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Paleoseismological field survey along the western coast of Myanmar

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Abstract: Our field survey was aimed to investigate the geological and geomorphological evidences of past earthquakes and tsunamis, particularly the AD 1750± and 1762 events, occurred along the northern extension of the 2004 Sumatra-Andaman earthquake source. Survey of tsunami deposit, marine terrace, coral reef as well as the 2004 tsunami heights, were made at 29 points around two cities, Sittway and Thandwe, on the western coast of Myanmar. No clear evidences of tsunami deposit and uplifted coral reef due to past earthquakes were recognized. However, marine terraces at Myengun and Tandin coasts near Sittway City indicate occurrence of three uplift events during the past 3000 years. Distribution and elevation, higher oceanward and lower continentward, of these terraces could also be considered as continentward crustal tilting due to subduction tectonics along the Sunda-Andaman trench offshore the western coast of Myanmar.

Keywords: Paleoseismological survey, Tsunami deposit, Marine terrace, Coral, Western coast of Myanmar

1. Introduction

The giant Sumatra-Andaman earthquake and ensuring tsunami on 2004 December 26 is one of the recent examples exhibiting the activity of subduction along the Sunda Trench. Occurrences of such large earthquakes and tsunamis, Mw > 7.0 since the 1797 along the Sunda-Andaman Trench off west coast of Java, Sumatra and Andaman islands over the period of about three hundreds years have now been verified based on the paleoseismological and historical records (Chhibber 1934, Heck 1947, Berninghausen 1966, Ortiz and Bilham 2003, Sieh *et al*. 2004). However, the paleoseismicity of the northern extension of Sunda-Andaman Trench along the western coast of Myanmar has been poorly known.

In December 2005, “Memorial conference on the 2004 Giant Earthquake and Tsunami in the Indian Ocean” was held in Tokyo with a support from the Japanese Ministry of Education, Sports, Culture, Science and Technology. Scientists from various research organizations, from Japan and the affected countries around northeastern Indian Ocean, and also from other experienced international societies, were gathered. The conference outlined several action plans that should be necessarily worked out for prevention of future tsunami and earthquake disaster around the Indian Ocean, mainly focusing on the 2004 event. Paleoseismology of the western coast of Myanmar and the Sagaing strike-slip fault in the central Myanmar were also listed as the action plans. Under these circumstances, scientists from Geological Survey of Japan/AIST planned to conduct the paleoseismology survey of the western coast of Myanmar with collaboration of Myanmar Earthquake Committee (MEC) and Myanmar Department of Meteorology and Hydrology (DMH).

2. Tectonics and Seismicity of Sunda Trench and Its Northern Extension, the Western Coast of Myanmar

The Sunda Trench is tectonically and seismically quite active subduction zone along which the Indian plate has been subducting beneath the Burma microplate. Tectonic configurations of Sunda trench and its northern extension offshore western coast of Myanmar can be generally explained by the movement of Indian plate with respect to the Eurasia plate. The northeastward motion of Indian plate with relative velocity ~ 3.5 cm/yr decomposes into ~ 2.0 cm/yr of oblique subduction along the Sunda-Andaman trench offshore the western coast of Myanmar (northern portion of survey area by Nielsen *et al*. 2004), ~ 1.8 cm/yr right-lateral motion along the Sagaing Fault, inland part of Myanmar (Vigny *et al*. 2003, Socquet *et al*. 2006) and eastward motion beneath the Sumatra Island (Fig. 1). However, kinematics of two minor plates between the two major plates, Burma microplate and Sunda plate, are still controversial.

The Burma microplate, the name firstly proposed by Fitch (1972) as partitioned zone bounded by the Sunda-Andaman subduction zone in the west and right-lateral strike-slip fault in the Andaman Sea which extends to the onshore central Myanmar as the Sagain Fault in the east, is driven by the oblique convergence of the Indian plate relative to the Eurasia and Sunda plates. According to digitized geodetic data, the Burma microplate has an arch shaped with north-south elongation of ~ 1500 km and maximum width in east-west of ~ 400 km (Bird 2003). The formation of this microplate is considered due to the collision of Indian plate with Sunda plate since 32Ma, and its present motion and deformation is chiefly governed by the back-arc opening at Andaman ridge since 4 Ma and the motion of the two plates, India and Sunda plates (Curray 2005).

Kinematics of these plate motions makes the crustal deformation and intense seismicity in and around the Sunda-Andaman Trench. Past seismicity (1897-1997) from both inland and western coast of Myanmar are quite shallow (< 70 km) and show active nature of plate boundaries around the Burma microplate. GPS data also support high seismicity, and fault models based on GPS measurement give forecast of possibility to produce a magnitude 8.5 earthquake on every century (Socquet *et al*. 2006).

3. Past Earthquakes Documented in Myanmar

To forecast the future, it is essential to know what has happened in the past. The historical and past scientific records revealed that 1750± and 1762 events affected the western coast of Myanmar (Chhibber 1933, Heck 1947, Berninghausen 1966) (Fig. 1).

Chhibber (1934, p.48) described the 1762 earthquake as follows.

The earliest earthquake on record, which affected Burma, took place at 5 p.m. on 2nd April, 1762. It was very violent and destructive, and was felt all over Bengal, Arakan etc., chiefly and more severely in the northern part of the east of coast of the Bay of Bengal. The effects of this earthquake, causing, according to Halsted, and elevation of the coast of Arakan, are given in the sequel, though Mallet was inclined to be sceptical about his observations.

About the ca. 1750 earthquake, Chhibber (1934, pp. 66-67) stated that

There is unmistakable evidence of recent upheaval in the Arakan Division, and this is believed to have alternated locally with periods of relative quiescence or submergence, which is always difficult to identify…… A map of the latter (Flat Island) that accompanies Captian Halsted's paper shows the present island to consist of three terraces differing each other in level by 6 or 8 feet, showing that the island underwent elevation three times. It is believed that the main movements took place about the middle of the seventeenth century, while the last phase occurred about the year 1750, when it was accompanied by a very violent earthquake.

But he seems to be somewhat suspicious about the ca 1750 earthquake, as he further continues as follows.

These changes in the elevation of the Arakan coast, stated to extend over more than 100 miles, were attributed by Captain Halsted to the severe earthquake of 1762. Men were living at the time of Captain Halsted's visit in 1841 who had fished over the then dry land. But the evidence was considered by Mallet to be extremely vague, and the attribution of the changes to the earthquake is entirely vague, and the attribution of the changes to the earthquake is entirely a matter of assumption.

In the catalog of tsunamis in the Indian Ocean, Berninghausen (1966) listed both ca 1750 and 1762 events, while he noted the possibility of one event.

1750± Burma coast, Chedula Island, Several small non-damaging waves; fish were stranded. These waves may have been caused by and eruption of a mud volcanoe or more likely by the earthquake of April 12, 1762, (Mallet, 1878), see below.

1762 April 12, Earthquake felt most severely along the north western coast of the Bay of Bengal. Waves as high as six feet were reported from the distributaries of the Ganges Delta.

The 1881 earthquake with Mw 7.9, epicentered around the Car Nicobar Island also caused tsunami waves and flooded large area of coasts of the Indian Ocean while no waves were recorded at the tide stations on the Burma coast (Berninghausen, 1966; Ortiz and Bilham 2003).

4. Paleoseismological Survey

We targeted to investigate tsunami deposits and coastal land level changes with respect to the current sea level. Recent research tools on the identification of earthquake recurrency are chronological and sedimentological studies of the coastal sediments commonly found in tidal flat and coastal lagoon, because earthquake and tsunami events along the subduction zone occasionally promote the tsunami deposit and/or land level subsidence or uplift. This coseismic subsidence or uplift of the coast causes the inter-layering of marine and non-marine sediments along coast. As an example, earthquake induced tsunami deposit found at the Mochirippu lake along the Pacific coast of eastern Hokkaido were intercalated with tidal peat and mud succession, and radiocarbon age of the sand layer confirmed the evidence for the 17th century earthquake occurred along the Kuril subduction zone (Sawai *et al*. 2004).

We further planned to investigate geomorphology of the coastal land form. It includes investigation of marine terraces, coral reef and coral micro atoll. Height of marine terraces is measured by level profiling of such landforms. Presence of emerged coral reef and microatoll along the coast could give a firm evidence for the vertical crustal movement with respect to sea level because their limitation for living environment is limited under sea surface. Dating records of annual growth ring of coral microatoll were best implied to coseismic uplift of the giant December 2004 Sumatra earthquake and past earthquake recurrence along the west coast of Sumatra (Natawidjaja *et al*., 2004, 2006).

By utilizing the available geographic map (Tactical Pilotage Map, 1:500,000; Defense Mapping Agency Aerospace Center, 1989) and satellite images (ASTER taken at 2003-11-21T04:31:26Z), survey areas for the tidal flat, coastal lagoon and coral reef exposure are chosen. The survey areas fall on surrounding regions of the two cities of Rakhine state, the western coast of Myanmar, namely Sittway and Thandwe cities (Fig 2). Five localities around these two cities were investigated during the survey period of 10 days (February 4-13, 2006). These are

1. Lagoon at the west coast of Sittway City
2. Coast of Myengun island, Sittway City
3. Coast of Tandin island, Sittway City
4. West coast of Shwehle Town, Thandwe City
5. Coast of Lontha, Mawyon and Thabyu Chaing, Thandwe City

Portable GPS for recording survey localities, auto level and hand-held laser instrument (Impulse 200LR; Laser Technology Inc.) for measurements of terrace profile, handy corer and geoslicer for sediments sampling and observation, were used in this survey. In addition, we investigated tsunami heights at five survey points due to 2004 Sumatra-Andaman earthquake, by conventional Rise-and-Fall method.

Total of 29 survey points, numbered MM0601 to 29, with description of survey date, locality name, survey point number, GPS location, type of survey (TD: Tsunami Deposit, TH: 2004 Tsunami Height, MT: Marine Terrace and CR: Coral Reef) and collected samples are listed in Table 1. We hereby describe the details of survey from north to south (see Fig. 1).

5. Survey at Sittway City and Its Surrounding Regions

Sittway city is the capital of Rakhine state which covers almost the western coast of Myanmar. The western coast of Myanmar including Sittwe city and its surrounding areas fall on the tropical monsoon climate and receive very high mean annual rain fall with > 2500 mm/yr (Bender 1983). Because of the tropical monsoon climate storm surges, such as cyclones, occurred several times in the past and, the coastal regions of Sittway and Kyaukphu cities have been flooded by large storm surges of cyclones (Murty *et al*. 1986). Coastal zones near by and around Sittway city have broader area than other regions of western coast of Myanmar, up to ~ 70 km near the city, due to extensive detritus fans and fluvial sediments brought down from the north by the rivers Mayu, Kaladan and Lemro (Bender 1983). We choose the coastal lagoon, the west coast of Sittway city, to investigate tsunami deposit and Myengun and Tandin islands, the surrounding regions of Sittway city, to investigate the marine terraces and uplifted coral reef.

5.1 Survey at Lagoon, West Coast of Sittway City (MM0601 – 10, MM0619 – 22)

Survey was done for investigation of tsunami deposit in the lagoon of the west coast of Sittway city (Fig. 3). For two days, coring and trenching of lagoon sediments were conducted. Total of 14 survey points were investigated for tsunami deposits and accounts for the 2004 tsunami height were taken at three of them (Table 2). The lagoon trends NNW-SSE and is ~ 15 km long and ~ 1 km wide. Muddy bioturbated sediments, dead trees and partially intercalated lens-shape sand were collected mainly in the southern parts of the lagoon (Fig. 4 A-D and 5), while sandy sediments are predominant in the northern parts. In the central part, 7 cores (MM0601, MM0603 – 09) were taken in NE-SW traverse across the lagoon and 4 cores were collected in the southern part (MM0610, MM0619 – 21). Sediment sections in the central and southern portion were predominantly soil and mud, and in some cores, sandy mud (Fig. 5) with shell fragments and plant's stems and leaves were characterized. A few probable event sand layers were intercalated into mud at MM0601, MM0609 and MM0620-21.

MM0601: At the survey point in the same lagoon near The-Chaung Village, we collected a 1.0 m long core section of silty sand with shell fragments capped by recent soil (0 - 0.08 m) and very coarse sand (0.78 - 1.0 m) at the base. However between 0.45 - 0.53 m, a coarse grain sand layer, probably event deposit, was observed with sharp basal contact with the lower silty sand layer.

For the height of 2004 Sumatra tsunami, we made measurement based on the account of the eyewitness. The measured tsunami height was 1.49 m above sea level at the time of survey (2006 February 05; 16:15). The tide levels at the time of measurement and at tsunami can be computed to be 1.47 m and 1.68 m above datum respectively by using WXTide32 program. Then actual tsunami height is converted to be 1.28 m (Table 3).

MM0602: At the northernmost survey point of the lagoon near Ohndaw village, the section was totally covered by sand (Figs. 4C and D). Here we could also grasp the information of height of 2004 Sumatra tsunami. Measured tsunami height was 2.7 m at the time of survey (2006 February 05; 17:45), and actual tsunami height was estimated to be 2.88 m.

MM0603: The survey point locates ~ 200 m west of MM0601 and a 0.9 m long core composed of bioturbated fine sand at the top (0 – 0.4 m) and muddy sand layer (0.4 – 0.9 m) at the base was taken. Tiny plant stems and leaves were observed in the muddy sand layer.

MM0604: At this survey point, ~ 130 m SW from MM0603, a (0.55 – 0.95 m) long sediment section was cored. The observed lithofacies are mud layer (0.55 – 0.6 m) at the top and fine to medium sand (0.6 – 0.95 m) layer at base.

MM0605: About 400 m SW of MM0604, a core was taken and all the section was composed of sand.

MM0606: At 100 m south of MM0605, a core section (0 – 0.6 m) was fully characterized by sand and a fragment of plant's stem was observed at the depth of 0.4 m. The survey point was located near a small stream channel probably caused by the low and high tide flowage.

MM0607: The survey point was an about 1 m deep trench being dug by the locals in making embankment of ponds for shrimp hatcheries. (Fig. 4A and B). The trench was located about 100m southeast of MM0604. The lithofacies observed at the trench wall were brown bioturbated sandy mud intercalated with several centimeters long lens-shaped sand at upper part (0 – 0.4 m) and grayish muddy sediments with fragments of plant's stem and roots at the base (0.4 – 0.85 m). Level measurement gave that the elevation of the top of trench wall is 0.58 m above the sea level at the time of investigation . The sea level at 2006 February 06; 14:40 is 0.67 m and mean sea level is 1.48 m, hence the top of trench wall is below 0.23 m below the mean sea level.

MM0608: At about 70 m southwest of MM0601, 1 meter deep core section was taken. Soil (0 – 0.1 m), muddy sand (0.1 – 0.5 m) and beach sand (0.5 – 1.0 m) were observed. Fragments of plant's stem were found at the depth of 0.55 m.

MM0609: The survey point is the same location as MM0601 and was re-cored by handy geoslicer for the confirmation of the event deposit (observed at 0.45 – 0.53 m in MM0601). A section (0.3 – 0.8 m) by handy geosclicer was observed. The lithofacies are nearly identical to the core section of MM0601.

MM0610: The survey point is one of the four points investigated in the southern part of the lagoon (Fig. 3) near Bazar village, characterized sand layer (0 – 0.14 m) at the top, bioturbated mud layer with lens-shaped sand (0.14 – 0.7 m) in the middle and grayish mud layer (0.8 – 1.0 m) at the base.

MM0619: 1 m depth sediment section was cored at the survey points at Barsar village, very close to MM0610, and composed of a mud layer with leaves and stems of grasses (0 – 0.1 m) at the top, bioturbated mud layer (0.1 – 0.4 m) in the middle and mud layer with lens-shaped sand (0.4 – 1.0 m) at the base. Plant's roots and stems are observed at 0.45 m and 0.85 m.

MM0620: A 1.3 m long core was taken at the survey point, about 130 m north of MM0619, of Barsar village. The lithofacies until the depth of 1.05 m were identical to those of MM0619 and a sand layer with few mud clasts was observed at (1.05 – 1.3 m).

MM0621: Survey point very close to MM0620 was cored with depth to 1.5 m to investigate a deeper section of MM0620. A sand layer was observed at (1.42 – 1.5 m). Plant's stem above the basement sand at 0.85 m was collected for radiocarbon sample. It was measured as 280-170, 150-10 cal yrBP (Table 2),

MM0622: Height of 2004 Tsunami was measured based on eyewitness' accounts at the survey point, with the locality name of Barsar village. Measured tsunami height was 2.3 m above sea level at the time of (2006 February 06; 10:00), and actual tsunami height was estimated to be 2.1 m.

5.2 Survey at Myengun Coast, Sittway city (MM0611 – 16)

Myengun locality is on the west coast of an isolated island located a few kilometers southeast of Sittway City. On Myengun coast, investigation of tsunami deposit, marine terrace and coral reef were conducted at 6 survey points (MM0611 – MM0616). Contrast to the lagoon on the west coast of Sittway City, sediments were mostly very loose sand (probably beach sand) with very tiny fragments of shell. At the higher elevation of the coast, on the marine terrace, sediments were quite dry and the ground surface was too hard to drill core sections. We could not find event deposit in this area. Profiles of marine terraces and a sand bar were taken by auto level and laser ranging instrument. Information on tsunami height of the 2004 Sumatra tsunami was also collected at one of the survey points.

MM0611: At this survey point, height of the 2004 tsunami was obtained as the measured height, 1.95 m, at the time of survey (2006 February 07; 11:00). Actual tsunami height was estimated to be 1.23 m.

MM0612: From this survey point on the tidal flat on the east side of Myengun coast (see Fig.7B), 0.4 m depth of sediments were able to core. The sediments are mud layer (0 – 0.15 m), mud with plant's stems (0.15 – 0.25 m), and sand with tiny shell fragments at the base (0.25 – 0.4 m).

MM0613: The sand bar was observed at this survey point and a topographic profile was taken by level measurement. The height of sand bar is ~ 2.0 m above sea level at the time of survey (2006 February 07; 12:30) (Fig. 7).

MM0614: The survey point located on a terrace and a 0.3 m long sediment core section was taken. The observed sediment section was mud with tiny shell fragments (0.14 – 0.3 m).

MM0615: The point was several tens of meters to the inland from MM0614. Several large sandstone boulders with eroded shell imprints were investigated there.

MM0616: At this survey point, marine terraces of three levels were recognized as the lower terrace (~ 250 m in width and ~ 2 m in height), middle terrace (~ 200 m in width and ~ 7.5 m in height) and the upper terrace (~ 200 m in width and 19 m in height) (Fig. 8). Samples of fossil corals found on the surface of the upper terrace (~ 13 m in height) were collected for radiocarbon dating. They were dated to between 3030 and 2650 cal yBP (Table 2).

5.3 Survey at Tandin Coast, Sittway City (MM0617 & MM0618)

Tandin coast is ~ 50 km southeast from the Sittway City. We were able to make investigation of marine terraces and coral at two survey points (Figs. 9 and 10). Three levels of marine terraces were recognized and a profile was made by auto level and laser ranging measurements.

MM0618: Marine terraces observed at north survey point of Tandin coast have three steps of lower, middle and upper. The lower terrace with 80 m in width was raised with 1.0 m in height above sea level. Then, middle terrace (~ 150 m in width and ~ 4.0 m in height) and the upper terrace (~ 60 m in width and ~ 6.5 m in height) were recognized. Below the lower terrace, wave cut bench (~ 20 m in width and ~ 0.5 m in height) is formed at present time (Figs. 10A and B)).

MM0617: Survey point is several hundreds meter south from MM0618. The lower terrace (~ 20 m in width and 1.0 m in height), the middle terrace (~ 20 m in width and 2.5 m in height) and the upper terrace (~ 30 m in width and 5.5 m in height) were identified. Coral fragments were found on the surface of the upper terrace (~ 5 m in height) (Figs. 10C and D). Three broken pieces of fossil corals were collected for radiocarbon dating. They were dated to between 2720 and 2480 cal yBP (Table 2) (Fig. 8D).

6. Survey at Thandwe City and Its Surrounding Regions (MM0623 –29)

Thandwe City is a resort city located about 250 km south from Sittway City. We chose the coast of Shwehle Town to investigate the tsunami deposit and coasts of Lontha, Mawyon and Thabyuchaing villages for investigation of uplifted coral reefs to identify land level changes (Figs. 11 and 12). However, no significant evidence, either tsunami deposits or uplifted coral reefs, to identify the past earthquake evidence, was found. The height of 2004 Sumatra tsunami was obtained at MM0624.

6.1 Survey at Shwehle Town, Thandwe City (MM0627–28)

A marine terrace was investigated at the survey point, west coast of Shwehle Town. The terraces consists of two levels; the lower terrace (~ 150 m in width and 3 m in height) and the upper terrace (~ 150 m in width and 4.5 to 5.5 m in height) (Fig. 11C).

MM0627: Two trenches 0.4 m and 0.44 m in depth were dug up on the surface of the lower terrace to investigate tsunami deposit. No tsunami deposit was found and the observed sediments were only dry recent soils and mud.

MM0628: One trench with the depth of 0.3 m was dug up on the surface of the upper terrace. No tsunami deposit was found and the observed sediments were only dry recent soils and mud (Figs. 11D and E).

6.2 Survey at Lontha, Mawyon and Thabyuchaing (MM0623 – 26, MM0629)

MM0623 – 26, MM0629: No coral reef was found out except fragments of dead corals, probably recent in age. At MM0626 table-shaped coral with 0.5 m in width was observed and the elevation of the table coral was above 0.18 m above sea level at the time of measurement (sea level at 2006 February 10; 12:10 is 0.96 m and mean sea level is 1.48 m, and hence the elevation coral was 0.34 m below mean sea level) (Figs. 12A and E). At MM0624 measured tsunami height was 1.6 m at the time of survey (2006 February 10; 9:00), and actual tsunami height was estimated to be 0.85 m.

7. Summary of Survey

Total of 29 survey points around Sittway and Thandwe cities along the western coast of Myanmar were investigated to find out the evidences of past subduction zone earthquakes.

7.1 Tsunami Deposit

Along the west coast of Sittway City, we made coring on several survey points in the lagoon to find out tsunami deposit. The lagoon was mostly characterized by muddy sediments with sand lensoids in some places. These sand lenses, a few centimeters to tens of centimeters in length, are possibly of marine origin, and are thought to be deposited by storm or tsunami. In MM0601 a sand layer was supposed to be of event deposit because sharp boundary on its base could be considered one of the characteristics of abrupt deposition due to storm or tsunami. In core sections of MM0620-21, several sand layers were recognized but But no correlation of such sand layer was found in the cores collected around the MM0601. Most of the core sections do not provide significant depositional layering and lithofacies, and in some cores parts of woods and man-made materials are mixing in the upper coverage (0 ~ 0.4 m) of sediments. It could be considered that the sediment section (coverage 0 ~ 0.4 m) of the lagoon will have to be suffered by artificial effects. Age of a sample of plant's stem above the basement sand from MM0621 core was measured as after 280 cal yBP (Table 2), and it reveals that the lagoon was formed since or before that time.

7.2 Tsunami Height

Based on local people' accounts, we could also collect the information of tsunami heights along the western coast of Myanmar due to 2004 Sumatra-Andaman earthquake at five survey points. The results were less than 3.0 m and are the same as those of the Tanintharyi coast and the Ayeyarwaddy delta (Satake *et al*., 2006) (Fig. 13).

7.3 Marine Terrace

Although no clear sedimentological evidences for the past earthquake events were obtained, uplifted marine terraces were recorded along Myengun and Tandin coasts south of the Sittway City. At Myengun coast, three levels of emerged coastal terraces were recognized with the maximum height of ~ 19 m above mean sea level. Similarly, marine terraces were investigated at the Tandin coast ~ 30 km far south from the Myengun coast. In Tandin coast, three levels of marine terraces at two sites were investigated and the maximum height of the higher terrace was up to 6 m at the northern site and up to 5.5 m at the southern site. Based on the dating of the fossil coral samples collected from the uppermost terraces of Myengun and Tandin coasts, three uplift events occurred during the past ~ 3000 yrBP (Table 2). Around Thandwe City, we also tried to find out the uplifted coral reef to infer relative sea level change. No reef system of corals was found in investigation in four survey points.

The collected fossil coral samples from Myengun and Tandin coasts have almost the same age of ~3000 yrBP, but their elevations are different as ~ 13 m in at Myengun coast and ~ 5 m at Tandin coast. Thus elevations of terraces were higher in the oceanward (e.g. Myengun coast) than continentward (e.g. Tandin coast) (Fig. 14), suggesting probably continentward tilting of these coastal areas. We believe that the terraces are the records of past subduction zone earthquakes along the plate boundary off western coast of Myanmar.

8. Conclusions and Future Work

Three main remarks can be conclusively drawn based on the investigation of 29 survey points of geological and geomorphological evidences along the western coast of Myanmar.

1. We aimed to find out tsunami deposit and uplifted coral reef (atoll) due to past earthquakes, 1750 and others. But no clear evidence for tsunami deposit and uplifted coral reef system, except fragments of fossil coral, was found for identification of the inferred land level changes due to past earthquakes.
2. Three levels of emerged terraces were found, suggesting that episodic uplifts occurred along the coast. Based on radiocarbon age of corals found on the upper most terraces, the western coast of Myanmar suffered three uplift events during the last ~ 3000 years. And continentward crustal tilting could also be considered.
3. Tsunami heights along the western coast of Myanmar due to 2004 Sumatra-Andaman earthquake were < 3.0 m.

More detailed fieldwork is needed to estimate when the uplifts of marine terraces (higher, middle and lower terraces) occurred. Additionally, mapping the lateral extents of uplifted terraces is also needed to ensure that these terraces were formed by tectonic activity associated with the subduction-zone earthquakes. Thus we plan to continue our survey on the western coast of Myanmar in early 2007.

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Table 1. Brief description of survey localities carried out along the western coast of Myanmar.

Stop	Locality	Date	Latitude	Longitude	Survey Type	Sample Type	No. of Sample	Time at measurement	Tide at measurement, m
MM0601	The Chaung, Sittway	2006/02/05	20° 09' 23.9"	92° 50' 14.0"	TD, TH	S	3	16:15	1.48
MM0602	Ohndaw, Sittway	2006/02/05	20° 11' 15.1"	92° 47' 17.4"	TD, TH			17:45	1.86
MM0603	The Chaung, Sittway	2006/02/06	20° 09' 16.6"	92° 50' 13.6"	TD	S	4		
MM0604	The Chaung, Sittway	2006/02/06	20° 09' 12.9"	92° 50' 11.4"	TD				
MM0605	The Chaung, Sittway	2006/02/06	20° 09' 02.6"	92° 50' 02.9"	TD				
MM0606	The Chaung, Sittway	2006/02/06	20° 08' 55.9"	92° 50' 03.2"	TD	S	3	13:30	0.51
MM0607	The Chaung, Sittway	2006/02/06	20° 09' 07.2"	92° 50' 12.5"	TD	S	2	14:40	0.62
MM0608	The Chaung, Sittway	2006/02/06	20° 09' 21.7"	92° 50' 15.2"	TD	S	2	15:06	0.76
MM0609	The Chaung, Sittway	2006/02/06	20° 09' 23.9"	92° 50' 14.0"	TD	S	1		
MM0610	The Chaung, Sittway	2006/02/06	20° 07' 24.7"	92° 52' 17.0"	TD				
MM0611	Myengun coast, Sittway	2006/02/07	20° 04' 57.7"	92° 55' 06.4"	TH			11:00	0.95
MM0612	Myengun coast, Sittway	2006/02/07	20° 04' 59.2"	92° 55' 15.3"	TD	S	2		
MM0613	Myengun coast, Sittway	2006/02/07	20° 05' 04.2"	92° 55' 12.7"	MT, CR			12:30	0.65
MM0614	Myengun coast, Sittway	2006/02/07	20° 04' 28.4"	92° 55' 01.0"	TD	S	1		
MM0615	Myengun coast, Sittway	2006/02/07	20° 04' 27.1"	92° 55' 08.2"	TD				
MM0616	Myengun coast, Sittway	2006/02/07	20° 02' 21.3"	92° 56' 08.3"	MT, CR	C	2	17:00	0.87
MM0617	Tandin coast, Sittway	2006/02/08	19° 50' 26.7"	93° 07' 58.3"	MT, CR			12:30	1.04
MM0618	Tandin coast, Sittway	2006/02/08	19° 50' 40.2"	93° 07' 56.1"	MT, CR	C	4	15:35	0.58
MM0619	Basar village, Sittway	2006/02/09	20° 07' 25.4"	92° 52' 17.1"	TD				
MM0620	Basar village, Sittway	2006/02/09	20° 07' 26.9"	92° 52' 12.9"	TD	S	3		
MM0621	Basar village, Sittway	2006/02/09	20° 07' 27.7"	92° 52' 06.4"	TD	S	2	9:30	1.36
MM0622	Basar village, Sittway	2006/02/09	20° 07' 12.0"	92° 52' 54.1"	TH			10:00	1.48
MM0623	Lontha, Thandwe	2006/02/09	18° 21' 47.3"	94° 20' 14.8"	CR	C	1		
MM0624	Mawyon, Thandwe	2006/02/10	18° 14' 45.3"	94° 20' 05.3"	TH			9:00	1.23
MM0625	Mawyon, Thandwe	2006/02/10	18° 14' 35.5"	94° 20' 13.8"	CR	C	1		
MM0626	Mawyon, Thandwe	2006/02/10	18° 18' 43.3"	94° 20' 56.3"	CR	C	1	12:10	1.62
MM0627	Kyauk Phyu Maw, Thandwe	2006/02/10	18° 35' 50.7"	94° 14' 42.0"	TD, MT			16:30	0.62
MM0628	Kyauk Phyu Maw, Thandwe	2006/02/10	18° 35' 53.3"	94° 14' 45.9"	TD				
MM0629	Thabyu Chaing, Thandwe	2006/02/11	18° 18' 05.9"	94° 22' 56.1"	CR	C	1		

Note Survey type: TD – Tsunami Deposit, TH – Tsunami Height, MT – Marine Terrace, CR – Coral Reef; Sample type:C – Coral; S – Sediment; Values of tide level are taken from WXTide32 Program. Tide level for Sittway, Myengun and Tandin are referred from *Sittwe station (92° 54.00'E, 20° 8.00'N)* and those for Lontha, Mawyon, Thabyuchaing and Shwehle are from *Andrew Bay station (94° 21.00'E, 18° 21.00'N).*

Table 2. Radiocarbon dating results of samples collected from the western coast of Myanmar.

Sample	Locality	GPS Location	Environment	Sample Material	Elevation of sample above MSL	$\delta^{13}C$ (‰)	Conventional ^{14}C age	Calendar age 1σ(△R=0) (cal yr BP)	Calendar age 2σ (△R=0) (cal yr BP)	Lab Code
06020703A	MM0616,Myengun Terrace (south)	20° 02' 18.6"N 92° 56' 01.6"E	Upper Terrace	Coral	~ 13 m	-5.31±0.16	2925±20	2735-2690	2755-2650	PLD-5758
06020703B	MM0616, Myengun Terrace (south)	20° 02' 18.6"N 92° 56' 01.6"E	Upper Terrace	Coral	~ 13 m	-1.19±0.17	3145±20	2970-2870	3030-2840	PLD-5759
06020802	MM0618, Tandin Terrace (south)	19° 50' 45.0"N 93° 08' 00.0"E	Upper Terrace	Coral	~ 5 m	-1.56±0.16	2830±20	2680-2550	2700-2480	PLD-5760
06020803	MM0618, Tandin Terrace (south)	19° 50' 45.0"N 93° 08' 00.0"E	Upper Terrace	Coral	~ 5.0 m	-0.54±0.12	2860±20	2705-2605	2720-2520	PLD-5761
06020901	MM0620, West coast of Sittway City	20° 07' 26.9"N 92° 52' 12.9"E	Tidal Lagoon	Buried Grass	~ 1.0 m Below MSL	-29.37±0.20	130±20	270-240 230-210 150-130 120-70 40-10	280-170 150-10	PLD-5762

Table 3. Tsunami heights along the western coast of Myanmar due to 2004 December Sumatra-Andaman Tsunami.

Locality	Stop	Latitude	Longitude	Tsunami Height, m (A)	Measured Height, m (B)	Time of Measurement	Tide Level Measurement, m (C)	Tide Level at Tsunami, m (D)
MM0601	The Chaung, Sittway City	20° 09' 23.9"	92° 50' 14.0"	**1.28**	1.49	16:15, 2006 Feb 5	1.47	1.68
MM0602	Ohndaw, Sittway City	20° 11' 15.1"	92° 47' 17.4"	**2.88**	2.7	17:45, 2006 Feb 5	1.86	1.68
MM0611	Myengun coast, Sittway City	20° 04' 57.7"	92° 55' 06.4"	**1.23**	1.95	11:00, 2006 Feb 7	0.95	1.68
MM0622	Basar, Sittway City	20° 07' 12.0"	92° 52' 54.1"	**2.1**	2.3	10:00, 2006 Feb 9	1.48	1.68
MM0624	Mawyon, Thandwe City	18° 14' 45.3"	94° 20' 05.3"	**0.85**	1.6	9:00, 2006 Feb 10	1.26	2.01

Note: Tsunami heights (A) are obtained by (B+(C-D)) (Satake *et al*. 2005, 2006). Tidal Level are computed by using WXTide32 program and tidal level for MM0624, Thandwe city is taken from *Andrew Bay (94 21.00'E, 18 21.00'N)* whereas the others from Sittway city are taken from *Sittwe station (92 54.00'E, 20 8.00'N)*. The tsunami arrival is assumed to be at 11:30am on 2004 December 26, which is as same as the arrival at Ayeyarwaddy Delta (Satake et al. 2006).

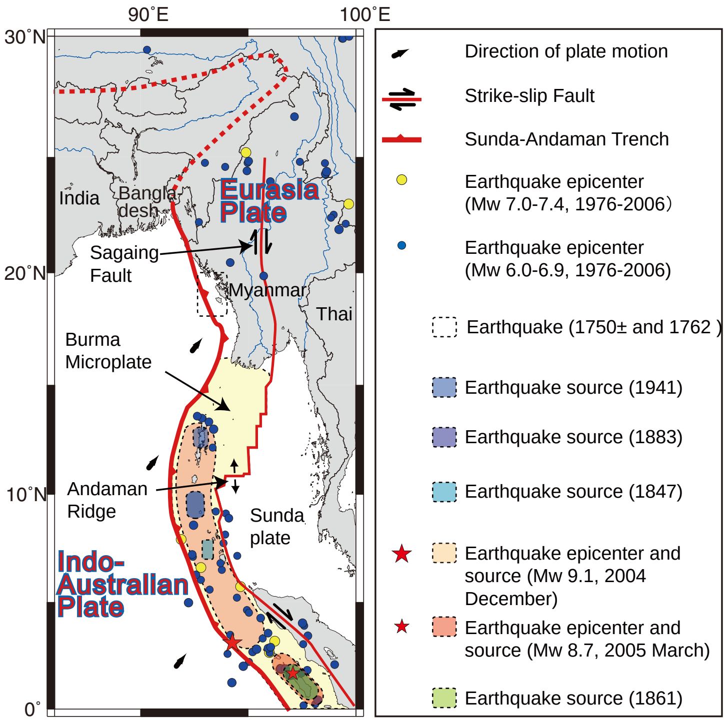

Fig. 1. A map showing tectonics and past earthquake and tsunami events in and around Sunda-Andaman Trench. Earthquake data for the period of 1976-2006 are referred as of Harvard CMT Catlalog, others are referred as Chhibber (1934), Heck (1947), Berninghausen (1966), Ortiz and Bilham (2003) and Sieh *et al.* (2004).

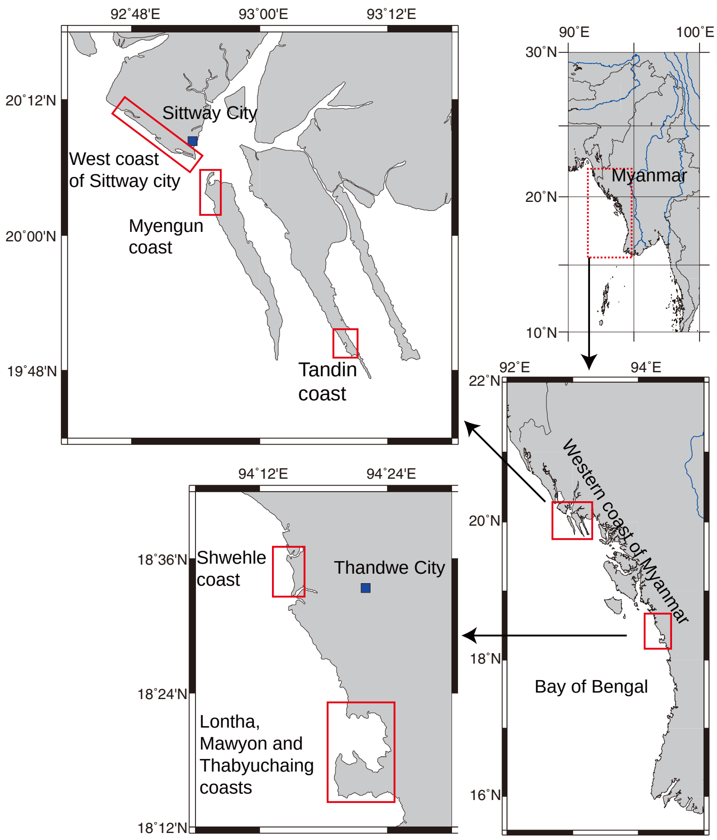

Fig. 2. Survey areas of the western coast of Myanmar. Paleoseismological survey was conducted two Cities of western coast of Myanmar, Sittway and Thandwe and their surrounding regions.

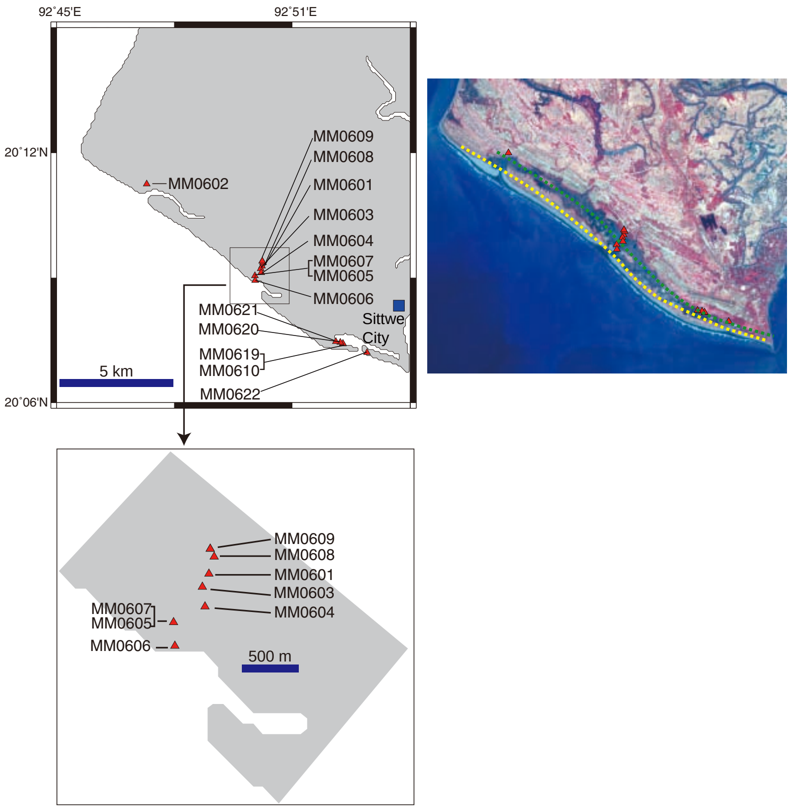

Fig. 3. Map showing survey points (red triangles; MM0601-10, 19-22) (left figure) and coastal topography of lagoon from satellite image (ASTER) (right figure), the west coast of Sittway city. Dotted lines, yellow and green, infer trends of the present beach and the lagoon.

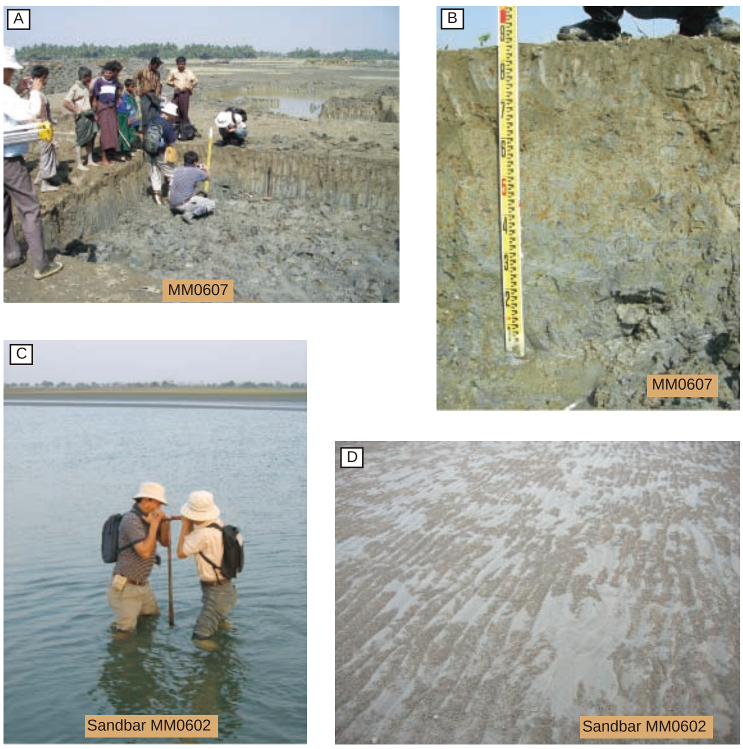

Fig. 4. Survey at lagoon of west coast of Sittway city. A. Observation at road construction trench (MM0607) B. Sediment section on the wall of trench, C. Coring in the sand bar of the northern part of lagoon (MM0602) and D. Sand bar.

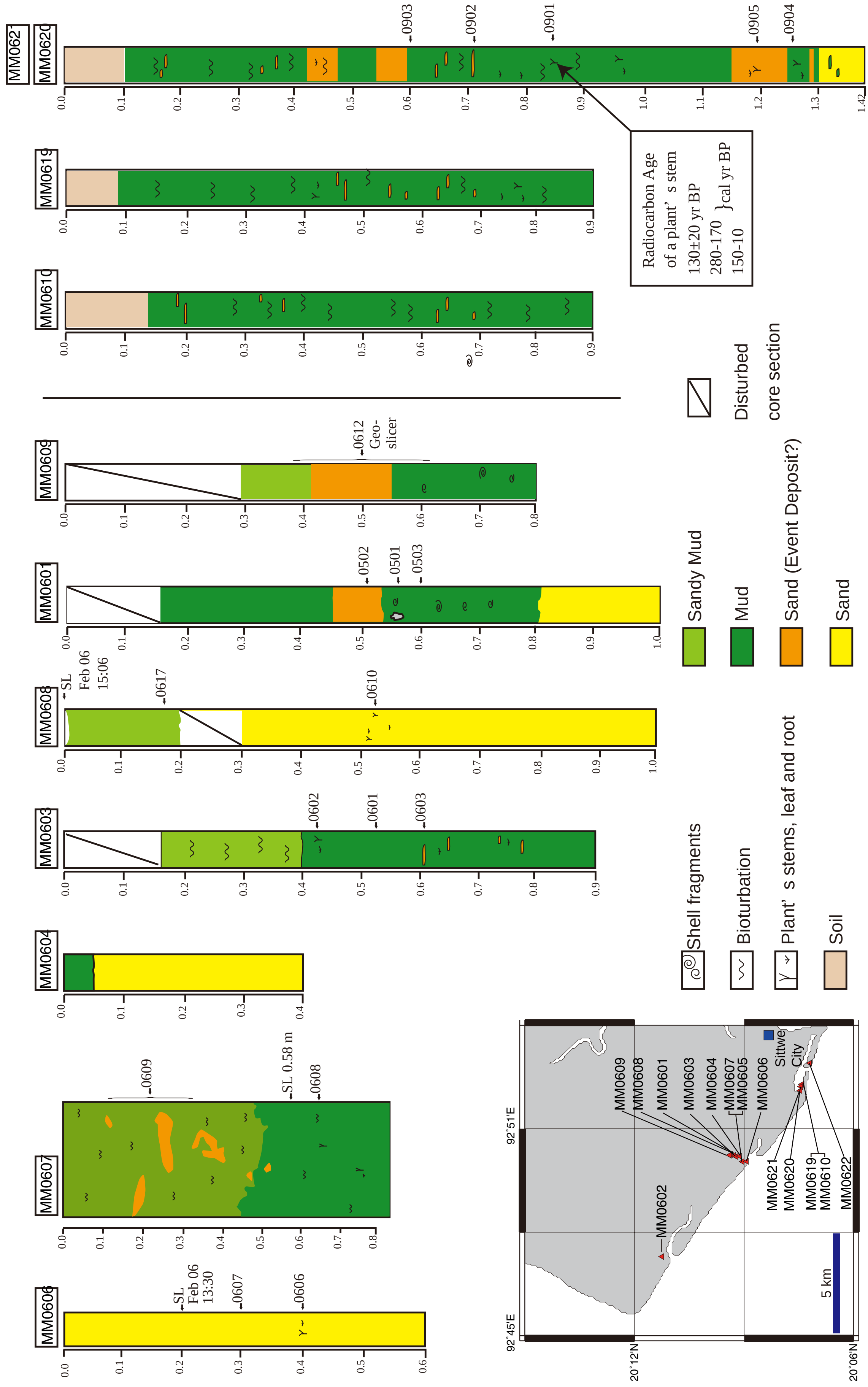

Fig. 5. Columnar sections of core sediments at lagoon, west coast of Sittway city.

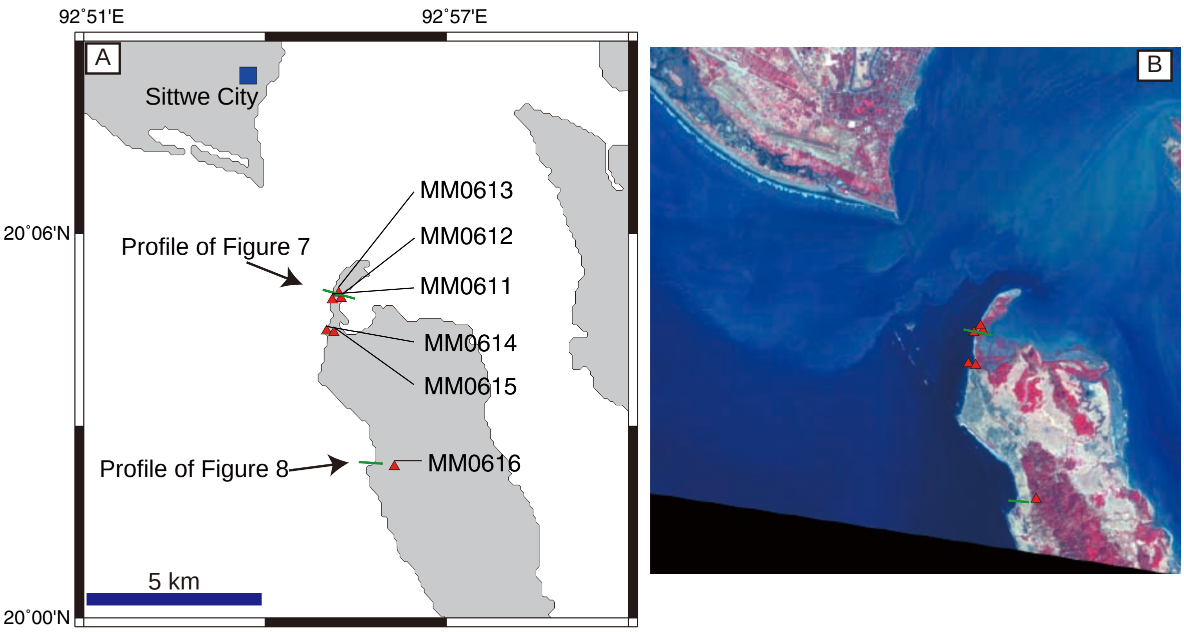

Fig. 6. A. Map showing survey points (red triangles; MM0611-16) (left figure), and B. coastal topography from satellite image (ASTER) (right figure) of Myengun coast, Sittway city, Green lines indicate the profiles of marine terraces (see Figures 7 and 8) where leveling measurement are made.

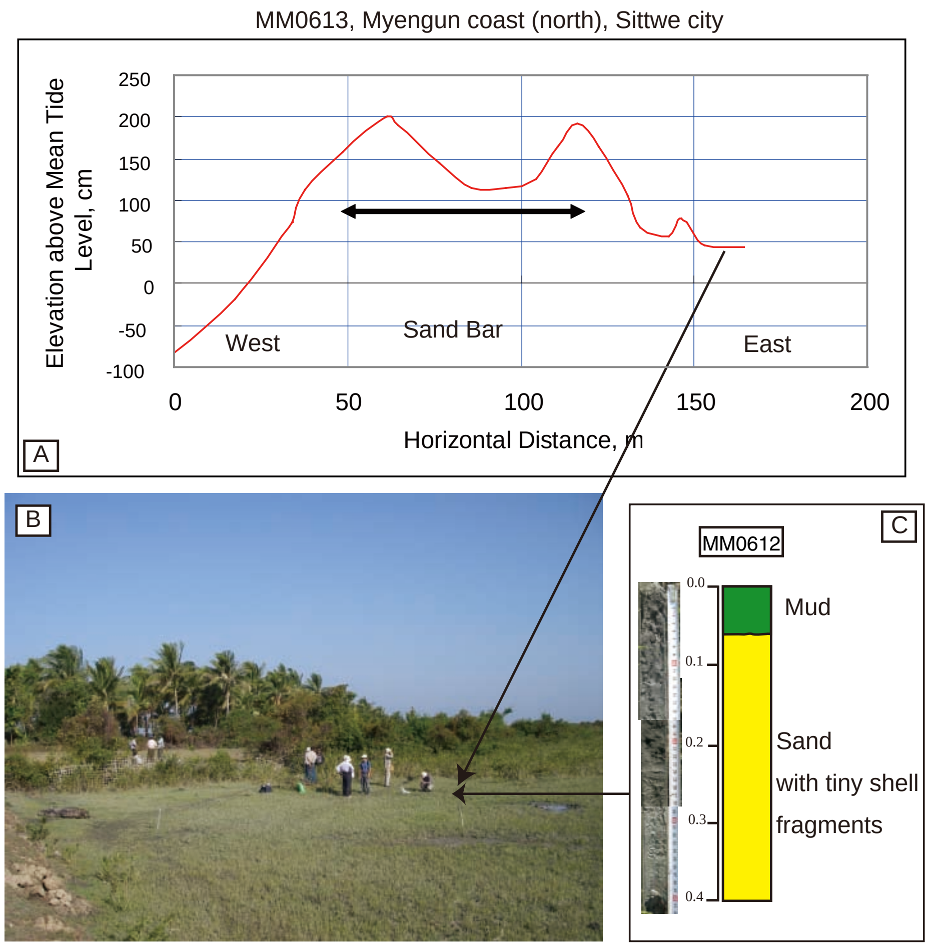

Fig. 7. A. Cross sectional profile of sand bar measured at MM0613, Myengun coast (north), Sittway city, B. Sediment coring at MM0-612 and C. Columnar section of observed core section at MM0612.

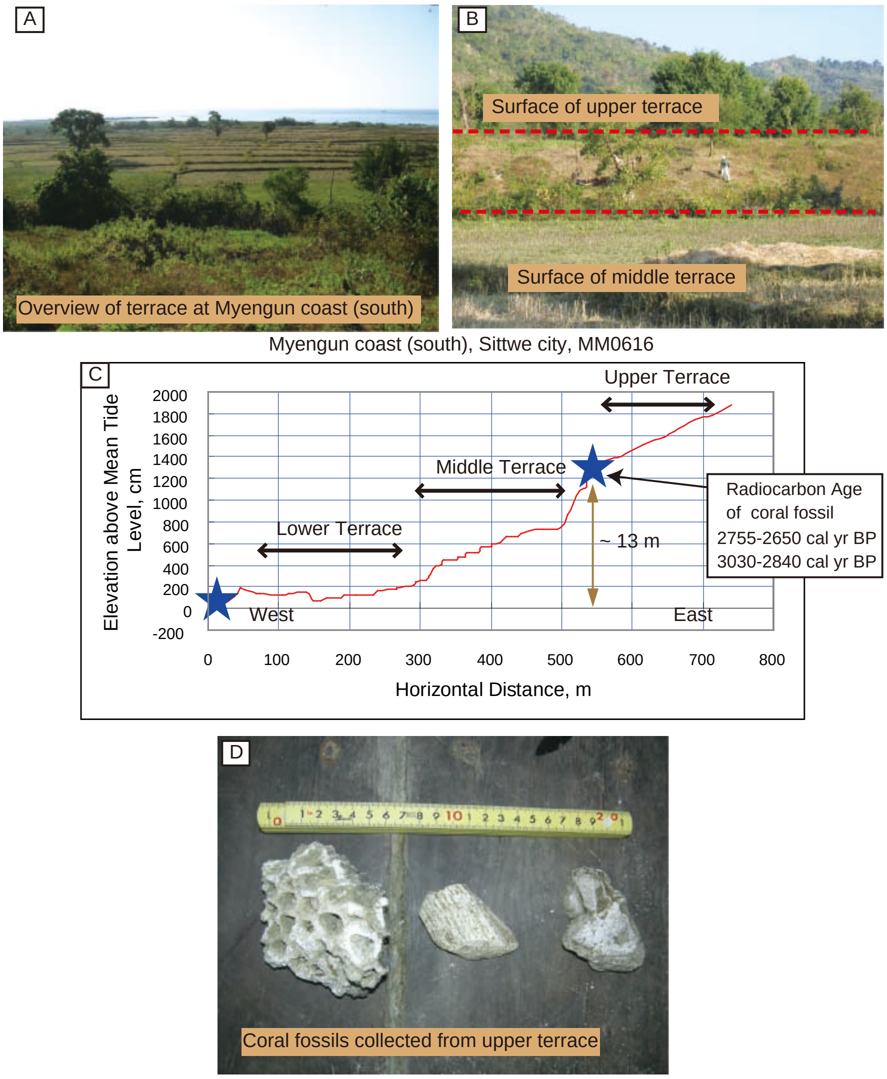

Fig. 8. A, B. Photo of terrace observed at Myengun coast (south), C. Cross sectional profile of terrace and D. Coral fossils collected from the upper step of the terrace. Star symbols on profile indicate the elevation of collected dead coral samples.

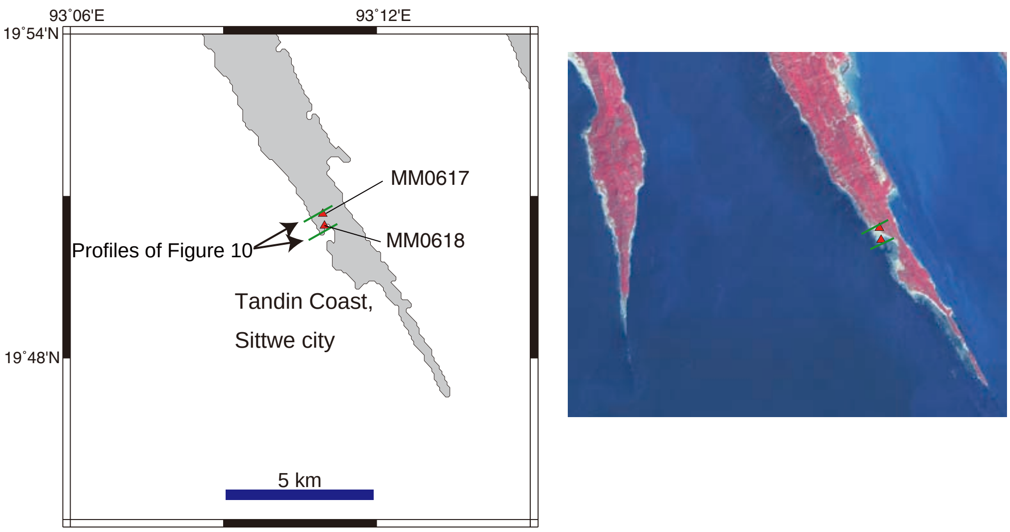

Fig. 9. Map showing survey points (red triangles; MM0617-18) (left figure) and coastal topography depicted from satellite image (ASTER) (right figure) of Tandin coast, Sittway city.

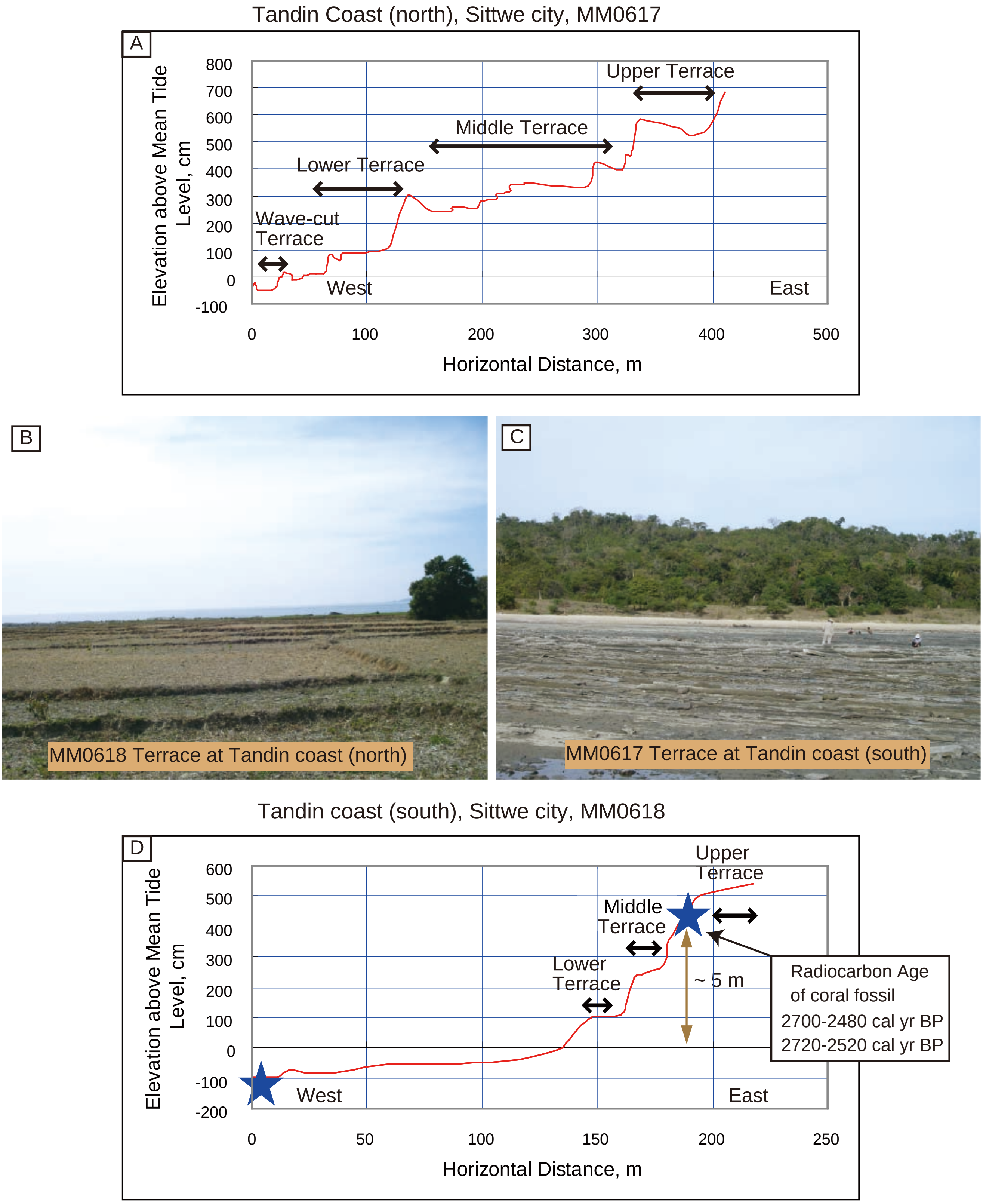

Fig. 10. A. Cross sectional profile of terrace at Tandin (north), B, C. Photos of terrace at Tandin (north) and D. Cross sectional profile of terrace at Tandin (south). Star symbols on profile indicate the elevation of collected dead coral samples.

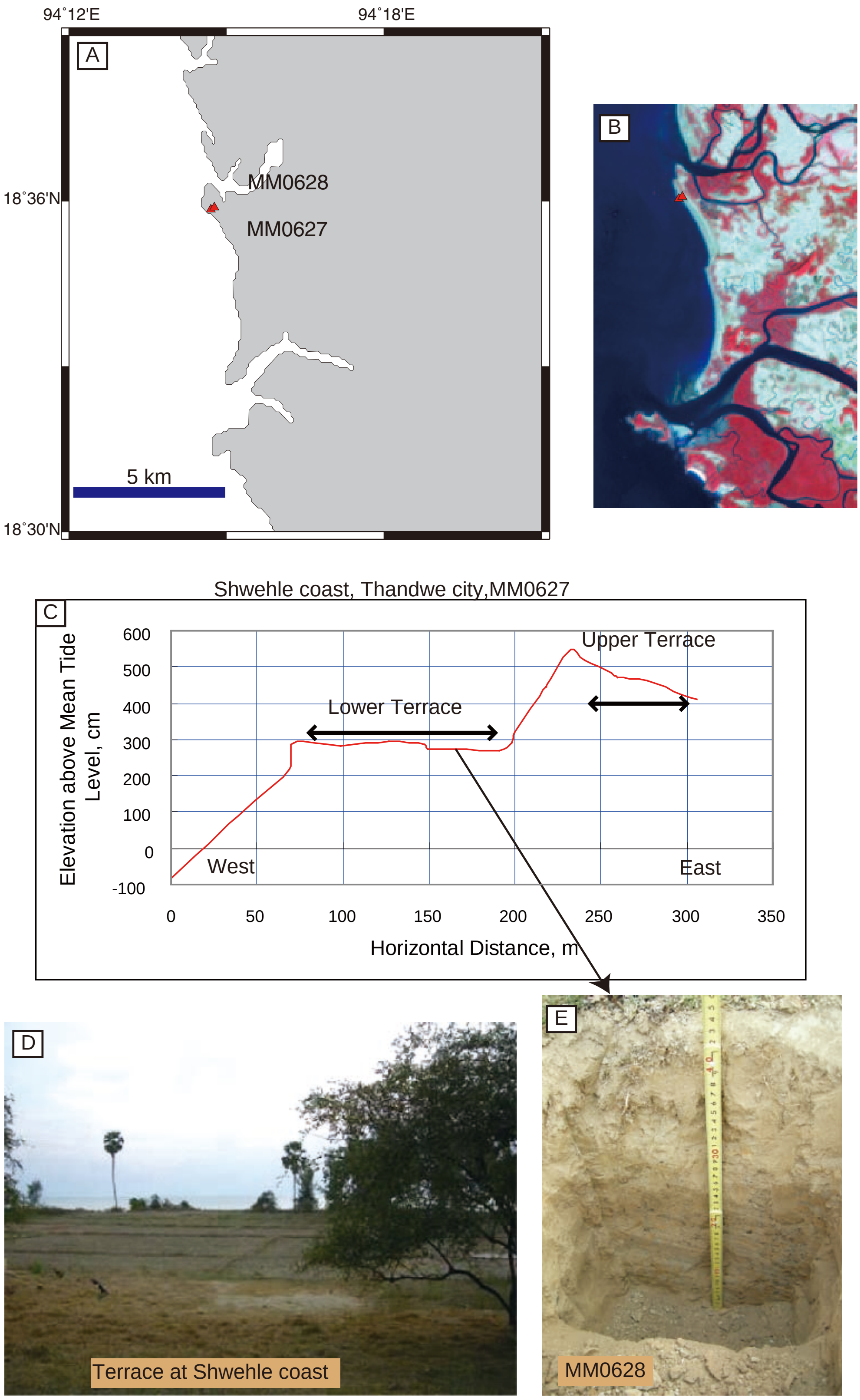

Fig. 11. A. Map showing survey points (red triangles; MM0627-29) B. Coastal topography from satellite image (ASTER) of Shwehle coast, Thandwe city, C. Cross sectional profile of terrace at Shwehle, Thandwe city, D. Photo of terrace at Shwehle, and E. Dry muddy sediments observed (MM0628) trench on the lower step of terrace, Shwehle coast.

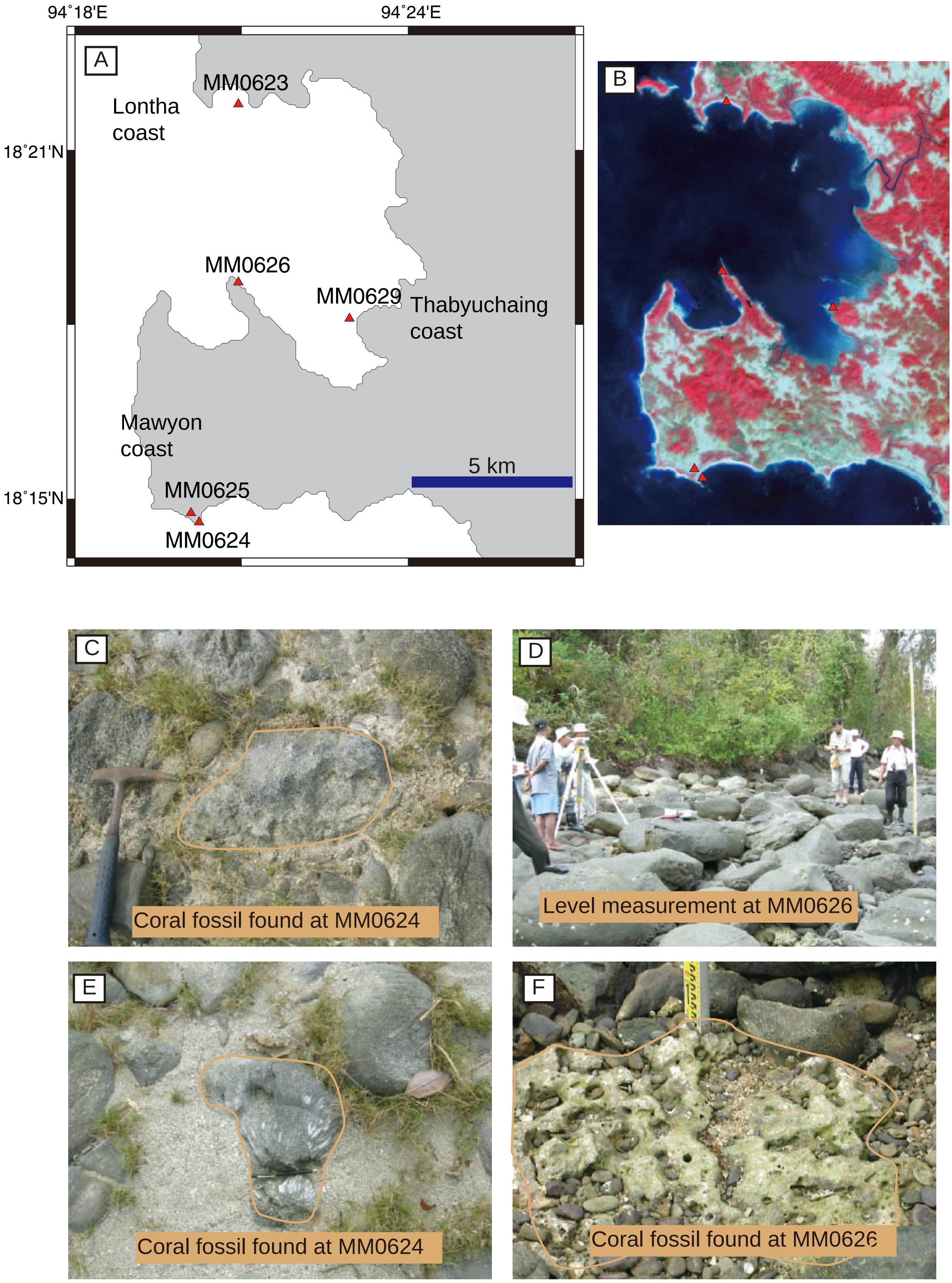

Fig. 12. A. Map showing survey points (red triangles; MM0623-26, 29), B. Coastal topography from satellite image (ASTER) of Lontha, Mawyon and Thabyuchaing coast, Thandwe city, C, E, F. Coral fossils found at Mawyon and Thanbyuchaing coasts (MM0624 and 26), D. Level measurement at MM0626.

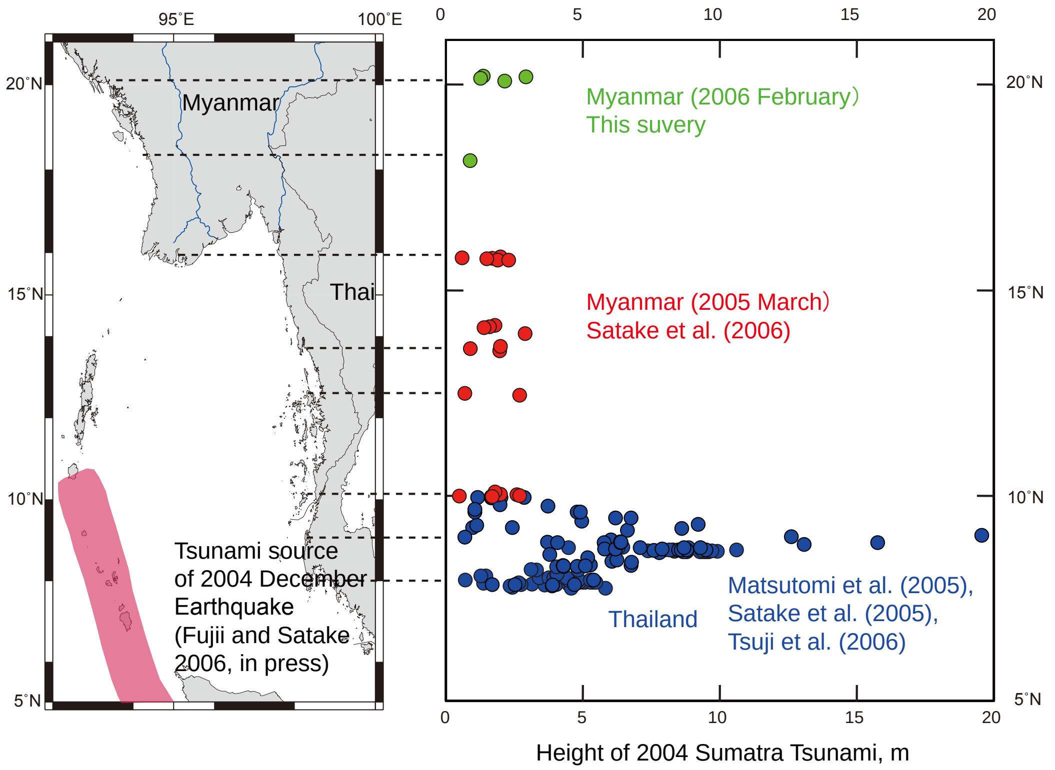

Fig. 13. Tsunami heights due to 2004 Sumatra-Andaman earthquake along Myanmar and Thai coasts (Matsutomi *et al*., 2005; Satake *et al*., 2005; and Tsuji *et al*., 2006). Green color data (< 3.0 m) of the western coast of Myanmar are obtained from this survey.

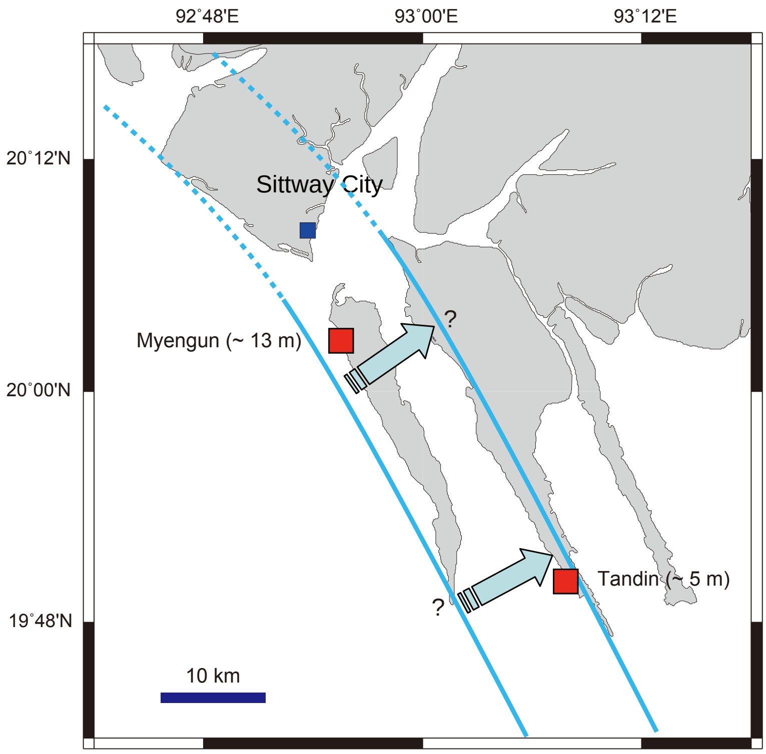

Fig. 14. Schematic illustrations of tectonically active belt inferred from the distribution and elevation of marine terraces at Myengun and Tandin coasts, Sittway city, western coast of Myanmar.