Chapter-6
Summary and Conclusions

The present study is an attempt to understand the evolutionary history of the Andaman Subduction Zone (ASZ) by unravelling the evidences preserved in its sedimentary record. As mentioned earlier the ASZ and its southward extension to Sumatra, is one of the youngest and seismically most active subduction zones of the planet. It is also well known for its high magnitude earthquakes and large and destructive volcanoes. It preserves most of the tectono-morphological features expected in a typical ocean-ocean subduction zone setting. These have made the ASZ an ideal site to study tectono-sedimentary processes, volcanism and paleoseismicity related to subduction. This thesis work was initiated with the objectives: (1) to decipher the past volcanic activities in the Andaman region; (2) to determine the timing of deposition of various formations on the islands and sedimentation in the Andaman Sea (3) to determine sediment provenances; (4) to understand the role of climate and tectonics on sedimentation and (5) to understand the evolution of the Andaman region as a whole. In order to achieve our objectives we had studied the sedimentary records on the Andaman Islands and that in the Andaman Sea. Detailed fieldwork was carried out on the Andaman Islands and suitable rock samples were collected from various formations. For the study of Andaman Sea sediments, a core (SK-234-60) was raised from the western part of the basin. The major conclusions of this study are listed below with answers to the major objectives of the thesis.

To determine the timing of major volcanic activities in the region, we have studied ash deposits preserved in the sedimentary records. The oldest record of volcanism from the Andaman region comes from the tephra interbedded in the Eocene age sedimentary rocks on the Andaman Islands. There exist numerous other tephra deposits in the Mio-Pliocene age rocks, which suggest enhanced volcanic activity during this time. In absence of evidences for existence of nearby arc volcanoes, the source(s) of these tephra deposits are difficult to interpret. The currently active inner volcanic arc, located east of the Andaman Islands, seems to be quite young and probably came into existence only after the opening of the Andaman Sea in the late Miocene. Towards this, we studied a sediment core (SK-234-60) from the Andaman Sea, in which we discovered seven discrete ash layers. Using isotopic and geochemical tracers we have clearly established that the Barren Island Volcano is the sole source to these ash layers. From our study, it appears that the Barren Island Volcano was the only major eruptive centre in the Andaman Sea during the late Pleistocene and the Holocene and its debris covered an extensive area around the volcano. We reconstructed the eruptive history of this volcano by dating foraminifers (AMS ^{14}C dating) in sediment layers. The seven ash layers present in the core found to represent major eruptions of the volcano at ~72, 71, 62, 24, 17, 12, and 8 ka. Through the study of these ash layers we made several other findings:

- The ash layers erupted from 72 ka through 17 ka have highly uniform ε_{Nd} composition, which indicates that the Nd isotopic composition of magma of the Barren Island had remained almost constant during this large time period.
- Since the ~12 ka eruption to the present the isotopic composition in magma has been highly variable as also observed in ε_{Nd} of historic and recent eruptions on Barren Island.
- Isotopically correlating the precaldera volcanics exposed on the volcano to the uppermost ash layer (AL-1) in the core, we infer that the caldera of Barren Island volcano is younger than 8 ka.
- We speculate that an eruption at ~62 ka, thickest in the entire record, with the coarsest particles, was quite large and during this time the volcano had grown to near sea level or above it.
- The ash layers in the core mostly consist of vesiculated lithic fragments that contained microcrystals of translucent plagioclase (labradorite and bytownite), pyroxene (augite, enstatite and diopside) and green olivine (fosterite), titaniferrous magnetite, spinel and amphibole embedded in a matrix of glass.
- Similar to most of the subaerial lava flows on the Barren Island Volcano, the glass matrix compositions of the lithic fragments represent sub-alkalic volcanic magma which is basaltic to andesitic in composition. The parental magmas during various eruptions in the past were more evolved than the modern flows.

- The glass matrix compositions of lithic fragments in a given layer suggest that those were derived from magma undergoing fractional crystallization during that particular volcanic event.

In order to understand the tectono-sedimentary processes occurring in the subduction zone environment we have studied the records preserved in the sediments from the Andaman Islands (Late Cretaceous to present) and the Andaman Sea (Pliocene to present). The study of sedimentary rocks from the Andaman Islands clearly suggests that the Mithakhari Group sediments, deposited during the early to middle Eocene, were derived predominantly from mafic igneous sources comprising suprasubduction ophiolites and volcanic arc rocks of the ASZ. We also found minor contributions from the Himalayan/Indian Shield sources to the basin during this time. In comparison to the Mithakhari Group sediments, the Andaman Flysch Group sediments deposited during the Oligocene appear to have been derived from mixed sources with dominance of Himalayan sources. Through the study of the sediments from the Andaman Islands we made several other findings as listed below.

- Geochemical results show that the sources for the Mithakhari sediments had undergone less weathering while the sources of sediment for the Andaman Flysch Group were highly weathered.
- The sediments to the Mithakhari Group did not get transported long distances and had not undergone much recycling and sorting before deposition, while the sediments contributed to the Andaman Flysch Group were transported to large distances before being deposited and had undergone substantial recycling and sorting.
- The sedimentary rocks from the Andamans show mixing of sediments derived from the Himalayas and Andaman arc/ophiolite sources. During the deposition of rocks of the Mithakhari Group, the local arc/ophiolite sources possibly contributed >80% of sediments, whereas the same sources contributed about 60-80 % during the deposition of the Andaman Flysch Group.
- We believe that the substantial increase in the sediment input from the rising Himalaya during the deposition of the Andaman Flysch Group was result of large scale weathering, erosion and transportation of sediments through the paleodrainage system developed along arc and suture zone. At this time (~40 Ma), probably major thrusting events occurred in the Himalaya which provided the essential height to act as

topographic barrier to the moisture-laden winds from the south. This resulted in the development of the first monsoon system which eventually led to increase weathering and erosion in the Himalaya.

In order to understand the impact of climate on weathering and erosion, and supply of sediments in the past, sediments in the core (SK-234-60) from the Andaman Sea were studied. From the study of these sediments we have been able to determine that the western Andaman Sea show relatively higher contribution of sediments from mafic sources of the Indo-Burman Ranges (mainly ophiolites), while sediments from the Irrawaddy river system dominate in the sediments deposited in the central and eastern Andaman Sea. The elemental and isotopic compositions of the sediments reveal significant variations in the relative supply of sediments from sources over glacial-interglacial timescale that correlate well with the variability of South-Asian monsoon. The changes observed reflect influence of climate on erosion in source areas and relative supply of sediments to sea. We made several other findings from the study of these sediments, as listed below.

- Significant increases were observed in the relative contribution of sediments from mafic Indo-Burman sources at ~8 kyr, ~20 kyr (LGM), ~36 kyr, ~44 kyr, ~52 kyr and ~58 kyr. We believe that these were related to the weakening of the Asian summer monsoon, which restricted material contribution from the Himalayan sources.
- Higher sediment contributions from higher Himalayas and continental Myanmar sources through Irrawaddy and Ganga-Brahmaputra rivers at ~6 kyr, ~10 kyr, ~15 kyr, ~46 kyr, ~54 kyr and ~60 kyr and ~72 kyr could have been resulted from intensification of Asian summer monsoon, which in turn could be correlated to the global events of warm climate during Pleistocene-Holocene transition, Bølling-Allerød (B/A) and Dansgaard-Oeschger (D-O).
- The increase in overall contribution of sediments derived from the Indo-Burman sources since the LGM is inferred to be related to the strengthening of the surface currents in the north-western Andaman Sea due to increase in the sea level after the LGM. This resulted in reopening of "Preparis North Channel" through which substantial quantity of sediments from the NE Bay of Bengal entered into the Andaman Sea.

To understand the pattern of earthquakes and history of deformation on the Andaman and Nicobar Islands, investigations were carried out along the uplifted coastlines of two islands. Based on radiocarbon ages of exposed coral reefs from studied sections, seismic history of the islands for past 9 kyr was reconstructed. From our study on the tectonically formed coastal terraces we made following conclusions.

- Earlier reports and our results reveal that the Andaman region had experienced a major earthquake and associated tsunami event at ~500 (or ~600) cal yr BP.
- Combining our data with the available data on such events in this region we have been able to determine that there have been at least 14 major landscape changing seismic events between ~40 kyr BP to present, with a hiatus between ~19.5 and ~8.5 cal kyr BP.
- We propose that in a similar fashion as observed subsequent to the 2004 earthquake, the Andaman Islands have been experiencing tectonic upliftments in the north and subsidences in the south, for the last ~40 kyr, along the so called ''pivot line'' proposed by Meltzner et al. (2006).

Scope for future work

Although the present work carried out on the sediments deposited in the Andaman forearc and backarc basins reveal many interesting aspects of this subduction zone and its evolution, there exist numerous gaps in our knowledge as our study area was very much restricted to the northern sector only. Also, our record has large time gap between 20 Ma and 70 ka. Therefore, a comprehensive understanding of the time evolution of the region would require studies in Archipelago Group and sediments from Mergui Basin. Besides this, future studies should also address the following topics.

- The stratigraphy of the Andaman and Nicobar Islands is still not well developed. There are many sedimentary units which are misidentified, unclassified or wrongly classified. Efforts should be made to improve this.
- There are several field of mud volcanoes on the Andaman Islands constantly emitting gases, water and mud breccias along with clasts derived from subsurface lithological units. These clasts may represent formations not exposed anywhere on the islands. Charcterization of these clasts can improve our overall understanding of the geology of the region.

- Apart from those studied in this work, several other coastal terraces have been observed on different islands in Andamans. These can be further studied to refine the paleoseismic record in the region.
- The rocks of Nicobar Islands have been completely neglected in earlier studies including ours. Their study can throw more light on the evolutionary aspect of the ASZ.
- In order to study volcanic history of the region we need to do more work on the tephra interbedded with sedimentary formations of Andaman Islands.
- Although we made an attempt to reconstruct the evolutionary history of the Barren Island Volcano, using a sediment core from the Andaman Sea, we admit that data from a single core may not be sufficient to reconstruct the complete eruption history of the volcano. It is quite possible that many of the past ash eruptions were simply not recorded at our core site because of their dispersal in other directions. Therefore, more cores need to be studied to reconstruct volcanic histories of the Barren Island Volcano as well as of Narcondam.