Summary of Ph.D. Thesis entitled

Geochemical and Isotopic studies of sediments from the Andaman Islands and the Andaman Sea

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SUMMARY

Subduction zones are tectonically most active regions on our planet. The tectonic processes related to subduction result in the formation of various morphological features such as trench, accretionary prism, volcanic arc, back-arc basin etc. Although such features are common in many subduction zones formed by convergence of oceanic plates, the Andaman Subduction Zone (ASZ) in the Indian Ocean is one of the few that contains the complete set of above morphological features. The ASZ came into existence during the Late Cretaceous, as a result of sinking of the Indian Plate under the Eurasian Plate. The ASZ and its southward extension to Sumatra, is one of the youngest and seismically most active subduction zones of the planet, well known for its high magnitude earthquakes and large and destructive volcanoes. These have made the ASZ an ideal site to study tectono-sedimentary processes, volcanism and paleoseismicity related to subduction. Our interests in the Andaman Subduction Zone lie in understanding its evolution since the Paleocene to the present by gathering valuable information from the sedimentary records of the Andaman Islands and the Andaman Sea.

In the ASZ, the Andaman-Nicobar archipelago represents the exposed part of the accretionary prism and the Andaman Sea is an extensional back-arc basin. The Andaman accretionary prism, formed as a result of various tectno-sedimentary processes, consists of suprasubduction ophiolites, pelagic sediments and trench-forearc turbidites. The sediments on the accretionary prism are believed to have started depositing since Paleocene and therefore, most likely preserve records of many important geological events of global significance happened during this Era such as India–Asia collision, the disappearance of Neo-Tethys, evolution of the Himalayas, creation of currently active volcanoes of south and southeast Asia, evolution of the South Asian monsoon system and major changes in the oceanic circulation in the northern Indian Ocean. Moreover, in the absence of extensive studies from the Andaman Islands, the knowledge about provenance for the sedimentary rocks deposited has remained inconclusive (Karunakaran et al., 1968; Pal et al., 2003; Curray et al., 1979; Curray, 2005; Allen et al. 2007). The different tectono-sedimentary processes which resulted in development of these islands in the subduction zone environment and the depositional history of the sediments on them have remained largely unknown. In this work we have done a comprehensive

geological and geochemical study on the sedimentary rocks to settle much of the outstanding issues related to the regional geology, stratigraphy and evolution of the Andaman region. We have not only attempted to resolve the issues pertaining to provenances but also tried to determine if the Himalayan-Tibetan orogen contributed sediments to the Andaman Islands. If indeed the Himalayan-Tibetan orogen supplied significant detritus to these islands, then the sedimentary record can reveal a lot about the early evolution of the orogen and the development of river systems in India and Myanmar, those originate from the Himalayas.

The Quaternary was most eventful of all geologic times and has observed major climatic changes, fluctuations in eustatic sea level in accordance with changing continental ice cover (Chappell and Shackleton, 1986). Understanding of past climatic variations and oceanographic changes during the Quaternary is important to fully understand present day climate. Climate and tectonics both largely control the physical and chemical weathering in the source regions and contribution of sediments to the ocean. Thus, marine sedimentary record is the most important and easily accessible repository of palaeoclimatic variations. The Andaman Sea in the North Eastern (NE) Indian Ocean, currently, receives sediments from Irrawaddy, Salween, and Sittang rivers of Myanmar (Rodolfo, 1969), but it is yet to be established if the scenario were similar in the past. The study of sediments from the Andaman Sea would not only reveal the pattern of sedimentation in the basin but also throw light on the impact of climate on weathering and erosion, and supply of sediments during the Quaternary. The study might also provide link between the South Asian and East Asian monsoons. Therefore, it is essential to delineate the sources contributing sediments to the Andaman Sea. The variations observed in provenance would likely to reveal information about climatic and tectonic changes those took place in the past.

Numerous volcanic and seismic activities are known to have shaped the morphology of the Andamans. The evidences of volcanic eruption are likely preserved in the sedimentary record of the region in the form of ash deposits. Ash can be linked to various eruptive centres in the region through isotope/geochemical fingerprinting. Once the links are established these records can be utilized to determine the timing of past major volcanic activities in the region. Also, the pattern of earthquakes and their effects on the geomorphic evolution of the region can be understood by studying the tectonically formed coastal terraces in Andaman and Nicobar Islands.

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 using petrographic, geochemical and isotopic techniques. Since, such studies require a satisfactory time framework, we have used geochronological data from literature (for ages >50 ka) and dated younger records (oceanic) using radiocarbon method.

The specific objectives of this thesis work were to:

- decipher the past volcanic activities in the Andaman region through the sedimentary records preserved on the islands and in the sea.
- determine the timing of deposition of various formations on the islands, and sedimentation in the Andaman Sea.
- determine sediment provenances and drainage patterns that transported the sediments
- understand the role of climate and tectonics on sedimentation.
- understand the origin and evolution of the Andaman region.

To achieve the above objectives we studied the sedimentary records on the Andaman Islands and that in the Andaman Sea a detailed fieldwork was carried out on the Andaman Islands and suitable rock samples were collected from various formations on the islands and a sediment core (SK-234-60) was raised from the western Andaman Sea. The major conclusions of this study are listed below:

- To determine the timing of major volcanic activities in the region, we have studied ash deposits preserved in the sedimentary records. 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 the Barren Island Volcano as the sole source to these ash layers.
- 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.
- 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.
- 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 with minor contributions from the Himalayan/Indian Shield sources.
- 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.
- 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.
- From the study of sediments in core (SK-234-60) 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.
- 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.

- Based on radiocarbon ages of exposed coral reefs from studied sections along the uplifted coastlines of two islands of Andaman, seismic history of the islands for past 9 kyr was reconstructed.
- Earlier reports and our results on the tectonically formed coastal terraces 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).

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