Chapter-2
Geology, Samples and Analytical Methods

2.1 Geology of the Andaman Islands

The Andaman group of islands includes about two hundred islands with an exposed area of 6,408 km^2 (Fig. 2.1). As mentioned earlier, in geological context, these islands represent the accretionary prism of the Andaman Subduction Zone which is believed to have been developed as a result of continuous subduction of Indian plate under Eurasian plate since the Late Cretaceous (Pal et al., 2003). According to Karig and Sharman (1975), an accretionary prism usually develops during a subduction as a result of scrapping off slices of ophiolite and pelagic sediments from the downgoing oceanic plate by the edge of the overriding plate. However, according to Pal (2011), the dismembered ophiolite slices present in the Andaman accretionary prism did not form in the above fashion, instead are generated from the mantle wedge in a suprasubduction zone environment at the time of initiation of subduction. Subsequent to obduction of ophiolites and associated pelagic sediments, various tectno-sedimentary processes resulted in formation of forearc basin and deposition of clastic sediments in it, in both deep and shallow water environments (Allen et al., 2007).

The focus of most of the earlier geological work on the Andaman and Nicobar Islands was on establishing the geology and stratigraphy of the region (Rink, 1847; Hochstetter, 1869; Ball, 1870; Oldham, 1885; Tipper, 1911; Gee, 1927). In the Andaman accretionary prism setting, because of lack of exposures and high degrees of folding and faulting, it has always been difficult to determine the stratigraphy accurately. The earliest proposed stratigraphy of these islands came from the work done by pioneer workers like Rink, (1847); Hochstetter, (1866); Ball, (1870); and Oldham, (1885). However, their studies were restricted only to a few islands. Oldham, (1885) was first to give a comprehensive description of the Andaman geology by dividing it into an older Port Blair Series consisting sandstones, shales, coal seams, conglomerates, limestones and jasper beds and a younger Archipelago Series, consisting of limestones, calcareous sandstones and white clays separated by volcanic rocks and serpentinites.

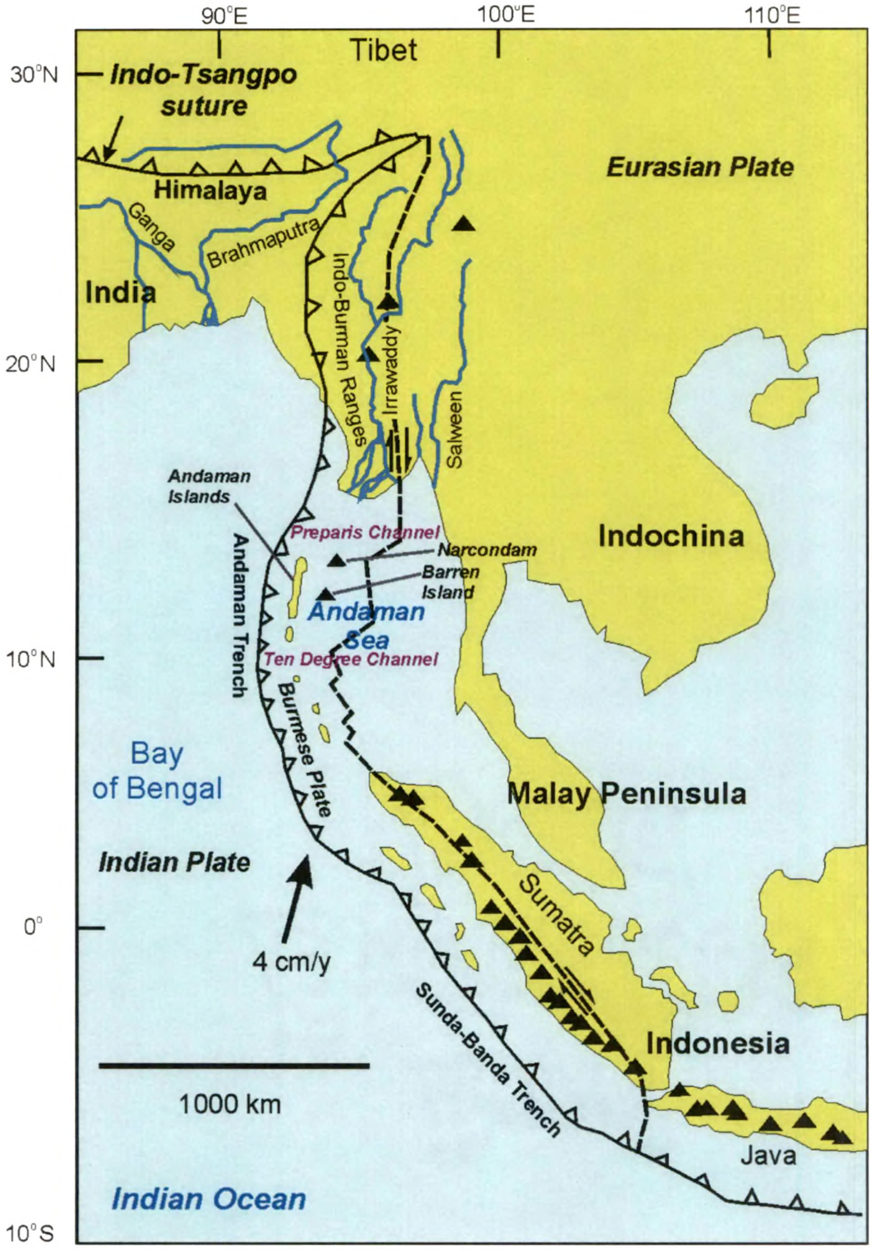

Fig. 2.1: Map of the northeastern Indian Ocean showing major geological and tectonic features along with locations of Andaman Islands and volcanoes of the Andaman Sea and Southeast Asia (solid triangles). 4 cm/y vector on the map shows the direction and rate of movement of the Indian Plate (Gahalaut et al., 2010).

The other geologists who made major contributions in improving the geological understanding of the Andaman stratigraphy were Tipper (1911), Gee (1927), Jacob (1954), Chatterjee (1967, 1984), Parthasarathy (1984), Roy et al. (1988), Bandopadhyay and Ghosh (1998), Acharyya et al. (1990), Acharyya (1997, 1998), Chakraborty and Pal (2001) and Chakraborty et al. (1999, 2002). In all these works although the lithological descriptions were similar, the proposed stratigraphic schemes were different with changes in the names of various formations. During 1960s, biostratigraphic principles were used along with lithostratigrapy to constrain depositional ages of various sedimentary units in the islands (Guha and Mohan, 1965; Karunakaran et al., 1968a & b). In mid-1970s, Oil and Natural Gas Commission (ONGC) of India started a detailed seismic reflection study across the island chain and correlated their results with those known from subsurface (through drilling) and outcrop stratigraphy, and placed the geology of the region within the context of the accretionary prism setting. In a series of papers, Srinivasan and his coworkers (e.g., Srinivasan and Azmi, 1979; and Srinivasan, 1977, 1979, 1984, 1986, 1988) published the first comprehensive work on the Archipelago Group or series. In the last few years there have been attempts to understand the origin and emplacement of ophiolites and other magmatic rocks, evolution of siliciclastics (Pal et al., 2003; Ghosh et al., 2009; Pederson et al., 2010), paleontological, petrological and geochemical evolution of chert sequences, and some of the ash (volcanoclastic) deposits (Jafri et al., 1993; Shastry et al., 2001; Srivastava et al., 2004; Bandhopadhay, 2005; Pal et al., 2010a). Pederson et al. (2010) and Sarma et al. (2010) constrained the age of the Andaman ophiolites to ~95 Ma by U-Pb dating of magmatic zircons. Through field, petrography and use of multiple isotopic tracers Allen et al. (2007) attempted to determine age and provenance of the sedimentary rocks of the Andaman Islands.

The currently accepted stratigraphy of Andaman Islands was established on the basis of the data collected and observations made by earlier workers on limited exposures in accessible areas, drill cores, road cuttings, seismic profiles etc. The stratigraphy followed in this work is given in Table 2.1 and comprises five groups, which from bottom to top consists of rocks of the Ophiolite Group and the overlying sedimentary rocks of the Mithakhari

Group, the Andaman Flysch Group, the Archipelago Group and the Nicobar Group grouped together with unclassified arc volcanic and recent sedimentary deposits (Curray, 2005) (Fig. 2.2). In the following paragraphs we have briefly described each of these groups.

2.1.1 Ophiolite Group

The Ophiolite Group is the lowermost unit in the Andaman and Nicobar Islands (Fig. 2.2). The north-south trending discontinuous thrust slices of ophiolites are present throughout the Andaman Islands in association with sediments, low-grade metamorphic rocks and tectonic melanges. The intensely schistose greenschist to amphibolite facies metamorphic rocks consist of metasediments (quartzites, quartz-mica schists and phyllites) and metabasics (amphibole-bearing chlorite-epidote carbonate schists) (Pal et al., 2003). These rocks occur either as blocks in a melange zone or as discontinuous patches along the thrust contacts. Melanges include fragments of basalt, ultramafic rocks, metamorphic rocks, brecciated sandstone and chert embedded in sheared basaltic and serpentinized matrices (Pal et al., 2003). In the Andaman Ophiolite suite all the members of a classic ophiolite stratigraphy are present with the sequence of a plutonic complex (harzburgites, dunites), intrusives (gabbros and plagiogranites), extrusive lava series (pillow lavas of dacitic to andesitic and tholelitic basalt composition) and marine pelagic sediments (red clay, jasper, red/white chert, cherty/micritic limestone and reddish-brown and purple shale-mudstone beds) except for the sheeted dykes which have been identified only in some zones that are heavily affected by faulting and folding (Halder, 1985; Ray et al., 1988; Roy, 1992; Bandopadhyay and Ghosh, 1998). Shales of tuffaceous origin, cherty limestone with thin layers of basaltic flows, deformed thin beds of fine-grained sandstones and siltstones have also been reported within the Ophiolite Group and these posses soft-sediment deformation features like the slump folds and cross-cutting by normal and thrust faults (Allen et al, 2007).

2.1.2 Mithakhari Group

Karunakaran et al. (1968a) first introduced the name "Mithakhari" to describe the group of rocks deposited immediately above the Ophiolites. On the basis of the bed geometry and sedimentary structures, Pal et al. (2003) recognized many different lithofacies in this group, which include disorganized and graded matrix supported conglomerate, graded pebbly sandstone, massive and thick bedded sandstone, plane laminated and cross-stratified sandstones, interbedded sandstone and mudstone, massive to faintly laminated shale and interbedded shale and coal. This 1.4 km thick sedimentary unit (Ray, 1982) is mainly divided into three formations with the Lipa Black Shale at the base, the Hope Town Conglomerate unit in the middle and the Namunagarh Grit at the top (Fig. 2.2).

(a) Lipa Black Shale

The Lipa Black Shale is described as a minor unit with very few outcrops (Allen et al, 2007) and mainly includes pyritiferous black shales, thin coals and gypsum layers (Fig. 2.3a).

(b) Hope Town Conglomerate

The Hope Town Conglomerate Formation consists of polymictic conglomerates and pebbly sandstone with alterations of thin beds of coarse and fine-grained sandstones. Rock clasts are mainly derived from basic-ultrabasic sources, with minor contributions from quartz veins, shale, limestone, sandstone, chert and porcellinite (Allen et al, 2007) (Fig. 2.3b & c). The outcrop at Hope Town (type locality) has been reported to have fining- and thinning-upward sequences with evidence of slumping and soft sediment deformation (Allen et al., 2007). Bed contacts are generally sharp and planar.

(c) Namunagarh Grit Formation

This unit is characterized by coarse to fine-grained, greenish to grayish coloured matrix supported sandstones beds, consisting of volcanic minerals and volcanic rock fragments, and minor conglomerate at the base (Bandopadhyay, 2005; Allen et al., 2007) (Fig. 2.3d). Sandstone units are massive and thickly bedded with plane-laminated and cross-stratified

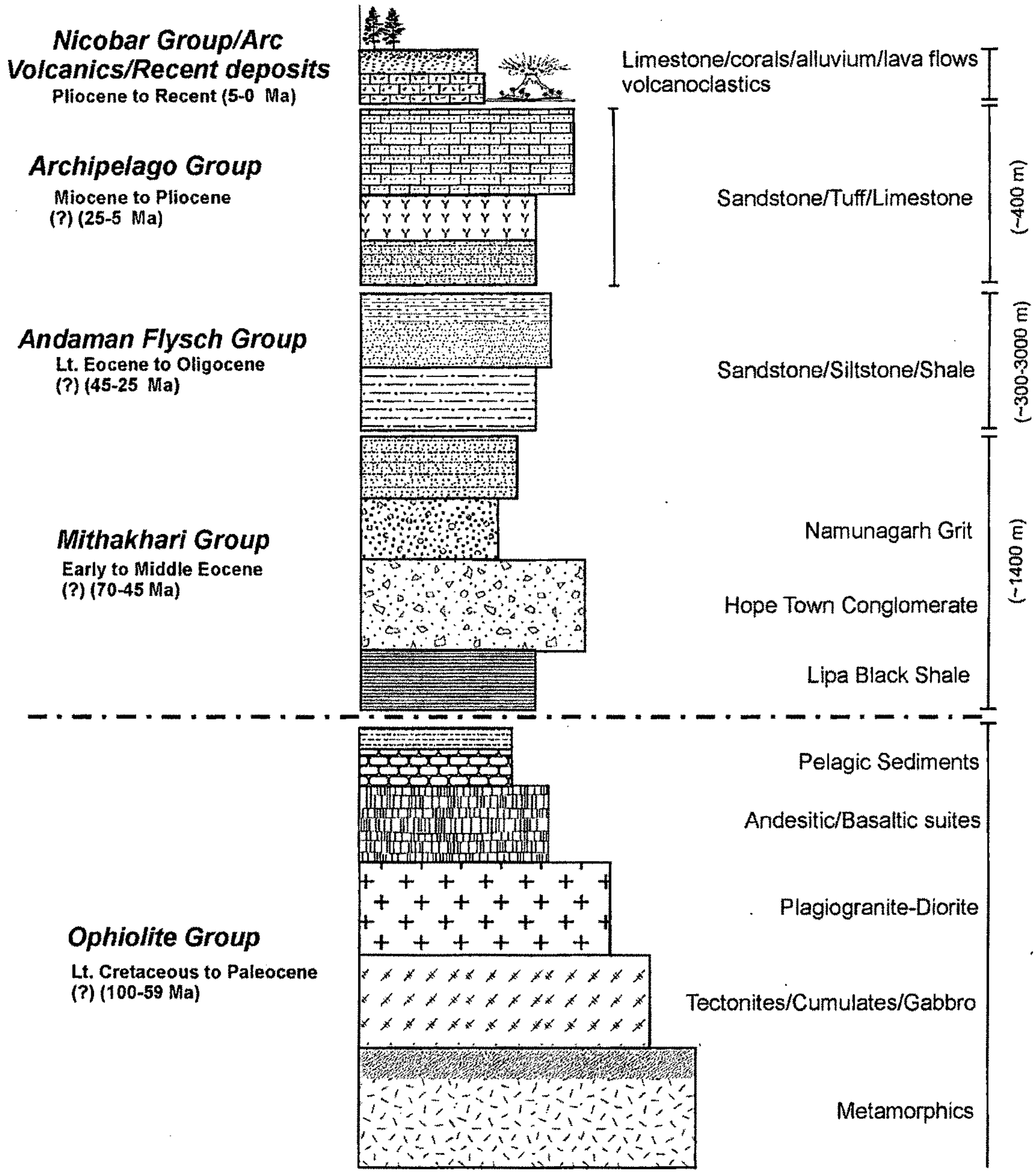

Fig. 2.2: Stratigraphic litholog showing different rock units exposed on the Andaman Islands. Modified after Guha and Mohan (1965); Karunakaran et al. (1968a); Ray (1982); Pal et al. (2003); Curray (2005) and based on our observations.

Table 2.1: Stratigraphy, lithology, depositional environments, tectonic settings and fossil records of the rocks of the Andaman & Nicobar Islands (based on studies by Guha and Mohan, 1965; Karunakaran et al., 1968; Ray, 1982; Pal et al., 2003; Curray, 2005).

Approximate depositional age range		Ltihostratigraphic Unit		Lithology		Sedimentary environments/ Tectonic settings	Fossil Record
Pliocene-Recent (Curray, 2005)	Plesitocene/ Holocene (0-1.95 Ma)	Nicobar Group (series)/Arc Volcanics/recent sedimentary deposits			Raised beaches, coral reefs, alluvium, swampy mud flats		Nanofossils Pelagic foraminifers, Lepidocyclina, Miogypsina,
			Shampenian		Shell Lmst.		
	Late Pliocene (1.95-3.7)		Taipian		Silty Mdst, lmst.		
	Early Pliocene (3.7-5 Ma)		Sawaian		Mdst., silty mdst., lmst.		
Miocene to Pliocene (Chatterjee, 1964; Ray, 1982)	Late Miocene (5-10 Ma)	Archipelago Group (400 m thick)	Neilian	Interbedded sequence of tuff, cross-stratified and graded sdst., silty mdst. & lmst. marls, and chalky lmst. (Lmst. is biohermal & biostromal)	Mdst., silty mdst., lmst.	Wave and current agitated shallow water shelf forearc setting. palaeocurrent direction: E, W and majority in SW (Pal et al., 2003).	Nanofossils Pelagic foraminifers, Lepidocyclina, Miogypsina,
	Middle Miocene (10-16 Ma)		Havelockian		Mdst., silty mdst., lmst.		
			Ongeian		Mdst., lmst.		
			Inglisian		creamish yellow calcareous chalk & marl		
	Early Miocene (16-25 Ma)		Jarawaian		creamish yellow calcareous chalk & marl		
			Andamanian		Grey sandy lmst., white siliceous chalk and silt		
—Unconformity—							
Oligocene–Late Eocene (Pawde & Ray, 1963)	(25-45 Ma)	Andaman Flysch Group (300 m thick)		Bouma sequences, interbedded sdst.-shale rhythmites and mdst.		Submarine fan/forearc setting). palaeocurrent direction: NE, SW and majority in SE (Pal et al., 2003).	Rotalia, Nodosaria, Amphistegina, Globorotalia, Opimanana, Globigerinoids
—Unconformity/transitional—							

Table2.1: Continued

Late Cretaceous to Middle/Upper Eocene (Curray 2005)	(45-70 Ma)	Mithakhari Group (1400 m thick)	Namunagarh Grit	Pebbly and coarse to fine-grained volcaniclastic sdst. & grits, interstratified massive and graded polymict conglomerates, massive cross-stratified and graded sdst., shales, and thin coal seams.	andesitic debris flows and turbidites deposited in forearc-volcanic arc setting basin adjacent to volcanic arc (Bandhopadhyay, 2005). palaeocurrent direction: NW, a few show trend between NE-SE (Pal et al., 2003).	Cunnulites atacicus, Assilina papillata,Pelatispira, Biplanispira
			Hope Town Conglomerate	Interstratified massive and graded polymictic conglomerates, cross-, massive-and graded - bedded sdst., up-section change over to interbedded shale and coal with minor conglomerates	Submarine slope, shelf and alluvial environments/deposited in faulted-controlled basins within a trench-slope setting (Chakraborty et al., 1999)	
			Lipa Black Shale	Pyritiferous black shale with olistoliths in sheared argillite matrix	Euxinic environment/Trench setting	
—Tectonic/unconformity—						
Late Cretaceous to Paleocene (Roy et al. 1988)	(~95 Ma)	Ophiolite Group (?)		Serpentized harzburgite, pyroxinite, unclassified plutonic rocks. Cumulates, tectonites and metamorphic. Pillow lavas, intrusive and pelagic sediments	Uplifted segments of ocean floor forming the basement of the accretionary prism	Radiolaria: Nasselaria spumellarion Planktonic foraminifera: Globigerina eugubina, G. trilloculinsides, G. fringa, G. velascoensis.Globorotalia compressa, Globotruncana arca. Globigerinelloides Pseudotextularia sp., Reugoglobigerina sp. Hagiastrids

Mdst: mudstone; Sdst: sandstone; Lmst: limestone

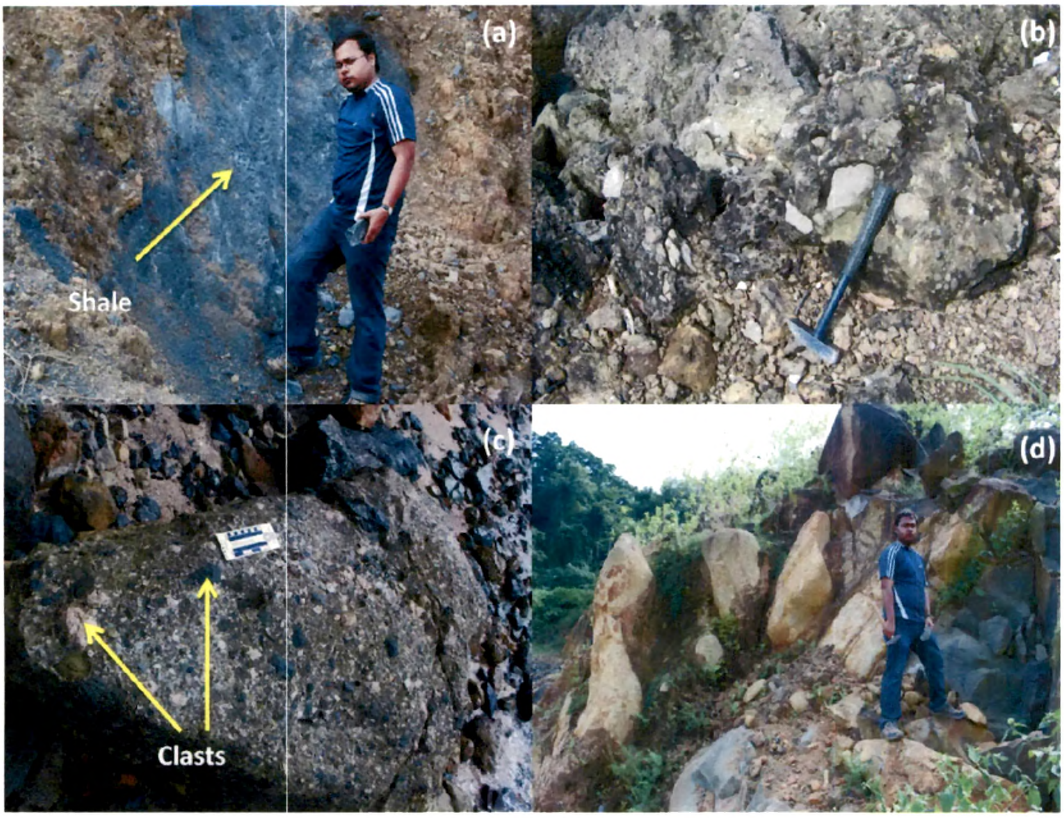

Fig.2.3: Field photographs of various formations of the Mithkhari Group (a) Lipa Black Shale from a road side section in Sippighat; (b) Hopetown conglomerate unit exposed at Chidiyatapu; (c) Hopetown conglomerate unit showing clasts derived from Ophiolite Group rocks; (d) Namunagarh Grit unit from quarry section in Namunagarh village, South Andaman.

facies. The finer grained beds consist of fine- to medium-grained sandstones inter-bedded with laminated shale. Bandopadhyay (2005) identified the sandstones of Namunagarh as tuff beds, and suggested their direct derivation from volcanic arc sources. However, a similar origin for Namungarh units, exposed elsewhere on the islands, has not yet been established.

Considering the presence of coal, gypsum, cross-bedded sandstone lenses and pyrite-bearing shale in the Mithakhari Group, Pal et al. (2003) suggested that these rocks were possibly deposited in a low gradient alluvial plain that suffered occasional marine transgression. According to these authors the coarse sediments including polymict conglomerates and grits were directly derived from the local ophiolite sources while the fine to very fine grained sediments (turbidites) were derived from distant sources. Highly variable bedding orientation and a complex deformation pattern are shown by the rocks of Mithakhari Group. These also show sedimenatry features like clast imbrication, sole marks, wave ripples and large-scale channel bedform. The palaeocurrent direction derived from sandstone facies indicate that dominant sediment influx was from the NW to NE (Pal et al., 2003).

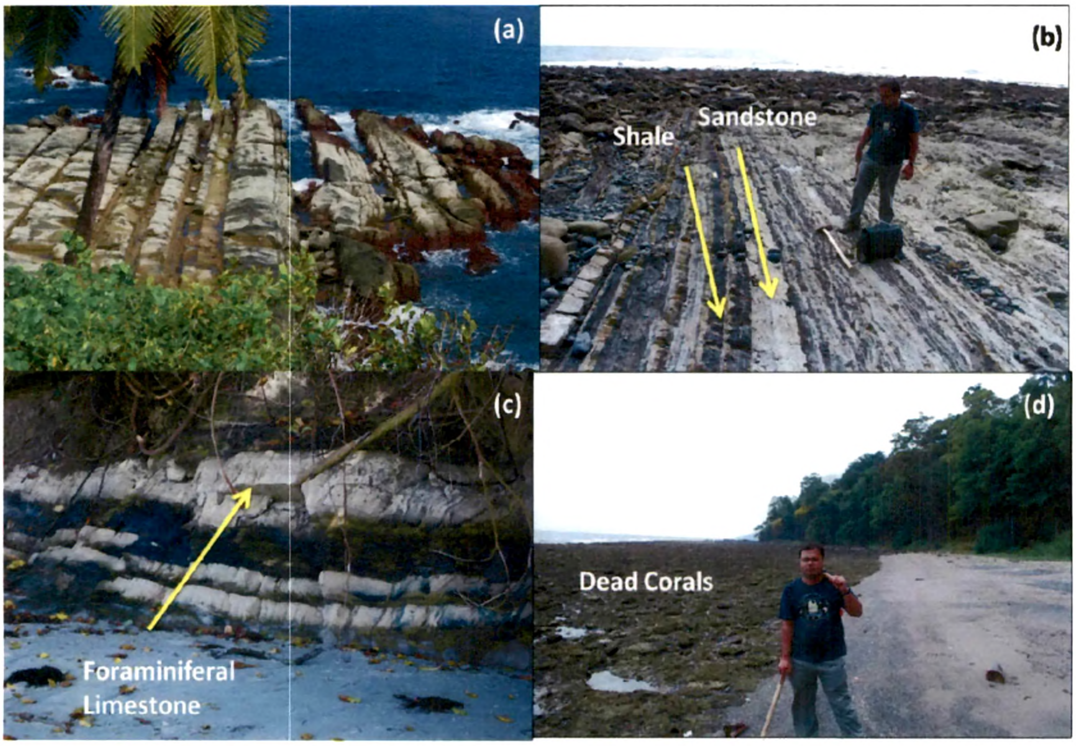

Fig. 2.4: Field photographs showing formations of the Andaman Flysch Group, Archipelago Group and exposed coral reefs. (a) Shale and sandstone beds at Corbyn's Cove, Port Blair; (b) Shale and sandstone beds at Lamiya Bay, Kalipur; (c) Foraminiferal limestone beds of Archipelago Group exposed at Radhanagar beach, Havelock Island; (d) Dead corals exposed on beach at Lamiya Bay, Kalipur, North Andaman.

2.1.3 Andaman Flysch Group

The Andaman Flysch unit overlying the Mithkhari Group is believed to have been deposited in a forearc environment (Pal et al., 2003). Chakraborty and Pal (2001) interpreted that the sequence was deposited in a submarine fan and observed three different facies associations: upper fan, mid fan and basin plain facies. The upper fan facies consists of fine-grained sediments derived from ophiolites and deposited in a high-density turbidity current or channelized debris flow environment. Mid-fan facies consists of thick beds of coarse to fine-grained sandstone and shale with well-defined Bouma cycles (Fig. 2.4a & b), also described as poorly sorted matrix-supported quartz wackes with framework grains of detrital quartz, lithic fragments, feldspar and pyroxene. Basin plain facies is characterized by hemipelagic mudstone interbedded with irregular and lenticular silt laminae and thin sand beds. The total thickness of this unit is not known, but estimates vary from 750 m (Roy, 1983) to 3000 m (Pal et al., 2003). N-S and NNE-SSW striking individual beds of this group can be traced for several kilometers. Sedimentary structures like flute cast, groove cast, and current bedding have also been identified in the sandstone beds and on the basis of their orientation southward-directed paleocurrent patterns have been identified (Pal et al., 2003). The siliciclastic turbidites of the Andaman Flysch Group are less deformed and are little affected by tectonics in comparison to rocks of underlying units of the Mithakhari Group (Macdonald, 1993). The beds show regular fold patterns and have a wide lateral extent.

2.1.4 Archipelago Group

The Archipelago Group, like the Andaman Flysch Group, is also believed to have been deposited in a forearc basin environment (Pal et al., 2003). The ongoing tectonics resulted in gradual shallowing of the basin and change in depositional environment subsequent to the deposition of flysch sediments. Due to which the sediment facies changed from siliciclastic to carbonate turbidites with alternations of pyroclastics layers. The pyroclastics were apparently derived from the inner arc volcanoes and deposited as ash falls or subaqueous pyroclastic flows (Srinivasan, 1988). Previous studies have divided the Archipelago Group sediments mainly into two major litho-assemblages. The lower one contains pyroclastics deposited in subaqueous condition and siliciclastic turbidites consisting of coarse-graded, cross-laminated and parallel laminated greywackes, siltstone and mud (Pal et al., 2003). The pyroclastics and turbidites are well developed in South and Middle Andaman Islands. The upper part consists of ash turbidites overlain by carbonate turbidites (Fig. 2.4c). This unit is well exposed in the Havelock Islands in the east.

Although, synsedimentary basinal disturbances are indicated by micrograbens and slump structures, in general beds show very regular fold geometry. Environment of deposition of the sediments of the Archipelago Group is still debated. Roy (1983) suggested their deposition in a shallow marine condition, while Srinivasan (1986) interpreted it to have been deposited in deep water to neritic or outer neritic condition. Curray (2005) inferred the presence of both the facies.

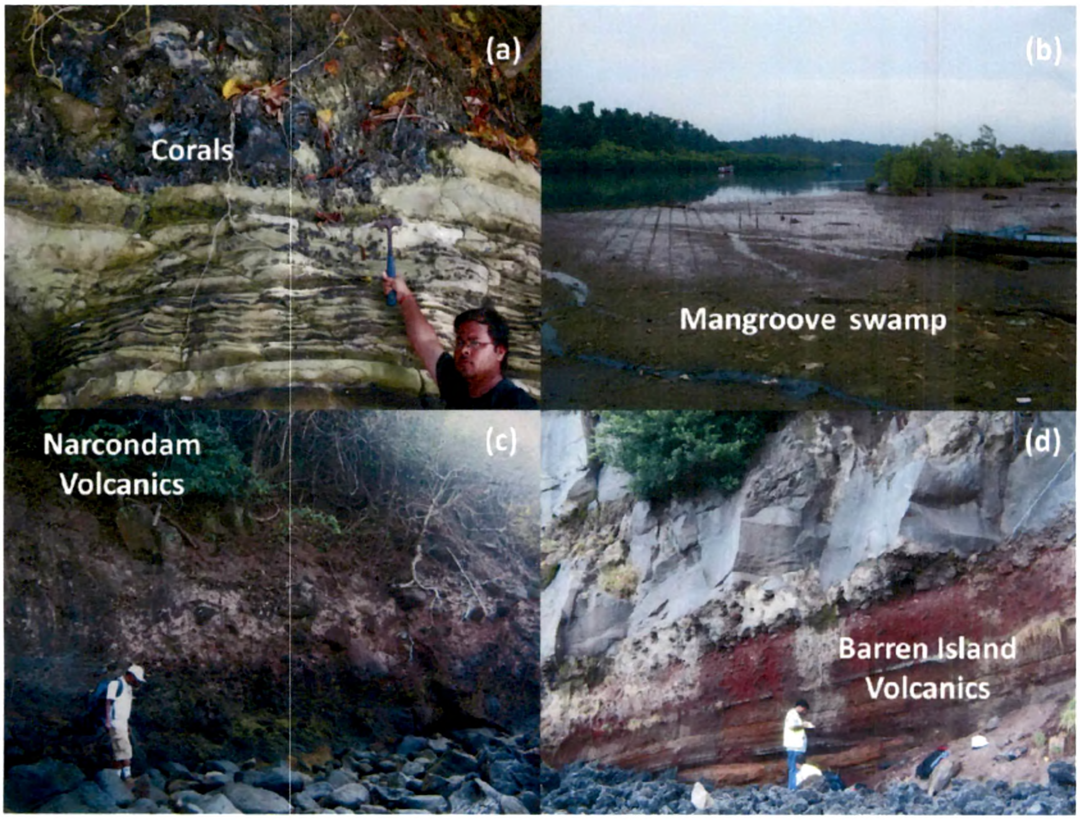

Fig. 2.5: Field photographs showing (a) uplifted coral bed at Radhanagar Beach, Havelock Island; (b) Mangroove swamp deposits at Nilambur Jetty, Baratang Island; (c) Narcondam Island volcanics; (d) Volcanic deposits on northern caldera wall of the Barren Island Volcano.

2.1.5 Nicobar Group/Volcanics/Recent sediments

This unit mainly comprises of rocks and sediments exposed on the Andaman and Nicobar Islands in the form of alluvium, raised beaches, coral reefs (Fig. 2.4d; 2.5a), calcareous tuffs, beach sand, mangrove swamp deposits (Fig. 2.5b), shell limestone along with volcanic rocks and ash produced by the two subaerial volcanic islands (Fig. 2.5c & d). Coral reefs, mangrove swamps, shell limestones and beach sands are present along the coast lines of the islands with large number of bays, lagoons and serpentine creeks, while alluvium is present along the local rainfed streams, in the valleys and on the hill tops. Volcanic products derived from younger volcanoes are restricted to the volcanic islands.

2.1.6 Geochronology of rocks of the Andaman Islands

The presently accepted chronology of the ophiolite and sedimentary sequences of the Andamans is primarily based on biostratigraphy. Based on the presence of key/index fossils of radiolarians (e.g. *Hagiastrids, Nassellarian*) in cherts, and planktic foraminifera (*Globoratalia and Discocyclina*) in pelagic sediments of the ophiolite sequence, the age of the Ophiolite Group has been constrained to Late Cretaceous to Paleocene (Jafri, 1986; Roy et al., 1988; Pal et al., 2003). However, from recent geochronological information based on U-Pb dating of zircons from plagiogranite, it has been suggested that the ophiolitic rocks could have formed as early as ~95 Ma (Pederson et al., 2010 Sarma et al., 2010). Compared to the Paleogene sedimentary rocks of the Mithakhari Group, the Andaman Flysch Group rocks are largely barren in nature in terms of their fossil content (Allen et al., 2007). The reason behind this could be that either fossils were not present in these sedimentary rocks from the beginning or got dissolved/removed later by weathering processes (Allen et al., 2007). The possibility of dissolution of planktic shells below the carbonate compensation depth and abrasion by reworking cannot be ruled out. The presence of fossils of shallow benthic life forms (*e.g. Nummulites atacicus, Nummulites spp., small miliolids and rare Morozovella spp., fragments of rhodophyte algae, and dasycladaceans*) in the Mithakhari Group, suggests Late Palaeocene to Eocene age of deposition (Karunakaran et al., 1967, 1968a; Roy et al. 1988). Biostratigraphic evidences are vague in the Andaman Flysch Group but based on a few fossils recognized, it is believed to have been deposited between Oligocene to the early Miocene (ca. 36–21 Ma) (Pal et al., 2003). Radiolarians, planktic foraminifers, and calcareous nanofossils are present in abundance in the calcareous sedimentary rocks of Archipelago Group (Singh et al., 2000) and are inferred to have been deposited during Miocene to Pliocene (Pal et al., 2005).

Since the chronological constraints based on biostratigraphy were very imprecise, Allen et al. (2007) made an attempt to date these sequences using Fission-Track (FT) and (U/Th)-He methods on apatites and zircons and ^{40}Ar-^{39}Ar method on detrital micas. Although these methods are known to be more suitable for understanding thermal history of the basin, Allen et al. (2007) could successfully constrain the depositional age of the Mithakhari Group to <60 Ma and that of the Andaman Flysch Group to <40 Ma.

2.2 Field studies and Sampling details

2.2.1 Field Studies and Mapping

A comprehensive study on geological mapping and stratigraphy has not yet been done for the Andamans, therefore, it is quite likely that earlier studies have missed or misidentified many lithounits. Due to poorly developed biostratigraphy and lack of isotopic ages, stratigraphic correlations on the islands are very rudimentary. With exposures limited to quarries, coastal areas, and road cuts and presence of thick forest that includes large restricted tribal reserves, sampling has been the most difficult part of this work. Most of the earlier studies have been carried out in and around Port Blair, the capital city of the Andaman and Nicobar Islands. A large part of the middle and north Andaman islands are either restricted or difficult to access, resulting in very little, if any, geological information, whereas owing to easier access, the south Andaman island is well mapped. For the current study, we have made our sampling strategy on the basis of the existing maps and sample locations given in earlier works. The samples were mainly collected in three field campaigns conducted during March-April and December of 2009 and during December of 2011. Since the focus of this work was sedimentary rocks, considerable efforts were put to cover all the accessible outcrops and most of the formations/lithounits. We have divided our sampling areas into four sectors: North, Middle, South Andamans and Havelock Island within Ritchie's Archipelago (Fig. 2.6). After a thorough field survey we have prepared

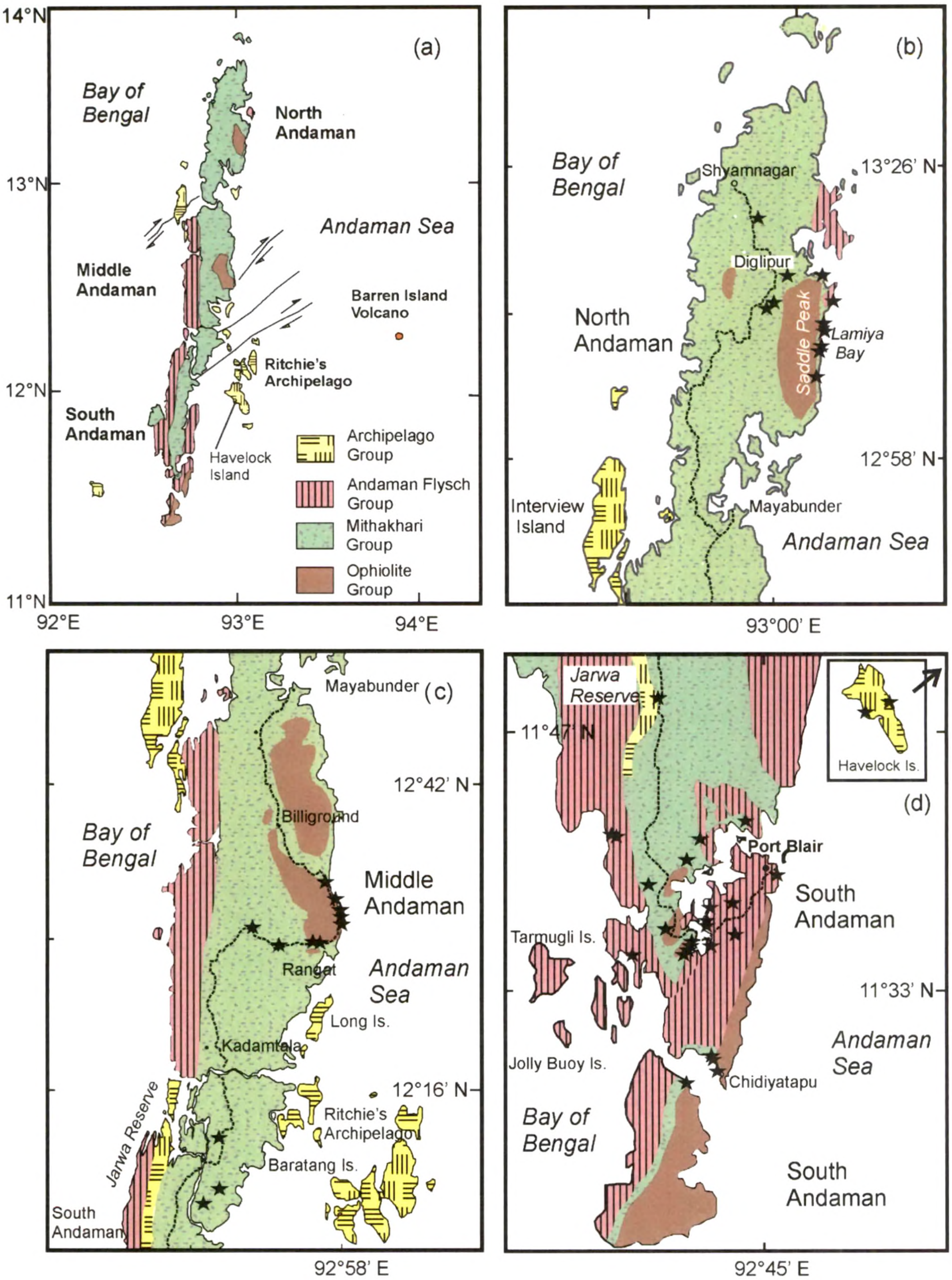

Fig. 2.6: The geological maps of the (a) entire Andaman archipelago, (b) North Andamans, (c) Middle Andamans and (d) South Andamans. Sampling locations are marked as stars.

Table 2.2: Description of samples collected from the Andaman Islands

Sample	Lat/Long	Location	Group/Formation	Description
South Andaman				
AND-09-01*	N 11°30.338', E 92°42.430'	Chidiyatapu	Mithakhari Group	Coarse sandstone with clasts of reef carbonate, ophiolite rocks
AND-09-02	N 11°30.338', E 92°42.430'	Chidiyatapu	Mithakhari Group	Gritty coarse sandstone
AND-09-03	N 11°30.168', E 92°42.029'	Chidiyatapu	Andaman Flysch	Greenish sandstone
AND-09-04*	N 11°38.058', E 92°43.180'	Dollyganj	Andaman Flysch	Dark grey carbonaceous shale
AND-09-05	N 11°38.058', E 92°43.180'	Dollyganj	Andaman Flysch	Dark grey carbonaceous siltstone
AND-09-36*	N 11°37.985', E 92°42.180'	Attampahar	Andaman Flysch	Weathered fine grained mudrock
AND-09-37	N 11°37.585', E 92°42.439'	Gyaracharma	Mithakhari Group	Sandstone
AND-09-39	N 11°37.585', E 92°42.439'	Gyaracharma	Mithakhari Group	Gritty coarse sandstone
AND-09-41	N 11°37.437', E 92°42.466'	Gyaracharma	Mithakhari Group	Rusty-brown shale with calcite veins
AND-09-42*	N 11°36.674', E 92°42.544'	Gyaracharma	Andaman Flysch	Sandstone
AND-09-43	N 11°36.674', E 92°42.544'	Gyaracharma	Andaman Flysch	Grey shale
AND-09-44	N 11°36.112', E 92°40.956'	Sippighat	Mithakhari Group	Shale
AND-09-45	N 11°36.112', E 92°40.956'	Sippighat	Mithakhari Group	Sandstone
AND-09-48	N 11°35.523', E 92°40.330'	Nayasar	Mithakhari Group	Dark grey shale
AND-09-49	N 11°35.523', E 92°40.330'	Nayasar	Mithakhari Group	Purple coloured shale
AND-09-51*	N 11°40.347', E 92°41.046'	Namunagarh	Mithakhari Group	Clasts
AND-09-52	N 11°40.347', E 92°41.046'	Namunagarh	Mithakhari Group	Shale and coal
AND-09-53	N 11°40.347', E 92°41.046'	Namunagarh	Mithakhari Group	Clasts
AND-09-54*	N 11°40.248', E 92°42.492'	Namunagarh	Mithakhari Group	Gritty coarse sandstone
AND-09-55*	N 11°40.280', E 92°41.339'	Hopetown	Mithakhari Group	Grit/conglomerate
AND-09-56	N 11°30.262', E 92°42.065'	Chidiyatapu	Mithakhari Group	Clasts
AND-09-57	N 11°29.557', E 92°42.419'	Chidiyatapu	Mithakhari Group	Clasts
AND-09-61	N 11°37.246', E 92°43.567'	Protherapur	Andaman Flysch	Sandstone & shale
PB-08-07	N 11°39.700', E 92°45.336'	South Point	Andaman Flysch	Shale
PB-08-08*	N 11°39.700', E 92°45.336'	South Point	Andaman Flysch	Sandstone
PB-08-09	N 11°35.423', E 92°37.139'	Wandoor	Andaman Flysch	Sandstone
PB-08-13*	N 11°35.849', E 92°40.916'	Sippighat	Andaman Flysch	Sandstone
AND-11-05	N 11°29.190', E 92°40.144'	Rutaland	Mithakhari Group	Gritty coarse sandstone
AND-11-20	N 11°36.473', E 92°39.924'	Chouldhari	Mithakhari Group	Weathered hard sandstone
AND-11-21	N 11°39.971', E 92°38.191'	Hobdaypur	Mithakhari Group	Sandstone
AND-11-22	N 11°41.327', E 92°36.468'	Collinpur	Mithakhari Group	Black sandstone
AND-11-23	N 11°41.394', E 92°36.309'	Collinpur	Mithakhari Group	Yellow weathered micaceous sandstone
AND-11-54	N 11°47.881', E 92°39.192'	Mile Tilek	Mithakhari Group	Greenish-white tuff
Middle				
AND-09-06	N 12°07.822', E 92°46.989'	Katang	Mithakhari Group	Greenish sandstone
AND-09-07*	N 12°05.731', E 92°44.702'	Baratang cave	Archipelago Group	Sandy limestone
AND-09-08	N 12°05.654', E 92°44.653'	Baratang cave	Archipelago Group	Sandy limestone
AND-09-09*	N 12°11.277', E 92°47.543'	Oralkatcha	Mithakhari Group	Greenish sandstone
AND-09-10	N 12°11.277', E 92°47.543'	Oralkatcha	Mithakhari Group	Greenish sandstone
AND-09-11*	N 12°11.277', E 92°47.543'	Oralkatcha	Mithakhari Group	Gritty coarse sandstone

Table 2.2: Continued

Sample	Lat/Long	Location	Group/Formation	Description
AND-09-12	N 12°31.692', E 92°49.890'	Kaushalyanagar	Andaman Flysch	Sandstone
AND-09-13	N 12°31.870', E 92°58.424'	Panchvati	Mithakhari Group	Gritty/coarse sandstone
AND-09-14	N 12°31.870', E 92°58.424'	Panchvati	Mithakhari Group	Coarse sandstone with clasts
AND-09-16	N 12°34.146', E 92°57.901'	Panchvati	Mithakhari Group	Coarse sandstone with clasts
AND-09-17	N 12°34.146', E 92°57.901'	Panchvati	Mithakhari Group	Coarse sandstone with clasts
AND-11-32	N 12°30.067', E 92°52.473'	Bakutala	Mithakhari Group	Limestone
AND-11-33	N 12°30.022', E 92°52.687'	Bakutala	Mithakhari Group	Rusty-brown shale with calcite veins
AND-11-41A	N 12°32.303', E 92°58.445'	Panchvati	Mithakhari Group	Limestone
AND-11-51	N 12°35.733', E 92°57.405'	Shivapuram	Mithakhari Group	Rusty-brown shale with calcite veins
North				
AND-09-18	N 13°14.586', E 92°57.935'	Diglipur	Mithakhari Group	Coarse sandstone
AND-09-19*	N 13°14.284', E 92°57.551'	Subhasgram	Mithakhari Group	Coarse sandstone
AND-09-20	N 13°13.580', E 92°02.650'	Radhanagar	Mithakhari Group	Coarse sandstone
AND-09-21	N 13°15.514', E 92°58.612'	Madhupur	Mithakhari Group	Sandstone
AND-09-22	N 13°15.514', E 92°58.612'	Madhupur	Mithakhari Group	Coarse sandstone
AND-09-23	N 13°15.514', E 92°58.612'	Madhupur	Mithakhari Group	White sandstone
AND-09-24	N 13°12.186', E 93°02.422'	Lamiya Bay	Mithakhari Group	Gritty coarse sandstone
AND-09-25	N 13°12.106', E 93°02.430'	Lamiya Bay	Mithakhari Group	Gritty coarse sandstone
AND-09-26	N 13°12.005', E 93°02.403'	Lamiya Bay	Mithakhari Group	E-W trending bed of white sandstone
AND-09-27*	N 13°12.005', E 93°02.403'	Lamiya Bay	Mithakhari Group	E-W trending bed of shale
AND-09-28	N 13°12.005', E 93°02.403'	Lamiya Bay	Mithakhari Group	E-W trending bed of hard sandstone
AND-09-30	N 13°16.718', E 93°01.747'	Aerial Bay	Mithakhari Group	Gritty coarse sandstone
AND-09-33	N 13°13.630', E 93°03.074'	Kalipur	Andaman Flysch	Sandstone
LB-10-01	N 13°11.994', E 93°02.377'	Lamiya Bay	Recent deposits	Coral fragments
LB-10-02	N 13°11.953', E 93°02.327'	Lamiya Bay	Recent deposits	Coral fragments
LB-10-03	N 13°11.625', E 93°02.181'	Lamiya Bay	Recent deposits	Coral fragments
Havelock Island				
AND-09-63*	N 12°00.207', E 93°00.408'	Kalapathar	Archipelago Group	Limestone
AND-09-64	N 12°00.207', E 93°00.408'	Kalapathar	Archipelago Group	Limestone
AND-09-64A	N 11°59.609', E 93°00.620'	Kalapathar	Archipelago Group	Limestone
AND-09-65*	N 11°58.806', E 92°57.646'	Radhanagar Beach	Archipelago Group	Limestone
AND-09-66	N 11°58.806', E 92°57.646'	Radhanagar Beach	Archipelago Group	Limestone
AND-09-67	N 11°58.806', E 92°57.646'	Radhanagar Beach	Archipelago Group	Limestone
AND-09-68	N 11°58.806', E 92°57.646'	Radhanagar Beach	Recent deposits	Coral fragments
AND-09-69	N 11°58.806', E 92°57.646'	Radhanagar Beach	Recent deposits	Coral fragments

Samples marked with '*' were used for petrographic studies.

new geological maps for North, Middle and South Andamans and attempted to establish the interrelationship of different stratigraphic units in various sectors (Fig. 2.6).

On the Andaman Islands, the Ophiolite Group rocks are exposed mainly on the east coast of North, Middle and South Andaman Islands, where individual magmatic/sedimentary units of the ophiolite sequence occur (Fig. 2.6). There are also some small isolated patches of ophiolite exposed in the western part of North Andaman and South Andaman Islands. The continuous and best-preserved outcrops of the Ophiolite Group rocks occur in South Andaman, extending from Corbyn's Cove to Chidiyatapu and continues into Rutland Island in south. The type areas for the Mithakhari Group formations are also located in South Andaman, with a few good easily accessible outcrops of the Hope Town Conglomerate at Hopetown and Chidiyatapu, while the Namunagarh Grit is well exposed in a quarry at of Namunagarh Village. Extensive outcrops of these rocks occur in North and Middle Andaman Islands as well. In South Andaman, the lithology is mainly dominated by the Andaman Flysch Group rocks with the best exposures found at Corbyn's Cove where outcrops of steeply dipping beds are seen (Fig. 2.6). The Andaman Flysch rocks are generally found along the eastern and the western coastlines (Fig. 2.6). The Archipelago Group occurs as a thin band in the centre of the main Andaman Island in NNE-SSW direction, which is the general strike of the island chain. However, the best exposures are confined to the islands of Richie's Archipelago and Interview Island. It is believed that the Archipelago Group of rocks had formed a blanket over the Andamans earlier; however, later events of upliftment resulted in erosion of these relatively softer rocks, leaving behind small patches of outcrops on the main islands (Allen et al., 2007).

2.2.2 Sampling of sedimentary sequences

One of the main objectives of this study was to decipher the provenances for the siliciclastic formations belonging to the Mithakhari and Andaman Flysch Groups. Apart from the sediments from these groups, we also collected rock samples from the Ophiolite Group, considering that the igneous and metamorphic rocks of this group could be one of the most likely sources of sediments. The lowermost unit of the Mithakhari Group, the Lipa Black shale is not well exposed and hence could not be sampled. Samples of conglomeratic and gritty sandstones were mainly collected from Chidiyatapu, Sippighat, Namunagarh, Hopetown and Hobadaypur in South Andaman, Baratang Island in Middle Andaman and from area around Diglipur in North Andaman, where these units are well exposed. In the main island of Middle Andaman most of the accessible terrain contains outcrops of ophiolite. The Andaman Flysch Group samples were mostly collected from various locations on South Andaman Island. List of samples with their locations and other relevant information are given in Table 2.2 and are marked in Fig. 2.6.

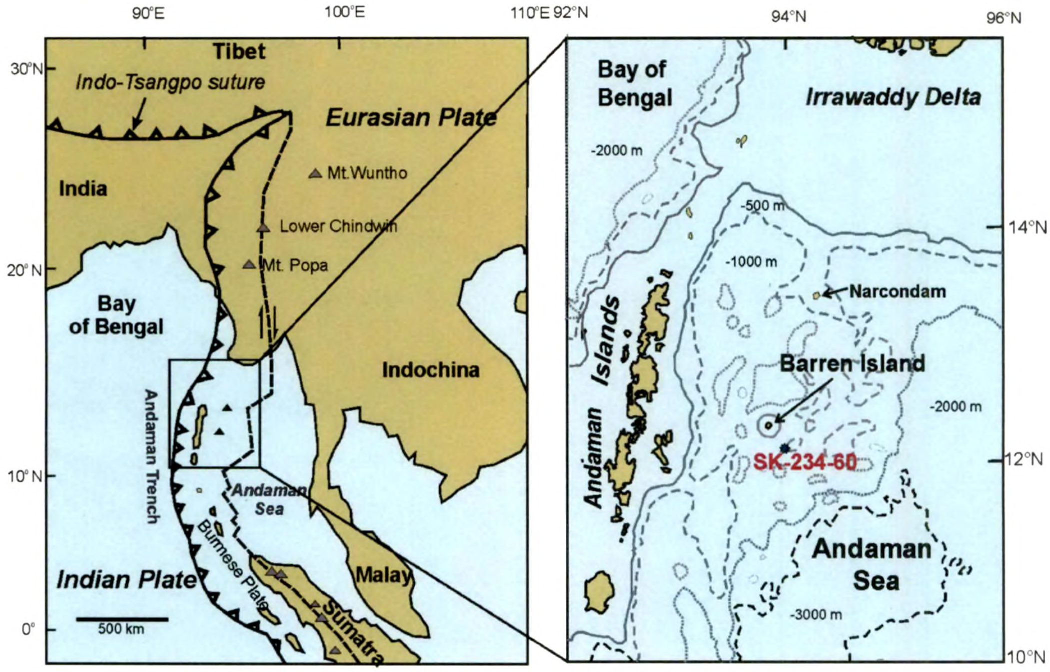

Fig. 2.7: Map of the northeastern Indian Ocean showing the locations of Andaman Islands, Barren Island and the studied core SK-234-60 (N12°05′46″, E94°05′18″) in the Andaman Sea.

2.2.3 *Sampling of Coral terraces*

To study the timing of upliftment of Andaman coastline and its causes we collected samples from exposed dead coral from coastal terraces of some islands of Andamans. Our study areas include Lamiya Bay (Kalipur) on the eastern coastline of North Andaman and Radhanagar Beach on the west coast of Havelock Island (Fig. 2.6). Three coral samples were collected from terraces of Lamiya Bay and two from Radhanagar. These terraces represent recent sedimentary deposits belonging to topmost unit of our stratigraphic divison. At Lamiya Bay three step-like terraces were recognized, while at Radhanagar Beach section, two terraces were recognised. At Radhanagar, like that in

Lamiya Bay dead corals occur at sea level and on a raised terrace at a height of ~3.5m. On this terrace, the dead coral reef is present above the foraminiferal limestones of the Archipelago Group.

2.2.4 Sampling of modern sediments from the Andaman Sea

To decipher the provenance of the modern sediments deposited in the Andaman Sea, a sediment core (SK-234-60) was raised from a location 32 km (great circle distance) southeast of the Barren Island Volcano (Fig. 2.7). This 4-m-long and 12-cm-diameter core was collected during the expedition no. 234 of R/V 'Sagar Kanya' on June 02, 2007 at station no. 60 (N12°05′46", E94°05′18"; Fig. 2.7) at a water depth of 2000 m using a cylindrical gravity corer. The core was cut along with the casing into four ~1m sections on the board before being shipped and back to our laboratory for further study. In the laboratory, each ~1m section of the core was split into two halves; one half of such a section is shown in Fig 2.8(a). One of the halves was sub-sampled at 5 cm intervals and the other half at 2 cm intervals for geochemistry and geochronology, respectively. We did not observe any deformation on the edges of the sediment layers in the core except for the top 20 cm, which was disturbed during coring (Fig. 2.8b).

Bathymetry of the region suggests that the site of the core was far from the submarine base of the Barren Island Volcano (Fig. 2.7), and thus well shielded from direct slides or slumps on the flanks of the volcano. Based on colour and grain size of sediments, seven discrete ash layers were identified within the olive-grey to very dark grey pelagic sediments (Fig. 2.7b, c & d), which were later confirmed by their contents of glass and primary igneous minerals through microscopy and X-ray diffractometry. These ash layers occur at intervals of 53-57, 73-75, 90-94, 109-112, 302-321, 372-377 and 380-387 cm and are labelled AL1 to AL7 from the top to the bottom of the core (Fig. 2.8b). A detailed description of these layers is given in Chapter-3.

2.3 Analytical Methods

To achieve the objectives set for the work, various methodologies were used to generate analytical data for chronology, mineralogy and geochemistry. The chemical procedures for separation of Sr and Nd from samples and associated mass spectrometric analyses on Thermal Ionization Mass Spectrometer (TIMS) are mentioned only briefly in this section as they were based on already established routine procedures of our laboratory. Appropriate care was taken during the analyses to avoid contamination. For geochemical and isotopic analyses well homogenized powdered samples were used.

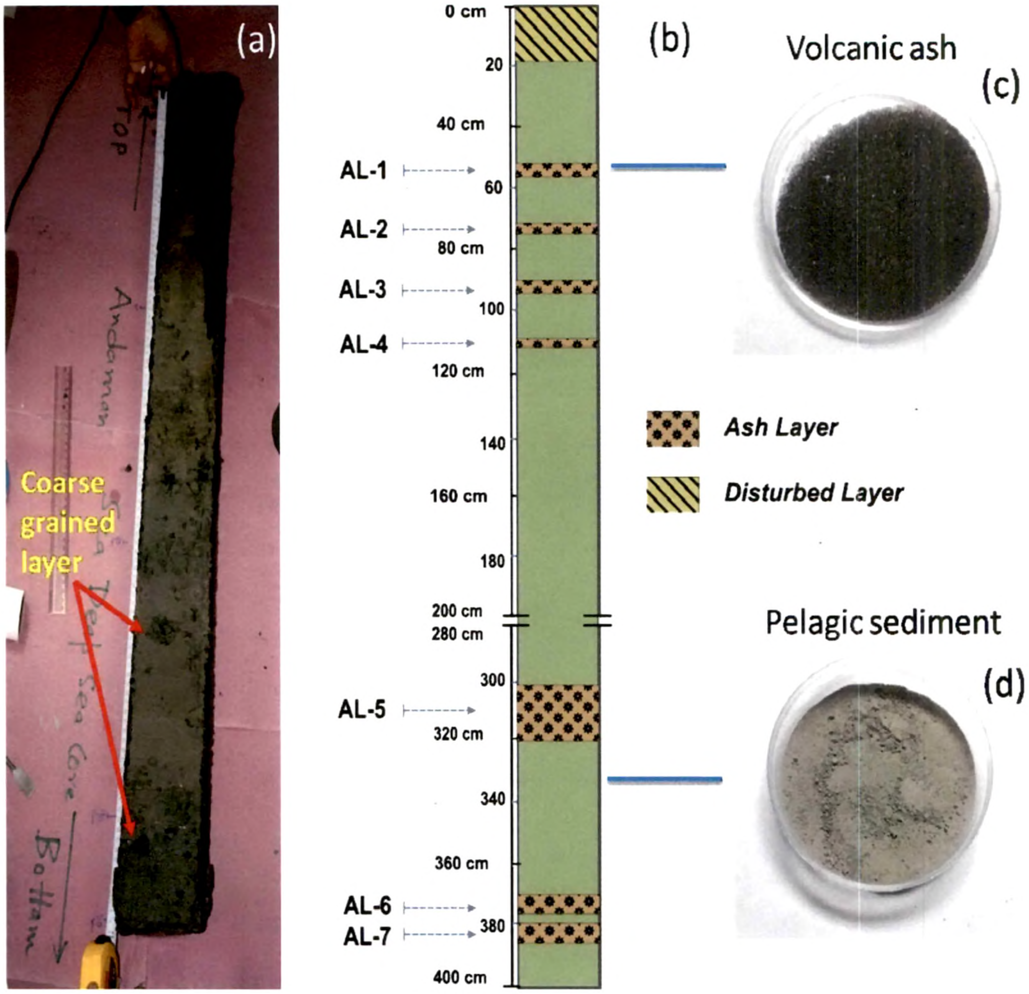

Fig. 2.8: (a) Photograph of one half of a 1m section of the core; (b) Litholog of the same core, 4m in length, showing volcanic ash layers (AL-1 to 7) in normal ocean sediments. The top 20cm is disturbed; (c) photograph of pure volcanic ash separated from one of the layers; (d) photograph of normal sediment.

The sediment core from the Andaman Sea contained silt-clay sized siliciclastics, foraminiferal carbonates and coarser ash material consisting of lithic fragments, minerals and glass shards. We separated coarse ash from the rest by gravity separation. ~250g of sediments were taken in a clean glass beaker and ultrasonicated repeatedly in order to disaggregate ash from the mud. The less dense slurry was then decanted off and collected in a separate beaker and dried down for further analysis. The ash and mud fractions were individually treated with 20 % acetic acid and washed several times to remove carbonates. These were then dried at ~70°C and powdered using an agate mortar. Rock samples were wrapped in polyethylene bags and crushed into smaller pieces. Selected chips were cleaned in water and alcohol using an ultrasonicator to remove finer impurities. Dried chips were then powdered by an agate mortar.

2.3.1 Petrography

Thin section studies of the Andaman sedimentary rocks were done to decipher mineralogy, identify fossils present and determine degree of secondary alteration. Grains from the coarse grained layers in the core were studied under microscope to identify magmatic minerals and lithic fragments. X-ray diffraction of some of these layers was also done to confirm the mineralogy and hence the volcanic nature of the coarse grained layers.

2.3.2 Major element analysis

(A) X-ray Fluorescence (XRF) Spectrometry

Analyses of major element concentrations in rocks and sediments were done by XRF spectrometry. Measurements were done in a Philips AXIOS X-Ray Spectrometer fitted with an Rh X-Ray tube, operated at 50 kV and 55 mA, of 4 kW power. The instrument belongs to the National facility for Planetary and Exploration Program (PLANEX) of Indian Space Research Organization (ISRO) and located at PRL. The instrument was set-up, installed and calibrated for routine measurement of rock samples during this research activity (Ray et al., 2008). Several international standards such as AGV-1, G-2, GSP-1, JLS-1, JMS-2, JSo-1, MAG-1, NOVA-13, NUSSI, SCo-1, SDO-1 and SOIL-5 supplied by United State Geological Survey (USGS) and Japanese Geological Survey were used for calibration purpose during our measurements. Oxides of major elements: SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, K_2O, Na_2O, MnO, and P_2O_5 were analysed on pressed pellets of finely powdered samples, which were already demoisturized at 110 °C. Sample pellets were prepared using 2.0 gm of sample powder mixed with 0.5 gm wax binder. The mixtures were homogenized in an agate mortar and taken in 37 mm aluminum cups with more wax at the bottom. The cups were pressed in a hydraulic press at 150 kN pressure for a minute to make the pellets. Figure 2.9 gives the typical

XRF calibration curves for various major element oxides obtained during our analyses. With each set of samples an international rock standard was also analyzed as unknown for accuracy check. The measured values are in good agreement with the reported values within 2σ error (Table 2.3). The precision of measurements based on repeated analyses of standards is better than 3% at 2σ level except for Fe, Na and Mn, for which it is better than 10% at 2σ.

(B) Major element analysis by Electron Probe Micro-Analyzer (EPMA)

For major element analysis of ash in core, bulk analysis was not possible because of limited sample amount. Grains of minerals and lithic fragments were picked up from the ash under a stereomicroscope and EPMA mounds were prepared. The mounds were polished on an automated polish wheel and coated with carbon. Major element concentrations were measured on 42 samples using a Cameca SX100 EPMA, at PLANEX facility of PRL, in wavelength-dispersive mode. Analyses were performed with an electron beam current of 10 nA and accelerating voltage of 15 kV. A glass standard (USNM 113716, Jarosewich et al., 1980) was periodically analysed to check both the accuracy and precision. Table 2.4 presents the recommended and measured data for this standard. Analytical data of individual glass analyses were normalized to 100 weight percent.

Table 2.3: A comparison of measured and reported concentrations of various element oxides in the international standard SDO-1 (Devonian Ohio shale)

	Measured		Reported*	
	(n=15)	±2σ		±2σ
(%)				
SiO_2	49.29	0.75	49.28	1.26
TiO_2	0.71	0.02	0.71	0.06
Al_2O_3	12.46	0.28	12.27	0.46
Fe_2O_3	9.65	0.69	9.34	0.42
CaO	1.04	0.04	1.05	0.05
MgO	1.52	0.08	1.54	0.08
MnO	0.05	0.01	0.04	0.01
K_2O	3.24	0.10	3.35	0.12
Na_2O	0.43	0.06	0.38	0.05
P_2O_5	0.11	0.01	0.11	0.01

*Reported data are from USGS

Table 2.4: A comparison of measured and reported concentrations of various element oxides in the glass standard USNM 113716 (Basalt glass)

	Measured		Reported
	(n=7)	±2σ	
(%)			
SiO_2	50.67	0.54	51.52*
TiO_2	1.34	0.06	1.30*
Al_2O_3	14.83	0.23	15.39*
FeO	9.52	1.07	9.24*
CaO	11.24	0.22	11.31*
MgO	7.91	0.14	8.21
MnO	0.16	0.10	0.17*
K_2O	0.08	0.02	0.09*
Na_2O	2.70	0.19	2.49*
P_2O_5	0.26	0.05	0.13*
Cr_2O_3	0.02	0.04	0.06#
CoO	0.03	0.07	-
NiO	0.03	0.07	0.02#

Reported data marked with '*'are taken from Jarosewich et al. (1980) and marked with '#' are taken from Thompson, (1980).

2.3.3 Analysis of Trace elements

(A) Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Concentrations of trace elements including fourteen Rare Earth Elements (REEs) in our samples were measured using a Thermoelectron X-Series^{II} ICPMS at PLANEX facility of PRL. The instrument was set-up, installed and calibrated for routine measurement of rock samples during this research activity (Ray et al., 2008). A known weight of finely powdered and carbonate free sediment was taken in quartz crucibles and combusted at ~600 °C to oxidize and remove organic matter. About 50 mg of organic carbon free sample was taken in a Savillex Teflon vial and digested using a combination of ultra pure HF and HNO_3 (2:1) acid mixture (Acids were from Seastar Chemicals®). A stock sample solution (~50 ml) was prepared in 2% HNO_3 with ~1000 dilution factor.

To check the accuracy and precision of analyses, several aliquots of BHVO-2, an international rock standard from USGS, were digested and analysed as unknowns. Calibration curves were generated using blank solutions and various dilutions of BHVO-2 standard. Calibration curves for some elements are given in Fig. 2.10. Reproducibility based on the repeated analyses of standards was ≤5% at 2σ level, for REEs and ≤10% for all other trace elements. In Table 2.5 we report our data for BHVO-2 along with the recommended values.

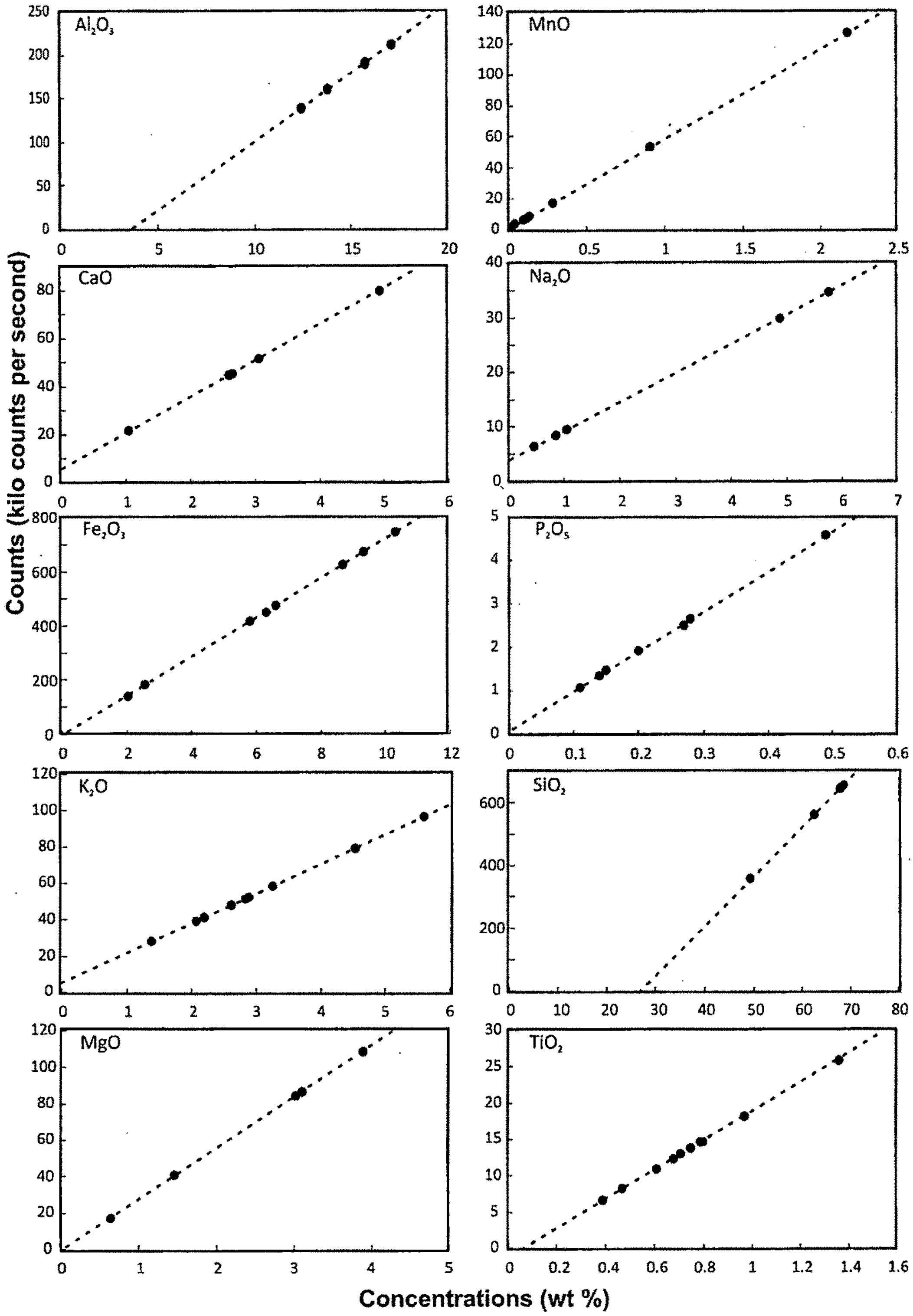

Fig: 2.9: Typical calibration curves for various major element oxides generated on XRF using multiple international rock standards.

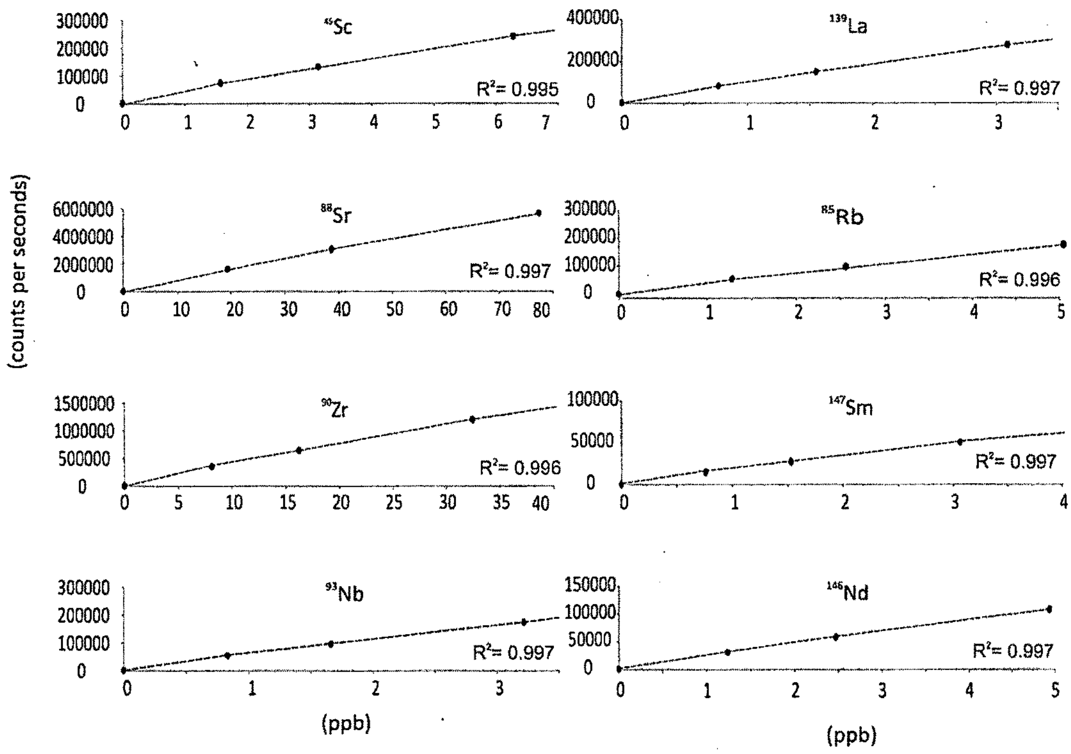

Fig. 2.10: Typical calibration curves for different trace elements generated on ICP-MS using various dilutions of BHVO-2.

2.3.4 Analysis of Radiogenic Isotopic Ratios

Sr and Nd isotopic ratios ($^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$) were measured on selected samples from siliciclastic rocks of the Andaman Islands, decarbonated sediments and ash layers of the Andaman Sea core. These analyses were carried out on powdered samples, using the standard HF-HNO_3-HCl dissolution procedure for silicate rocks. Sr separation was done by conventional cation exchange column chemistry (Resin AG 50WX8, 200-400 mesh size), and Nd was separated from other rare earth elements using Ln-specific resin from Eichrom(R) (50-100 μm grain size) with dilute HCl (0.18N) as elutant. Measurements were carried out in static multi-collection mode on an ISOPROBE-T thermal ionization mass spectrometer (TIMS) at the Physical Research Laboratory (PRL), Ahmedabad. Sr samples were loaded with 0.1 M phosphoric acid on pre-degassed, oxidized single Ta filaments while Nd samples were loaded on the outer Ta filaments of triple (Ta-Re-Ta) filament arrangements. Some Nd isotope analyses were also performed on Multicollector-Inductively Coupled Plasma Mass Spectrometer at PRL.

Table 2.5: Measured Trace element concentrations in BHVO-2 compared with reported values

Elements	Measured concentration (ppm)	±2σ	Reported concentration* (ppm)	±2σ
Sc	29.00	2.98	31.00	2.00
V	304.71	30.75	329.00	18.00
Cr	263.38	27.36	285.00	28.00
Co	44.28	4.44	47.00	4.00
Ni	103.32	10.21	112.00	18.00
Rb	10.17	0.48	10.10	1.20
Cs	0.106	0.009	0.110	0.040
Sr	359.55	28.05	382.00	20.00
Y	21.69	1.74	23.00	2.00
Zr	149.81	12.42	160.00	16.00
Nb	16.33	0.91	16.40	1.40
Ba	113.46	25.31	128.00	8.00
La	15.37	0.83	15.25	0.04
Ce	38.03	2.12	37.84	0.38
Pr	5.45	0.29	5.35	0.03
Nd	24.95	1.35	24.39	0.04
Sm	6.21	0.34	6.03	0.02
Eu	2.08	0.12	2.04	0.01
Gd	6.39	0.36	6.23	0.01
Tb	0.89	0.05	0.86	0.12
Dy	5.45	0.29	5.30	0.02
Ho	0.94	0.05	0.91	0.12
Er	2.62	0.14	2.55	0.01
Tm	0.31	0.02	0.30	0.10
Yb	2.01	0.11	1.96	0.01
Lu	0.28	0.01	0.27	0.00
Hf	4.22	0.24	4.10	0.80
Ta	0.93	0.04	0.94	0.14
Pb	1.62	0.57	1.40	0.40
Th	1.21	0.06	1.18	0.18
U	0.45	0.02	0.44	0.06

*Gao et al., (2002); Raczek et al., (2003); Kent et al., (2004).

Sr and Nd isotope ratios were corrected for fractionation using $^{86}Sr/^{88}Sr = 0.1194$ and $^{146}Nd/^{144}Nd = 0.7219$, respectively. The average values for NBS987 and JNdi analyzed over a period of 4 years on TIMS are $^{87}Sr/^{86}Sr = 0.71023 \pm 0.00001$ and $^{143}Nd/^{144}Nd = 0.512104 \pm 0.000004$ (± 0.1 in ε_{Nd} units) at the 2σ level of uncertainty. The value of $^{143}Nd/^{144}Nd = 0.512104$ for JNdi corresponds to a value of 0.511847 for the widely used La Jolla Nd standard (Tanaka et al., 2000). For comparison with literature data, the $^{87}Sr/^{86}Sr$ data were normalized to a value of 0.71025 for NBS987 and the

$^{143}Nd/^{144}Nd$ data were normalized to a value of 0.511858 for La Jolla. All plots and discussion in this work are based on the normalized ratios. Also, USGS standard BHVO-2, processed regularly with each set of samples, was analysed for $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ during the course of this work. Its average measured value for $^{87}Sr/^{86}Sr$ is 0.70345 ± 0.00004 (2σ) (n=7) and for $^{143}Nd/^{144}Nd$ is 0.512949 ± 0.000080 (2σ) (n=13), which are well in agreement with the reported values of 0.70344 and 0.512957, respectively (Raczek et al., 2003).

2.3.5 Dating of the sediment core and dead corals

(A) Conventional C-14 Dating

Radiocarbon dating was done on coral samples from the coastal terraces of the Andamans and bulk sediments of the core (SK-234-60), to determine their ages of deposition, by the conventional β-counting method. For radiocarbon dating in the core, samples were selected in such a way that their depositional ages could be utilized to estimate the ages of the ash layers, and the rates of sedimentation of the layers in-between. Since this method required ≥ 1 g of carbon for high precision, a large amount of sediment was needed (assuming an average inorganic carbon content of 1 wt%) and therefore, we sampled the core in 5-cm intervals, and 5 such layers were dated.

Radiocarbon dating of the carbonate fraction in the bulk sediments was carried out by liquid scintillation spectrometry method at the PRL following procedures described in Yadava and Ramesh (1999). For coral samples, ~10 g of powdered sample, selected from the least altered portion close to the top surface of a fragment and for marine core ~100 g of bulk sediment, was taken in an evacuated flask and reacted with orthophosphoric acid. The resulting carbon dioxide was converted to benzene and its C-14 activity was measured using a liquid scintillation counter (Quantulus 1220). An aliquot of each sample in CO_2 phase was analyzed for $\delta^{13}C$ on a stable isotope ratio mass spectrometer (GEO 20-20) and used for fractionation correction. The average $\delta^{13}C$ value used for fractionation correction was 0±2‰, with respect to V-PDB.

(B) C-14 dating by Accelerator Mass Spectrometer (AMS)

For more precise dating of the sediment core we employed AMS C-14 dating using planktic foraminifera separated from various layers (2 cm thick). ~15mg (200 individuals) of planktic foraminifers were handpicked from13 different layers down the core. AMS C-14 dating was carried out at the NSF Arizona AMS Facility, University of Arizona, USA (Linick et al., 1986; Jull et al., 1989; Somayajulu et al., 1999). The following planktic foraminifera were utilized for this study- *Globigerinoides ruber, Globigerinoides sacculifer, Orbulina universa and Neogloboquadrina dutertrei.*

For both the dates (conventional and AMS) obtained on bulk carbonate and on foraminifers, ages <26000 years were calibrated using radiocarbon calibration program CALIB 6.0 (Hughen et al., 2004), considering reservoir correction (ΔR) value of 11 ± 35 yrs for the Andaman Sea (Dutta et al., 2001). Ages >26000 years were calibrated using "Marine09" and "IntCal09" radiocarbon age calibration curves (Reimer et al., 2009; Stuiver and Reimer, 1993). Our results are reported with errors at one standard deviation (1σ).