Chapter-1
Introduction

1.1 Subduction Zone

1.1.1 Plate Tectonics and importance of Subduction Zone

On the basis of physical properties, the silicate portion of the Earth has been classified into two distinct layers, known as: the lithosphere and asthenosphere. The lithosphere is the rigid outermost rocky part of the Earth, which comprises the crust and a portion of the upper mantle, while asthenosphere, underlying it, is the deeper part of the upper mantle and is comparatively weaker, hotter and more viscous. The lithosphere of the Earth is broken into several continental and oceanic tectonic plates, which constantly move with respect to each other. The driving force behind these movements is the mantle convection currents produced in the Earth's interior due its internal energy. The science which deals with the study of cause of, and relative motions of, lithospheric plates is known as plate tectonics. Seven major and several minor plates have been recognized. The motions of these plates are extremely slow but they continuously interact among themselves in both constructive as well as in destructive manner and reshape the surface morphology of our planet. Based on the relative motions of these plates, three types of plate boundaries have been recognized: divergent, transform and convergent.

At divergent plate boundaries, two plates move away from each other resulting in upwelling of mantle, which then melts to fill the gap and form new oceanic crust. Within continents, these plate boundaries produce rift valleys while between oceanic plates; these exist as mid-oceanic ridges (MOR). The transform plate boundaries are another type, where the plates slide past one another predominantly in horizontal direction which can be either sinistral or dextral. These are also known as conservative plate boundaries, since at these boundaries lithosphere is neither created nor destroyed. The transform faults are connected on both ends to other faults, ridges, or subduction zones. Most of the transform faults are located in the deep oceans where they are present as zigzags accommodating seafloor spreading, but a few present on land too, e.g., San Andreas Fault in USA.

At the convergent boundaries the lithospheric plates are destroyed. These are also known as subduction zones. At subduction zones, the colder and denser tectonic plates (subducting plates) sink into the mantle beneath comparatively hotter and lighter tectonic plates (overriding plates). Subduction zones are our planet's largest recycling system and are also the places where new continental crust gets generated on the overridding plate (Hawkesworth, 1993). These are also tectonically most active regions on our planet and often known for their association with volcanism, earthquakes and mountain building activities.

A Subduction Zone provides exposures and allows easy access to study the lower oceanic crust and upper mantle in place and provide a unique opportunity to study the magmatic products associated with the initiation of subduction. Study of rocks in convergent plate margins can provide answers to several questions pertaining to role of fluids in modifying the chemistry of recycled material, in metamorphism at such zones and in generation of partial melts in the mantle wedge. These can also help understand the pathways of elemental recycling into the mantle and processes that lead to chemical modification of the mantle. Sedimentary rocks deposited at such zones can reveal a lot about the tectonic processes and their timings in the development of important geomorphic features that shape the convergent margins.

1.1.2 Earthquakes and Volcanism in Subduction Zones

The earthquake and volcanic activities are indicators and consequences of the movements along the lithospheric plate boundaries and based on their worldwide distribution, tectonically active regions of the world and the margins of the lithospheric plates have been defined. The most destructive, high magnitude (M>6) and deepest earthquakes are known to occur at subduction and collision zones in comparison to divergent and transform boundaries which are characterized by smaller magnitude and much shallower earthquakes. In subduction zones, the earthquake hypocentres lie in a plane known as the Wadati-Benioff zone, which represents the brittle region in the upper 10-20 km of the subducting lithospheric slab. Earthquakes at convergent margins many a times cause rapid deformation of the sea floor leading to tsunamis.

Subduction Zone volcanism has the greatest impact on humans, because of their violent eruptions and long term effect on global climate. At subduction zones, oceanic lithosphere, sediments and seawater reequilibrate with Earth's mantle and then return to surface through arc volcanoes (Stern, 2002). The source and type of magma genarated depends on tectonic environment, e.g., angle of subduction, depth of subduction, thinness of mantle wedge etc. At subduction zones, magma generated has its origin from the partial melting of heavily metasomatized mantle wedge in presence of fluids derived from subducting oceanic crusts. The compositions of lava generated are complex, but incipient island arcs tend to be more basaltic in composition, whereas mature volcanic arcs tend to be more andesitic in composition. The volcanoes of subduction zones are usually stratovolcanoes, which eject large amounts of pyroclastics that get dispersed to large distances due to high energy eruptions.

1.1.3 Structure of a subduction zone

Despite the fact that subduction zones are the most well studied regions of the globe, the processes that lead to the evolution of various geo-morpho-tectonic features in these zones are not very clearly understood. This is partly because, the efforts in this regard are limited by absence of exposures of active regions and lack of understanding of important tectonic controls that lead to morphological changes (Dickinson and Seely, 1979; Underwood and Bachanan, 1982; Moore, et al., 1982). The current understanding of subduction zones is based primarily on geological and geophysical studies done on active and ancient subduction complexes now exposed on land (Karig, 1974; Seely, et al., 1974; Karig and Sharman, 1975). Although, a complete set of morphological components of subduction zone is rarely exposed at a single margin, studies on numerous subduction zones suggest a generalized morphology consisting of features, which in order includes: a peripheral bulge (or outer swell), trench, accretionary prism, forearc basin, volcanic arc and backarc basin (van der Pluijm and Marshal, 2004) (Fig. 1.1). In the following paragraphs brief description on some of these features are given.

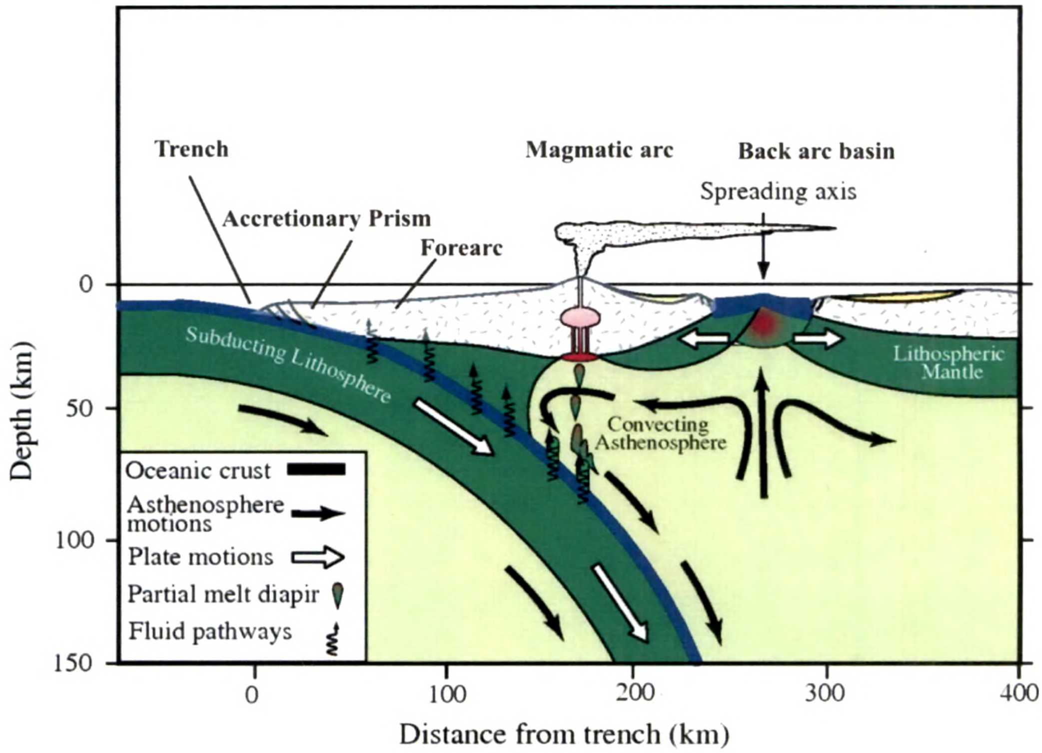

Fig. 1.1: A schematic diagram showing various morphological components of an ocean- ocean plate subduction zone: viz. trench, accretionary prism, forearc basin, volcanic arc and backarc basin. (Source: http://en.wikipedia.org/wiki/File:SubZone.jpg).

(A) Trench

In a convergent plate boundary, a peripheral bulge is encountered on the subducting plate before the trench, where the surface rises to form a broad arc due to flexural rigidity of the lithosphere (Uyeda and Kanamori, 1979). But the 'Trench' marks the actual boundary between the downgoing plate and the overriding plate where the former bends from its horizontal position to dipping position (Fig. 1.1). The trench is long but narrow topographic depressions of the sea floor, created by the gravitational pull of the relatively dense subducting plate pulling the leading edge of the plate downward. Trenches, near continents, are sometimes buried under great volumes of sediment supplied by large rivers or glaciers. Such trenches lack bathymetric expressions. Trenches distant from influx of continental sediments lack accretionary prism and the inner slope of such trenches is commonly composed of igneous or metamorphic rocks.

(B) Accretionary Prism

An accretionary prism or wedge is formed from sediments that are accreted on the overriding plate near the trench (Fig. 1.1). Materials incorporated in accretionary wedges include: ophiolitic rocks, pelagic sediments and deformed turbidites and in some cases the erosional products of volcanic island arcs. An accretionary prism develops either by frontal accretion whereby sediments are scraped off from the edge of downgoing oceanic plate, or by underplating of subducted sediments and perhaps oceanic crust (ophiolites) along the shallow parts of the subduction decollement. Ophiolite rocks representing obducted uppermost part of oceanic lithospheres (Dewey and Bird, 1971; Coleman, 1977; Nicolas et al., 1989) are categorized into two types- subduction related and subduction-unrelated types (Dilek and Furnes, 2011). Subduction related ophiolites are of suprasubduction zone varieties, develop during the initial stages of subduction prior to the development of any volcanic arc (Pearce et al., 1984) and are geochemically similar to island arc magmas.

Structurally, an accretionary prism is imbricate stack of fault slices formed by thrust-controlled emplacement of discontinuous slices of ophiolites and trench fill sediments (Condie, 1989; Platt, 1986; Moores et al. 1984). The continuous accretion of new thrust wedges of ophiolite occur from the bottom, which expose the older thrust wedges to the seafloor (Platt, 1986). With continuous subduction and upliftment with time, a series of thrust slices of ophiolites were thus emplaced with complex folds in them. These thrusts slices show listric faults, steeply dipping towards the arc (Dickinson, 1977; Roy, 1992; Pal et al., 2003). Several isolated slope basins develop in between these thrust-bounded structural ridges of ophiolite, which trap the material derived from the eroding thrust wedges in a deep-water environment. Sediment transport in this environment is controlled by submarine landslides, debris flows, and turbidity currents. Submarine canyons transport siliciclastic sediment from beaches and rivers of nearby landmasses down the upper slope which is further carried via channels and a series of fault-controlled basins. Frontal accretion results in younger sediments defining the outermost part of the accretionary prism and the oldest sediments defining the innermost portion.

The accretionary prisms are also sites for mud volcanoes and fluid activities, wherein Earth's most dynamic and complex interactions between aqueous fluids and rocks occur. The upper lithosphere and sediments of the subducting plate, and sediments accreted to the forearc contains large volume of water entrapped in their pores and fractures. These sediments having hydrous minerals are progressively squeezed with increasing pressure and temperature as they are subducted which forces fluid out along the decollement and numerous thrust faults up into the overlying forearc. Water released by dehydration accompanying phase transitions, is another source of fluids. These fluids along with solid materials may travel through the accretionary prism diffusely, via interconnected pore spaces in sediments, or may follow discrete channels along faults. Sites of venting may take the form of mud volcanoes or seeps and serve as windows to the subducting slab. These fluids are dominated by water but also contain dissolved ions and organic molecules, especially methane. At greater depths the fluid released alters the bulk composition of the mantle wedge and trigger partial melting reactions which are responsible for magma generation (Peacock, 1990).

(C) Magmatic/Volcanic Island Arc

As discussed above during the process of subduction, when the descending slab saturated with water and volatiles comes in contact with mantle wedge, causes release of fluids which cause partial melting in the mantle wedge. The melts generated rise from the point of melting through the overriding plate and erupt on surface to form volcanoes (Fig. 1.1). These volcanoes generally occur in arc-shaped chain of volcanic islands, often parallel to trench and popularly known as Magmatic/Island Arc. The volcanoes of Japan, Aleutian, Mariana and Lesser Antilles are some of the best examples of volcanic arcs.

(D) Fore-Arc and Back-Arc Basins

In later stages of subduction, a forearc basin develops between the accretionary prism and volcanic arc due to extensional processes (Fig. 1.1). Typically, it is filled with siliciclastic sediments (flysch) from the adjacent landmass and material trapped from oceanic crustal sources. Subsequent shallowing of the basin results in deposition of calcareous sediments along with frequent pyroclastic influx from volcanic arc sources. It is observed that the strata of a forearc usually cover the top of the accretionary wedge and/or trapped oceanic crust or submerged parts of volcanic arc. Sometimes, outer part of forearc gets uplifted to form outer arc ridge running parallel to it (ten Veen, and Kleinspehn, 2003; Yanagi, 2011).

A back arc basin develops on the inner concave side of the volcanic arc (Fig. 1.1). Several hypotheses have been proposed for its development. Earlier it was believed that convergent plate margins were zones of compression, thus zones of extension (back-arc basins) above subduction zones were not expected. It was only in 1970, when Dan Karig, based on several marine geologic expeditions to the Western Pacific, first proposed that some convergent plate margins were actively spreading. Karig (1971) proposed that development of back arc basin, due to extension, resulted from the forcible intrusion of basaltic mantle diapirs. Packham and Falvey (1971) believed that the spreading was because of passive magma upwelling, due to the trench suction force resulted from a roll-back of the trench. The term 'roll-back of the trench' describes the backward motion of the subduction zone relative to the motion of the plate which is being subducted. This causes regional extensional stresses in the back arc region and makes the lithosphere considerably thinner (Chase, 1978; Fein and Jurdy, 1986). Hsui and Toksoz (1981) and Jurdy and Stefanick (1983) suggested that extension occurs due to formation of secondary convection cells in the mantle wedge overlying the benioff zone, induced by descent of the subducting slab.

Back-arc basins are usually very long and relatively narrow, with spreading rates which vary from very slow, a few cm/yr to very fast >10 cm/yr (Taylor and Martinez, 2003). The ridges in back-arc basins erupt basalts derived from depleted mantle similar to those erupted at the mid-ocean ridges (Hart et al., 1972). The main difference lies only in their magmatic water content and correlated trace elements, which is higher in back-arc basin basalt magmas (Stolper and Newman, 1994). Sedimentation in the back arc basin is strongly asymmetric, with most of the sediment supplied from the active magmatic arc and adjacent landmasses. Not all subduction zones have back-arc basins, some of the active back-arc basins are found in the Marianas, Tonga-Kermadec, S. Scotia, Manus, N. Fiji, and Tyrrhenian Sea regions, but most are found in the Western Pacific.

1.1.4 Sedimentary records in Subduction Zones

Deposition of sediments within a subducton zone occurs in the trench, and in the fore arc and back arc basins. Although the trenches receive sediments throughout the evolution of a Subduction Zone, the oldest trench materials are generally found obducted onto the accretionary wedges. Since a part of the trench sediments ultimately undergo subduction into the mantle, study of these rocks can shed some light on the recycled crustal components. Sediment deposited in the forearcs, which are generally found on the accretionary wedges, can reveal a lot about the evolution of the subduction zone. In particular these may provide information on timing and processes that led to the formation of accretionary wedge, and magmatic arc. In addition determining the sources of these sediments can lead us to understand the tectonic evolution of the surrounding landmasses and the drainage patterns therein. Sediments deposited in the backarc basins usually represent the latest phase of sedimentation in subduction zone and likely to yield information about the events that occurred subsequently to the opening of the backarc sea. These can also provide information about the volcanism in the arc during recent past.

1.1.5 Paleoseismic records in accretionary wedges

As already discussed, subduction zones are known for their high seismic activities and associated tsunamis, which are great natural hazards and cause large scale devastations of life and property. Many times paleoseismology studies have changed comforting notions about the seismicity of a region by unearthing evidences of extremely large earthquakes and tsunamis. Therefore, paleoseismological studies of subduction zones become necessary to understand the causes, effects and patterns of large earthquakes. In active subduction zones, local geomorphic features such as coastal terraces of accretionary prisms are often formed by tectonics and not by local fluctuations in the sea-level. In many cases, these coastal terraces have been proven to be very useful in understanding the relationship between earthquakes, active tectonics and individual faults in a region (e.g., Chappell, 1974; Kayanne et al., 2007; Ota, 1991, 1992; Rajendran et al., 2007, 2008).

1.2 Andaman Subduction Zone (ASZ)

The ASZ in the northeastern Indian Ocean is a part of the Burma-Andaman-Sumatra-Java (BASJ) subduction zone (Fig. 1.2). The ASZ and its southward extension to Sumatra are famous for high magnitude earthquakes. It is also well known for being home to some of the large and destructive volcanoes of the world. The young and seismically very active ASZ is one of the few convergent margins that contains the complete set of the morphological features of an ideal subduction zone setting. ASZ is believed to have come into existence after the early Cretaceous break-up of the Gondwanaland, when the Indian plate moved northward and started subducting under the Eurasian plate (Curray, 2005). At ~50 Ma, the northern edge of the Indian plate collided with the Eurasian plate (Rowley, 1996; Hodges, 2000), which subsequently gave rise to the Himalayas in the north. It is also believed that in the eastern and south-eastern margin, the subduction of Indian oceanic plate continued under the Eurasian plate (Acharyya, 1992). Studies suggest that the northward motion of the Indian plate was very rapid, 16-20 cm/yr between Late Cretaceous and early Paleogene (Patriat and Achache, 1984; Besse and Courtillot, 1988; Klootwijk et al., 1992; Lee and Lawver, 1995) and it covered a distance of about 2,000 km to 3,000 (Molnar, 1986).

Figure 1.3 shows schematic cross section across the ASZ along the A-B transect on Fig. 1.2. The regional tectonic setting of the ASZ is very complex. Chronological evidences from sedimentary record in the Bengal fan and obducted ophiolites (on the Andaman and Nicobar Islands) suggest the subduction in this region got initiated during the middle-late Cretaceous (Cenomanian, ~95 Ma) (Roy, 1992; Das Gupta and Mukhopadhyay, 1993;

Moore et al., 1982; Pederson et al., 2010). The subduction has resulted in the formation of morhpho-tectonic features like trench, accretionary prism, a volcanic arc and a back-arc basin with spreading center. The convergent margin is marked by the sinuous-arcuate Sunda-Andaman trench. Along the Andaman and Nicobar islands it is called the Andaman trench. The Andaman trench marks the active subduction zone where, at present, the northeast-moving Indian plate is obliquely subducting below a small tectonic sliver plate

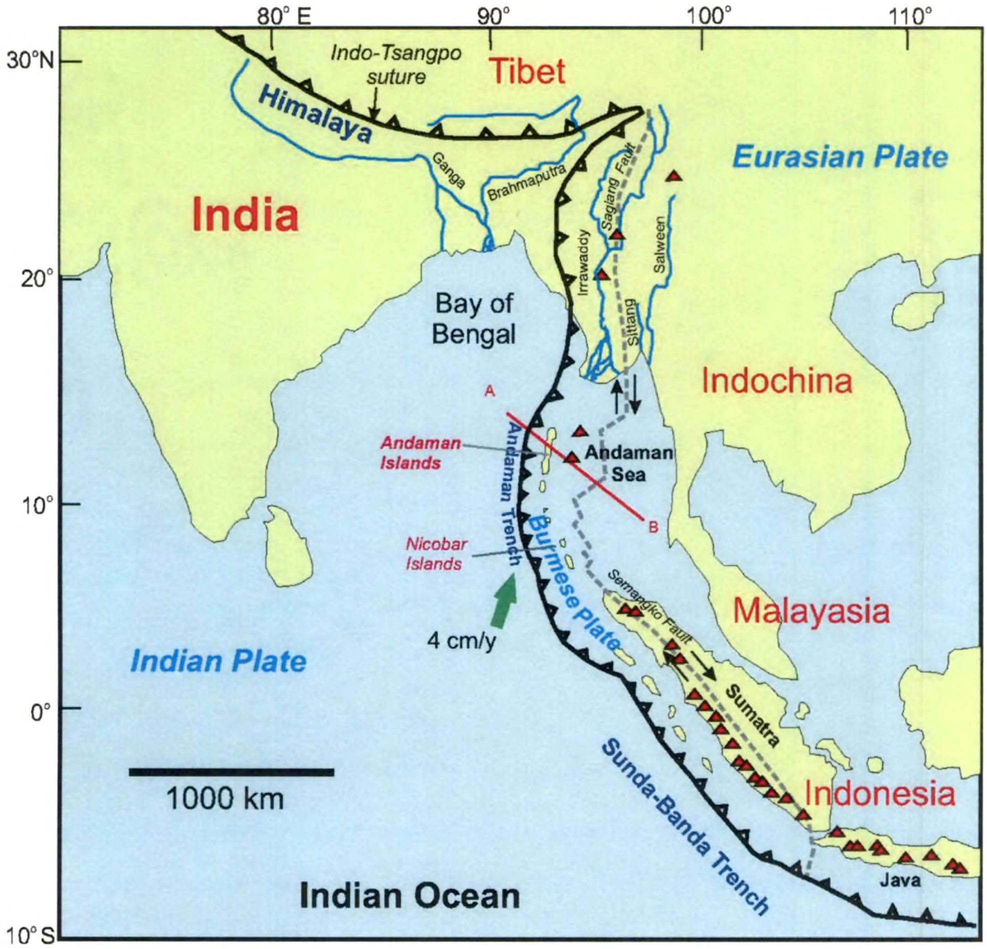

Fig. 1.2: Map showing northeastern Indian Ocean with major geological and tectonic features. The Indian Plate is obliquely subducting under the Burmese microplate along the Andaman Trench at the rate of 4 cm/yr (Gahalaut et al., 2010), arrow showing the direction of plate movement .Further south the Indian Plate is subducting under rest of Sunda Plate along the Sunda-Banda Trench. Red triangles represent volcanoes of volcanic arc whereas dotted line represents connected Sagaing and Semangko dextral strike–slip fault systems.

that has been referred to as the Burmese microplate (Dasgupta and Mukhopadhyay, 1993; Ortiz and Bilham, 2003; Kayal et al., 2004). Burmese microplate, believed to have formed during the Neogene (Curray, 2005), is separated from the rest of the Eurasian plate along a transform boundary running N-S through the Andaman Sea. The Andaman accretionary prism is located on this plate and has been discussed in detail later in this chapter. The Andaman Sea is an active extensional basin that encompasses backarc and forearc basins of the Andaman subduction zone, separated by a volcanic arc ridge containing subaerially exposed volcanoes of Barren Island and Narcondam. The complex tectonic setting has resulted in the development of several N-S trending thrust and strike-slip faults in the region.

The Andaman Subdution Zone has experienced several large-magnitude earthquakes in recent history (Rajendran et al., 2003; Bilham et al., 2005). The most devastating was the recent M9.1 earthquake that occurred on December 26, 2004, which generated a massive tsunami that killed approximately 229,800 people in continents surrounding the Indian Ocean. Most of the earthquakes in this region are generated by thrust and strike-slip faulting (Eguchi et al., 1979; Banghar, 1987). The seismicity of the region is marked by earthquakes with magnitudes varying from 4 to 8. Several reports and published data suggest that both shallow (10 km or less) and deeper (≧250 km) earthquakes are common in this region (e.g., Mukhopadhyay 1984, Eguchi et al., 1979, Banghar, 1987, Ortiz and Bilham, 2003, Kayal et al., 2004). These earthquakes are generally concentrated along the trench, on the east and west of the exposed accretionary prism and along the spreading center of backarc basin.

1.2.1 Andaman accretionary prism

Underthrusting of the Indian plate beneath the Eurasian plate resulted in the upliftment of ophiolites and pelagic sediments that developed a 3000-5000 km long outer-arc ridge. This outer arc ridge and associated forearc constitute the Andaman accretionary prism. Continued subduction and resultant tectonic upliftment exposed the accretionary prism

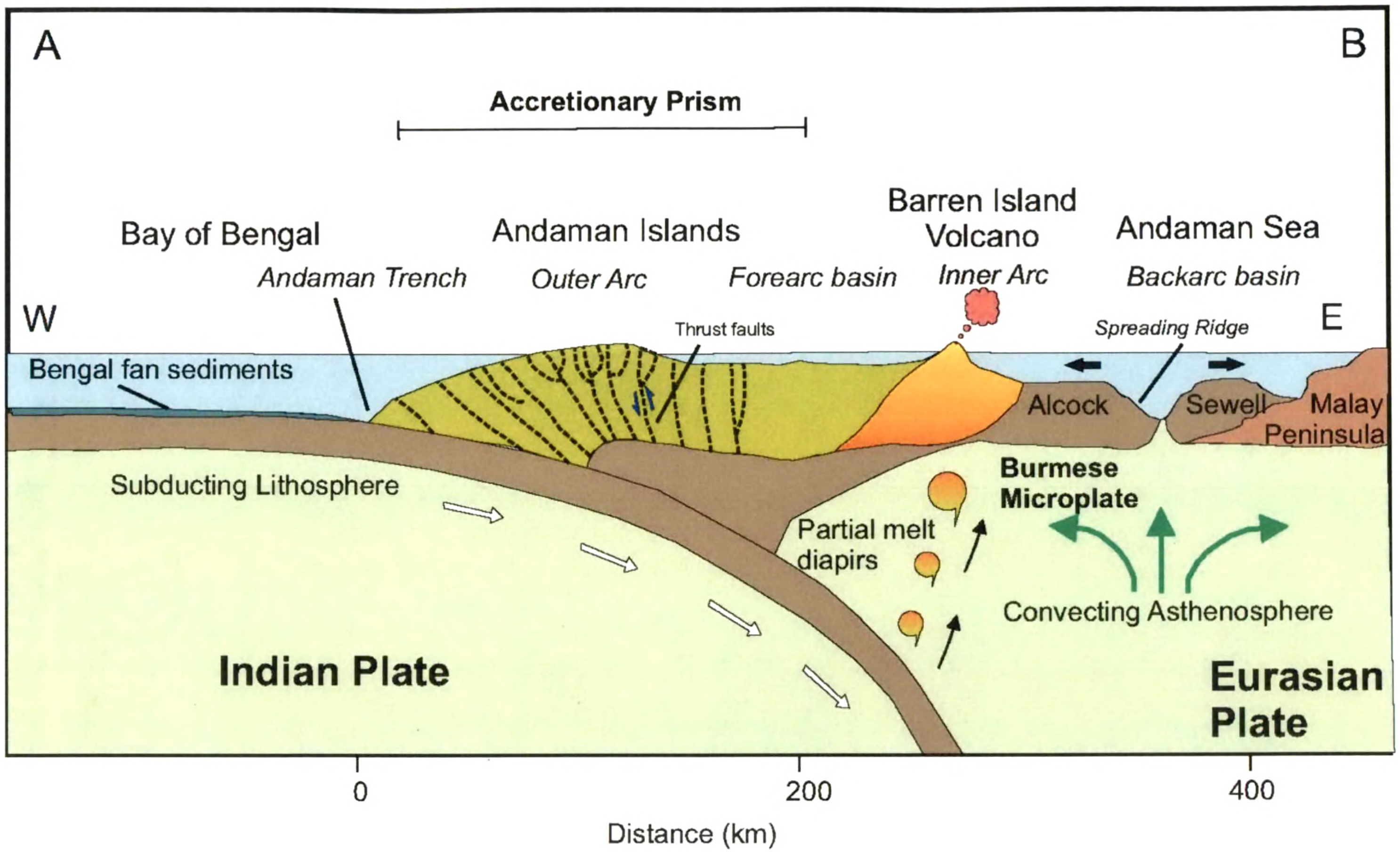

Fig. 1.3: A schematic cross-sectional profile of the Andaman Subduction Zone (along A-B in Fig 1.2) showing Andaman Trench, Andaman Accretionary Prism, Barren Island Volcano and Andaman Sea Back Arc Spreading Ridge.

above sea level as islands of Andaman and Nicobar (Fig. 1.2 and 1.3). The exposed part of the accretionary prism, consisting of 572 islands, extends from 6° to 14° N latitudes and from 92° to 94° E longitudes. These islands are aligned in a north-south direction in an arcuate shape. The Andaman group of islands is separated from the Cape Negaris of Myanmar by Preparis Channel and from Nicobar group of islands by the Ten Degree Channel. Except a few, most of the islands possess long hilly ranges, narrow valleys and sandy beaches. The highest point, known as Saddle Peak (732 m), is located in the North Andaman Island. The dense tropical forests that extend across the terrain cover ~86% of the total area. Mangroves are present almost on the entire coastline and coral reefs surround most of the islands.

The interpretation of geology of this accretionary prism is complex due to folding, thrusting and dynamic environments of deposition. Earlier studies have shown that it mainly consist of Late Cretaceous ophiolites and their erosional products, along with siliciclastic, carbonate and volcanoclastic sediments overlying it (Pal et al., 2003). Figure 1.4 shows a model for the tectono-sedimentary evolution of the Andaman accretionary prism, as proposed by Pal et al. (2003). According to this model, the accretionary prism started forming sometime between late Cretaceous and late Eocene in a compressional regime through frontal accretion process with emplacement of ophiolites and deposition of ophiolite-derived clastics and trench sediments in small isolated basin. During the Oligocene with change of compressional regime to extensional, siliciclastic turbidites alternated with ash turbidites started depositing. In Miocene-Pliocene time, carbonate turbidites also started depositing in the forearc region.

The western, outer slope of the accretionary prism is very steep, rising sharply from sea level within a short distance, whereas the eastern margin is bounded by faults. The ophiolite thrust sheets trend N–S and show dip towards the east except some back thrusts which dip towards the west. A few E–W trending out-of-sequence thrusts have also been reported (Pal et al., 2003). The thrusts on the western margin of the prism have been reported to have a ductile character while brittle behaviour has been reported in few thrusts from the eastern margin (Pal et al., 2003).

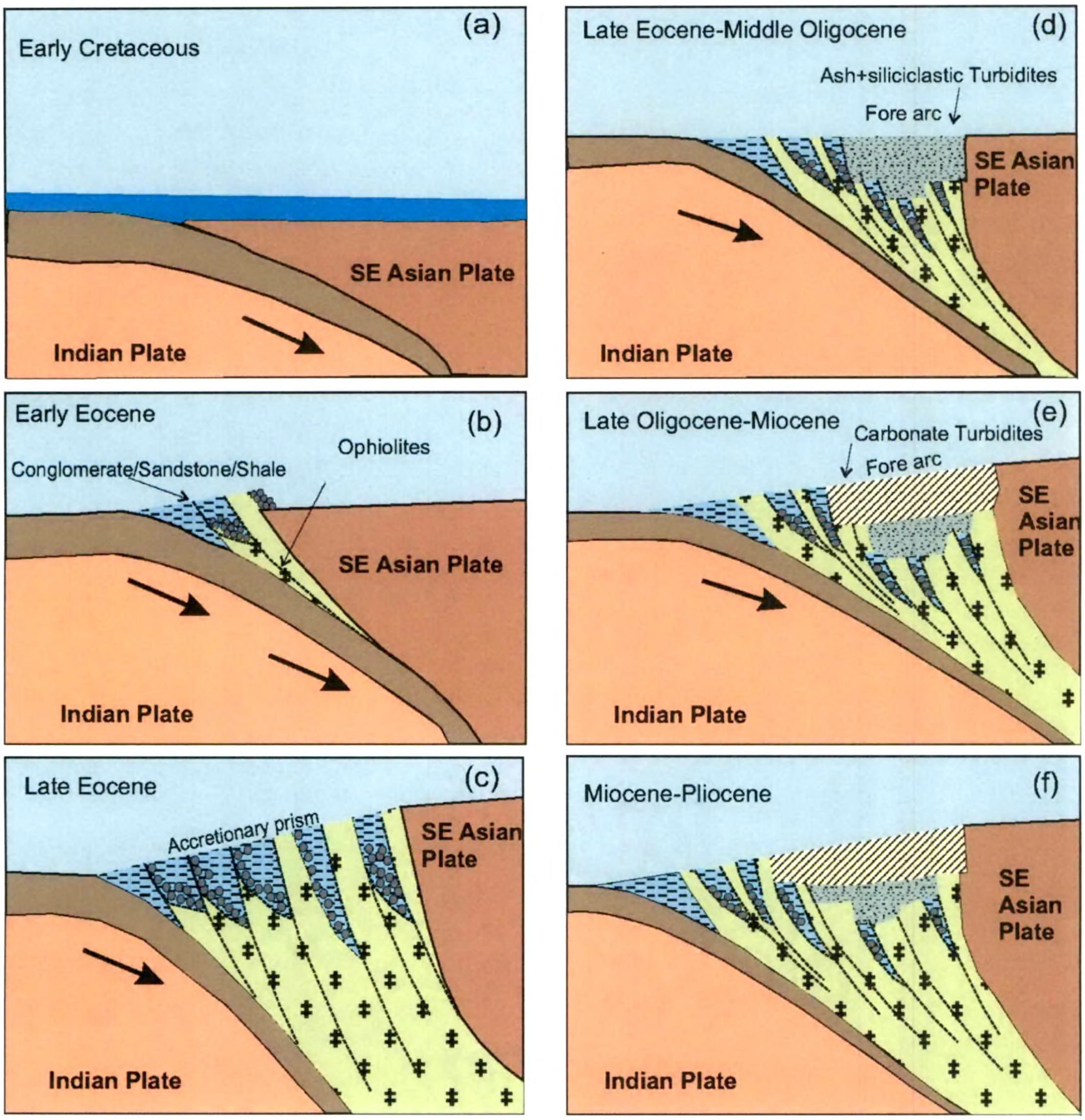

Fig. 1.4: A schematic diagram showing tectono-sedimentary events of Andaman Subduction Zone in different time periods (redrawn from Pal et al. 2003) (a) shows initial movement of subducting plate under overriding plate; (b) & (c) accretion and thrust controlled emplacement of ophiolite sheets and formation of trench-slope basins with deposition of ophiolite-derived clastics and trench sediments; (d) formation of extensional forearc basin on the rear side of wedge and deposition of siliciclastic turbidites alternated with pyroclastic flows (e) transition of siliciclastic to carbonate turbidites deposition along with pyroclastic flows.

The sedimentary rocks of the accretionary prism show variable bedding orientation. The lower formations deposited in trench-slope basins show folds with axial planes varying from inclined to vertical while upper formations deposited in forearc basin environment show folds with very regular geometry (Pal et al., 2003). Several SE–ESE-striking normal and reverse faults and a few right-lateral strike–slip faults have been reported within the accretionary prism (Dasgupta et al., 2003; Chakraborty and Khan, 2009).

The Andaman accretionary prism consists of several other interesting features like mud volcanoes, raised coral terraces and limestone cave deposits. There are at least 11 mud volcano fields on the Andaman Islands (Chakrabarti et al., 2006). These mud volcanoes constantly emit hydrocarbon gases, water and mud breccias and are known to occur in Middle and North Andaman islands and are linked to major east-dipping fault systems in the region (Roy, 1992). The raised coral reefs forming coastal terraces are present along numerous coastlines of the islands and appear to be quite young and believed to have been developed as a result of active tectonism in the region (Rajendran et al., 2007, 2008). The limestone cave deposits are found on Baratang Island in the middle Andaman.

1.2.2 Andaman Back Arc Basin

The Andaman back-arc basin is represented by the Andaman Sea, which extends 1200 km in N-S direction and 650 km in E-W direction. The Andaman-Nicobar ridge separates the Andaman Sea from the Bay of Bengal (Fig. 1.5). The central depression of the Andaman Sea, known as 'Central Andaman Basin,' is believed to have been developed due to rifting and extension (Curray, 2005) (Fig. 1.5). The basin has a basaltic oceanic crust (Rodolfo, 1969). According to Khan and Chakraborty (2005), this rift basin opened up as a result of counter clockwise rotation of south-eastern part of the Eurasian plate. This initiated the extensional activity along the transform fault segments connecting the two major right-lateral strike–slip fault systems, Sagaing and Semangko, during the middle Miocene (Curray et al., 1979; Hall, 2002; Kamesh Raju, 2005). The basin is home to prominent morphological features such as Barren and Narcondam volcanic islands, Invisible Bank, and Alcock and Sewell seamount complexes (Rodolfo, 1969) (Fig. 1.5). The swath bathymetry, magnetic, and seismological studies carried out by Kamesh Raju et al. (2004) suggested that the true seafloor spreading commenced only at about 4 Ma, which resulted in the separation of the Alcock and Sewell seamounts. The central deep valley divided the basin into two parts, east basin and west basin (Fig. 1.5) (Curray, 2005). During these phases of extension and rifting, the western shelf of the Malay Peninsula (the Martaban shelf and further south) was under the influence of rapid terrigenous sediment influx (Kamesh Raju et al., 2004). The arc volcanism resulted in upliftment of the western Andaman Sea and gave rise to several bathymetric highs and N-S trending fault systems which made it more complex compared to relatively smoother east basin (Fig. 1.5). This further prevented the high sediment dispersal into the west basins while the east basin underwent subsidence and received high volumes of sediments (Kamesh Raju, 2005).

The Andaman Sea received and currently receives large amount of sediments from the north through Irrawaddy, Salween and Sittang rivers of Myanmar and occasional minor volcanic tephra from arc volcanism east of the Andaman-Nicobar ridge (Rodolfo, 1969) (Fig. 1.2). This large sediments input was probably got initiated as a result of high weathering and erosion in rising Himalaya, Indo-Burman ranges and Tibet in response to tectonics and climate change. The South Asian summer and winter monsoons are known to affect the physical and chemical weathering of these source regions whereas surface ocean currents driven by monsoonal winds, play an important role in dispersal of sediments in the Andaman Sea (Rao et al., 2005; Ramaswamy et al., 2004). The Andaman Sea is a semi-enclosed basin and exchanges water and sediments with the Bay of Bengal and marginal seas of the Pacific Ocean through narrow channels such as the Preparis channel, Ten Degree channel, Great channel, Strait of Malacca (Rodolfo, 1969; Dutta et al., 2007; Keller, 1967; Ibrahin and Yanagi, 2006) (Fig. 1.5). Therefore, the sedimentary record of the Andaman Sea is likely to provide information about the changes in the tectonic and climatic conditions in the surrounding continents, volcanic activities in the region and changes in the ocean circulation patterns resulting from climate and sea-level fluctuations.

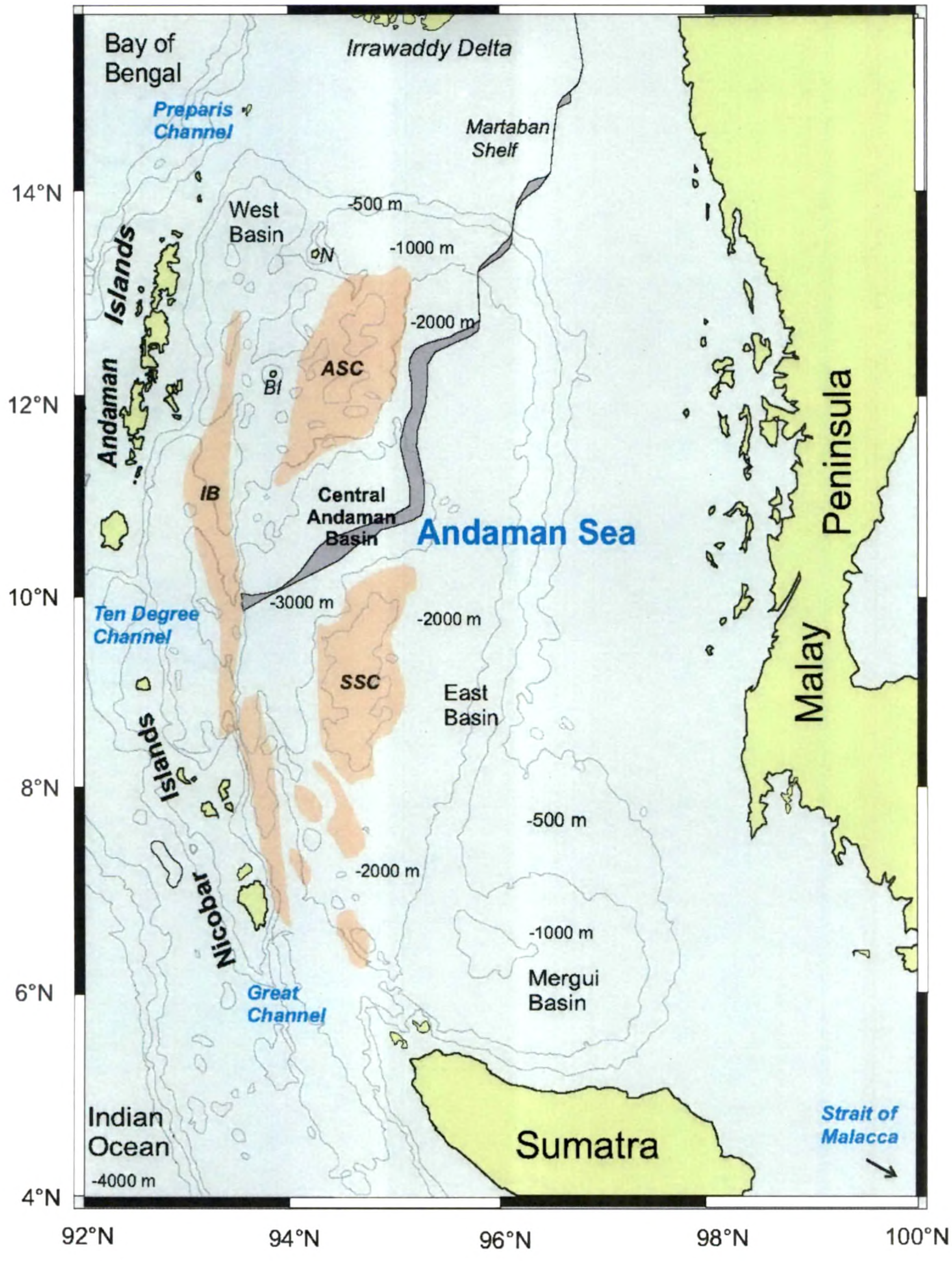

Fig. 1.5: Bathymetric map of the Andaman Sea showing the islands, continents, seaways and prominent ocean-bottom ridges/highs and basins. Abbreviations for this figure: N= Narcondam Volcano; BI= Barren Island Volcano; IB= Invisible Bank; ASC= Alcock Seamount Complex; SSC= Sewell Seamount Complex.

While the paleoceanographic and paleoclimatic studies from the Arabian Sea and Bay of Bengal are numerous (e.g., Anderson and Prell, 1991, 1993; Clemens, et al., 1991, Siroko et al., 1991, 1993; Naidu and Malmgren, 1995, 1996, 1999, 2005; Naidu, 2004; Rostek et al., 1997; Thamban et al., 2001, 2002, 2007; Singh et al., 2011; Cullen, 1981; Chauhan et al., 2001, 2004; Burton and Vance, 2000, Goodbred and Kuehl, 2000 etc.), only a handful of such studies exist from the Andaman Sea (Rodolfo, 1969; Rao, 1983; Curray, 2005; Naqvi et al., 1994, Ramaswamy et al., 2004; Rao et al., 1996, 2005; Chernova et al., 2001; Roonwal et al., 1997; Ahmad et al., 2000; Colin et al., 1998, 1999, 2006; Kurian et al., 2008; Rashid et al., 2007; Alagarsamy et al., 2010). In addition, studies from the Andaman Sea are not exhaustive compared to their counterparts in other parts of the Indian Ocean. These studies generally focused on clay mineralogy of the sediments (Rao, 1983), nature of organic matter (Ramaswamy et al., 2008), grain sizes and role of monsoon in their dispersal and transport (Rao et al., 2005; Ramaswamy et al., 2004), carbon and oxygen isotopic signatures on foraminifers (Naqvi et al., 1994; Rashid et al., 2007) and hydrothermal activity (Rao et al., 1996 Kurian et al., 2008; Chernova et al., 2001). Curray (2005) described the tectonic history of the Andaman Sea while Colin et al. (1998, 1999, 2006) discussed the weathering-erosional history and magnetic properties of sediments.

1.3 Rationale

1.3.1 Significance of this work

In Indian context, the Cenozoic time period is very important because many important geological events of global significance happened during this Era. These include the 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. The paleogeographic positions of the Andaman Islands and Andaman Sea during these times makes them most suitable localities for preservation of records of most of these events. The sedimentary records from these terrains are likely to reveal a great deal of information about the events like closure of the Neo-Tethys, tectonics related to Indian

Plate subduction, uplift, weathering and erosion in the Himalayas, the evolution of Bengal fan and the initiation of volcanism in this region.

In the absence of extensive studies from the Andaman Islands, the knowledge about provenance for the sedimentary rocks deposited on them 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. A comprehensive geological and geochemical study on the sedimentary rocks is required to settle much of the outstanding issues related to the regional geology, stratigraphy and evolution of the Burmese microplate since its creation. This would not only resolve the issues pertaining to provenances but also help us 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 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 in kilo year timescale. 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.

1.3.2 Aim of the thesis

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 present work we have made an attempt to use petrolographic, geochemical and isotopic techniques to determine the sources of sediments, their weathering history and control of climate and tectonics on them. 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. For this purpose rock samples were collected from various formations on the islands and a sediment core was raised from the central (or eastern) Andaman Sea.

1.4 Structure of the Thesis

The present thesis is divided into six chapters.

The **First Chapter (Introduction)**, as already described above, provides an introduction to the Andaman subduction zone and various morphological features associated with it and introduces the scope of the work and its importance in understanding of the geology of the region. It also lists the major objectives of this work.

The **Second Chapter (Geology, Samples and Analytical Methods)** deals with geology of the Andaman Islands, field observations, sampling procedures and details of the samples collected from the Andaman Islands and core collected from Andaman Sea. Sample preparation methods for various geochemical techniques are discussed in this chapter. The analytical methods utilized in this work include:

- Radiocarbon dating by conventional and Accelerator Mass Spectrometry (AMS) methods.
- Petrographic and mineralogical studies of sedimentary rocks of the Andaman Islands using microscopy (thin section), and EPMA (for ash layers in the core).
- Major and trace elemental geochemistry of the core sediments and sedimentary rocks of the Andaman Islands.
- Sr-Nd isotopic ratio analyses in silicate fraction of the sediments.

The **third chapter (Study of volcanic tephra deposits in the Andaman region)** presents the analytical results of our study on ash layers, interbedded with marine sediments, in the core collected from the Andaman Sea. Here, I discuss the volcanic history of the region as recorded in the literature and as revealed by our results using isotopic and geochemical proxies.

In the **Chapter four (Provenance of sediments deposited in the Andaman Region)** an attempt has been made to delineate the provenances of the sediments deposited in the Andaman region through time using geochemical and isotopic tracers on sediments from the Andaman Islands and Andaman Sea and their implications in understanding tectonics, paleogeography, paleodrainage patterns, climate, erosion (of source areas) and sedimentary transport have been discussed.

In the **Chapter five (Chronology of major terrace forming events in the Andaman Islands during the last 40 kyrs)** results on the deformation history of the Andaman Islands have been presented. Focusing on tectonically formed coastal terraces and determining the timing of their formation from the exposed corals, we have been able to reconstruct the history of major earthquakes in these islands for the last 40 kyr.

This last **sixth chapter (Summary & Conclusions)** summarizes important findings of the study and describes future research directions in the Andaman region.