CHAPTER 1

INTRODUCTION

1.1 Regional Tectonic overview

The Andaman-Nicobar archipelago, an arcuate melange of the Indo–Burmese Collision represents the central part of the 5000 km long Burma–Java subduction complex striking major tectonostratigraphic elements approximately parallel to the trend of Java-Andaman Trench (Tapan Pal, 2003; Banerjee et al. 2005; Ishii et al. 2005; Lay et al. 2005; Ni et al. 2005; Stein and Okal, 2005; Vigny et al. 2005; Meltzner et al. 2006; Allen, 2007 and Chakraborthy, 2009). The Burmese- Indonesian arc system extends from the Eastern Himalayan syntaxis Southward through Burma, Andaman-Nicobar, Sumatra and Eastward through Java to atleast Sunda (Tapan pal, 2003; Kamesh Raju, 2004; Allen et al. 2007 and Chakraborthy, 2009). The Andaman and Nicobar Islands are bounded by the Andaman trench to the West and the Sunda fault system to the East along with the Andaman spreading zone between latitudes 10° N and 12° N (Malik, 2006; Fig. 1.1). The Andaman- Sunda trench marks the active subduction zone where oceanic part of the Indian Plate is subducting eastwardly and obliquely below the oceanic part of the Southeast Asian (Eurasian) Plate (Fig.1.2; Fitch, 1970; Seely et al. 1974; Curray et al. 1979; Rajendran and Gupta, 1989; Dasgupta and Mukhopadhyay, 1993 and Curray, 2005). The Andaman and Nicobar Island chain acts as a small tectonic plate that has also been referred as the Burma microplate (Dasgupta and Mukhopadhyay, 1993; Ortiz and Bilham, 2003 and Kayal et al. 2004). Subduction-related deformation along the trench has been operating either continuously or intermittently since the Cretaceous which resulted in the development of several active thrust and strike-slip faults (Tapan pal, 2003; Malik et al. 2006 and Chakraborthy, 2009). The oblique subduction has initiated strike–slip motion in the Northern Sumatra–Andaman sector, and has formed a sliver plate between the subduction zone and a complex, right-lateral fault system (Chakraborthy, 2009). The late Paleocene collision of Greater India and Asia with approximately normal convergence started clockwise rotation and bending of the Northern and Western Sunda Arc. The initial sliver fault, which probably started in the Eocene, extended through the outer arc ridge offshore from Sumatra, through the present region of the Andaman Sea into the Sagaing Fault. With more oblique convergence due to the rotation, the rate of strike-slip motion increased and a series of extensional basins opened obliquely by the combination of backarc extension and the strike-slip motion. The oblique motion between the Indo-Australia and Burma–Sunda plates is accommodated through predominantly thrust motion in the Sumatra–Andaman trench region and strike-slip motion in the Andaman Sea, ridge-transform system in the back arc region and the Sumatra fault system in the South (McCaffrey, 1992; Sieh and Natawidjaja, 2000 and Curry, 2005).

The rate of convergence in the Andaman and Sumatra region is not well constrained and the estimate ranges from 14 to 68 mm/yr (Prawirodirdjo et al. 1997; Sieh and Natawidjaja, 2000; Paul et al. 2001; Bock et al. 2003 and Simoes et al 2004). In N23°E direction, Indian plate converge with a rate of about 54 mm/yr at 9^o N and 92^o E (DeMets et al. 1990) and the deformational kinematics of subduction interface with accretionary wedge is likely to differ from South to North of Andaman Group of Islands. However, at the Sumatra subduction zone, the India and Australia plates subduct obliquely beneath the Sunda forearc at a rate of 50 mm/yr (McCaffrey, 2009). Recent global plate reconstruction data suggest that the Northeast moving Indian plate converges obliquely at 54 mm/yr with respect to the Eurasian plate (DeMets et al. 1994). Along Sumatra, the convergence is oblique to the trench and the relative plate motion is partitioned into nearly perpendicular thrusting at 45 mm/yr $^{-1}$and trench-parallel, right-lateral slip along the Sumatra fault at 11 to 28 mm/yr (Subarya, 2006). Orientation of velocity vectors, geometry of plate margin and angle of obliquity between the two gives rise to a combination of both simple shear and pure shear (Beck, 1991 and Molnar, 1992). The combination of these two shear components develop transpression–transtension environments. (McCaffrey, 1992; Dewey et al. 1998 and Jones et al. 2004).

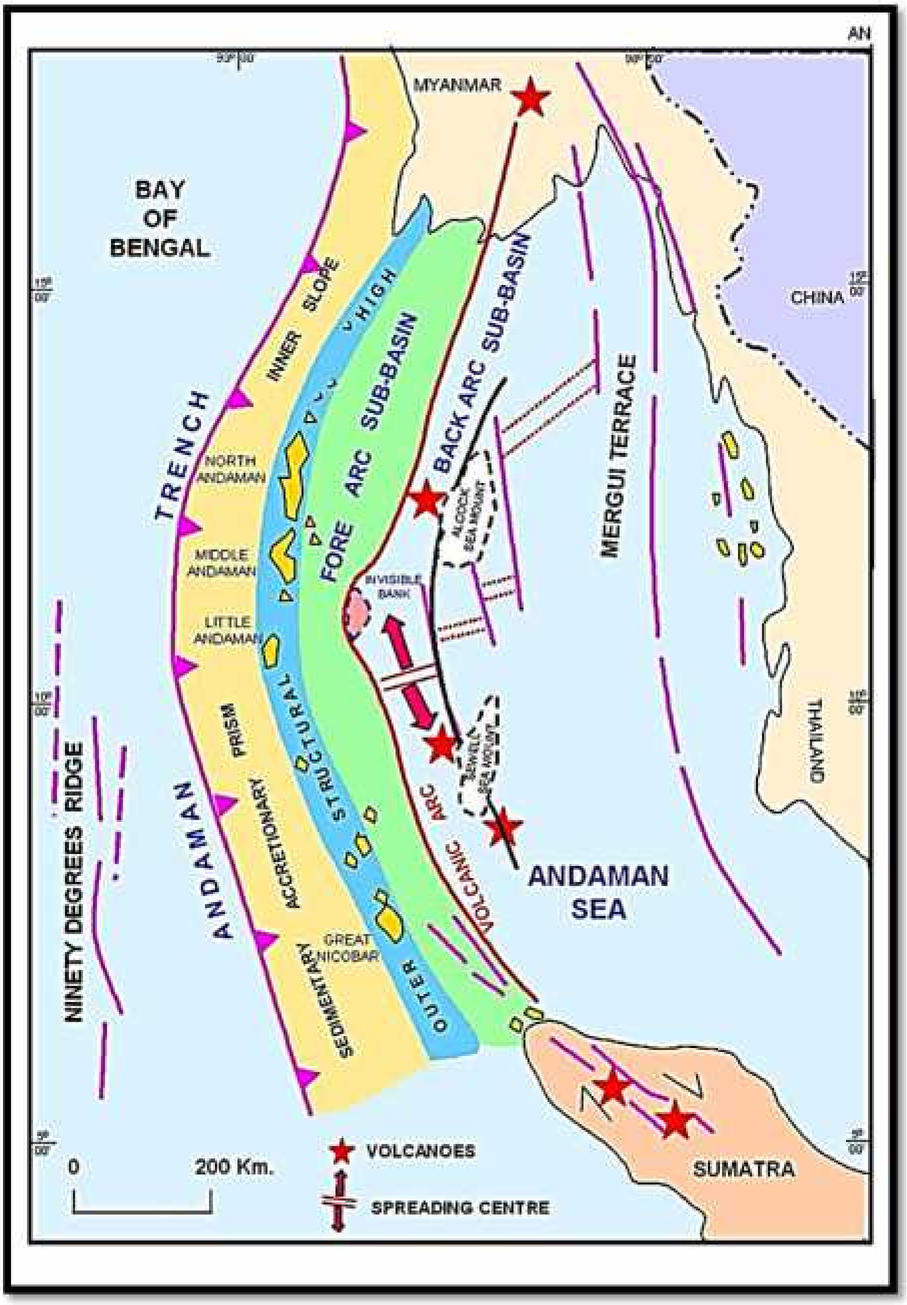

Fig. 1.1 Morphotectonics of Andaman and Nicobar arc system.

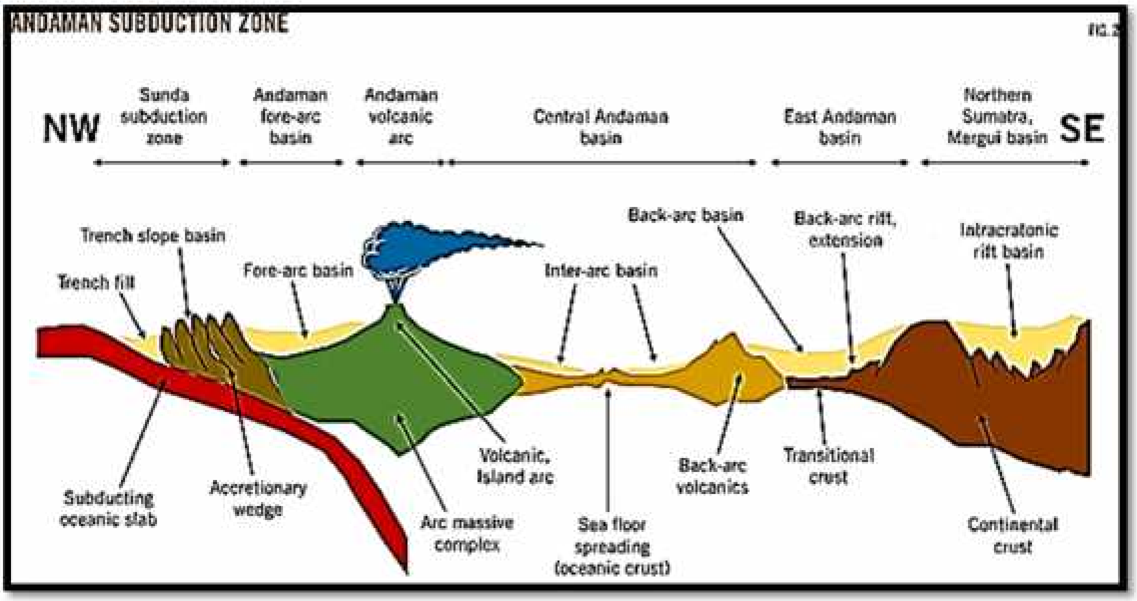

Fig. 1.2 Andaman Subduction Zone and the arc settings.

1.2 Morphotectonic Settings

The Andaman–Sumatra margin displays prominent regional morphotectonic features such as subduction–accretion complexes (accretionary prism), Java Trench, a tectonic (outer arc) prism, a sliver plate, a forearc, oceanic rises, inner-arc volcanoes, and an extensional back-arc with active spreading, Sagaing fault systems in the North and Semongko fault systems in the South, Alcock and Swell seamount complexes, Invisible Bank fault and West Andaman Fault (WAF), a right lateral active strike slip fault that has continuity all along the islands (Roy, 1992; Kamesh et al. 2004, Kamesh Raju, 2005; Malik et al. 2006 and Chakraborthy, 2009) (Fig.1.3). Andaman-Sumatra trench lies at the Western base of the Andaman–Nicobar ridge and the trench is filled with sediments of the Bengal Fan. The Andaman–Nicobar ridge is suggested to have formed during Oligocene or Late Eocene period and consist of seafloor ophiolites and sediments scrapped-off from the underthrusting Indian plate, overlain by autochthonous sediments of shallow water fore-arc environment (Allen et al. 2007).

A number of North-South trending dismembered ophiolite slices of Cretaceous age, occurring at different structural levels with Eocene trench-slope sediments, were uplifted and emplaced by a series of East-dipping thrusts to shape the outer-arc prism. North–South and East–West strike–slip faults controlled the subsidence, resulting in the development of a forearc basins and record Oligocene to Miocene–Pliocene sedimentation within mixed siliciclastic–carbonate systems (Chakraborthy, 2009).

The accretionary prism of the subduction zone is an imbricate stack of Eastward-dipping fault slices and folds that young to the West with Cretaceous ophiolites and older deep sea sedimentary rocks lying generally at the top and on the Eastern side of the pile, and progressively younger Neogene sedimentary rocks at the Western side and bottom of the pile immediately above the trench (Curray, 2005). The Andaman Sea is an active backarc extensional basin lying above and behind the Sunda subduction zone and opened during the Cenozoic era by a succession of extensional episodes (Curray, 2005). This is indicated by the presence of a series of E–W/NE–SW seismogenic faults at the leading edge of the Indian plate all along the subduction complex (Das Gupta and Nandy, 1995).

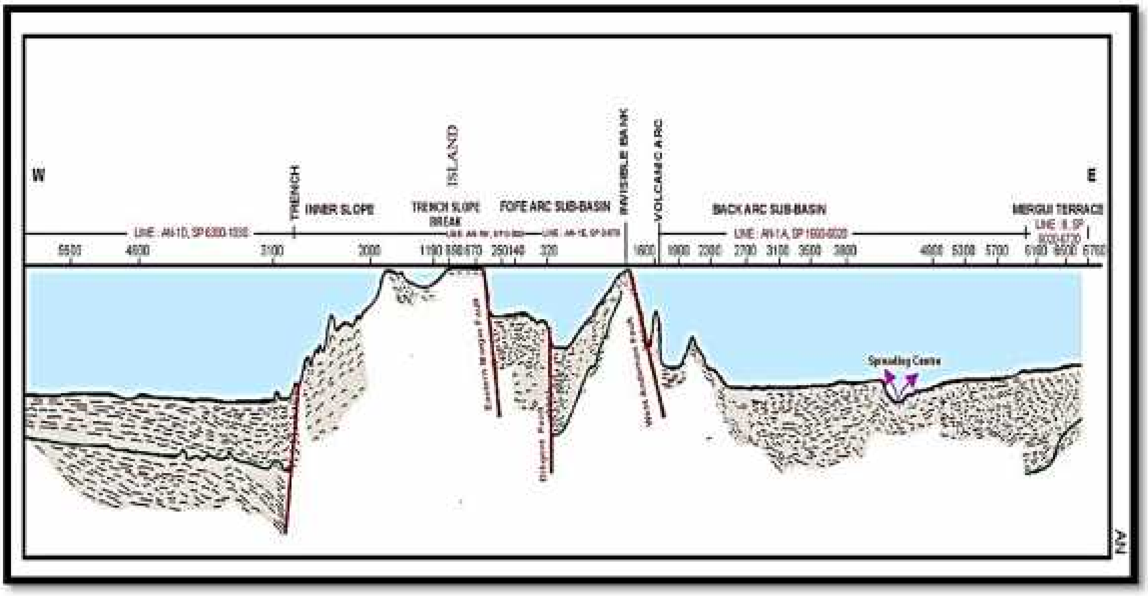

Fig. 1.3 Transverse section showing the trench, regional active faults and arc settings.

1.3 Active tectonics

The Andaman–Nicobar region lies in seismic zone V and is part of the interface between the Indo-Australian plate and the Burma microplate that have experienced moderate-to-large magnitude earthquakes during recent and historic times (Malik et al. 2006). The Andaman–Nicobar region provides an ideal tectonic setting for the occurrence of megathrust earthquakes and tsunami waves triggered by such events (Rajendran et al. 2003). The great Aceh-Andaman earthquake of December 26, 2004 and its tragic consequences brought the Sumatran region and its active tectonics into the world's focus (Mccafrey, 2009). The Sumatra–Andaman earthquake of 26 December 2004 is the first giant earthquake (moment magnitude Mw. 9.0) to have occurred since the advent of modern space-based geodesy and broadband seismology (Lay et al. 2005; Stein and Okal, 2005 and Subarya, 2006). The region not only poses a major earthquake hazard due to the tectonic dynamism of the convergent margin and unique tectonic setting such as Sumatra fault systems (Kamesh raju, 2004; Acharya, 2005; Curry, 2005 and Kamesh raju et al. 2007). The Andaman and Nicobar region have experienced prolific catastrophic geological events recorded both historically and instrumentally such as earthquake 1833 (Mw 9); 1847, (Mw 7.5); 1861 (Mw 8.5); 1881, (Mw 7.9); 1941, (Mw 7.7); 2004, (Mw 9.3); 2009, (Mw 7.5; Bilham, 2004; Rajendran et al. 2005; Acharya, 2005; Gahalaut et al. 2006; Malik and Mohanty, 2007) that falls in vulnerable index zone V (Radakrishna and Sanu, 2002; Malik et al. 2006 and Gahalaut, 2006; Fig. 1.4). Oritz and Bilham, (2003) spotted that Southern Sumatra had engendered several large and great magnitude earthquakes, whereas overall seismicity of Andaman and Nicobar region is low and involving few earthquakes, but no historical record of great earthquakes ($M \geq 8$) have been reported from the Andaman-Nicobar and Northern Sumatra region, though major events have occurred in 1847 (M7.5), 1868, 1881 (M7.9) and 1941 (M7.7) (Subarya et al. 2006). Great earthquakes in 1861, 1979, 1833 and 2004 have been reported from subduction zone near Sumatra (Bilham et al. 2005 and Lay et al. 2005).

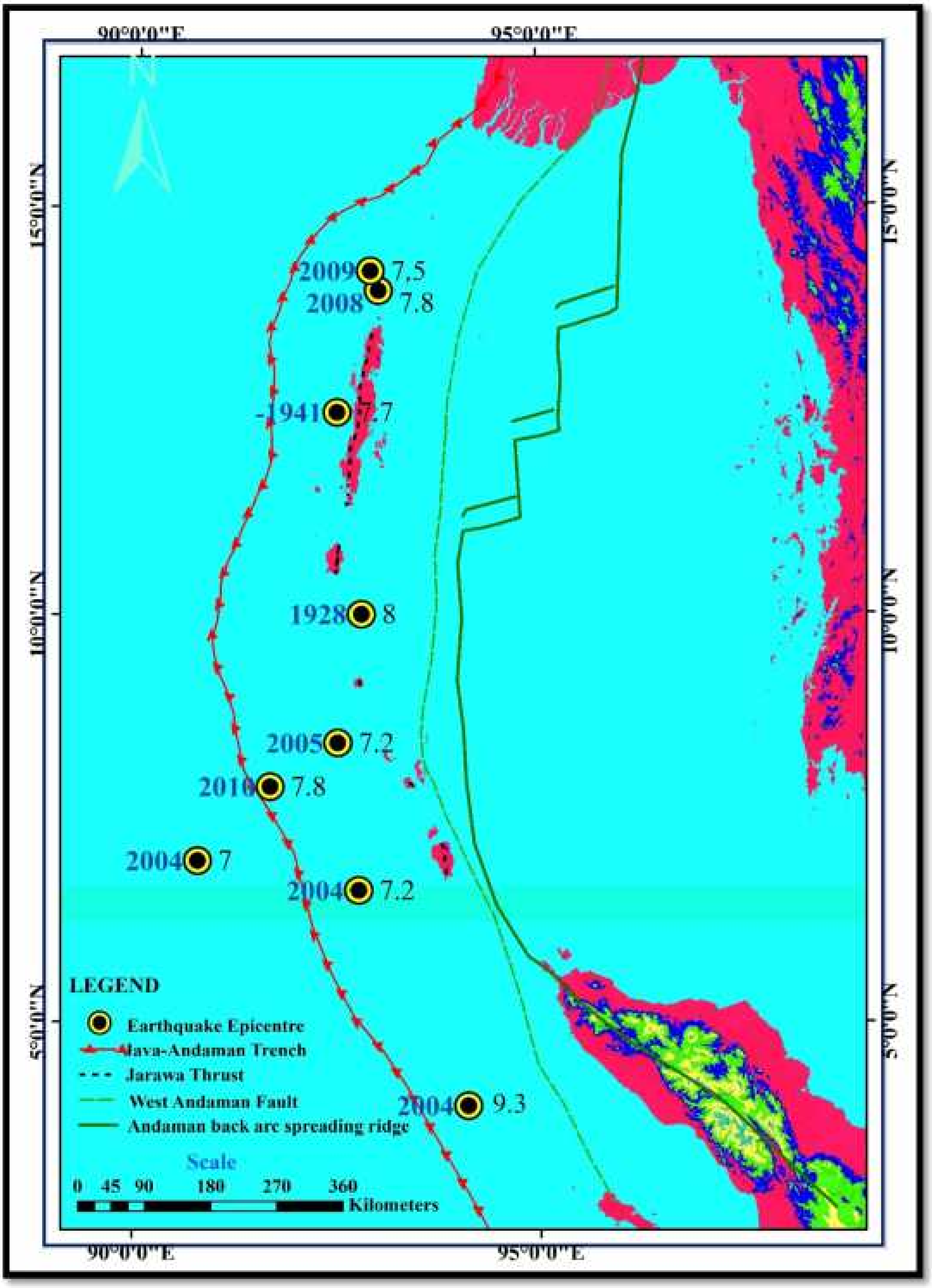

Fig. 1.4. Showing megathrust earthquakes that ruptured along Andaman-Sunda trench.

1.4 Evaluation of Active Faulting and Associated Hazards

Active faulting is a geologic hazard with a causative relation to earthquakes and associated strong ground motion, surface faulting, tectonic deformation, landslides and rockfalls, liquefaction, tsunamis, and seiches. Plate-tectonic models for the Earth's crust show that most active faults occur near plate boundaries. Intraplate regions represent a potential hazard that only recently has been recognized. Faults are delineated by geologic, remote-sensing, GPR, seismic reflection, gravity, magnetic, and trenching methods. Fault activity is assessed using geologic, geomorphic, geodetic, and seismologic data. Correlations of fault length, displacement, and area with earthquake magnitude are utilized to assess earthquake hazards of faults and form the principal data for risk analysis. Estimation of earthquake recurrence rates and characterization of fault behavior provide additional input data for risk analysis. The Andaman-Sumatra-Java trench-arc and the adjoining region are seismically very active, characterized by earthquakes with depth of around 700 km. Many previous workers have studied the overall tectonics of the region and their studies gave valuable information on seismotectonics, subduction process and plate kinematic setting of the region (Rodolfo, 1969; Fitch, 1970, I972; Curray et al. I977, I979, 1982; Hamilton, 1979; Moore and Curray, I982; Huchon and Le Pichon,1984; Chandra I984; Curray, 2005; Mukhopadhyay and Krishna, I991; Krishna et al. I995; Ravikumar et al. I996; Slancova et al. 2000; Sieh, and Natawidjaja. 2000; Prawirodirjo, 2000; Schluter et al. 2002; Kamesh Raju, 2005 and Khan and Chakraborty, 2005). In addition, morphometric analysis such as mountain front sinuosity (Smf), Transverse topography symmetry, Asymmetry factor, Basin Elongation Ratio, Longitudinal profile and Hypsometric Index confirm the active tectonics of the region (Bull and McFadden, 1977; Bull, 1977b; Keller and Pinter, 2002; Silva et al. 2003 and Zovoili et al. 2004).

1.5 Rationale

Paul et al. (2001) reported campaign mode of GPS measurements at CARI (Central Agricultural Research Institute) in the SE of Port Blair in 1996, 1998, 1999 and the data sets provided by SOI (Survey of India) and GPS measurements (1995-2004) strongly suggest high rate of strain accumulation in Andaman region both in space and time. This emphasizes that Andaman is at risk from earthquakes in the future on active faults. Therefore, active fault identification and characterization bears paramount significance towards recognizing the regional seismic hazard of tectonically active zones (McCalpin, 1996, 2009; Malik and Nakata. 2003; Thenhaus and Campbell, 2003). Several active thrust belts and strikeslip faults in the forearc region of Andaman subduction zone contribute greatly in terms of seismicity and accommodates some of the plate convergence. Therefore, most of the earthquakes in this region show thrust and strike-slip faulting associated with oblique subduction of the Indian plate, along with some faulting associated with extensional stresses in the Northern Andaman Sea (Eguchi et al. 1979; Malik and Murty 2005, Malik et al. 2006, 2011; Rajendran et al. 2007; Earnest et al. 2005; Acharya, 2005; Gahalaut et al. 2006 and Meltzener, 2010). Therefore, the active faults should be thoroughly investigated through the detailed evaluation of the seismotectonics, morphotectonics, morphometric and paleoseismological investigations for the hazard analysis and vulnerability assessment.

1.6 Lithostratigraphy

The stratigraphy of the Andaman Islands was first described in some detail by (Oldham, 1885) of the GSI, who mentions the fragmentary observations of others, 0 Nicobar Islands, and some other early explorers in the Andaman Islands. The stratigraphy of Andaman and Nicobar islands were studied by (Oldham, 1885; Tipper, 1911; Gee, 1927; Chatterji, 1964; Karunakaran, 1968 and Pandey et al. 1993). Tapan Pal et al. (2003) accounted the Andaman stratigraphy into four groups viz. Ophiolite group of Cretaceous, Archipelago group of Mio-Pliocene, Andaman Flysch group of Oligocene and Mithakhari group of Eocene age (Table 1.1; Fig. 1.5).

The geology of an accretionary wedge is complex, reflecting its dynamic environments and involving subduction, folding, and thrusting. Many accretionary complex rocks are referred to as mélange. Melange, a chaotic mixture of diverse rocks, occurs at the base of the Ophiolite and is exposed mainly in the Eastern part of the Middle Andaman Islands. The Andaman ophiolite contains the main components of an ophiolite sequence that includes upper mantle–depleted harzburgites and dunites, lower crustal cumulate gabbros and peridotites, and upper crustal sheeted dikes, pillow lavas, and marine pelagic sediments (Halder, 1985; Ray et al. 1988 and Roy, 1992).

Table 1.1 Generalized stratigraphy of Andaman and Nicobar Island (revised after Karunakaran, Ray and Saha, 1967; Ray 1982).

Tectonic Setting	Age	Unit	Lithocharacters
Forearc	Pliocene (cf. Ray, 1982 Miocene (Chatterjee,1964)	Archipelago Group (400 m thick)	Interbedded sequence of tuff, limestone, sandstone and clay
	-Unconformity-		
	Upper Eocene-Oligocene (Pawde & Ray, 1963), Oligocene–Lower Miocene (Present work)	Andaman Flysch Group (300 m thick)	sequence of sandstone, siltstone and shale
	- Unconformity/transitional-		
Trench-slope	Middle to Late Eocene (Karunakaran Ray & Saha, 1967)	Mithakhari Group (1400 m thick)	sandstone and shale
	- Tectonic/unconformity-		
Accretionary slices	Cretaceous to Paleocene (Roy et al. 1988) Early Cretaceous (Jafri, 1986)	Ophiolite Group	Metamorphic, tectonites, cumulates, plagiogranite-diorite-andesite suite, basalt and pelagic sediments

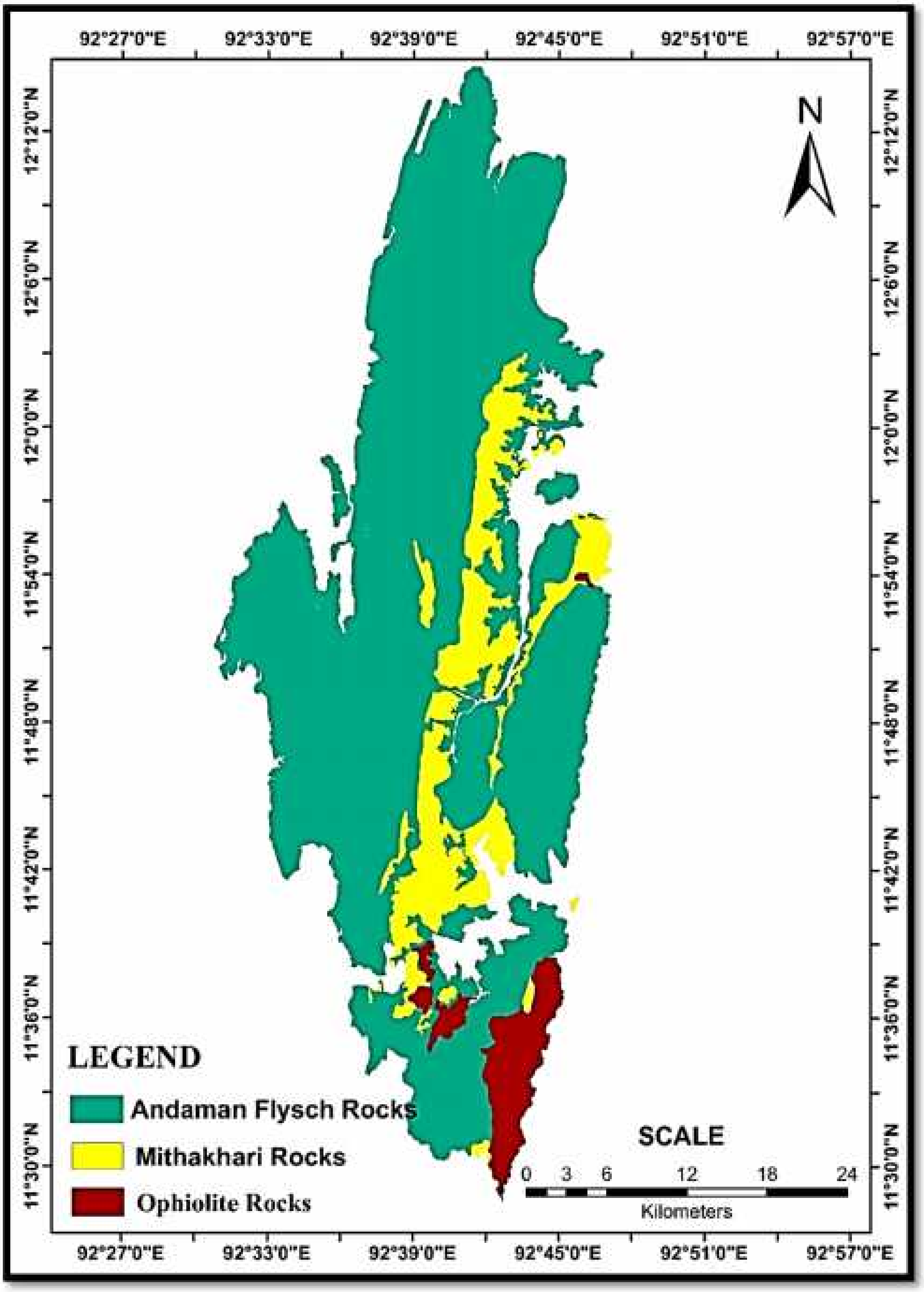

Fig. 1.5 Lithostratigraphy of South Andaman Island.

Ophiolite Group rocks occur as dismembered bodies. The ophiolite slices invariably show thrust contacts with underlying sediments and occasionally with overlying sediments. Towards the West, ophiolites are exposed in small isolated patches, whereas in the East, individual ophiolite slices are narrow and their strike extensions are traced for kilometres. In the Eastern part, most ophiolitic rocks occur in sequences with normal ophiolite stratigraphy. Dominantly N–S to NE–SW-trending discontinuous slices of ophiolites occurring at different structural levels having tectonic contacts with underlying sediments indicate thrust-controlled emplacement in an accretionary environment. A complete sequence from the Moho is exposed in the South Andaman Islands. South Andaman has the best preserved and most complete sequence of ophiolite, which extends for ~30 km from Carbyn's Cove in the North to Chidyatapu in the South.

The Mithakhari Group consists of immature gravels and coarse- to fine-grained sandstones, pebbly to fine-grained pyroclastic sandstones, and minor thin beds of mudstones and coal. The Mithakhari Group dominates the geology of the North and Middle Andaman. In South Andaman, the Mithakhari Group occurs as a North-South trending outcrop that extends for ~50 km, but the best sections are found only near Hope Town, Mungleton, Namunagarh, and Chidiyatapu (Fig. 1.5).

The Andaman Flysch is a siliciclastic turbidite sequence deposited on a submarine fan. It is bounded between the Mithakhari Group below and the Archipelago Group above. The term flysch is derived from the resemblance of the turbidites to the classic Bouma turbidites described in the Swiss Alps. The Andaman Flysch is described as cropping out over a N-S strike length of 200 km from the Southern part of South Andaman to the Northern tip of North Andaman. The overall thickness is not well defined, with estimates varying from 750 m (Roy, 1983) to 3000 m (Pal et al. 2003). The best and most completely documented exposures are found in South Andaman at Carbyn's Cove, where outcrops of steep, Westerly dipping beds are seen adjacent to the pillow basalt of the ophiolite sequence. The Archipelago Group represents the topmost stratigraphic unit of the Tertiary succession. They comprise of basal conglomerates, sandstones, chalk and Shell limestone with some argillaceous limestones and shale. Their main exposure is confined to Havelock Island and associated smaller islands to the East of South Andaman in Richie's Archipelago.

1.7 Objectives

- To delineate and interpret the structural trendline and faults/lineaments of South Andaman Island through Remote Sensing and Geographical Information System (GIS)
- To map and establish the Geological and Geomorphological evidences of faulting through field observations
- To validate and assess the geomorphic response to neotectonic activity through geomorphic indices and drainage analysis.
- To characterize the subsurface manifestation of structures using Geophysical techniques viz Ground Penetrating Radar (GPR).
- To study the Seismotectonic regionalization through Geological, Tectonic and Faulting pattern in order to identify the diverse active seismogenic zone/faults
- To evaluate the b-value, Palaeostress pattern and fault types through earthquake parameters.
- To integrate the Remote Sensing, Geomorphological, Morphotectonic and Seismotectonic findings to establish the active tectonics of the region.

1.8 Thesis Structure

The thesis work has been approached through the following Chapters.

Chapter 1: Discusses the Introductory, a regional tectonic overview, stating the problem, necessity and scope of the study, Objectives of the present study and Thesis Structure.

Chapter 2: Summarises the Review of Literature relevant to the present study viz in the field of Morphotectonic, Morphometric, GPR and Seismotectonic contributed by International and National researches.

Chapter 3: Deals with Materials and Methodology adopted in the present research.

Chapter 4: Details the Morphotectonic concepts, Morphotectonic evaluation, Remote Sensing study, Field Investigations etc.

Chapter 5: Accounts on the Morphometric concepts and Morphometric parameters, Evaluation of Morphometric parameters.

Chapter 6: Details the Seismotectonic, G-R relation, Evaluation of b values and stress.

Chapter 7: Discusses the GPR applications in subsurface analysis of folding, fracturing, faulting and thrusting.

Chapter 8: Synthesis Results and Discussion.

Chapter 9: Culminates with the Conclusions.

1.9 Study area

The area taken for the present study is South Andaman Island. It is the southern group of Andaman Islands. The capital of Andaman and Nicobar islands is Port Blair which is located in South Andaman. The South Andaman is endowed with trench parallel and trench perpendicular structure. The South Andaman is traversed through by a number of N-S, NE-SW and E-W faults in compressive, tensional and shear regimes. Thrust, shear and normal faults are more common. Folding intensity increases from east to west. The drainages are mostly controlled by faults and fractures. The drainages are mostly of trellis and dendritic types.

The South Andaman comprise of Andaman Flysch, Mithakhari and Ophiolite type of rocks. The Andaman Flysch rocks cover the region predominantly. The Ophiolite occur as slices with the Easterly dipping thrust.

Morphotectonic, Morphometric and Geophysical analysis (GPR) have been carried out along the active faults of South Andaman (Fig. 1.6). Field evidences were collected wherever the feasibility of field work was possible depending upon the accessibility and forest cover.

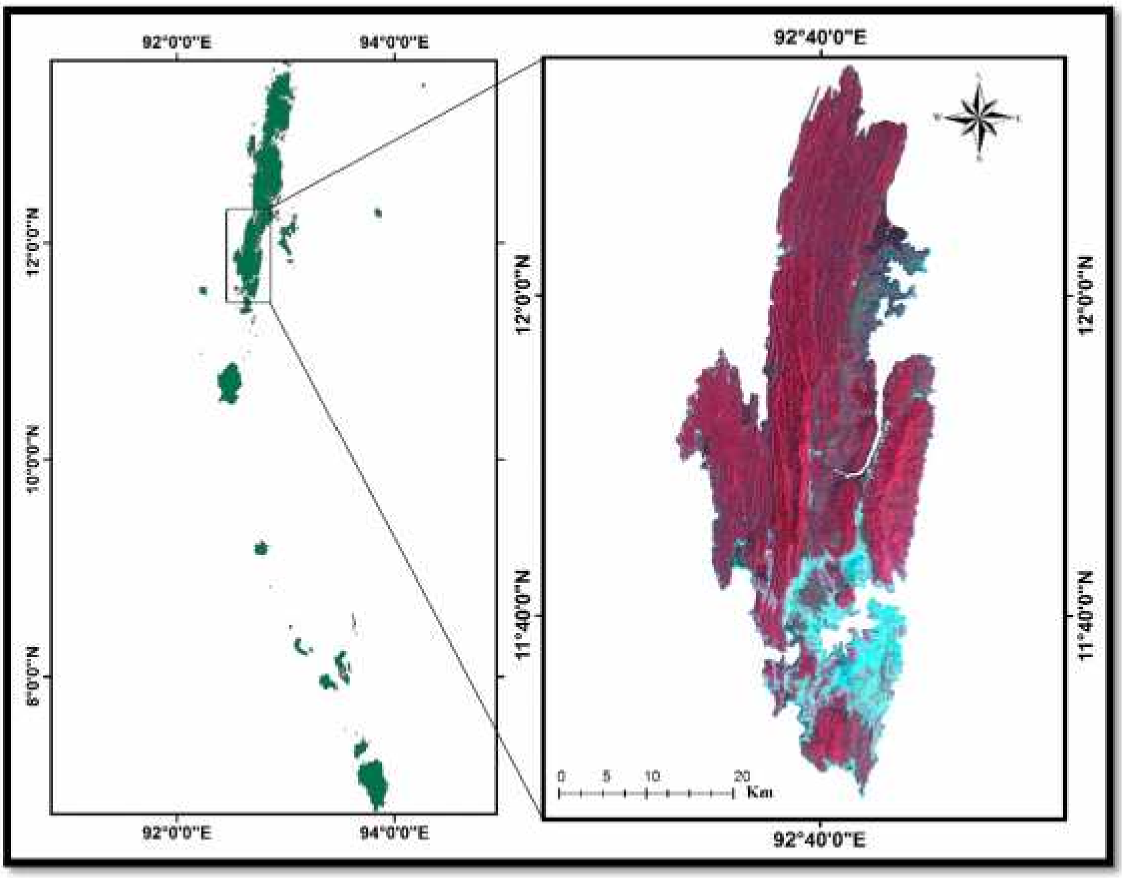

Fig. 1.6 Study area - South Andaman Island.