Long-term Indian Ocean tsunami record reveals alternating event clusters punctuated by quiet interludes

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Key Points:

- Established the record of tsunamis in the last 6.5 ka using sediment cores from South Andaman
- Timeline of Indian Ocean tsunamis marked by hiatuses of variable timescales between event clusters
- This data can be used for theoretical models as an independent observational validation

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Abstract

[The analyses of sediment cores retrieved near Port Blair (South Andaman) revealed alternate bands out-of-sequence layers at various depths identified by their sediment characteristics and microfossil content. The 'out-of-sequence' layers are found to be in the age ranges of 596-606; 819-856; 1358-1522; 2899-3145; 3718-3461; 4584-4837; 5390-5823; and 6239-6472 yr BP, and show a remarkable chronological equivalence with paleo-tsunami deposits identified from far-field locations in the Indian Ocean region. The long-term tsunami record implies temporally clustered sequence of causative earthquakes alternating with interevent gaps and stand-alone events. This variable recurrence pattern of tsunamigenic great earthquakes is supported by the theoretical models espousing the characteristics of long-term stress re-cycling processes active within the subduction zones and transfer processes between the lower viscoelastic layer and the upper seismogenic crust.]

Plain Language Summary

[This paper reports tsunami history of the Indian Ocean during the last 6000 years that has bearing on the predecessors of the 2004 tsunami sourced in the Andaman-Sumatra subduction zone. The conclusions are drawn from comparing the results from various sites of the Indian ocean littoral countries with that of the chronologically constrained out-of-sequence layers identified from the sedimentary cores located in the south Andaman, a near-field site. Using the Andaman site as a template, we have identified nine tsunami event layers, including the 2004 deposits. The combined time-series of Indian Ocean sites provide some fresh insights into the recurrence pattern of the 2004-type transoceanic tsunamis. The long-term tsunami record implies temporally clustered events occasionally punctuated by stand-alone events. Using the tsunami record as a proxy to the causative mega-earthquakes, we say that this observational evidence can be used to validate the theoretical models espousing the earthquake cycles marked by long and irregular quiescent intervals between the periods of a succession of earthquake occurrences that are ultimately related to the characteristics of tectonic loading rates and visco-elastic relaxation within the subduction zones.]

1 Introduction

Sourced off Banda Aceh, Sumatra Island, the Mw 9.2 earthquake of December 26, 2004 generated a massive tsunami in the Indian Ocean (Figure 1a). The earthquake rupture unilaterally extended northward and terminated near the northern tip of the Andaman Island chain and the ensued tsunami devastated the shores of littoral countries of the Bay of Bengal (Figure 1a). The waves as high 30 m reached Banda Aceh and the Nicobar (A&N) Islands within 30 minutes. Much reduced in height (5 m), the waves arrived at the Andaman Coast in 40 minutes. The tsunami impacted the distant coasts of Thailand, Sri Lanka, the southeast coast of India, the Maldives Islands and the southeastern coast of Africa, after 2 to 4 hours (Figures 1a and b). The post-tsunami studies from Thailand and Sumatra report a paleotsunami in the range of 1250-1450 CE (Jankaew et al., 2008; Monecke et al., 2008) and is also correlative of well-dated coral uplifts located off Sumatra (Meltzner et al., 2010). A still older tsunami in the range of 770-1040 CE was also construed from the Sumatra (Monecke et al., 2008) as well as from the A&N Islands and southeastern coast of India (C. Rajendran et al., 2011, 2013).

The cores from the coastal lagoons in the far-field regions (Sri Lanka and Maldives) had revealed much older tsunami record (Jackson et al., 2014; Klostermann et al., 2014). From the cave deposits of Sumatra, (Rubin et al., 2017) deciphered a timeline of eleven tsunamis, between 2900 and 7400 years. A 6600-year long record of earthquakes was deciphered from the turbidite sequences, off Sumatra, from the southern part of the 2004 source zone (Patton et al., 2015). Their results are representative of both the mega 2004-type tsunamigenic as well as local slip events. A recent study from South Andaman sug-

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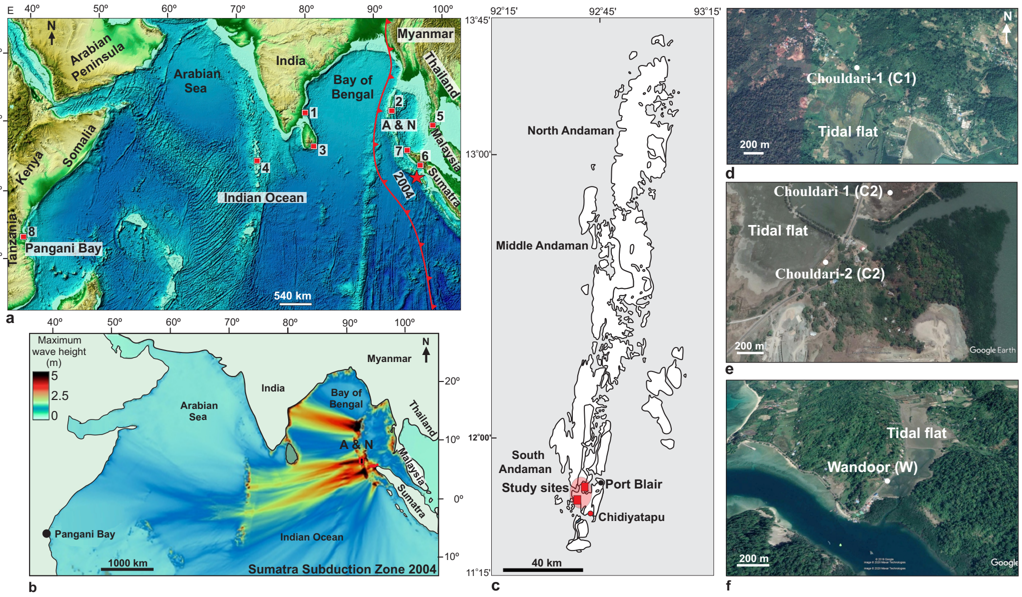

Figure 1. a. Map showing the Indian Ocean region and source region of the 2004 (Mw 9.2) earthquake; A&N: Andaman Nicobar Islands, MA: Maldives and SL: Sri Lanka. Paleotsunami sites: 1.(C. Rajendran et al., 2006, 2011) 2.(C. Rajendran et al., 2013) 3.(Jackson et al., 2014) 4.(Klostermann et al., 2014) 5.(Jankaew et al., 2008) 6.(Monecke et al., 2008) 7.(Rubin et al., 2017) 8.(Maselli et al., 2020). b. Map shows the maximum wave heights during 2004 Tsunami (modified after Maselli et al., 2020). c. Map of Andaman Islands with present study sites (red-filled squares inside the hilighted circle) and an earlier sampling site by (Malik et al., 2019) (red-filled circle). d, e and f. Close-up views of the coring sites: Chouldari-1 (C1); Chouldari-2 (C2) and Wandoor (W) near Port Blair South Andaman.

gests evidence for six tsunami depositions are linked to the historically reported local events of 1881 (Mw 7.9; Car Nicobar), 1762 (Mw $\leq$ 8.5; Arakan Coast, Myanmar) and 1679 (North Andaman?) and older ones (1300-1400 CE, 2000-3000 BCE, 2810-3200 BCE/2892-1895 BCE) (Malik et al., 2019) (Figure 1c). Designed to develop an independent authentication of long-term history ($\sim$ 6,500 years) of the transoceanic tsunamis we use core lithology from the near-field sites in South Andaman (Figures 1c-f) that would also facilitate comparison with the data from distant sites.

2 Materials and Methods

We chose some of the accessible marshes and tidal inlets located in the South Andaman, which lie within the tsunami reach (Figures 1c-f; S 1a-c). We expected that these locales where the land-derived erosive processes are apparently less dominant offer favorable depositional environments for off-shore borne sediment. From the selected three sites near Port Bair, namely, Chouldari-1 (4.1 m), Chouldari-2 (3.4 m) and Wandoor (8.6 m), the sediment cores were collected (Figures 2a-c). Our initial examination of the cores from all the three drill sites, aided by the CAT scan images, helped in demarcating alternating lighter colored layers of coarse materials within dark colored muddy sediments (Figures S3a-c). The lithology of cores that consists of the dark colored mud is representative of in-situ sediment deposited in tidal environment, and intermittent bands of coarser material (Figures S4b-d). The ^{137}Cs concentration provided corroboration for the presence of the 2004 tsunami deposits at the top level of the cores (Figure S5). The intermittent bands of the coarser sediment from the cores comprise silica rich mud, silt and sand, plant debris along with broken shells and coral fragments (Figures S6a-c; 7a-e; 8a-b; 9, 10 and 11). The dominant foraminifers in these layers have affinity with marine shelf environment (Figure S12). The broken shells make $\tilde{3}5\%$ of the total sediment, while the organic-rich debris make $\tilde{4}5\%$ in these deposits (Figures S13b-d). These characteristics help in categorizing the bands of coarse material as a mixture of transported material from the open sea and those incorporated from the landward part of coastal water. The 'out-of-sequence' layers are comparable to the 2004 tsunami deposits identified at the upper levels of the cores in terms of textural and faunal content (Figures S12a-c; 14a and b). Thus, these coarser bands are attributed to the deposition by the previous sea inundation episodes as specified by their sedimentary characteristics, micro-faunal assemblages and the transporting mechanism include either a cyclonic storm or a tsunami (Figures S14a-b; 15a-c; S16).

The inundation limit of storm surge is reported to be minimal in these areas and is authenticated by documentary evidence on near absence of cyclone impacts on the island (Department, 2008). The maximum tsunami inundation limit during the 2004 tsunami is reported to be 1320 m in Wandoor settlement area (Dharanirajan et al., 2007). All the coring sites mentioned here are located within or near narrow bays which have been impacted during the 2004 tsunami. As the 2004 tsunami inundation demonstrated that these narrow bays offered focused pathways for the tsunami waves and facilitated their propagation further inland. We targeted the tidal inlets as they provide the ideal depositional environment from the repeated high energy sea inundations. The core lithology thus retrieved from such environment was expected to reveal out-of-sequence deposition within the low-energy regular sedimentary facies.

3 Chronology of event layers

Event 1: The top levels from the cores recovered from Chouldari-1 and Wandoor contain 20-120 cm-thick bands of shell and plant debris (Figure 2a and c, Figures S4a-d). The deposition of these debris occurred during the 2004 tsunami as confirmed at Wandoor site, indicated by ^{137}Cs concentration from 45 to 150 cm from the top (Figure S5). However, we were not able to obtain similar signal from the site at Chouldari-1, except

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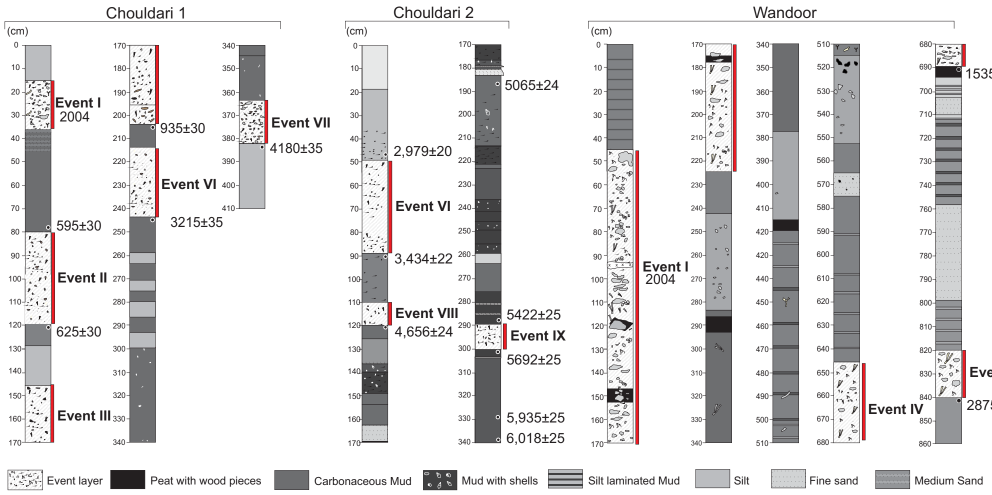

Figure 2. Lithologs from the study sites: a. Chouldari-1 (C1); b. Chouldari-2 (C2) and c. Wandoor (W), near Port Blair, South Andaman.

some modern ages (Figures 2a and c; Table 1 and Table S2 for calibrated ages of event layers).

Event 2: An out-of-sequence band of coarse material was identified at a depth of 80 cm from Chouldari-1 (Figures 2a, Figure S6a to d). The bulk sediment samples collected from above and below this layer are dated at 595±30 and 625±30 yr BP, respectively. This depositional event correlates with the 14th century tsunami inundation reported from Sumatra, Thailand, A&N Islands and the southwest coast of India (Monecke et al., 2008; Jankaew et al., 2008; C. Rajendran et al., 2013; Patton et al., 2015; C. Rajendran, 2019) (Figure 3). Recently,(Malik et al., 2019) reported a subsequent paleotsunami event from North Andaman with minimum and maximum age ranges from 311 to 663 cal yr BP.

Event 3: Characterized by coarse to medium sand with transported coral fragments and broken shells, an out-of-sequence deposit occur at the depth of 147 cm from Chouldari-1(Figure 2a; Figure S7a). The bulk sediment collected from top and the base of this layer is dated at 885±30 and 935±30 yr BP. Within the margins of error, this event between 819 and 856 cal yr BP may correlate with the paleo-tsunami reported near Port Blair and the southeastern coast of India (Monecke et al., 2008; C. Rajendran et al., 2006; K. Rajendran et al., 2008; Fujino et al., 2009; Patton et al., 2015). A contemporary event ranging from 726-984 cal. yr BP is also reported from Maldives, a far-field site located in the southern Arabian Sea (Klostermann et al., 2014) (Figure 3).(Maselli et al., 2020) identified an inundation zone from Tanzanian coast of east Africa that was dated between 802 and 1008 cal. yr BP and was attributed to a transoceanic tsunami source from the Andaman-Sumatra region.

Event 4: Yet another layer of coarse sediment identified from Wandoor site at a depth of 645 cm is dated at 1535±30 yr BP from the organic debris within this layer (Figure 2c; Figure S7b). This is considered to have been deposited by an inundation contemporaneous with the paleo-tsunami sand sheet identified from the southeast coast of India, which is dated at 1,470±70 and 1400±90 yr BP (C. Rajendran et al., 2006; K. Rajendran et al., 2008) (Figure 3).(Klostermann et al., 2014) reported a tsunami event from Maldives with an age range between 1485 and 1956 cal yr BP. with the maximum and minimum ages ranging from 1610±30 and 2000±30 cal yr BP. And, the event may also coincide with an earthquake identified using turbidities as a proxy off Sumatra with a date of 1,500±110 yr BP (Patton et al., 2015).

Event 5: Overlying the undisturbed laminated organic-rich mud another transportation event is identified in the range of 2899 and 3145 cal. yr BP at two sites: Chouldari-2 (C2) (Figures S7b-c) and Wandoor (W) (Figures S8a). The minimum ages of this event derived from bulk sediment of the upper boundary of the undisturbed layer at both sites (C2 and W) are 2725±35 and 2875±35 yr. BP, respectively. The maximum age of this event is dated as 2979±20 yr BP, from the lower boundary of undisturbed laminated mud (Figure 2b and c). The organic debris at the depth 835 cm within the out of sequence layer is dated at 2875±35 yr BP at Wandoor (W). These dates are comparable with the OSL dates of a paleotsunami deposit in the range of 2400-3020 cal. yr BP (2710±310 yr BP) reported from the southern Sri Lankan coast(Premasiri et al., 2015). (Jackson et al., 2014) and(Klostermann et al., 2014) also found an analogous event from the western Sri Lanka and Maldives respectively (Figure 3). A contemporary event is also recognized from a coastal cave in Aceh, Indonesia with the maximum and minimum ages ranging from 2862 to 2975 cal. yr BP and 2772 to 2859 cal. yr BP respectively(Rubin et al., 2017).

Event 6: We obtained evidence of another event from two sites at Chouldari-1 and Chouldari-2 (Figure S8b). The timing of this event ranges from 3461 to 3718 yr BP, estimated using the maximum and minimum ages of 3434±22 and 3215±35 yr BP obtained from the bulk sediment at the lower and top contact zones of the event layer with the organic mud (Figure 2b). This event may correspond to an earlier event dated from Maldives with the minimum and maximum age ranging from 3210±30 and 3280±30 cal. yr BP(Klostermann et al., 2014)(Figure 3). Similar timing for an event is reported with the OSL age of 3170±320 yr BP (2850-3490 yr BP) from the southern coast of Sri Lanka (Premasiri et al., 2015). The tsunami sand sheet recognized from a coastal cave in Aceh, Indonesia constrained between 3068 and 3464 cal. yr BP(Rubin et al., 2017) might be indicative of a regional contemporaneous tsunami (Figure 3).

Event 7: Identified only at Chouldari-1 (C1), the depositional age of event 7 at a depth of 365cm is constrained based on bulk sediment age of 4180±35 yr BP, obtained from the organic debris within the sand sheet (Figure 2a). This may correspond to an earlier event of tsunami dated from Maldives ranging from 4110±30 to 4210±30 cal. yr BP(Klostermann et al., 2014)(Figure 3).(Rubin et al., 2017) also reported the range of 5231-4515 and 5258-4552 cal. yr BP (Figure 3); within the age uncertainty this event may also coincide with the date of a turbidite (5033-3212 cal. yr BP) off Sumatra, as a proxy for an earthquake(Patton et al., 2015)(Figure 3).

Event 8: The minimum and maximum ages of the bulk sediment collected from the undisturbed organic mud above and below the 20 cm thick out-of-sequence deposit from Chouldari-2 is dated at 4656±24 and 5065±24 cal. yr BP (ranging between 5390-5823 cal. yr BP) is ascribed to event 8 that is represented by the coarse sand layer at the depth of 145 cm (Figure 2).(Rubin et al., 2017) also reported a similar event from Indonesia (5331-5583 and 5357-5575 cal. yr BP). Contemporaneously, an earthquake is also reported from the turbidite sequence off Sumatra-Andaman subduction zone (5902-4864 cal. yr BP: 4720±220 yr BP)(Patton et al., 2015)(Figure 3).

Event 9: Sedimentary evidence of an oldest tsunami in this sequence is identified from Chouldari-2 (Figure S8d). The bottom of the event layer is dated at 5692±25 yr BP while the top is dated at 5422±25 yr BP. Using these constraints, the timing of the event 9 can be approximated between 6239 and 6472 cal. yr BP that may correspond with an event dated at 5400±30 cal. yr BP (6121-6287 cal. yr BP) reported from Maldives(Klostermann et al., 2014)(Figure 3). The contemporaneous tsunami deposition dated between 6155 to 6248 and 6248 to 6458 cal. yr BP from Karagan Lagoon, Sri Lanka may also indicate

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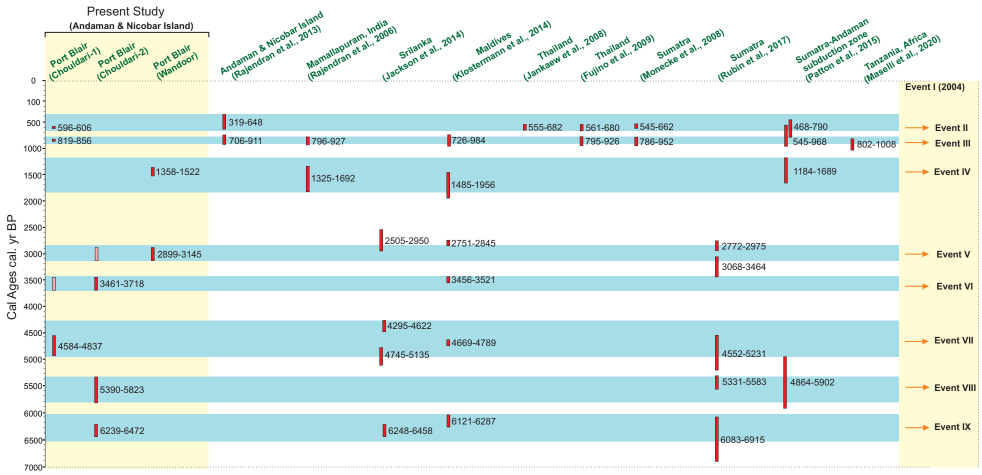

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Figure 3. Comparative space-time correlation of tsunami event ranges from different parts of the Indian Ocean region. For each event, the age data is calibrated using the Calib 7.0.2 with 2 σ range.

contemporaneity(Jackson et al., 2014) (Figure 3). A tsunami has also been constrained between 5857-6680 and 6083-6915 cal. yr BP from a coastal cave in Indonesia(Rubin et al., 2017)(Figure 3). Timings of paleotsunamis reported in the aforementioned age ranges match with an episode of subsidence in South Andaman that is dated at 6643±107 yr BP and 6739±85 yr BP(K. Rajendran et al., 2008). Evidence for an old earthquake in the similar range (6500-7000 cal. yr BP)(Pre et al., 2012) is reported from Aceh, Indonesia that may also correlate with this event.

4 Conclusions and Implications

We have identified nine event layers in the cores collected from the South Andaman Coast including the 2004 tsunami within a timescale of 6500 years (Figures 2a-c). The timeline developed in this study and the chronologically equivalent events identified in the distant sites in the Indian Ocean imply that all those depositions could be attributed transoceanic tsunamis. The timeline suggests hiatuses (intervals longer than the recurrence periods between the events within a cluster) of variable time-intervals between the tsunamigenic earthquake clusters (Figure 4). As shown in Figure 4, two quiet periods of lasting 655 and 602 yr, respectively are estimated, before and after the event clusters I. A long hiatus of about 1578 yr is estimated between a stand-alone event and the cluster II, which is also followed by a long quiet interlude lasting up to 1121 yr. A repeat of hiatus lasting for about 896 yr is estimated between the event cluster III and another stand-alone event. We conclude that the tsunamigenic great earthquakes along the Andaman-

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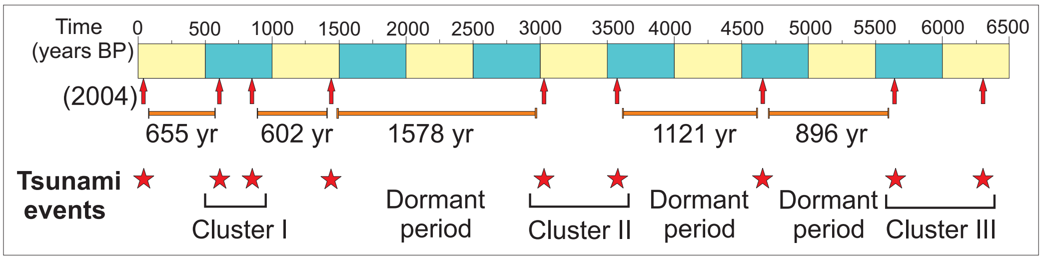

Figure 4. The time series showing the long-term occurrence pattern of earthquakes along the Sumatra-Andaman subduction zone.

Sumatra subduction zone have occurred in pulses separated by either long or short periods of quiescence with stand-alone events occurring in between such cycles (Figure 4). Overall, the pattern of earthquake occurrences suggests non-periodic variability from cycle to the next. Temporal variability in earthquake cycles has been suggested for the southern part of the Sunda megathrust(Sieh et al., 2008) and the Cascadia margin in the northwest United States(Goldfinger et al., 2012).

The numerical models have repeatedly shown that an earthquake cluster is expected to occur when a reservoir of stress is stored in the viscoelastic layer. This scenario promotes dormant periods to last longer until the reservoir of stress is exhausted and yield stress increases leading to reloading of the fault(Weldon et al., 2004; DiCaprio et al., 2008).(Chen et al., 2020) mathematically characterize clusters of earthquakes separated by longer and irregular intervals of quiescence as the 'Devil's staircase pattern'. They conclude that the lengths of the quiescent intervals between clusters are inversely related to tectonic-loading rates, whereas earthquake clustering can be attributed to many factors, including earthquake-induced viscoelastic relaxation and fault interaction. The data presented in this study presents an independent observational validation from an active tectonic regime for the theoretical models.

Acknowledgments

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References

Chen, Y., Liu, M., & Luo, G. (2020). Complex temporal patterns of large earthquakes: Devil's staircases. *Bulletin of the Seismological Society of America*, *110*(3), 1064–1076.

Department, I. M. (2008). Tracks of cyclones and depressions in the bay of bengal

and arabian sea 1891–2007.
Dharanirajan, K., Kasinatha Pandian, P., Gurugnanam, B., Narayanan, R., & Ramachandran, S. (2007). An integrated study for the assessment of tsunami impacts: a case study of south andaman island, india using remote sensing and gis. *Coastal engineering journal*, *49*(03), 229–266.
DiCaprio, C. J., Simons, M., Kenner, S. J., & Williams, C. A. (2008). Post-seismic reloading and temporal clustering on a single fault. *Geophysical Journal International*, *172*(2), 581–592.
Fujino, S., Naruse, H., Matsumoto, D., Jarupongsakul, T., Sphawajruksakul, A., & Sakakura, N. (2009). Stratigraphic evidence for pre-2004 tsunamis in southwestern thailand. *Marine Geology*, *262*(1-4), 25–28.
Goldfinger, C., Nelson, C. H., Morey, A., Johnson, J. E., Gutierrez-Pastor, J., Eriksson, A., … others (2012). Turbidite event history: Methods and implications for holocene paleoseismicity of the cascadia subduction zone, usgs professional paper# 1661f. *US Geological Survey, Reston, VA*, *184*.
Jackson, K. L., Eberli, G. P., Amelung, F., McFadden, M. A., Moore, A. L., Rankey, E. C., & Jayasena, H. (2014). Holocene indian ocean tsunami history in sri lanka. *Geology*, *42*(10), 859–862.
Jankaew, K., Atwater, B. F., Sawai, Y., Choowong, M., Charoentitirat, T., Martin, M. E., & Prendergast, A. (2008). Medieval forewarning of the 2004 indian ocean tsunami in thailand. *Nature*, *455*(7217), 1228–1231.
Klostermann, L., Gischler, E., Storz, D., & Hudson, J. H. (2014). Sedimentary record of late holocene event beds in a mid-ocean atoll lagoon, maldives, indian ocean: potential for deposition by tsunamis. *Marine Geology*, *348*, 37–43.
Malik, J. N., Johnson, F. C., Khan, A., Sahoo, S., Irshad, R., Paul, D., … Chopra, S. (2019). Tsunami records of the last 8000 years in the andaman island, india, from mega and large earthquakes: Insights on recurrence interval. *Scientific reports*, *9*(1), 1–14.
Maselli, V., Oppo, D., Moore, A. L., Gusman, A. R., Mtelela, C., Iacopini, D., … others (2020). A 1000-yr-old tsunami in the indian ocean points to greater risk for east africa. *Geology*.
Meltzner, A. J., Sieh, K., Chiang, H.-W., Shen, C.-C., Suwargadi, B. W., Natawidjaja, D. H., … Galetzka, J. (2010). Coral evidence for earthquake recurrence and an ad 1390–1455 cluster at the south end of the 2004 aceh–andaman rupture. *Journal of Geophysical Research: Solid Earth*, *115*(B10).
Monecke, K., Finger, W., Klarer, D., Kongko, W., McAdoo, B. G., Moore, A. L., & Sudrajat, S. U. (2008). A 1,000-year sediment record of tsunami recurrence in northern sumatra. *Nature*, *455*(7217), 1232–1234.
Patton, J. R., Goldfinger, C., Morey, A. E., Ikehara, K., Romsos, C., Stoner, J., … Vizcaino, A. (2015). A 6600 year earthquake history in the region of the 2004 sumatra-andaman subduction zone earthquake. *Geosphere*, *11*(6), 2067–2129.
Pre, C. A. G., Horton, B. P., Kelsey, H. M., Rubin, C. M., Hawkes, A. D., Daryono, M. R., … Culver, S. J. (2012). Stratigraphic evidence for an early holocene earthquake in aceh, indonesia. *Quaternary Science Reviews*, *54*, 142–151.
Premasiri, R., Styles, P., Shrira, V., Cassidy, N., & Schwenninger, J.-L. (2015). Osl dating and gpr mapping of palaeotsunami inundation: A 4000-year history of indian ocean tsunamis as recorded in sri lanka. *Pure and Applied Geophysics*, *172*(12), 3357–3384.
Rajendran, C. (2019). Historical accounts of sea disturbances from south india and their bearing on the penultimate predecessor of the 2004 tsunami. *Seismological Research Letters*, *90*(2A), 774–783.
Rajendran, C., Rajendran, K., Andrade, V., & Srinivasalu, S. (2013). Ages and relative sizes of pre-2004 tsunamis in the bay of bengal inferred from geologic evidence in the andaman and nicobar islands. *Journal of Geophysical Research:*

Solid Earth, *118*(4), 1345–1362.

Rajendran, C., Rajendran, K., Machado, T., Satyamurthy, T., Aravazhi, P., & Jaiswal, M. (2006). Evidence of ancient sea surges at the mamallapuram coast of india and implications for previous indian ocean tsunami events. *Current Science*, 1242–1247.

Rajendran, C., Rajendran, K., Srinivasalu, S., Andrade, V., Aravazhi, P., & Sanwal, J. (2011). Geoarchaeological evidence of a chola-period tsunami from an ancient port at kaveripattinam on the southeastern coast of india. *Geoarchaeology*, *26*(6), 867–887.

Rajendran, K., Rajendran, C., Earnest, A., Prasad, G. R., Dutta, K., Ray, D., & Anu, R. (2008). Age estimates of coastal terraces in the andaman and nicobar islands and their tectonic implications. *Tectonophysics*, *455*(1-4), 53–60.

Rubin, C. M., Horton, B. P., Sieh, K., Pilarczyk, J. E., Daly, P., Ismail, N., & Parnell, A. C. (2017). Highly variable recurrence of tsunamis in the 7,400 years before the 2004 indian ocean tsunami. *Nature communications*, *8*, 16019.

Sieh, K., Natawidjaja, D. H., Meltzner, A. J., Shen, C.-C., Cheng, H., Li, K.-S., ... Edwards, R. L. (2008). Earthquake supercycles inferred from sea-level changes recorded in the corals of west sumatra. *Science*, *322*(5908), 1674–1678.

Weldon, R., Scharer, K., Fumal, T., & Biasi, G. (2004). Wrightwood and the earthquake cycle: What a long recurrence record tells us about how faults work. *GSA today*, *14*(9), 4–10.

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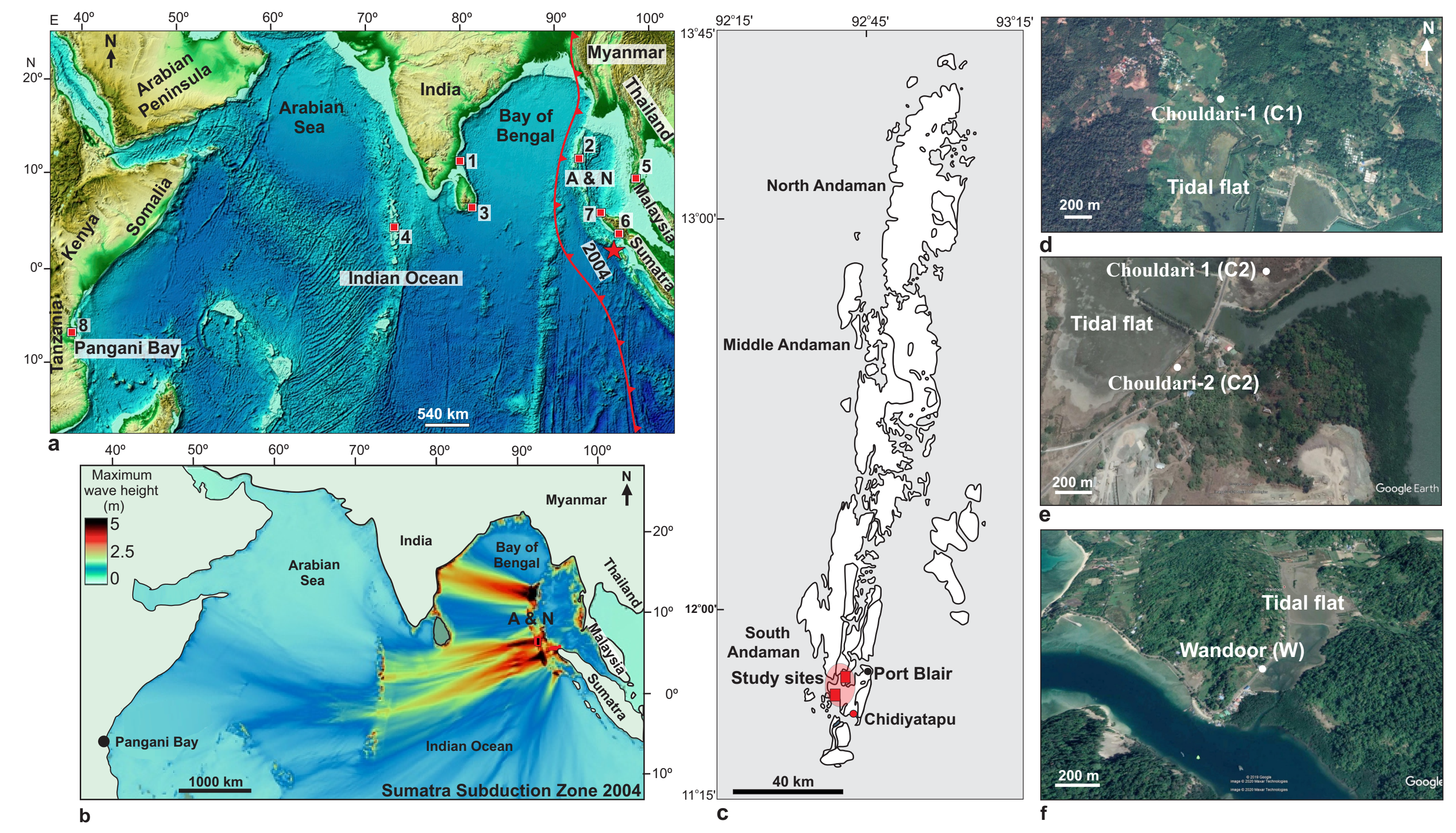

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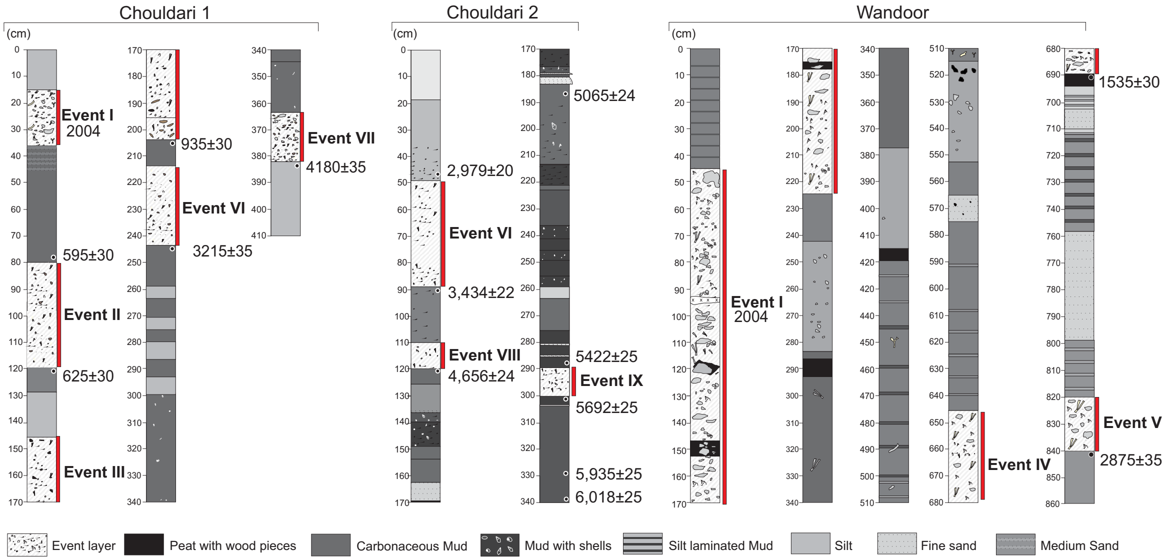
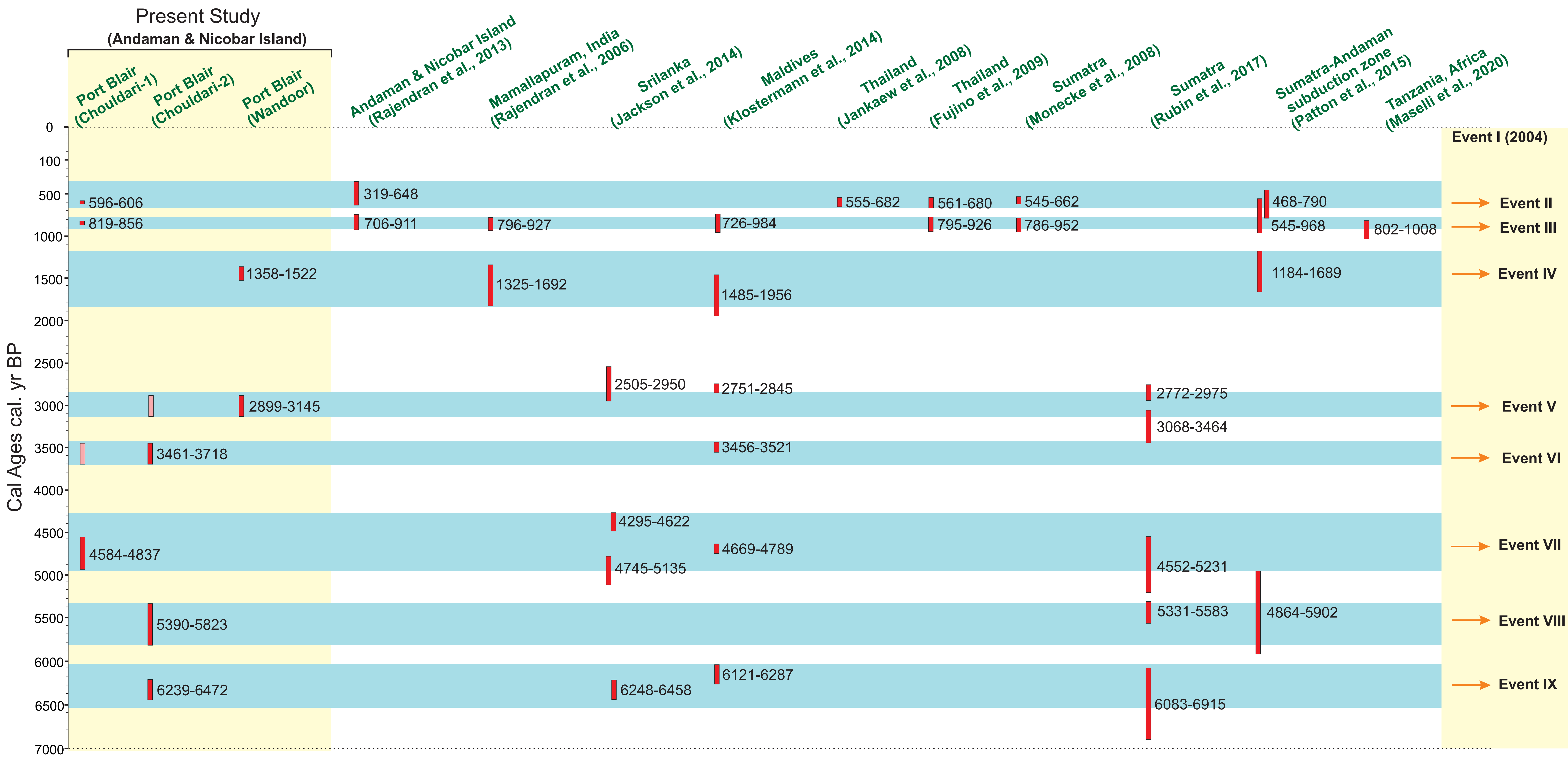


Chouldari 1
Chouldari 2
Wandoor
(cm)
Event I
2004
595±30
Event II
625±30
Event III
935±30
Event VI
3215±35
Event VII
4180±35
2,979±20
Event VI
3,434±22
Event VIII
4,656±24
5065±24
5422±25
Event IX
5692±25
5,935±25
6,018±25
Event I
2004
Event IV
1535±30
Event V
2875±35
Event layer
Peat with wood pieces
Carbonaceous Mud
Mud with shells
Silt laminated Mud
Silt
Fine sand
Medium Sand

Figure 3.pdf.



Present Study
(Andaman & Nicobar Island)
Port Blair (Chouldari-1)
Port Blair (Chouldari-2)
Port Blair (Wandoor)
Andaman & Nicobar Island (Rajendran et al., 2013)
Mamallapuram, India (Rajendran et al., 2006)
Srilanka (Jackson et al., 2014)
Maldives (Klostermann et al., 2014)
Thailand (Jankaew et al., 2008)
Thailand (Fujino et al., 2009)
Sumatra (Monecke et al., 2008)
Sumatra (Rubin et al., 2017)
Sumatra-Andaman subduction zone (Patton et al., 2015)
Tanzania, Africa (Maselli et al., 2020)
Cal Ages cal. yr BP
Event I (2004)
Event II
Event III
Event IV
Event V
Event VI
Event VII
Event VIII
Event IX
596-606
819-856
319-648
706-911
796-927
726-984
555-682
561-680
795-926
545-662
786-952
468-790
545-968
802-1008
1358-1522
1325-1692
1485-1956
1184-1689
2505-2950
2751-2845
2772-2975
2899-3145
3068-3464
3461-3718
3456-3521
4295-4622
4584-4837
4669-4789
4745-5135
4552-5231
5390-5823
5331-5583
4864-5902
6121-6287
6239-6472
6248-6458
6083-6915

Figure. 3

Figure 4.pdf.

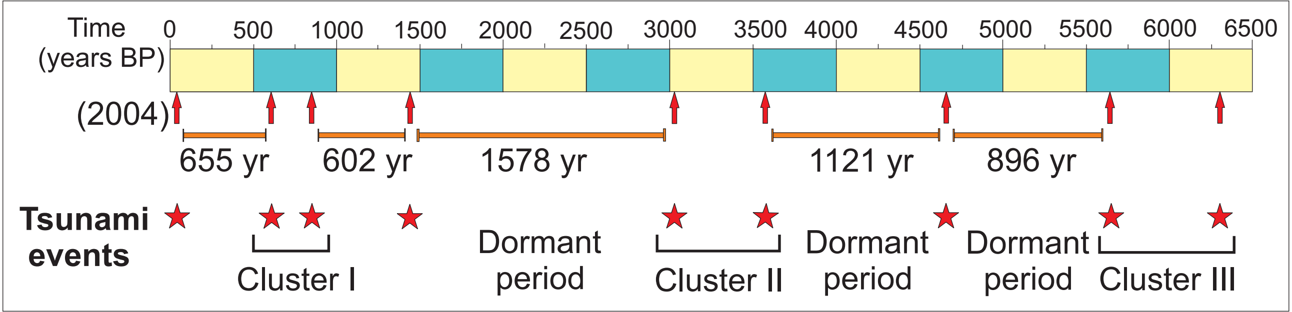

Time
(years BP)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
(2004)
655 yr
602 yr
1578 yr
1121 yr
896 yr
Tsunami events
Cluster I
Dormant period
Cluster II
Dormant period
Dormant period
Cluster III

Table 1. Radiocarbon ages of tsunami deposits recorded in Port Blair, South Andaman

Event	Depth from surface (cm)	Thickness of the sediment (cm)	Age above tsunami deposit (μ±2σ calendar yr BP) (Calibrated ages (BCE/CE)	Age below tsunami deposit (μ±2σ calendar yr BP) (Calibrated ages (BCE/CE)	Age within the deposit (μ±2σ calendar yr BP) (Calibrated ages (BCE/CE)	Midpoint age of the tsunami deposits	Sites
Event 1 (I)	15	20				**2004**	Chouldari-1
	45	180				**2004**	Wandoor
Event 2 (II)	80	40	595±30 (1298-1410CE)	625±30 (1290-1398 CE)		**1349 CE**	Chouldari-1
Event 3 (III)	147	60	885±30 (1042-1219 CE)	935±30 (1027-1161 CE)		**1113 CE**	Chouldari-1
Event 4 (IV)	645	45			1535±30 (428-592 CE)	**510 CE**	Wandoor
Event 5 (V)	820	20	2725±35 (967-808 BCE)		2875±35 (1192-930 BCE)	**1068 BCE**	Wandoor
	835						
	50	30	2840±30 (1107-917 BCE)	2979±20 (1262-1127 BCE)			Chouldari-2
Event 6 (VI)	105	20		3434±22 (1872-1666 BCE)		**1641 BCE**	Chouldari-2
	240	30	3215±35 (1606-1417 BCE)				Chouldari-1
Event 7 (VII)	365	20			4180±35 (2888-2635 BCE)	**2762 BCE**	Chouldari-1
Event 8 (VIII)	145	20	4656±24 (3516-3366 BCE)	5065±24 (3950-3797)		**3657 BCE**	Chouldari-2
Event 9 (IX)	280	20	5422±25 (4336-4244 BCE)	5692±25 (4586-4456 BCE)		**4407 BCE**	Chouldari-2

Note: AMS dating of charcoal samples were conducted at Poznan Radiocarbon Laboratory (Poz), Poland. Radiocarbon ages were calibrated using CALIB (Version 7.0.4) (Stuiver and Reimer, 1993; Reimer et al., 2013). The 2 sigma ranges have maximum area under the probability distribution curve. All samples are taken from organic-rich bulk sediment.