duration” (nl: *tijdsbepalling*; nl: *duur*), “direction (nl: *richting*), “intensity” (nl: *intensiteit*; nl: *kracht*) and “nature, remarks (nl: *bijkomende verschijnselen*). Observer assigned RF intensities briefly appeared in the NTNI until 1897, no intensity scale was formally used by the Observatory until the introduction of the “Batavia Scale” in 1919 (*Anonymous*, 1920).

Later annual summaries from 1920 until 1938 (*Anonymous*, 1940), converted these intensities to Rossi-Forel or RF intensities. This scale was almost always listed alongside the Rossi-Forel scale. The “Batavia” scale has been largely forgotten and is even missing from a history of early macroseismic scales (*Davison*, 1921; 1933). We do not utilise this scale in our intensity assessments or in any of our analyses but record it here (**Table S5**) for the sake of completeness and out of scientific interest.

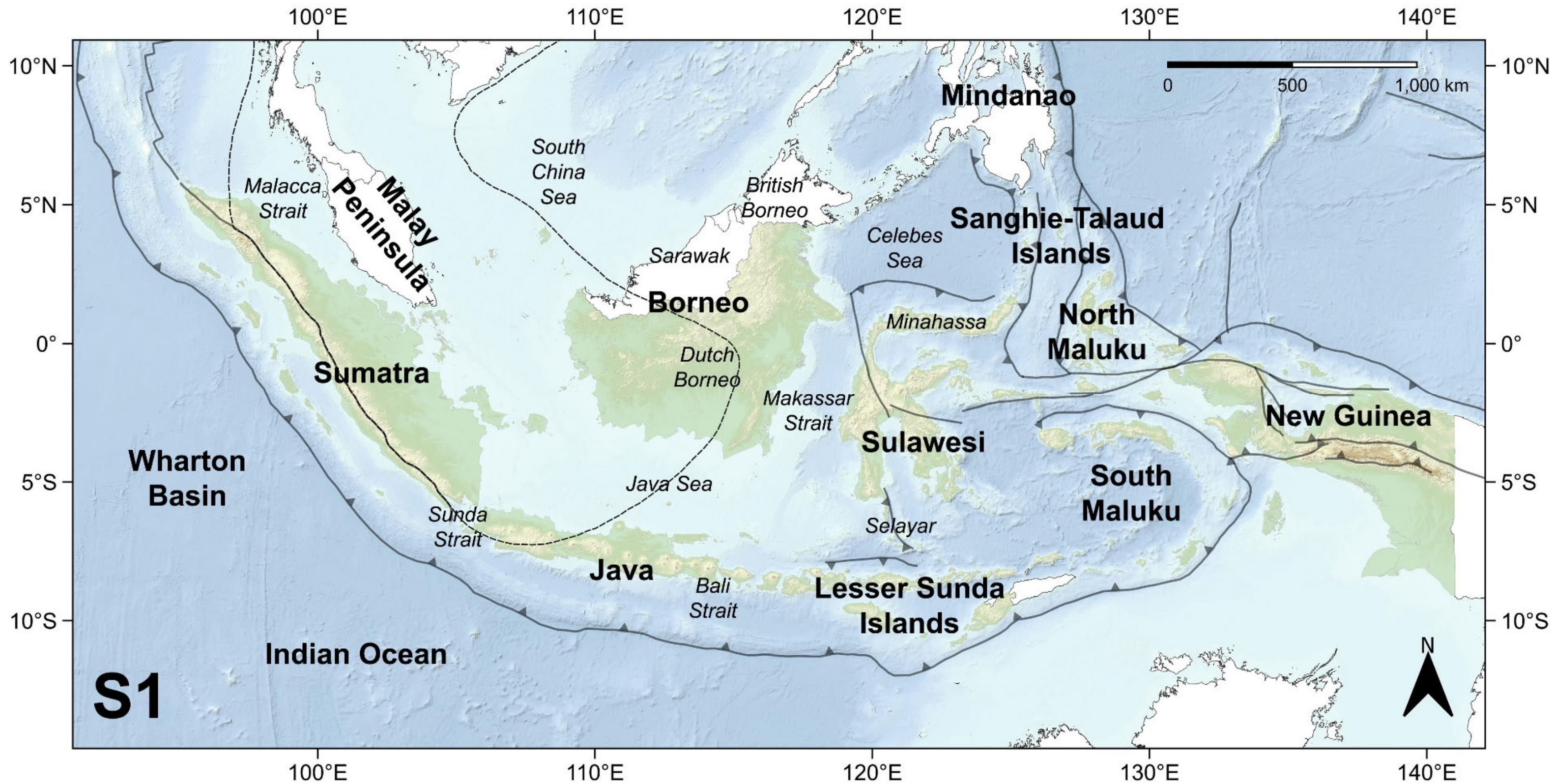

Figure S1: Zones used in the naming of events in Column B (**Table S1, S2**)

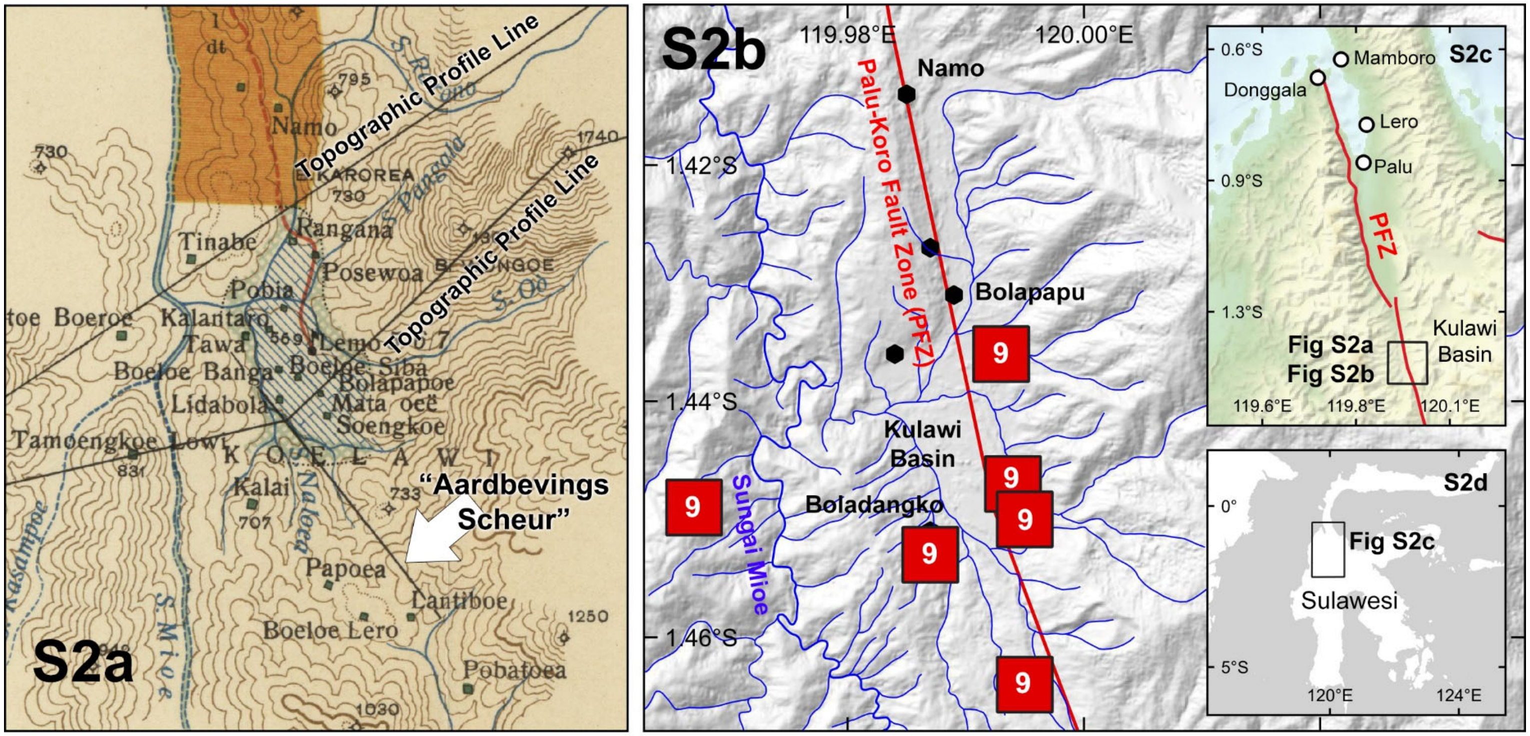

Figure S2: Location of the surface rupture from the 1909 Sulawesi earthquake (GN-0736) from *Abendanon* (1916). In **Figure S2a**, linear black line indicated by a white arrow shows the approximate location of the “earthquake fissure” (nl: *aardbevings scheur*) as drawn by *Abendanon* (1916). **FigureS2b** shows the same region with drainage and 2018 observation locations (filled diamonds) from *Jaya et al* (2019) for the 2018 Palu earthquake as well as intensity observations (red numbered squares) from the 1909 earthquake. **Figures S2c** and **S2d** indicate approximate locations of **Figure S2a**. Image in **Figure S2a** is cropped to the Kulawi basin but a full and high-resolution image from *Abendanon* (1916) is available in the public domain from the National Library of Australia (https://nla.gov.au/nla.obj-230968818). (PKZ = Palu-Koro Fault zone).

References

Abendanon, E.C. (1915). “Midden-Celebes-Expeditie: Geologische en geographische doorkruisingen van Midden-Celebes,” **2**, *Koninklijk Nederlandsch Aardrijkskundig Genootschaap*, Leiden, pp. 835 – 836, pp. 871 – 878 (in Dutch).

Abendanon, E.C. (1916), Plates 12 and 13, in Atlas to “Midden-Celebes-Expeditie: Geologische en geographische doorkruisingen van Midden-Celebes 1909 – 1910”, *Koninklijk Nederlandsch Aardrijkskundig Genootschaap* (in French and Dutch).

Albini, P., R.W. Musson, A. Rovida. M. Locati, A. Gomez Capera, and D. Viganò (2014), The global earthquake history, *Earthquake Spectra*, **30**, 2, pp. 607 – 624.

Ambraseys, N.N., and R. Bilham (2003). Earthquakes and Associated Deformation in Northern Baluchistan 1892–2001, *Bulletin of the Seismological Society of America*, **93**, 2, pp. 1573 – 1605.

Ambraseys, N.N., and C.P. Melville (1982). A history of Persian earthquakes, Cambridge University Press, 219 p.

Ambraseys, N., E. Banda, J. Irving, D. Mallard, C. Melville, T. Morse, R. Muir-Wood, D. Muñoz, L. Serva, D. Shilton, E. Surinach, and J. Vogt (1983). Notes on historical seismicity, *Bulletin of the Seismological Society of America*, **73**, 6, pp. 1917 – 1920.

Anonymous (1920), Vulkanische verschijnselen en aardbevingen in den Oost Indischen Archipel waargenomen gedurende het jaar 1919, *Natuurkundig tijdschrift voor Nederlandsch Indië*, **80**, 3, pp. 191 – 259 (in Dutch).

Anonymous (1940), Aardbevingen in den Oost Indischen Archipel waargenomen gedurende het jaar 1938, *Natuurkundig tijdschrift voor Nederlandsch Indië*, **100**, 1, pp. 38 – 75 (in Dutch).

Anonymous (1957), Earthquakes in Indonesia: 1948 – 1955, Series A, No. 45, *Department of Communications, Meteorological and Geophysical Institute*, Jakarta, 72p.

Aung, L.T., S. Martin, Y. Wang, S. Wei, M. Thant, K.N. Htay, H.M. Aung, T.Z. Kyaw, S. Min, K. Sithu, T. Naing, E.H.N. Myo, T.H. Oo, S. N. Khaing, G. Suresh, W. Chen, P. M. Maung, and V.K. Gahalaut (2019). A comprehensive assessment of ground motions from two 2016 intra-slab earthquakes in Myanmar, *Tectonophysics*, **765**, 146 – 160, doi: 10.1016/j.tecto.2019.04.016.

Berlage, H.P. (1934). De aardbeving in Zuid-Sumatra van 25 Juni 1933 (waarnemingen in het epicentrale gebied), *Natuurkundig tijdschrift voor Nederlandsch Indië*, **94**, 1, pp. 15 – 36 (in Dutch).

de Rossi, M.S. (1883), Programma dell'Osservatorio ed archivio geodinamico presso il Regio Comitato geologico d'Italia con istruzioni per gli osservatorii e descrizioni d'instrumenti, Rome. Pp. 66 – 68.

Davison, C. (1921), Scales of seismic intensity – Supplementary paper, *Bulletin of the Seismological Society of America*, **11**, 2, pp. 95 – 130.

Davison, C. (1933), On scales of seismic intensity and on the construction and use of isoseismal lines, *Bulletin of the Seismological Society of America*, **24**, 4, pp. 158 – 166.

Dawson, B., and J. Gillow (1994). The traditional architecture of Indonesia, Thames and Hudson, New York, 192 p.

Figee, S., H. Onnen, and J.A. Schuurman (1886), Circulaire gezonden aan H.H. medewerkers tot het verzamelen van aardbevingswaarnemingen, *Natuurkundig tijdschrift voor Nederlandsch Indië*, **45**, 2, pp. 233 – 234 (in Dutch).

Grünthal, G. (Editor) (1998). The European Macroseismic Scale EMS-98, Conseil de l'Europe, Cahiers du Centre Européen de Géodynamique et de Séismologie, **15**, Luxembourg, 101 p.

Harris, R, and J. Major (2016) Waves of destruction in the East Indies: The Wichmann catalog of earthquakes and tsunami in the Indonesian region from 1538 to 1877, *Geological Society, London*, Special Publications, **441**, pp. 9 – 46.

Hough, S.E., and S.S. Martin (2021), Which earthquake accounts matter? *Seismological Research Letters*. **92**, 2A, pp. 1069 – 1084.

Martin, S.S. and S.E. Hough (2016). Reply to, "Comment on 'Ground Motions from the 2015 Mw 7.8 Gorkha, Nepal, Earthquake Constrained by a Detailed Assessment of Macroseismic Data' by Stacey Martin, Susan E. Hough and Charleen Hung" by Andrea Tertulliani, Laura Graziani, Corrado Castellano, Alessandra Maramai, Antonio Rossi, *Seismological Research Letters*, **87**, 4, pp. 369 – 377, doi:10.1785/0220160061.

Martin, S.S., L. Li, E. Okal, J. Morin, A. Tetteroo, A. Switzer, K. Sieh (2019), Reassessment of the 1907 Sumatra "tsunami earthquake" based on macroseismic, seismological and tsunami observations, and modelling, *Pure and Applied Geophysics*, **176**, pp. 2831 – 2868.

Martin, S.S., Y. Wang, M. Muzli, and S. Wei (2020). The 1922 Peninsula Malaysia Earthquakes: Rare intraplate seismicity within the Sundaland block in Southeast Asia, *Seismological Research Letters,* **91**, 5, pp. 2531 – 2545.

Medvedev, S. V., W. Sponheuer, and V. Kárník (1965). Шкала Сейсмической Интенсивности MSK 1964 (Seismic Intensity Scale Version MSK 1964, in Russian), Akademii Nauk SSSR Geofiz. Kom., Moscow, 280.

Musson, R. M. W. (1998). Intensity assignments from historical earthquake data: issues of certainty and quality, *Annali di Geofsica*, **41**, 1, 79-91.

Musson, R. M. W. (2012), A provisional catalogue of historical earthquakes in Indonesia, Earth Hazards and Systems Programme Open Rept. OR/12/073, 22 pp.

Musson, R. M. W, and I., Cecić (2012). Intensity and Intensity Scales, New Manual of Seismological Observatory Practice 2 (NMSOP-2), GFZ Potsdam, 1-41, doi: h10.2312/gfz.nmsop-2_ch12.

Musson, R.M.W., G. Grunthal, and M. Stucchi (2010). The comparison of macroseismic intensity scales, *Journal of Seismology*, **14**, p. 413 – 428.

Nas, P. (2007)(ed). The past in the present: Architecture in Indonesia, Leiden, 286 p.

Richter, C.F. (1958). Intensities and isoseismals, Elementary Seismology, W.H. Freeman, San Francisco, pp. 135 – 149.

Rudolph, E. (1887). Ueber Submarine Erdbeben en Eruptionen, *Beiträge für Geofisik: Zeitschrift für physikalische Erdkunde*, **1**.

Rudolph, E. (1895). Ueber Submarine Erdbeben en Eruptionen (Zweite Beitrag), *Beiträge für Geofisik: Zeitschrift für physikalische Erdkunde*, **2**, pp. 537 – 667 (in German).

Stehn, Ch. E. (1925). De aardbeving van Maos op 15 Mei 1923, Vulkanologische en Seismologicsche Mededeelingen, 8, pp. 22 – 28 (in Dutch).

Sumintardja, J. (1978). Kompendium sejarah arsitektur, Bandung, 218 p.

Taverne, N.J.M. (1925). De aardbevingen van Wonosobo op 12 November en 2 December 1924, *Vulkanologische en Seismologicsche Mededeelingen*, **8**, pp. 1 – 21.

Tertulliani, A., L. Graziani, C. Castellano, A. Maramai, & A. Rossi (2016). Comment on "Ground Motions from the 2015 Mw7.8 Gorkha, Nepal, Earthquake Constrained by a Detailed Assessment of Macroseismic Data" by Stacey S. Martin, Susan E. Hough, and Charleen Hung, *Seismological Research Letters*.

van Dijk, P. (1885), Voorloopige instructive omtrent de waarneming van aardbevings- verschijnselen, *Natuurkundig tijdschrift voor Nederlandsch Indië*, **44**, 3, 280 – 292 (in Dutch).

van Dijk, P. and J.J. Poortman (1885), Circulaire gezonden aan alle personen, die hunne medewerking bij de waarneming van aardbevings-verschijnselen hebben togezegd, *Natuurkundig tijdschrift voor Nederlandsch Indië*, **44**, 3, 277 – 279 (in Dutch).

Valentijn, F. (1724). Oud- en nieuw Oost-Indiën, 1, Dordrecht – Amsterdam, p. 331 – 332.

Vogt, J., R.M.W. Musson and M. Stucchi (1994). Seismogeological and hydrological criteria for the New European Macroseismic Scale (MSK-92), *Natural Hazards*, **10**, pp. 1 – 6.

Wood, H.O. and F. Neumann (1931). Modified Mercalli intensity scale of 1931, *Bulletin of the Seismological Society of America.* **21**, pp. 277 – 283.