Tectonic deformation along the Arakan megathrust, Myanmar (Burma)

— Age, distribution and historical account of elevated marine terraces in Ramree and Cheduba Island.

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Summary

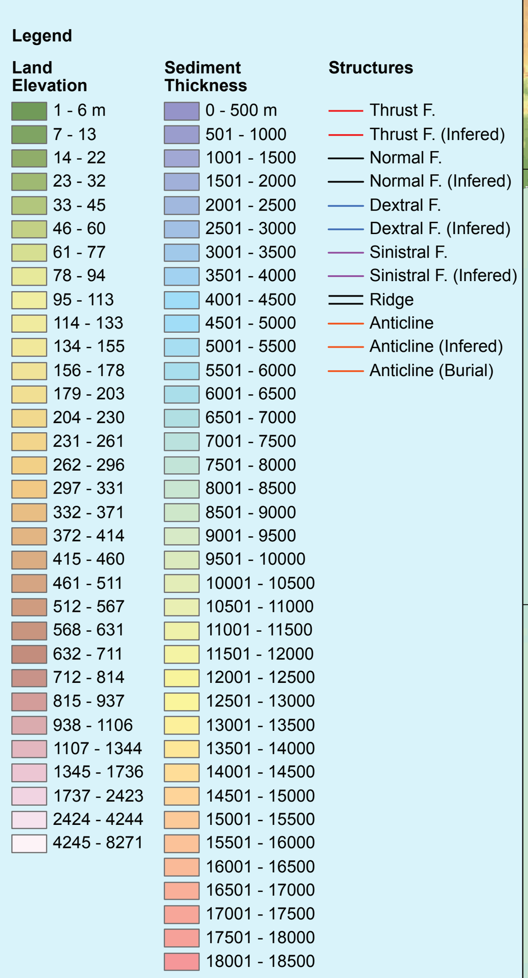
Marine terraces and uplifted beaches in Cheduba and Ramree Island had long been described by the surveyors and geologists since the mid-19th century. These terraces are believed to be uplifted during major earthquakes along the western coast of the Indo-Burma range. However, there were only few studies that addressed on the age and the distribution of these marine terraces.

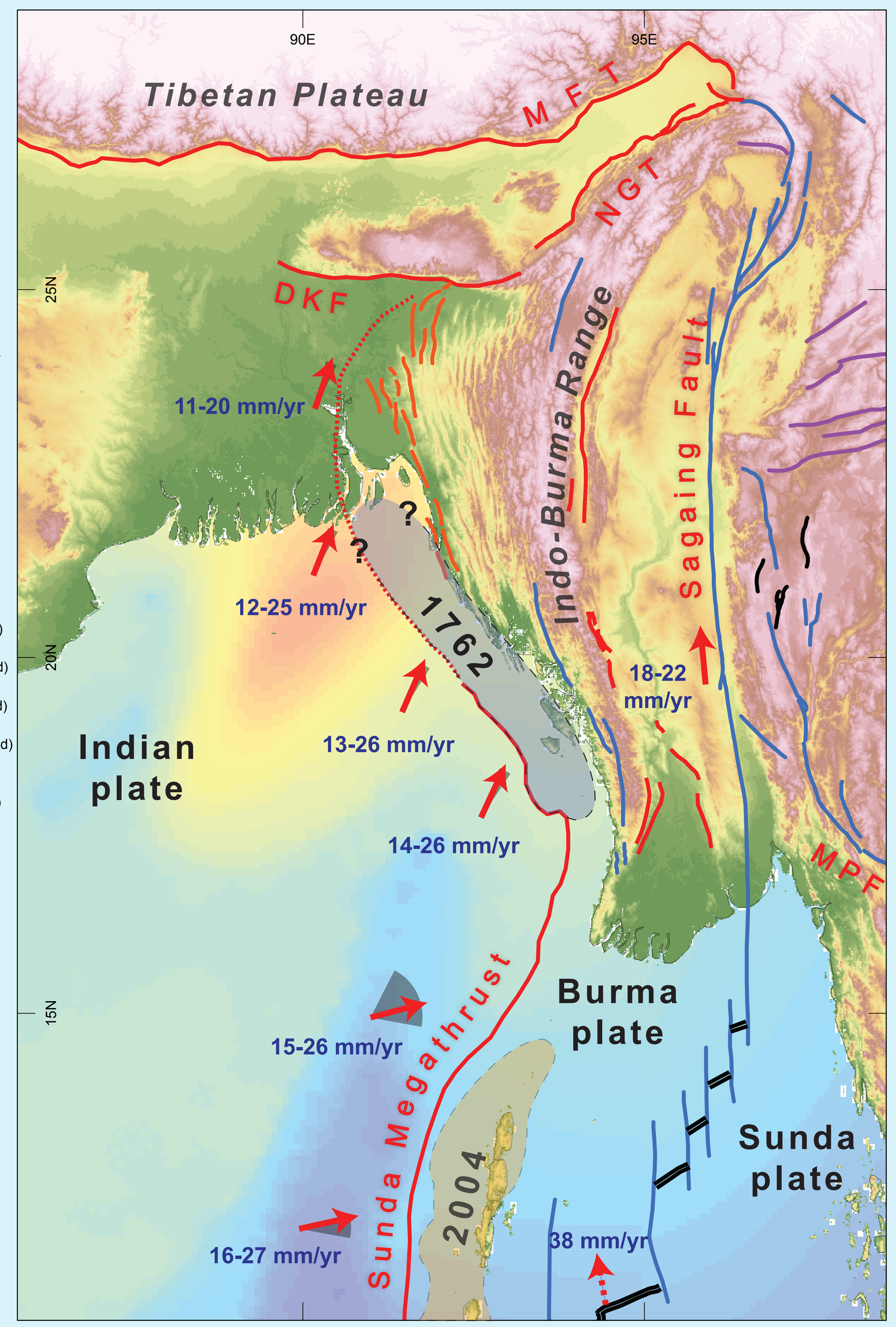
In this study, we conducted a preliminary field survey in Ramree Island to map the age and elevation of marine terraces where few studies addressed on before. Our goal is to understand the vertical tectonic deformation pattern along a transect that is perpendicular to the strike of the megathrust offshore Myanmar, and to explore potential sites and materials for future detail study. We were able to find good evidence that indicates the recent uplifting event along the western coast of Ramree Island; however, along its eastern coast, our observation suggests the uplifting rate is much slower. The preliminary radiocarbon dating result of the elevated oyster and coral suggests the age of the lowest terrace in the western Ramree Island is compatible with the age in the Cheduba Island's lowest terrace. These samples suggest the last uplifting event in Ramree Island occurred after AD 1480 – 1680, and may correlate to 1762 Bengal earthquake, or another earthquake event in mid-17th century.

We are able to fit the distribution and the age of observed marine terraces from Cheduba Island to Ramree Island by a multiple-thrust simple dislocation model. This model suggests that the activity from a secondary thrust fault offshore western Cheduba Island is able to explain the uplifting and subsidence pattern in the southern Cheduba and Ramree Island. The other hypothesis is that the terrace distributions are controlled by the geometry of megathrust. More comprehensive study is needed to distinguish these two structural hypotheses.

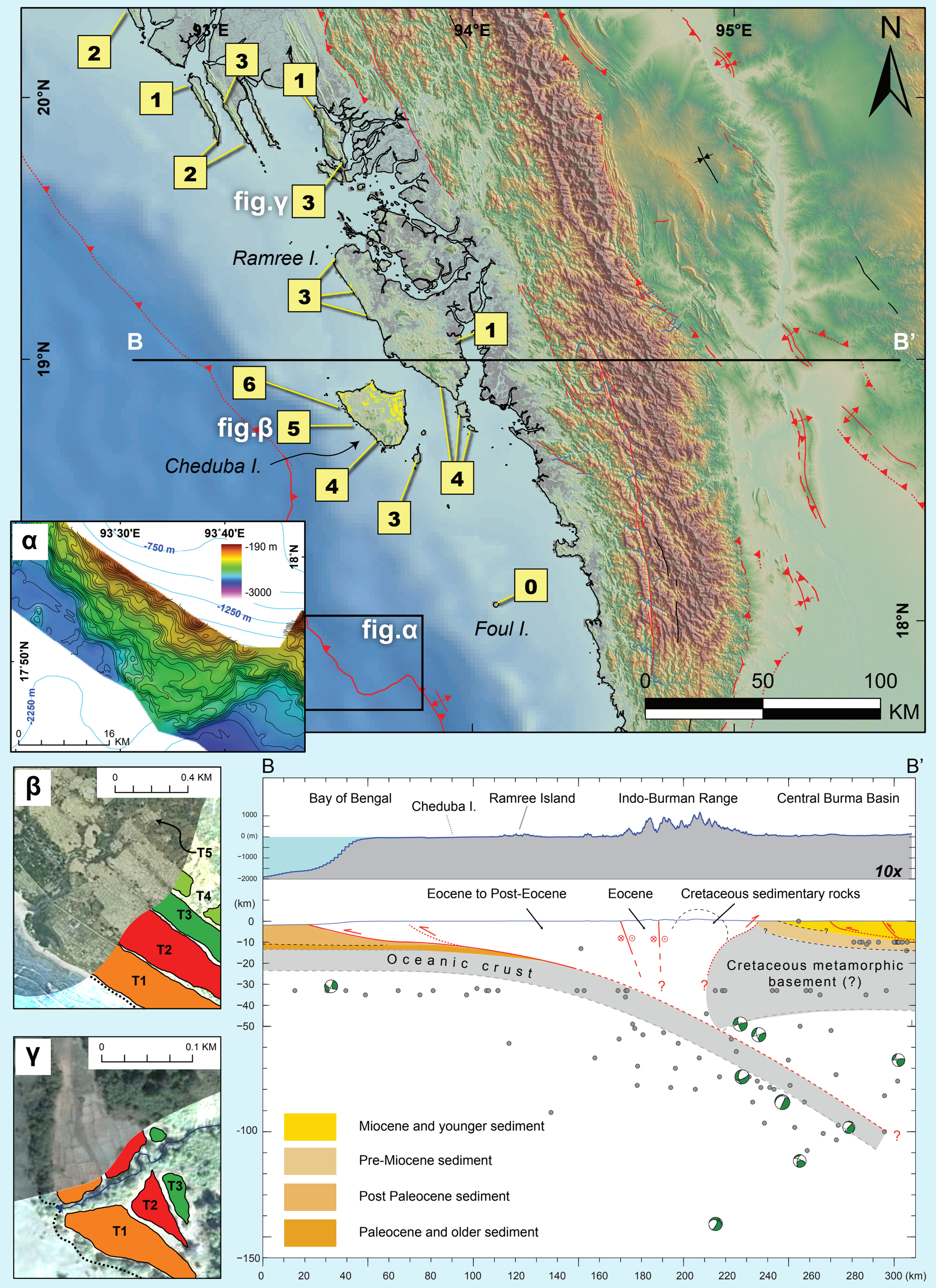
Tectonic setting

Myanmar (Burma) is currently experiencing strain partitioning between the Indian and Sunda plates. In the west the Indian plate is colliding obliquely with the Burma plate along the northern extension of the Sunda megathrust. In the east, relative motion between the Burma and Sunda plates occurs along the 1200-km-long Sagaing fault. Farther south, this relative motion rifts the Andaman Sea Basin and bisects Sumatra along the 1900-km-long Sumatran fault (Sieh and Natawidjaja, 2000) and West Andaman fault (Berglar et al., 2010). Red lines represent major thrust and reverse faults. Blue lines show the major right-lateral fault. Purple lines mark the left-lateral fault and normal faults are showed in blackline. Arrows indicate the plate motion directions that are calculated from regional model. The shade represents possible error of motion direction. Orange patch marks the 2004 earthquake patch, and purple patch marks the possible patch of 1762 earthquake from historical record. Its northern distribution is not well constrained from the historical data. MFT = Main Frontal Thrust; NTF = Naga thrust fault; MPF = Mae Ping fault; GKF = Dauki fault.





Ramree Island and Cheduba Island



The distribution of marine terraces and active structures in the Ramree and Cheduba islands from remote sensing study. Geomorphic observations suggest the landforms from Foul Island to Cheduba and Ramree Islands are mainly controlled by structures that are related to mud diapirism, and without the clear trend of their orientations. Further offshore, detail bathymetry study along the deformation front, west of Foul Island shows a clear imagery of an active fold and thrust belt (fig.α, Nelson et al., 2004). This trench-parallel deformation belt can be traced to the area further north and may connect to the Chittagong-Tripura Folded Belt north of 20˚N.

Marine terraces (yellow-color patch) are mainly found around islands offshore mainland north of 18.5˚N. Along the western coast of Cheduba Island, 4-6 steps of terraces can be identified from satellite imagery (Fig.β); 4-5 steps in the southern tip of Ramree Island. To the east, only one widely distributed coastal plain can be found along the eastern Ramree Island and mainland-coast. The amount of terrace-step also decreases northward. Only 1-3 steps of marine terrace can be observed around islands north of 19.5˚N from the remote sensing imagery (Fig.γ). Field survey around this area not only confirms our observations, they also points out the same phenomenon in the Cheduba-Ramree Islands that the heights of terraces decrease toward the mainland can be observed further north.

We also find that there are several active trench-parallel strike-slip faults in the western flank of Indo-Burma Range south of 19˚N. We believe these faults accommodate about 10 km deformations that partitioned from the subduction interface. These faults may result from the internal rotation of Indo-Burma deformation belt, where the trench-orientation changes from 10° to 330° south of Foul Island.

After putting these active-tectonic observations, regional geological information and seismicity together, we can then draw a schematic geological cross-section to illustrate the tectonic geometry across the Indo-Burma range in the Ramree-Cheduba Island area. This section suggests a fairly flat basal detachment beneath the outer deformation belt. West of Cheduba Island, there are at least one active-branching thrust in the accretionary wedge that may play as the out-of sequence thrust fault. Further east, Right-later faults that may reactivate from old reverse faults appear in the western flank of Indo-Burma range due to the strain partitioning and distributed strains. These distributed strains also affect the structure in the central Burma basin, where several normal-fault-reactivate reverse faults and bedding slip reverse fault appears on the surface.

Historical records of 1762 earthquake

Selected surface deformation records after the 1762 earthquake. Right after the earthquake, only the change of landforms near Chittagong were record by british. Other places were not discript until 1841 when E.P. Halstead R.N lead H.M.S Childers in 1841 to survey the western Burma coast. HIs report provides the observation of uplifted marine terrace in the Cheduba island and other island along the coast. Other observations are recorded by Robert Mallet around 1878, which filled some data gap in the southern patch. Red circles show the place that had been resurveyed recently. black circles show the place that the deformation have not been comfirmed by modern studies.

Culston (1762) ...and the ground also sinks every day by little and little... ...And from the reports of the people there we hear that these places were never before overflowed by the water... ... The Katwall of Islamabad Chittagong informed us with his own mouth that in a place called Baramcharah the water was up to a man's waist and the people there have betaken themselves to flight through fear of perishing ... **> -1 m**

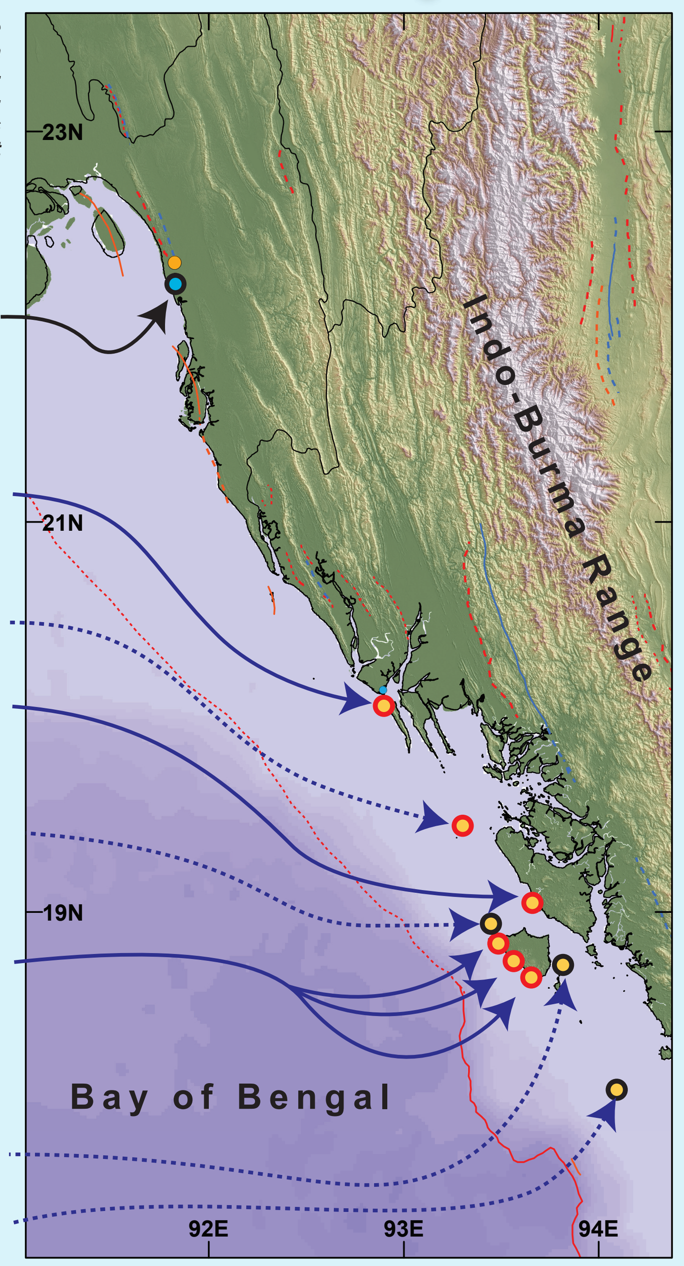
Mallet (1878) "The elevation at the Baranga Islands has been comparatively slight... at the north end, I observed oysters sticking to the rock about 2 feet above the spring high water mark." **+0.6 m**

Halstead (1841) "The elevation has been greatest towards the centre of the line examined; at the Terribles about 13 feet...." **+3.9 m**

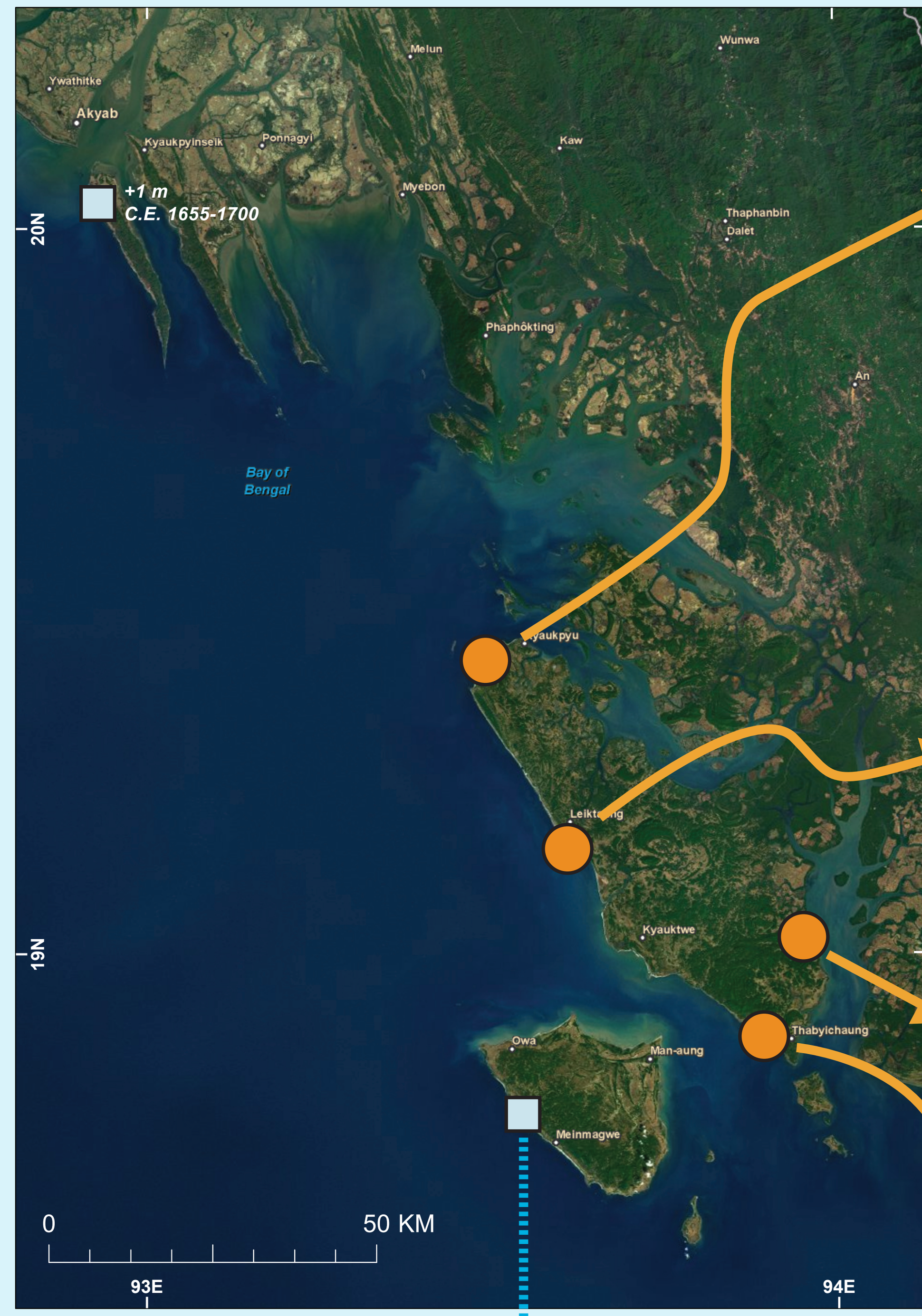
Mallet (1878) "..On the (Ramri) western coast, between Konbaung and Kyauk Gale there is a raised beach about 20 feet above the sea, strewn over with worn lump of coral, and of rock bored by *Pholadide*, whose shells still remain in the holes..." **+6 m**

Halstead (1841) "on various parts of the N. W. reef of Chedooba 22 feet, at the north point of the Island 16 feet, at the centre of the Island on the west coast 13 feet, at the southern end 12, and at the Islands south of it, as far as Foul Island from that to 9 feet.... ..a remarkable column or rock, about 40 feet high, standing on the beach shewed the remains of a second line of rock.· Oysters adhering to it, at an equal elevation of 13 feet above the first, as it was again, above the one which on all the rocks of the western coast distinctly points out the limit of the present high water." **+6.6 m** **+4.8 to +3.6 m**

Mallet (1878) "...a detached rock on the beach which strikingly illustrates the elevation, crowned, as it is, by an aggregated mass of marine shells, the base of which is about six feet above the present high-tide level.... ... A map of the latter is appended to Captain Halsted's paper, showing the present island to consist of three terraces differing from each other in level by six or eight feet." **+1.8 m** **+2.7 m**



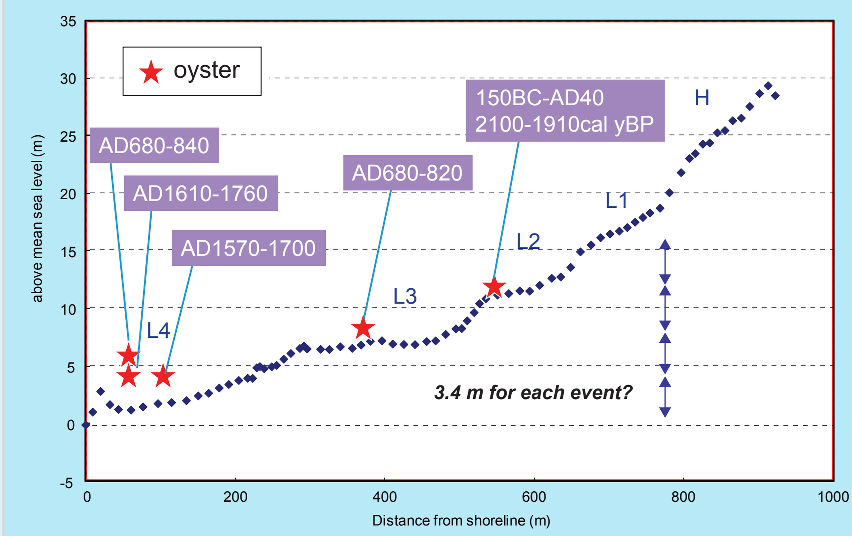
Terrace elevation and age



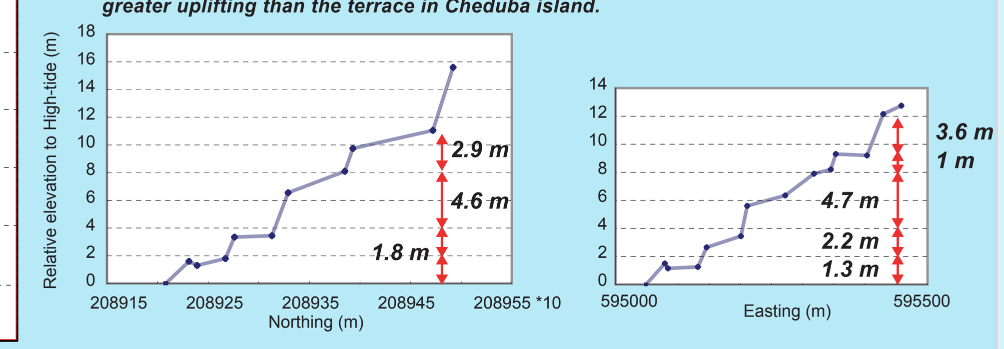
a dead-oyster line 90cm above the moder high-tide marks the last uplifting event in the northern Ramree island. Its 14C ages are similar to the 14C age of the coral sample in Cheduba island. It suggests they may result from the same tectonic event, which could be 1762 earthquake or earlier event.

The uplifted terrace in the central Ramree Island. This is the 20-feet terrace that discript by Mallet in 1878. Eye-leveling result suggest the terrace is 5.5m above the modern high-tide. It suggests the inter-seismic subsidence is ~ 50cm in the last century. The age of terrace is the same to northern Ramree island from 14C.

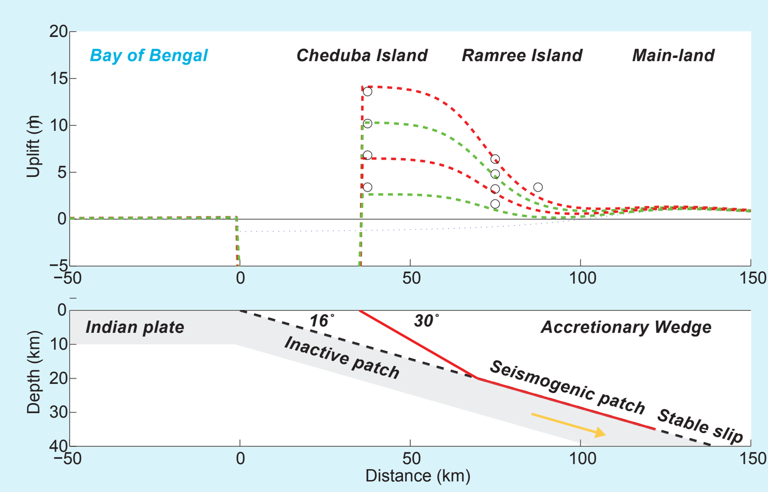
Old sea notch in the eastern Ramree island. This is the only abandand sea notch (and highest) that we found in the eastern island. It may result from the mid-Holocene high stand in this region, The lack of uplifting evidence here suggest the minor uplifting during the seismic event.



Terrace elevation in the central Cheduba [Left] and southern tip of the Ramree island [Right]. The terrace survey and age in Cheduba island is from Shishikura et al (2009). The elevation in the southern Ramree island is from eye-leveling result. Our result in Ramree island suggests the amount tectonic uplifting in the last two events is less significant than the uplifting in the Cheduba island. However, the earlier event shows greater uplifting than the terrace in Cheduba island.



2D deformation model



The simple dislocation model that may explain the surface deformation in the southern Ramree and Cheduba Island in the past several seismic circles. We use the marine-terrace age from Shishikura (2009) to constrain the timing of uplifting events. We also assume the average slip rate on the plateinterface is 21 mm/yr. The general fault dip is 16 degree, and the secondary active thrust is set as a 30 degree thrust fault. The transition zone is set to 35 km, and the secondary fault is branching out from 20 km deep.

During the seismic event, we assume the secondary thrust fault takes most of the slip, and main frontal fault is inactive in this model. This model provides a resonable explanation of the terrace distribution in different island. However, It dose not explain the higher terrace in southern Ramree island well. It may result from the incomplete records of marine terraces, or other active structures that dose not include in this simple dislocation nodel.

Acknowledgements

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