GSA Data Repository 2014237

"Accommodation space, relative sea level and the archiving of paleoearthquakes along subduction zones"

POLLEN ANALYSIS: Detailed data table (Table DR1) to support results presented in text

Palynomorphs (pollen and fern spores) were isolated using standard palynological preparation techniques (Traverse, 2007). When possible, at least 300 pollen grains and spores were counted from each sample to determine percent abundance and concentration of palynomorphs. Identification was aided by reference material from the United States Geological Survey (Reston, Virginia) and pollen atlases from the region (Huang, 1972; Mao et al., 2012; Thanikaimoni, 1987).

Percent abundance of major taxa (>2%) are presented in Table DR1. Palynomorphs are arranged alphabetically with fern spores and form taxa listed at the end.

Table DR1. Palynomorph (pollen and fern spore) data, percent abundance of major taxa, i.e., taxa that have greater than 2% abundance. Tabulation for core PU 11 16, Pulot field site. Thirty-two Palynomorph types, listed by row headings in alphabetical order.

Depth, cm	*Acrostichum*	Apiaceae	*Avicennia*	*Bombax*	*Brownlowia*	*Casuarina*	*Ceriops/ Brugeria*	Combretatceae
330-331	11	1	8	0	0	1	11	0
332-333	9	2	6	0	0	2	14	0
334-335	7	2	5	0	0	1	17	3
341-342	6	0	6	0	0	1	13	1
344-345	0	1	4	1	0	1	9	0
348-349	2	0	1	2	1	0	11	1
395-397	28	1	1	1	1	2	0	1
398-399	39	0	1	1	2	1	0	0
402-403	25	0	0	0	0	1	1	1
407-408	8	0	0	1	3	10	1	1
412-413	25	0	1	1	1	3	0	1
421-422	55	0	0	0	0	5	0	0
426-427	17	0	0	2	0	1	0	0
430-431	38	0	1	0	0	0	1	0
433-434	21	0	0	2	0	0	0	0
439-440	5	1	3	1	0	0	1	0

Depth, cm	Cucurbitaceae	Euphoribiaceae	*Excocaria*	Fabaceae	*Ilex*	Illiciaceae	Malvaceae	Olecaeae
330-331	0	4	0	2	0	0	0	0
332-333	0	4	1	3	3	0	0	0
334-335	1	5	1	0	5	0	0	0
341-342	0	7	0	0	3	0	0	0
344-345	0	4	1	2	1	0	0	0
348-349	0	0	4	1	1	0	0	0
395-397	0	1	1	3	2	0	0	0
398-399	0	1	0	4	1	0	0	5
402-403	3	0	2	4	0	0	0	6
407-408	0	0	2	8	0	0	0	6
412-413	0	0	0	5	0	0	0	5
421-422	0	0	0	0	0	0	0	0
426-427	0	0	2	0	3	4	2	0
430-431	0	0	3	0	0	0	1	1
433-434	0	0	0	0	1	0	1	1
439-440	0	0	0	1	4	0	0	4

Depth, cm	Poaceae	*Pterospermum*	*Quercus*	*Rhizophora*	Rosaceae	Solanaceae	Sonnera-tiaceae	Sterculaceae
330-331	1	4	1	11	3	1	0	0
332-333	0	0	0	5	1	1	0	0
334-335	0	1	0	9	1	3	2	0
341-342	0	1	3	17	0	0	3	0
344-345	0	1	0	18	1	2	0	0
348-349	4	1	3	16	2	0	1	3
395-397	0	6	0	0	0	0	0	0
398-399	0	3	0	1	0	0	0	0
402-403	1	3	0	1	0	0	1	0
407-408	0	6	0	0	0	0	0	0
412-413	1	5	0	0	0	0	1	0
421-422	0	0	0	0	0	0	0	0
426-427	1	6	1	2	0	0	1	0
430-431	0	4	0	0	0	0	1	0
433-434	2	5	0	0	0	0	2	0
439-440	1	6	2	1	0	1	4	0

Depth, cm	*Symplocos*	Tiliaceae	*Xylocarpus*	Tricolpate Pollen	Tricolporate Pollen	Triporate Pollen	Monolete Fern Spores	Trilete Fern Spores
330-331	3	1	0	5	13	0	8	1
332-333	2	1	1	8	16	2	7	0
334-335	0	1	2	9	16	1	7	2
341-342	0	3	0	1	19	1	3	6
344-345	0	2	0	10	17	1	2	1
348-349	1	3	1	4	16	3	7	1
395-397	0	0	1	2	9	0	34	1
398-399	0	0	0	0	6	1	28	4
402-403	0	0	0	1	13	0	32	2
407-408	0	0	0	4	14	0	26	7
412-413	0	0	0	4	9	2	23	5
421-422	0	0	0	10	0	0	15	5
426-427	0	0	0	9	3	1	21	15
430-431	0	0	1	4	0	0	13	15
433-434	0	0	0	3	7	2	31	11
439-440	0	0	2	7	19	1	22	4

Table DR2. Radiocarbon sample material and laboratory results, Aceh, Sumatra

Sample code*	Lab reported age ^{14}C yr BP †	$\delta^{13}C$ (‰)†	Material
PF 07 12 467	6690±50	-28.2	12 detrital wood fragments
PU 07 04 265	5090±40	-28.3	1 detrital wood fragment
PU 07 03 410	5770±30	-7.15	Shell, *Cerithidea cingulata*
PU 07 03 426	6060±40	-25.8	1 detrital wood fragment
PU 07 03 437	6160±40	-26.5	1 detrital wood fragment
PU 11 11 462	6170±35	-27.8	10 detrital wood fragments
PU 11 13 299	4770±35	-30.14	12 detrital wood fragments
PU 11 15 229	4630±30	-29.9	3 detrital wood fragments
PU 11 15 299	5070±30	-32.3	3 detrital wood fragments
PU 11 14 314	5680±30	-28.4	8 detrital wood fragments
PU 11 16 205	4270±40	-30.3	15 detrital wood fragments
PU 11 16 216	4580±30	-27.7	9 detrital wood fragments
PU 11 16 337	5710±35	-28.51	18 detrital wood fragments
PU 11 16 400	6130±40	-27.27	24 detrital wood fragments
PU 11 16 435	4580±30	-29.2	1 detrital wood fragment
PU 11 19 225	3420±40	-28.3	30 detrital wood fragments
PU 11 19 363	6180±35	-28.7	20 detrital wood fragments
SM 11 04 193	3910±30	-29.92	3 detrital wood fragments
SM 11 04 291	6030±30	-30.57	1 detrital wood fragment
SM 11 04B 306	6020±40	-28.0	3 detrital wood fragments
SM 11 13A 182	3540±30	-29.74	5 detrital wood fragments
SM 11 13B 186	3630±35	-29.13	31 detrital wood fragments
SM 11 13 265	3600±30	-29.04	48 detrital wood fragments
SM 11 13 268	3540±30	-30.1	6 detrital wood fragments
SM 11 13 490	6560±35	-27.49	25 detrital wood fragments
SM 11 13 596	7070±35	-29.25	10 detrital wood fragments
SM 11 16 451	6500±35	-29.27	9 detrital wood fragments
SM 11 16 498	6500±40	-29.74	3 detrital wood fragments
GL 11 02 124	4070±30	-27.7	2 detrital wood fragments

* Sample code has four components: site identifier (PF, Seudu; PU, Pulot; SM, Seungko Meulat; GL, Glee Putoh) . year sampled (either 2007 or 2011). number of core . depth of top of sample in cm.

† All analyses performed by NOSAMS, Woods Hole, USA, except for the four 07 analyses which were performed by Beta Analytic Inc.

Table DR3. Sea level index points and limiting data used to construct relative sea level (RSL), Aceh coastal plain, Sumatra. The calculation of the vertical error for RSL determinations is detailed on the next page.

Sea level index point and limiting data	Location, core number and core depth*	Latitude, decimal degrees north	Longitude, decimal degrees east	Lab code†	Lab reported age ^{14}C yr BP	Calibrated age, 2 σ cal yr BP §	RSL m #	Evidence that led to classification **
Index point								
1.	PF 07 12 467	5.3384	95.2438	Beta-236191	6690±50	7474-7656	-5.12 ± 0.40	A.
2.	PU 07 04 265	5.3633	95.2520	Beta-236194	5090±40	5743-5917	-1.60 ± 0.39	A.
3.	PU 07 03 426	5.3632	95.2517	Beta-236192	6060±40	6791-7142	-3.21 ± 0.40	A.
4.	PU 07 03 437	5.3632	95.2517	Beta-236193	6160±40	6949-7166	-3.31 ± 0.40	A.
5.	PU 11 15 299	5.3634	95.2523	Os-95228	5070±30	5745-5904	-1.94 ± 0.39	A.
6.	PU 11 14 314	5.3628	95.2524	Os-95240	5680±30	6402-6537	-2.09 ± 0.40	A.
7.	PU 11 16 337	5.3629	95.2523	Os-100363	5710±35	6409-6626	-2.32 ± 0.40	A.
8.	PU 11 16 400	5.3629	95.2523	Os-100364	6130±40	6912-7160	-2.95 ± 0.40	A.
9.	SM 11 04 291	5.2930	95.2351	Os-91627	6030±30	6789-6951	-1.69 ± 0.39	A.
10.	SM 11 04B 306	5.2930	95.2351	Os-95270	6020±40	6748-6958	-1.84 ± 0.39	A.
11.	SM 11 16 451	5.2924	95.2336	Os-91628	6500±35	7324-7475	-3.22 ± 0.39	A.
12.	SM 11 16 498	5.2924	95.2336	Os-91657	6500±40	7320-7482	-3.69 ± 0.39	A.
Terrestrial limiting								
13.	PU 11 11 462	5.3630	95.2512	Os-95247	6170±35	6966-7167	-3.01 ± 0.31	B.
14.	PU 11 15 229	5.3634	95.2523	Os-95155	4630±30	5301-5463	-0.68 ± 0.31	B.
15.	PU 11 16 205	5.3629	95.2523	Os-95272	4270±40	4654-4960	-0.44 ± 0.31	B.
16.	PU 11 16 216	5.3629	95.2523	Os-95227	4580±30	5066-5446	-0.55 ± 0.31	B.
17.	PU 11 19 363	5.3607	95.2526	Os-95246	6180±35	6965-7173	-2.02 ± 0.31	B.
18.	SM 11 04 193	5.2930	95.2351	Os-91626	3910±30	4248-4421	-0.17 ± 0.29	B.
19.	SM 11 13A 182	5.2924	95.2338	Os-91623	3540±30	3717-3902	-0.15 ± 0.29	B.
20.	SM 11 13B 186	5.2924	95.2338	Os-91629	3630±35	3844-4080	-0.18 ± 0.29	B.
21.	SM 11 13 490	5.2924	95.2338	Os-91624	6560±35	7424-7558	-3.22 ± 0.30	B.
22.	SM 11 13 596	5.2924	95.2338	Os-91625	7070±35	7837-7965	-4.28 ± 0.30	B.
Marine limiting								
23.	PU 07 03 410	5.3632	95.2517	Os-79207	5770±30	5893-6410††	-3.11 ± 0.31	C.

* Sample code has four components: site identifier (PF, Seudu; PU, Pulot; SM, Seungko Meulat; GL,) . year sampled (either 2007 or 2011). number of core . depth of top of sample in cm.

† Laboratory where analyses performed: Os, NOSAMS, Woods Hole, USA; Beta, Beta Analytic Inc. Florida, USA. Use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

§ Calibrated age ranges (yr BP) at 2 standard deviations, using Calib rev.6.0.0 (Reimer et al., 2013); yr BP = years before AD 1950.

Relative sea level (RSL) is the reference water level subtracted from the sample elevation. Calculation of vertical error for RSL, which follows established methods (e.g., Shennan and Horton, 2002), is described below.

** Code indicating the main line of evidence that led to the classification as an index point, terrestrial limiting or marine limiting:

A. Criteria for classification as an index point: foraminifera were present within the organic soils, or pollen demonstrated a mangrove source (e.g., *Rhizophora*, *Bruguiera/Ceriops*, *Avicennia* pollen). Index points are assigned a reference water level halfway between Highest Astronomical Tide (HAT) and Mean Tide Level (MTL), with an indicative range of (HAT-MTL)/2 (e.g., Engelhart et al., 2007).

B. Criteria for classification as an upper limiting data point with a reference water level of MTL (i.e. sample must have formed above this elevation): Organic content supported formation above MTL but foraminifera were absent and/or pollen evidence did not provide unequivocal support for a mangrove origin.

C. Criteria for classification as a lower limiting data point (below MTL): Sample consists of a marine gastropod, *Cerithidia cingulata*, that must have lived below MTL,

†† Shell corrected for marine reservoir effect using DR=15±119 (Grand Pre et al., 2012).

The calculation of vertical error for index points and limiting data points (Shennan and Horton, 2002) is as follows:

The total error (E_i) for each sample is:
$E_i=\text{sqrt}(e^2{}_1 + e^2{}_2 + e^2{}_3 + e^2{}_4 + e^2{}_5 + e^2{}_6 + e^2{}_7 + e^2{}_8)$.

The eight error sources:
1. ±0.3 m for the indicative range of a mangrove sample (where appropriate)
2. ±0.2 m for the error based on estimating tidal levels from a model (Egbert and Erofeeva, 2002)
3. ±0.005 to 0.01 m for the thickness of the sample
4. ±0.05 m for errors introduced by the gouge coring method
5. ±0.05 to 0.1 m for errors leveling the cores to the temporary benchmark (site specific) using an auto-level and staff
6. ±0.01 m for errors made during sampling (e.g., measuring depths)
7. ±0.2 m for the error in establishing the MTL datum
8. ±1% of core depth to account for angle errors during coring (±0.01 to 0.06 m).

FORAMINIFERAL ANALYSIS

Detailed methods to supplement methods presented in text

We conducted foraminiferal analysis on 49 core samples, 28 samples from Seungko Meulat core 11 4 and 21 samples on Pulot core 11 16P (Figs. 1, 2. 3).

Foraminiferal analysis followed the methods of Horton and Edwards (2006) where 2 cm^3 samples were sieved at 63 μm and examined in a liquid medium using a binocular microscope. Taxonomy followed Loeblich and Tappan (1987) and Debenay (2013). Taxa were categorized by ecology (intertidal, subtidal, or planktic). Intertidal and subtidal species were identified to the genus or species level. Planktics were grouped but were not identified to a higher taxonomic order. The following is a list of all foraminifera, from cores SM 11 4 and PU 11 16, identified to the genus or species level.

Intertidal species:

Ammonia parkinsoniana
Ammonia tepida
Elpidium craticulatum
Elphidium advenum
Elphidium spp.
Miliolids

Subtidal species:

Operculina ammonoides
Amphistegina spp.
Epinoides repandus
Cibicides refulgens
Homotrema rubra

Species spanning intertidal and subtidal zones:

Calcarina sp.
Nonion sp.
Peneroplis sp.

The test condition (i.e., taphonomic character) of individual foraminifera was categorized as pristine, abraded or fragmented following the taphonomic criteria of Pilarczyk et al. (2011).

Ecological (intertidal, subtidal, and planktic) and taphonomic (pristine, abraded, and fragmented) counts for each interval in each of two cores were weighted against the total number of individuals in the sample (Tables DR4, DR5). Pie charts in Fig. 4 are the averaged abundances for each stratigraphic unit.

Core SM 11 4: Detailed data table (Table DR4) that expands on results presented in Fig. 3.

At Seungko Meulat (SM 11 4), four stratigraphic units (2004 tsunami sand, soil, sandy mud to muddy sand unit, and paleo-tsunami sands) contained foraminifera (Table DR4). The 2004 tsunami deposit is characterized by a subtidal assemblage (75% of the assemblage consisted of subtidal species; e.g., *Epinoides repandus* and *Amphistegina* spp.), that also contains planktics (10%). Within the 2004 deposit, unaltered foraminifera (65%) were more abundant than fragmented (20%) or abraded (15%) individuals. The four paleo-tsunami sands also contained relatively high abundances of subtidal species (72 ± 9%). Individuals within these layers were more abraded (53 ± 18%) and fragmented (42 ± 25%) than those from the 2004 deposit, but overall less abraded than those contained within the sandy mud to muddy sand (where 65% of foraminifera were abraded).

The sandy mud to muddy sand unit consists of an assemblage that includes intertidal species (72% of species were intertidal) that showed evidence of subaerial exposure through a high degree of abrasion (65% of individuals) and subtidal and planktic species (28% of the assemblage; e.g., *Operculina ammonoides*, planktics).

Table DR4: Foraminiferal abundance (%) data for major stratigraphic units in SM 11 4. Pie charts in Fig. 3 are the averaged abundances for each stratigraphic unit.

Unit*	Core interval	Species: Intertidal†	Species: Subtidal†	Species: Planktic†	Test condition: Unaltered, 'Pristine'†	Test condition: Abraded†§	Test condition: Fragmented†§
2004 tsunami	6-7 cm	20	70	10	60	20	20
2004 tsunami	18-19 cm	10	80	10	70	10	20
Soil	35-36 cm	60	40	0	0	90	30
Soil	50-51 cm	0	0	0	0	0	0
Sandy mud to muddy sand	70-71 cm	0	0	0	0	0	0
Sandy mud to muddy sand	100-101 cm	0	0	0	0	0	0
Sandy mud to muddy sand	120-121 cm	0	0	0	0	0	0
Sandy mud to muddy sand-BSM	130-131 cm	80	20	0	0	100	30
Sandy mud to muddy sand-BSM	138-139 cm	70	30	0	0	100	40
Sandy mud to muddy sand-BSM	150-151 cm	60	30	10	0	90	80
Sandy mud to muddy sand	160-161 cm	80	20	0	0	70	30
Sandy mud to muddy sand-BSM	170-171 cm	70	30	0	0	40	40
Sandy mud to muddy sand-BSM	176-177 cm	0	0	0	0	0	0
Upper sand - Ts1	190-191 cm	40	60	0	20	60	40
Soil	200-201 cm	0	0	0	0	0	0
Middle sand -Ts2	222-223 cm	20	70	10	20	40	60
Soil	230-231 cm	0	0	0	0	0	0
Lower sand - Ts3	240-241 cm	10	80	10	0	20	80
Soil	255-256 cm	0	0	0	0	0	0
Soil	268-269 cm	0	0	0	0	0	0
Soil	280-281 cm	0	0	0	0	0	0
Lowest sand -Ts4	290-291 cm	10	60	20	10	60	30
Lowest sand -Ts4	295-296 cm	10	80	10	20	80	0
Lowest sand -Ts4	304-305 cm	20	80	0	10	60	40
Soil	315-316 cm	0	0	0	0	0	0
Soil	330-331 cm	0	0	0	0	0	0

* Units identified with BSM, Ts1, Ts2, Ts3 or Ts4 are samples that are summarized in Fig. 3 by pie diagrams for species ecology (subtidal, planktic, intertidal) and test condition (abraded, fragmented, pristine).

†Species were categorized by ecology (intertidal, subtidal, or planktic), and individual tests were categorized as unaltered ('pristine'), abraded and/or fragmented. Individuals that have not undergone taphonomic alteration are termed unaltered ('pristine') while those with rounded edges and pitting are termed abraded. An individual was considered fragmented if it was broken or missing part of its test (excluding bored individuals).

§ An individual foraminifera can be both abraded and fragmented at the same time, so that test conditions may sum to greater than 100%.

Core PU 11 16: Detailed data table (Table DR5) that expands on results presented in Fig. 3.

At Pulot (PU 11 16) the two lowest tsunamis sands were sampled in addition to the sandy mud to muddy sand unit and soil (Table DR5). The lowest sand was the only paleo-tsunami layer that contained foraminifera. The taxonomic (71% subtidal species, 15% planktics) and taphonomic (23% unaltered, 35% fragmented, 42% abraded) assemblages within the tsunami deposit were similar to tsunami deposits from SM 11 4. The sandy mud to muddy sand units in PU 11 16 and SM 11 4 are similar in terms of species ecology and test condition.

One notable difference between the two cores is the absence of foraminifera within soil layers from SM 11 4, but their presence in the lower soil of PU 11 16. Bioturbation is the likely cause. Foraminifera within this soil are similar to the overlying tsunami sand: (intertidal (70%), subtidal (26%) and planktic (4%) vs. subtidal (71%), intertidal (14%), and planktic (15%), respectively).

Table DR5. Foraminiferal abundance (%) in PU 11 16. Pie charts in Fig. 3 are the averaged abundances for each stratigraphic unit.

Unit*	Core interval	Species: Intertidal†	Species: Subtidal†	Species: Planktic†	Test condition: Unaltered, 'Pristine'†	Test condition: Abraded †§	Test condition: Fragmented †§
Tsunami sand	120-121 cm	0	0	0	0	0	0
Soil	145-146 cm	0	0	0	0	0	0
Soil	155-156 cm	0	0	0	0	0	0
Sandy mud to muddy sand	170-171 cm	0	0	0	0	0	0
Sandy mud to muddy sand- BSM	215-216 cm	70	30	0	0	100	40
Sandy mud to muddy sand- BSM	220-221 cm	80	20	0	0	90	80
Sandy mud to muddy sand- BSM	225-226 cm	80	20	0	0	100	60
Soil	230-231 cm	0	0	0	0	0	0
Soil	235-236 cm	0	0	0	0	0	0
Soil	240-241 cm	0	0	0	0	0	0
Sandy mud to muddy sand- BSM	270-271 cm	70	30	0	0	100	40
Sandy mud to muddy sand- BSM	275-276 cm	80	20	0	0	90	70
Detrital wood fragments	280-281 cm	0	0	0	0	0	0
Detrital wood fragments	286-287 cm	0	0	0	0	0	0
Tsunami sand- Ts6	290-291 cm	20	70	10	30	40	50
Tsunami sand- Ts6	295-296 cm	10	80	20	30	70	40
Soil - S	310-311 cm	60	20	20	10	90	60
Soil - S	316-317 cm	60	40	0	10	90	40
Soil - S	324-325 cm	100	0	0	0	70	30
Soil - S	330-331 cm	60	40	0	0	80	60
Soil - S	338-339 cm	70	30	0	0	90	40

* Units identified with BSM, Ts6 or S are samples that are summarized in Fig. 3 by pie diagrams for species ecology (subtidal, planktic, intertidal) and test condition (abraded, fragmented, pristine).

† Species were categorized by ecology (intertidal, subtidal, or planktic), and individual tests were categorized as unaltered ('pristine'), abraded and/or fragmented. Individuals that have not undergone taphonomic alteration are termed unaltered ('pristine') while those with rounded edges and pitting are termed abraded. An individual was considered fragmented if it was broken or missing part of its test (excluding bored individuals).

§ An individual foraminifera can be both abraded and fragmented at the same time, so that test conditions may sum to greater than 100%.

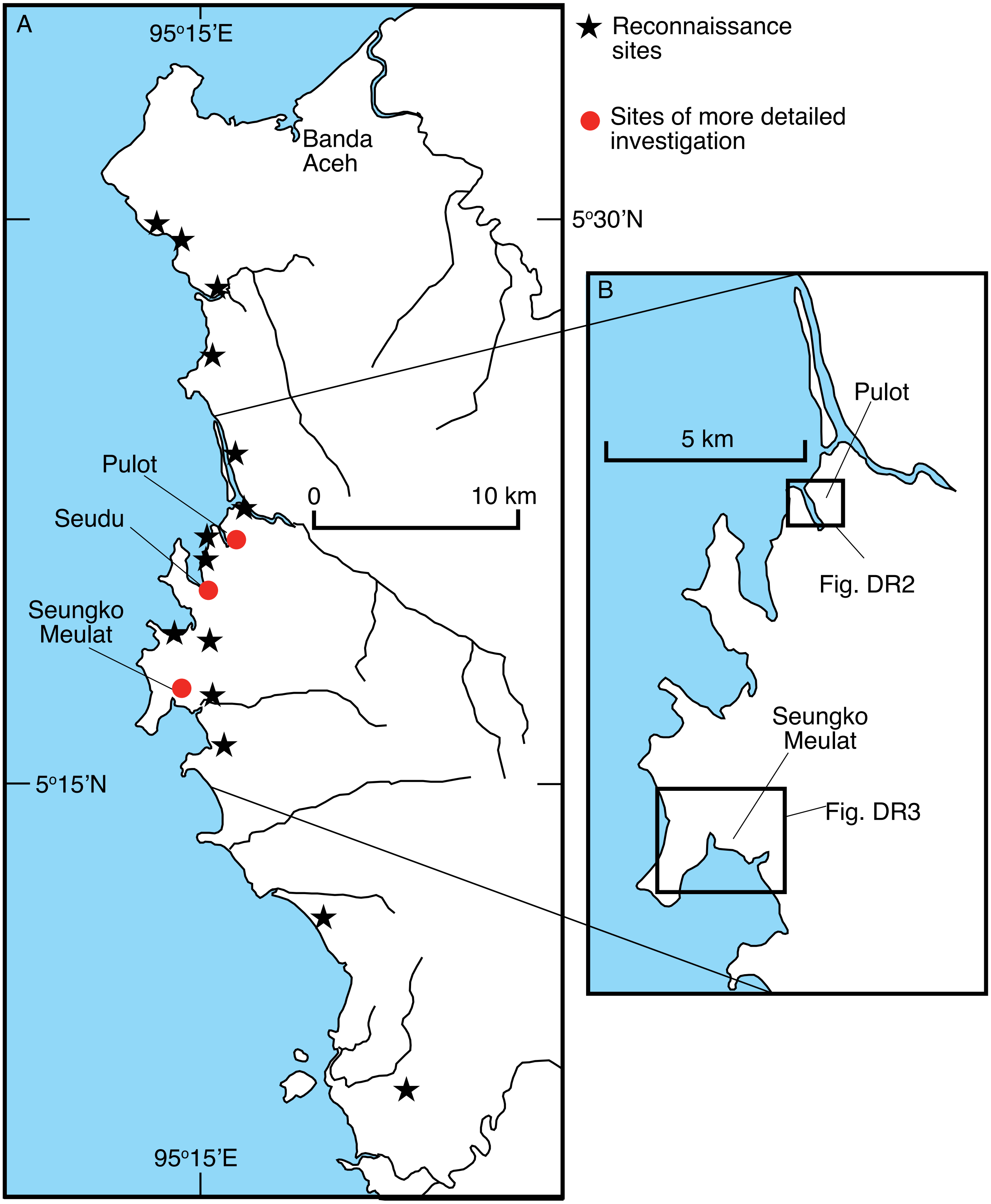


Figure DR1. A: Map of northern Aceh, Sumatra, that shows sites of coring. B: More detailed map of coastal section that shows the location of the Pulot and Seungko Meulat coring sites.

A

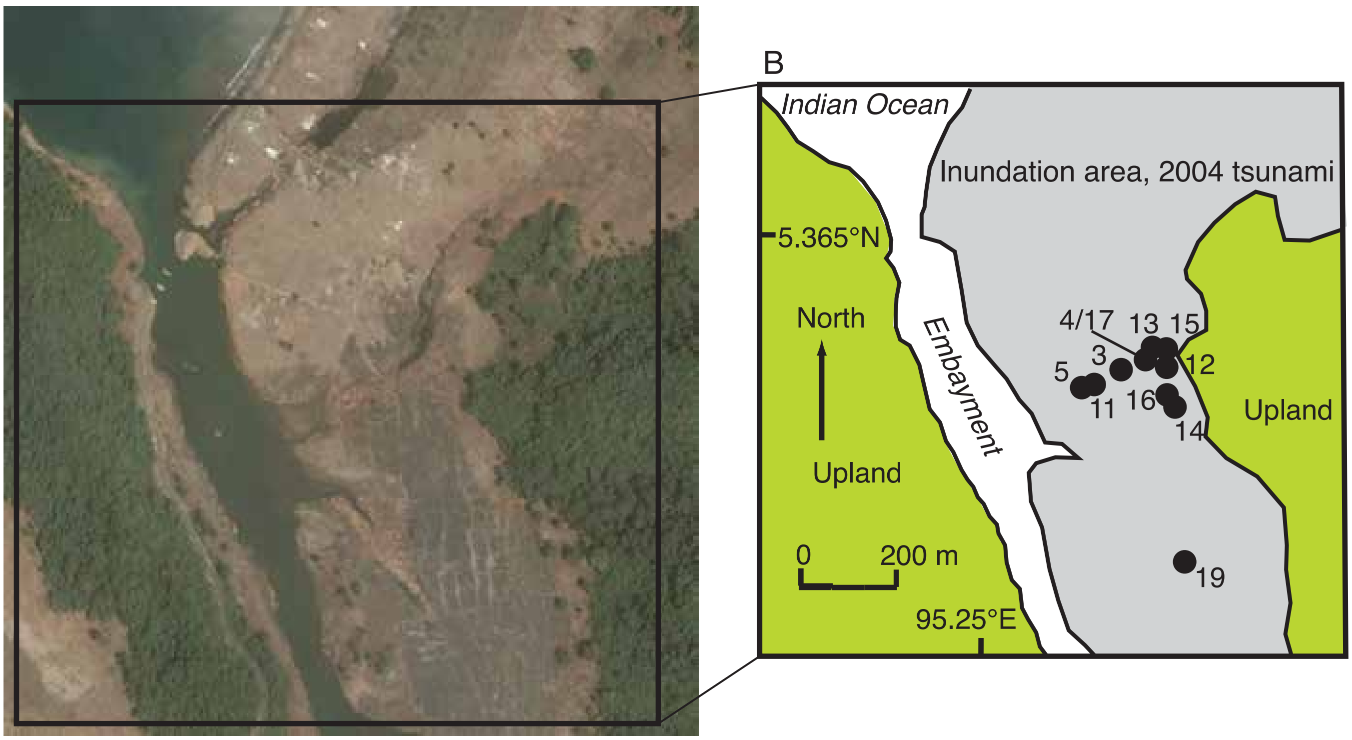


Figure DR2. A: Google Earth image of the Pulot site in February 2005 showing area denuded by December 2004 tsunami erosion and deposition. B: Map showing distribution of core sites (black dots) at Pulot site.

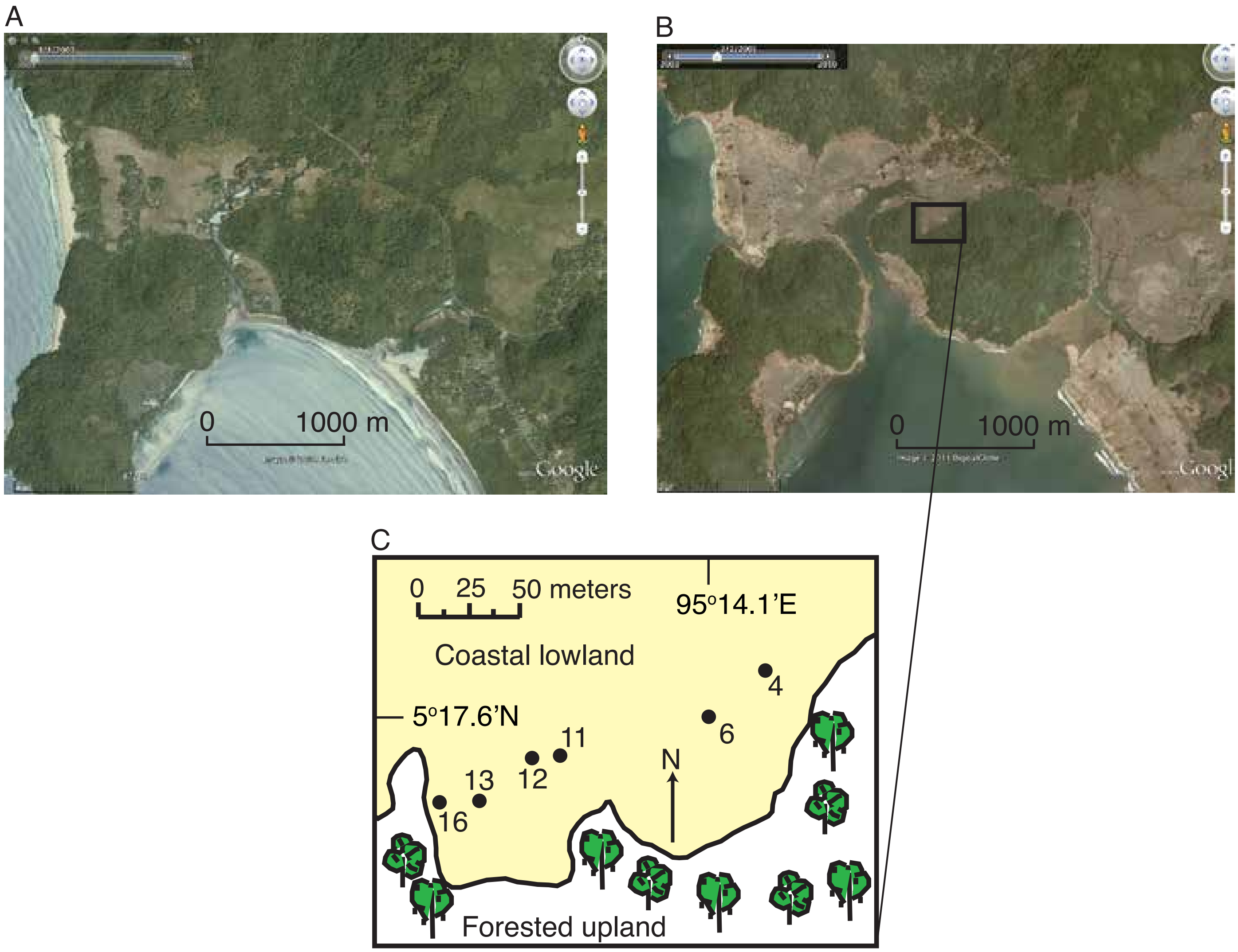
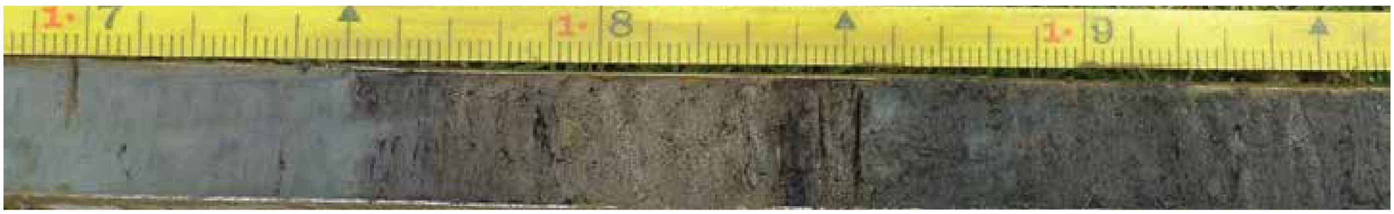


Figure DR3. A: Pre-2004-tsunami Google Earth image (March, 2003) of the Seunko Meulat site. B: Post-2004-tsunami Google Earth image (February, 2005) of the Seunko Meulat site showing area denuded by December 2004 tsunami erosion and deposition. C. Map showing distribution of core sites (black dots) at Seungko Meulat site.

Depth in centimeters: 169 cm (top), 196 cm (bottom)



Sandy mud

Tsunami sand, Ts1

Upper buried soil

Muddy sand

Figure DR4. Stratigraphic context of tsunami sand Ts1 in Seungko Meulat core 13.

Sandy mud Tsunami sand, Ts7 Sandy mud

Depth in centimeters: 479 cm (top), 493 cm (bottom)

Figure DR5. Stratgraphic context of tsnuami sand Ts7 in Seungko Meulat core 13.

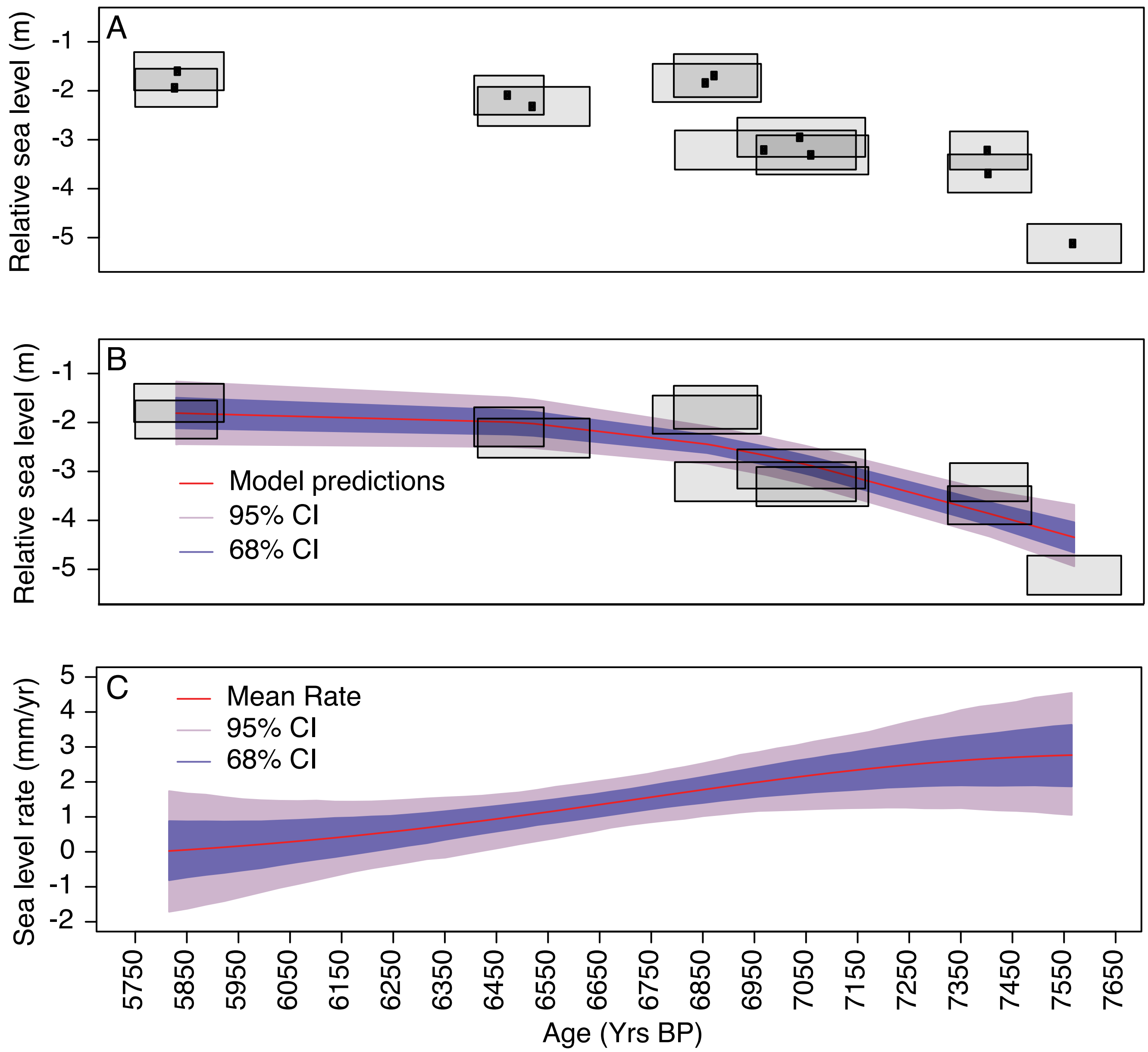


Figure DR6. A: Plot of sea-level index points defined by calibrated age range and relative sea level, including a 95% uncertainty region for each point. B: Predictions for sea level generated by fitting an integrated Gaussian process model (Holsclaw et al., 2013). Shading denotes 68% and 95% credible intervals (CI) for the posterior mean predictions. The model (Cahill et al., 2015) places a Gaussian process prior (Rasmussen and Williams, 2006) on rates of relative sea-level change and is embedded in an errors-in-variables frameword (Dey et al, 2000) to account for temporal uncertainty of index points. C: Rates of relative sea-level change calculated as the derivative of the fitted model.

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