1907, 1915, 1941: EXAMPLES OF THE CRITICAL VALUE OF HISTORICAL SEISMOGRAMS FOR THE STUDY OF SUBDUCTION PROCESSES

Emile A. OKAL

Department of Earth & Planetary Sciences
Northwestern University
Evanston, IL 60208 USA

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04 JAN 1907, Northern Sumatra

• This earthquake, assigned no greater than $M_{PAS} = 7.6$ by Gutenberg and Richter, generated a devastating tsunami, which killed more than 2000 people, suggesting its nature as a "tsunami earthquake".

→ However, it was also very strongly felt, which requires high frequencies generally absent from such events.

What can be done more than 100 years later?
RELOCATION

Modern relocations, including ours (red dot) place the event either on the outer rise (improbable for a tsunami earthquake), or **significantly updip** from the recent megathrusts, in a geometry comparable to that of the 2010 Mentawai tsunami earthquake.

04 JAN 1907 -- 05h19

Preferred, Final Solution
MACROSEISMICITY

Recompile all macroseismic data from original newspaper and bulletin reports.

→ The distribution of felt intensities is fundamentally incompatible with the preferred epicenter (•)  
[Martin et al., 2019]
MYSTERY CRAKED... at Manila

- Seismograms at Manila, miraculously published [Masó, 1907] before they were destroyed during WWII, solve this paradox.
There were two events!

The main shock was a slow "tsunami earthquake", followed 53 minutes later by a regular, or perhaps even fast, aftershock...

Note the obviously different spectra of the two events.

→ On the short-period records (a), the body waves are much larger for the aftershock than for the mainshock.

→ On the long-period records (b), the body waves appear comparable, and the surface waves are much larger for the mainshock.

→ This reconciles epicentral, macroseismic, and tsunami observations.
Scanned Wiechert seismograms at Göttingen allow quantification of Rayleigh and Love waveforms of the mainshock, suggesting

$$M_0 = 2.5 \times 10^{28} \text{ dyn*cm at mantle wave periods.}$$

Note systematic increase of moment with period, characteristic of tsunami earthquakes.

This value is then used to simulate the tsunami across the Indian Ocean, allowing a good match to locations reporting it (bull’s eyes) or not (triangles).
01 MAY 1915, Northern Kuriles

- This earthquake was assigned $M_{PAS} = 8.1$ by Gutenberg and Richter, but *no tsunami is reported* in the NOAA database. Also, to our knowledge, the event was never the subject of a modern study. In the wake of the now famous 2006-2007 doublet nearby, it is worth investigating in detail.

The earthquake relocates in the vicinity of the trench. It could be on the outer rise. Note the presence of numerous normal faulting CMT solutions (*small green dots*).
The 1915 earthquake is clearly a normal faulting event.

All twelve first motions personally read by author for this study.

The polarity of this P wave first arrival proves, by itself, that the earthquake cannot be a regular interplate thrust.
Note the spectacular quality of first arrivals on these 100-yr old records.

**IRK**

Up

Down

**SVE**

Up

**OSK**

South

**CLE**

Up

North

NOTE: Incorrect Epicentral Estimate!

NOTE: Undamped Instrument
Available waveforms at DBN, RIV and PAR yield an average seismic moment of

\[ M_0 = 1.2 \times 10^{28} \text{ dyn} \times \text{cm} \]

with no evidence of source slowness.

The earthquake looks very similar to the 2007 normal faulting event.

\[ M_c = 8.09 \pm 0.26 \]

20 km; 218, 79, 315

\[ M_0 = (0.122E+29 \times 1.81) \text{ dyn cm} \]

\[ M_c = 8.36 - 0.03 \times \text{FQC (mHz)} \]

\[ \Delta \text{ RIV R1} \]
\[ \Delta \text{ RIV G1} \]
\[ \Delta \text{ PAR R1} \]
\[ \Delta \text{ DBN G1} \]

The earthquake looks very similar to the 2007 normal faulting event.

However, it has no interplate thrust "partner" to form a doublet comparable to the 2006–2007 sequence.
THE ANDAMAN ISLANDS EARTHQUAKE of 26 JUNE 1941

Why study yet another old earthquake?

- Largest event recorded in the Andaman Islands ($M_{PAS} = 8.1$)
- Extremely oblique convergence between the Indian and Sunda plates, with partitioning through the Sumatra-Andaman sliver

→ AND... Disparities in magnitudes

* $M = 8.7$ (!) [Richter, 1958]
* $m_B = 8.0$ (at 8 s) [Abe, 1981]
* $M_s = 7.7$ [Abe, 1981]
* $M_{100} = 8.0$ [Brune, 1968]
* $M_0 = 3 \times 10^{27}$ dyn*cm (only) [Kanamori, 1977] "from $M_{100}$" ...
Other Intriguing Aspects

• The 2004 Sumatra event ruptured with significant moment release over the 1941 location.

  [Ishii et al., 2007]

• Also confirmed by GPS

  [Chlieh et al., 2007]

→ A large megathrust in 1941 would not have made this possible just 63 years later.


Other Intriguing Aspects

- This large earthquake ($M_{PAS} = 8.1$) was regarded as a "worst case scenario" in the Andaman Islands, prior to the 2004 disaster.

Murty and Rafiq [1991] suggested that its tsunami killed 5000 people in India [sic], but Bilham et al. [2005] failed to find any report of this alleged catastrophe.

$\rightarrow$ It is thus important to study this event in detail.
All relocations, including ours (red star) place the event either on the accretionary prism supporting the Andaman Islands, or under the islands themselves, thus suggesting poor transfer of tsunami energy to the deeper waters [Green, 1838].
FOCAL MECHANISM (First Motions)

First motions read on 14 original seismograms, complemented by 3 ISS reports, require a strike-slip mechanism, suggesting partitioning of the extremely oblique plate convergence.

Figure B.: Top Left (TS): Focal mechanism obtained in this study from $P$–wave first motions. Solid dots represent upwards (anaseismic) first motions, open dots downwards (kataseismic) ones; smaller symbols relate to data retrieved unverified from the ISS. Bottom and right: Mechanisms proposed in previous studies.

Previously published mechanisms are incompatible with these observations.
FOCAL MECHANISM (Mantle Surface Waves)

**BUT...**

A dataset of 12 mantle surface waves is not fit by the strike-slip mechanism, with moment values varying by as much as two orders of magnitude between stations.

which requires a more complex, composite, focal mechanism for the 1941 earthquake.
COMPOSITE MECHANISM

→ By contrast, a composite mechanism mixing

20% strike-slip ($M_0 = 2.2 \times 10^{27}$ dyn*cm)
and
80% normal faulting ($M_0 = 8.7 \times 10^{27}$ dyn*cm),

the latter in the average geometry of the numerous
nearby normal faulting intraplate CMT solutions,

provides an acceptable fit to the same spectral amplitudes.
The composite mechanism (with the normal component moved 40 km in the N135°E direction) can be used to compute static displacement, correctly fitting a reported ∼1.2–m subsidence in Port Blair (bull’s eye).

The same model is used for near- and far-field tsunami simulations (using MOST), which correctly predict minimal amplitudes in India and elsewhere in the Indian Ocean Basin.

Low far-field tsunami amplitudes are due to static displacement contained to very shallow waters (typically < 200 m), the wave then faltering in deep waters in application of Green’s Law [1838], this situation being fully reminiscent of the 2005 Nias tsunami.
CONCLUSION: THESE SAMPLE CASES REAFFIRM, if need be, the crucial value of historical seismograms and the need for their preservation (when possible in digital form).