Chapter 2
Geology and Earlier work

Andaman and Nicobar Islands of India are located between 6° N and 14° N latitudes in the northeast Indian Ocean. This archipelago consists of 319 islands (Bhoothalingam, 1972) in which the Andaman group of islands comprises 258 and the Nicobar group comprises 61 islands. A channel at 10° N latitude, which is popularly known as the "Ten Degree Channel", separates these islands. The archipelago forms a dividing line between the Bay of Bengal in the west and the Andaman Sea in the east. These islands are part of an accretionary prism or wedge which forms the outer arc ridge of the Andaman subduction zone (northernmost section of the Sunda-Banda subduction zone) (Fig. 1.10). This accretionary wedge is a result of the northward but oblique subduction of Indian plate below the Burmese microplate at a rate of 4-6 cm/year along the Andaman-Java Trench (Curray, 2005). This chain of islands, more than 4000 km long, extends from the Myanmar Arakan-Yoma coast in the north down to Sumatra and Java in the south. Sewell (1925) suggested that the Andaman–Nicobar Ridge had drifted toward the west away from the South-East Asian mainland, and had thus formed a pronounced curve with its apex in the region of 'Little Andaman' Island.

The first accounts on the geology and origin of the Andaman – Nicobar Ridge was given in mid nineteenth century. However these were localized restricted to an island or a part of it and was in the form of preliminary reports on lithology. Helfer (1840) was the first worker to carry out geological field work on these islands, in 1840. Rink (1847) suggested that this ridge had been formed of sediments uplifted from the deep ocean floor, and consisted 'partly of those stratified deposits which occupied the level bottom of the sea', an early statement of the modern

hypothesis of uplift and incorporation of sea floor deposits into an accretionary prism. He also divided the rocks of Nicobar Islands into three groups, viz., Brown Coal Formation, Plutonic Rocks and Older Alluvium, in ascending order of age. During the years 1850 to 1864, several geologists presented preliminary reports on lithology and petrography of some islands (Oldham 1885). Hochstetter (1869), a geologist from Austria pointed out that the same ridge extended southward as the outer arc ridge off Sumatra and Java after reorganization of two sedimentary units in Java. Ball (1870) was the first to describe the geology of the area around Port-Blair.

2.1 Geology of Andaman and Nicobar Islands

The tectonic evolution of Andaman and Nicobar Islands has been modelled based on three components these are i) tectonic features recorded from the Sea (Curray and Moore, et al., 1982). ii) seismic records (Dasgupta and Mukhopadhyay, 1993) and iii) regional correlation of tectonic elements of the eastern part of the Himalaya (Sengupta et al., 1990). The temporal history of subduction in this part (central part of Sunda arc) has been a matter of debate. There exist two schools of thoughts. The first school (Acharyya et al., 1990; Sengupta et al., 1990) argues that the present subduction, all around the western Sunda arc, began during Miocene times and onland emplacement of ophiolites took place during terminal collision in Oligocene. In their model, a second trench further east of the present trench with a protocontinent was assumed. Also, Cretaceous ophiolites and Eocene sediments were considered as a part of this accretionary prism related to second subduction margin and believed to have subsequently emplaced as east to west propagating allochthonous nappe sheets on present subduction margin. The second school of thought is based on the presence of melange and the highly deformed sediments. These authors suggest that the onset

of subduction took place during Late Cretaceous times, after the early Cretaceous break-up of the Gondwanaland (Curray and Moore, 1974; Karig et al., 1979) or from Late Palaeozoic (Hamilton, 1979; McCourt et al., 1996).

The currently accepted stratigraphy of the Andaman Islands (Table 2.1) is partly based on the earliest lithological mapping done by Oldham (1885). Who first divided the rocks of Andaman into two parts; older Port Blair series and younger Archipelago series, separated by volcanic rocks and serpentines, later recognized as an ophiolites sequence. In 1960s paleontological constraints were used to identify the Paleocene-Neogene lithostatigaphic units and subsequently in last five decades the stratigraphy has been modified and formation names have been changed. Allen et al. (2007) divided the Andaman Island stratigraphy in to four groups (Table 2.1). In this thesis I have modified this by introducing a new group at top, the Island Arc Group (Table 2.1). Accordingly, the present stratigraphy now comprises five units, which, in ascending order, are the ophiolites Group, the Mithakhari Group, the Andaman Flysch Group, The Archipelago Group and the Island Arc Group (Table 2.1).

2.1.1 The Ophiolite Group

The Ophiolite Group forms the basement of the Andaman Islands, a part of the Indo-Burma accretionary complex. It contains numerous north-south trending slices of Cretaceous-Palaeocene ophiolites. The group is made up of a plutonic complex, a volcanic sequence and pelagic sedimentary rocks (Fig. 2.1). Due to thick vegetation and soil, continuous ophiolite sections are rare. Pal and Bhattacharya (2010) developed regional ophiolites stratigraphy on the basis of local contact relationships. They reported that the lower part of the group (80% of the total outcrop) comprises foliated and highly serpentinized peridotite. The upper part

Table 2.1 Simplified stratigraphy of Andaman Island (modified after Allen et al., 2007)

Approximate Age	Group	Formation	Lithology
Pliocene to Quaternary	Island Arc Group		Subaerial lava flows and volcanoclastics of Narcondam Island and Barren Island Volcanoes
Miocene to Pliocene	Archipelago Group		Cross-stratified and graded sandstones, silty mudstone and limestone marls, and chalky limestones
Oligocene-Late Eocene (?)	Andaman Flysch Group (formerly Port Blair Group)		Bouma sequences, sandstone-shale and mudstones
Early to Middle Eocene (?)	Mithakhari Group (formerly Baratang and Port Meadow groups)	Namunagarh Grit	Pebbly and coarse to fine grained volcaniclastic sandstones and grits
		Hope Town Conglomerate	Interstratified massive and graded polymict conglomerates, massive cross-stratified and graded sandstone, shales and thin coals
		Lipa Black Shale	Pyritiferous black Shale
Late Cretaceous to Paleocene (?)	Ophiolite Group		Pillow lava, basalt, gabbro, pyroxinite, hurzburgite, serpentinite, andesite, diorite, plagiogranite, rhyolite, serpentinized harzburgite, pyroxinite , and pelagic sediments, radiolarian chert and hematitic mudstones

comprises a layered sequence of ultramafic–mafic rocks, an intrusive section of homogeneous gabbro–plagiogranite–diorite–dolerite and an extrusive section of boninite and tholeiitic basalt lavas (Fig. 2.1). Although ophiolite occurrences are reported from almost all the major Andaman Islands, the greatest numbers of ophiolites slices are present in South Andaman island, where the largest slices range in thickness from 300 to 750 m, but the largest volume of mantle sequences are exposed in Middle and North Andaman Islands (Pal et al., 2003). On the basis of lithology Pal (2011) divided the Ophiolite Group into five parts. In present study we would be following his classification. Fig 2.1 presents the geological map of the Andaman Island and a litholog of the Ophiolites Group. In the following subsections I discuss various units of the Ophiolite Group in details.

Mantle tectonite

This section contains foliated peridotites (maximum thickness ~ 750 m, in North Andaman) which are serpentinized lherzolites and harzburgites assemblage (Fig. 2.2a). It locally contains subconcordant lenses and pods (2 cm to 4 m long) of serpentinized dunite. The foliated peridotites, typical of many ophiolites, are also described here as tectonite (e.g., Gass, 1990). Lherzolite usually occurs in the lower part of this unit and is less abundant than harzburgite. Chromitite pods are restricted to the upper part of the tectonite near the contact with the layered sequence. Most of the chromitites form elliptical pods (up to 11 m by 3.5 m), and enveloped by a thin dunite rim within the host harzburgites. These peridotites as well as the dunite and chromitite pods represent the mantle rocks of the Andaman ophiolites (Pal, 2011).

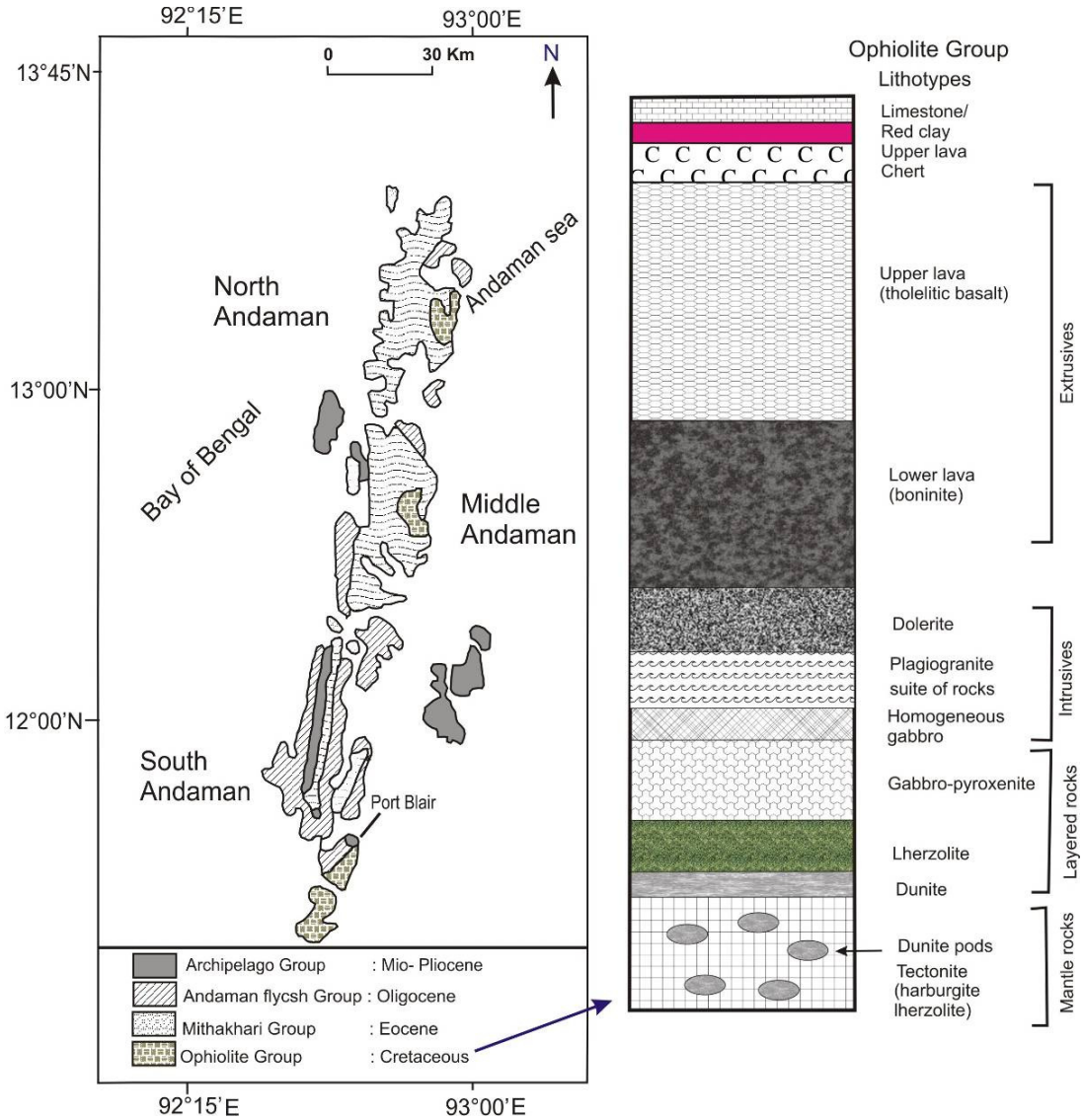

Fig.2.1 A geological map of the Andaman Islands and a schematic section of the Ophiolite Group displaying its different members (modified after Pal 2011)

Layered ultramafic–mafic sequence

The layered ultramafic–mafic sections (maximum thickness ~ 80 m, on South Andaman) are made up of mantle and crustal plutonic rocks. The mantle sequence consists of layered serpentinized dunite and lherzolites, whereas the crustal section constitutes plutonic rocks and extrusives such as layered gabbros and pyroxinites (Fig. 2.1; Fig. 2.2 b, c).

In the Kodiaghat section (South Andaman), mantle tectonite is overlain by layered gabbro–pyroxenite. The gabbro–pyroxenite unit here shows repetitive and undeformed parallel layers of alternating olivine gabbro or norite and pyroxenite that vary in thickness from 2 to 40 cm (Pal, 2011).

Intrusive units

These intrusive units of the Ophiolites Group are composed by a suite of homogeneous gabbro, plagiogranite, diorite and dolerite assemblage (Fig. 2.1 and 2.2). These intrusive rocks (maximum thickness ~ 60 m, in South Andaman) are intermingled with, and locally intrude, the layered ultramafic–mafic rocks. Unlike normal oceanic crust ophiolites the ophiolites of Andamans do not contain sheeted dykes in the sequence. However, a few thin dykes of basalt and dolerite are found intruding into the plagiogranite-diorite unit in South Andaman (Fig. 2.3d).

Extrusive lavas

The uppermost part of the ophiolite is a thick sequence of lavas (maximum thickness ~ 500 m, in South Andaman) that occur as two tectonic slices. One slice, more frequent, consists of dark-colored pillow lavas of basaltic composition (Fig. 2.2e and f) and consistently occurs along the eastern coast of the island and is called East coast volcanics (Ray, 1987).

Lava flows compositionally are of two types, dacitic to andesitic basalts and tholeitic basalts (Ray et al., 1988; Vohra et al., 1989). These rocks are plagioclase phyric and plagioclase-pyroxene phyric with minor quartz set in a ground mass of epidote-chlorite-glass (Pal et al., 2003; Acharyya, 2007). Tholeitic pillow basalts occupy a major part of the Ophiolite Group in south Andaman Islands. The first slice is more abundant than the second.

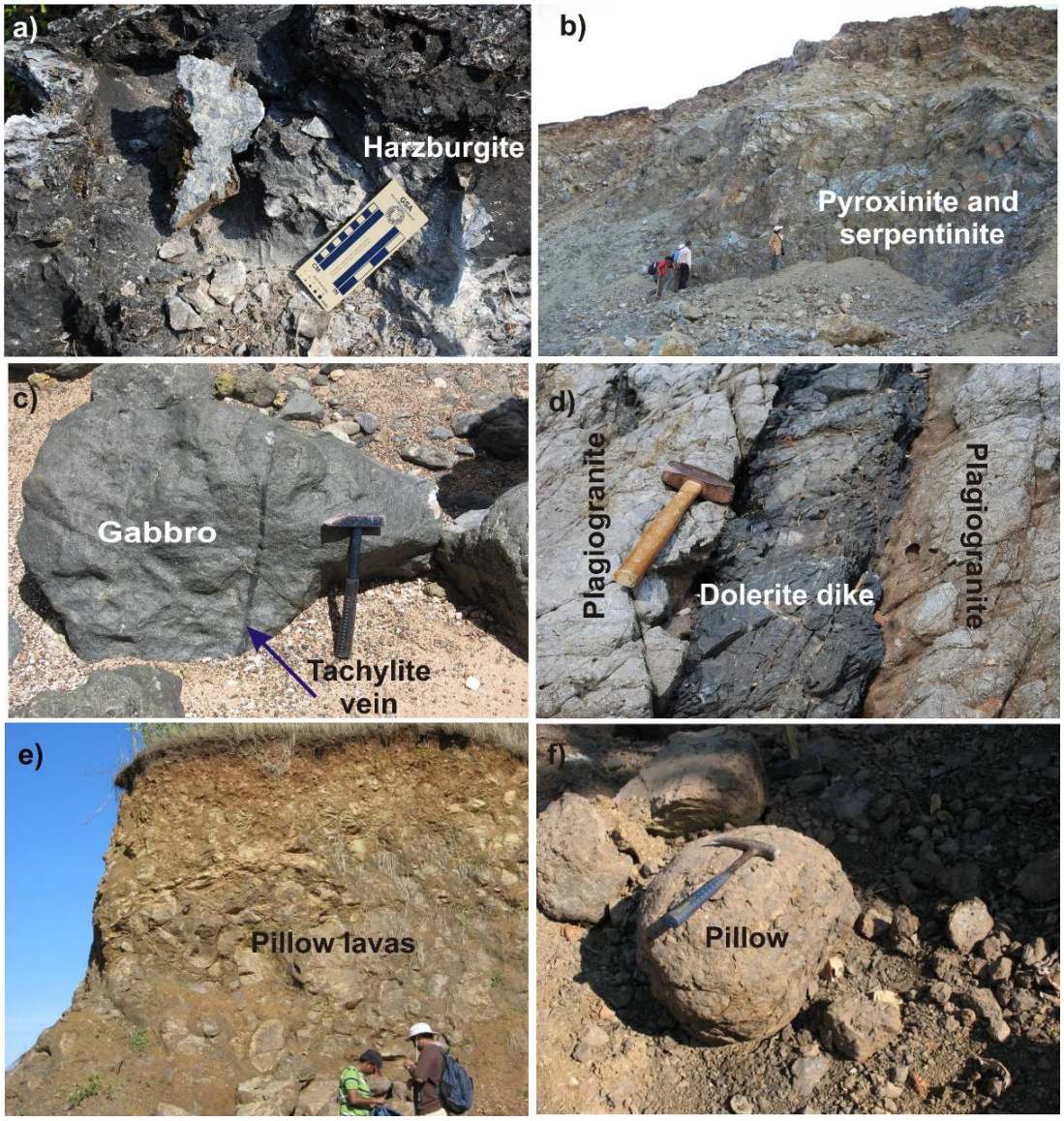

Fig. 2.2 Field photographs of various members of the ophiolite group a) harzburgite, South Andaman b) pyroxinite and serpentine out crop, Bachrapahar, South Andaman c) gabbro with tachylite vein, Kodiyaghat, South Andaman d) dolerite dike along with plagiogranite outcrop, Mundapahar, South Andaman e) outcrop of pillow lavas, Carbon cove, South Andaman f) pillow lava, Carbon cove, south Andaman

Sedimentary cover

The topmost portion of the ophiolite sequence is composed of sediments of heterogeneous origin, both compact and non-lithified, with remains of radiolarians and other planktons. It can be tectono-stratigraphically divided into oceano-pelagic sediments, ophiolite derived

clastics, rhythmites and olistostromal argillaceous sediments (Roy et al., 1988). The intercalated tuffaceous sediments are thought to be derived from sub oceanic transport by turbidite currents. The oceano-pelagic sediments consist of argillites, cherty limestone, clay stone and fossiliferous limestone. These sediments are directly associated with the pillow volcanics, and are richly enriched with foraminiferal assemblage of cretaceous to Eocene age, the earlier one being the predominant (Roy et al., 1988).

Sediments and basic rocks of Andaman have been subjected to metamorphic changes, in conditions of intense thrusting and deformation, to green schist to amphibolite facies. These are widely distributed along the thrust contact between ophiolites and trench slope sediments (Pal et al., 2003) as discontinuous patches. Metasediments are represented by quartzites, phyllites and quartz-mica schists while metabasics are represented by amphibolite bearing chlorite-epidote-carbonate schists.

There are a few studies which deal the geochemistry of Andaman ophiolites. Shastry et al. (2001) and Srivastava et al. (2004) studied mafic rocks of south Andaman ophiolite suite and suggested that the rocks are enriched in Fe- Ti. However based on Ti oxide Srivastava et al. (2004) suggested that the Andaman ophiolites are geochemically similar to N-MORB. This interpretation is supported by Pedersen et al. (2010) based on trace elements studies of pillow lavas from carbyn's cove and basaltic dyke from Chiriya Tapu of south Andaman.

The age of Andaman ophiolites and the timing of their obduction remain controversial. In a couple of studies recently, two independent groups of researchers, dated zircon from plagiogranites of the Ophiolite Group from south Andaman by U-Pb dating method, and suggested that

the formation age of these could not have been younger than ~ 95 Ma (Srinivasa Sarma et al., 2010, Pedersen et al., 2010). These workers also suggested that the new age of Andaman ophiolites is similar to that of the Oman and Troodos, Cyprus ophiolites and that it extends the range of Late Cretaceous ophiolite formation along the Tethyan suture zones from the Mediterranean to the Andaman Sea. The similarity in age between the Troodos, the Oman and now the Andaman ophiolite seems best explained by a suprasubduction zone origin (Pal, 2011).

2.1.2 The Mithakhari Group

Karunakaran (1968) was the first geologist who introduced the term Mithakhari Group. The thickness of this thick sedimentary unit is ~ 1.4 km, and is divided into three formations by Ray (1982): i) the Lipa Black Shale ii) the Hope town conglomerate iii) the Namunagarh Grit (Table 2.1). The Lipa Black Shale is a minor unit with very limited exposures. The rocks in this group consist of immature gravels, coarse to fine sandstone and pyroclastic sandstones, polymictic conglomerate and thin beds shale, mudstone and coal. Pal et al. (2003) recognized eight different lithofacies in these formations on the basis of the bed geometry and recorded sedimentary structures. These lithofacies 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. The conglomerates contain clasts of vein quartz, lithic shale fragments, limestone, sandstone, chert, ultramafic rocks, porcellinite and basalt. Sandstone units are massive, thickly bedded with some plane-laminated and cross-stratified facies. The shale facies consist of massive to laminated pyritiferous shale interbedded with silt/fine sandstone. Apart from above a number of mud volcanoes are also

reported in the Middle and North Andaman Islands in shale dominated facies of the Mithakhari Group.

2.1.3 The Andaman Flysch Group

The rocks of Andaman Flysch along with the Archipelago Group are deposited in a forearc environment. The Andaman Flysch Group overlies the Mithakhari and underlies the Archipelago Groups (Fig. 2.1). The Andaman Flysch is a siliciclastic turbidite sequence deposited on a submarine fan. The best and most completely documented exposures are found on South Andaman, at Corbyn's Cove, where outcrops of steep, westerly dipping beds are seen adjacent to the pillow basalt of the Ophiolite Group, although the nature of the contact is uncertain. The overall thickness is not well defined, with estimates varying from 750 m (Roy, 1983) to 3000 m (Pal et al., 2003). Individual sandstone beds can be traced along strike for distances of several kilometers, but the total thickness is only 250–300 m. Several sedimentary structures have been identified in sandstone beds including flute casts, groove casts, and current bedding. On the basis of the orientation of flute casts at the base of overturned sandstone beds near Corbyn's Cove southward-directed paleocurrents are suggested (Pal et al., 2003). The relationship between the turbidites and underlying lithostratigraphic units is unclear. Onlap of the Andaman Flysch with the Mithakhari Group has been reported (Chakraborty and Pal, 2001), but no supporting evidence was found in this study. However, there is a marked change in lithology and provenance with up to 50% quartz in the Andaman Flysch in contrast to the relatively quartz-free Mithakhari Group (Pal et al., 2003). Lithic fragments in the Andaman Flysch range from micaceous metamorphic clasts diagnostic of continental sources to cherts, basalts, and weathered volcanic glass consistent with derivation from volcanic arc and ophiolite sources.

2.1.4 The Archipelago Group

The Archipelago Group represents the topmost stratigraphic unit of the Andaman accretionary prism. The deposition of this unit was believed to have taken place mostly in a slope environment (Roy, 1983). The lower members of this group comprise basal conglomerates and sandstones, overlain by calcareous arenites of the Strait Formation. This is followed by chalk and limestone with some argillaceous limestones and shale, described as the Melville Limestone (Shell Limestone) Formation (Pal et al., 2005). These sedimentary rocks most likely covered most of the Andamans, but recent uplift and erosion means that today only small patches can be found on the main islands, with most exposures confined to Havelock Island and associated smaller islands to the east of South Andaman in Richie's Archipelago. On the basis of Radiolarian and planktonic forminiferas and calcareous nano fossils from Jhon Lawrence Island, Singh et al. (2000) reported depositional ages for this group in the range of 18.3-15.6 Ma, but Pal et al. (2005) has argued for a younger range.

2.1.5 Island Arc Group

The Island Arc Group, classified for the first time through this work, represents the topmost stratigraphic unit of Andaman Islands. The group consists of subaerial lava flows and volcaniclastic materials of extinct Narcondam Island and active Barren Island volcanoes. These volcanoes lie in the chain of inner arc volcanoes extending from Burma to Indonesia (Fig. 1.10). Well constrained radiometric ages are not available for the rocks of these islands; however a couple of recent studies by Awasthi et al. (2010) and Streck et al. (2011) provided rough estimates. On the basis of C-14 ages of inorganic carbon in ash layers sampled in a marine sediment core, Awasthi et al. (2010) suggest the prehistoric activities of the Barren Island volcano goes back to at least 72 ka, that its caldera may have formed earlier to 10 ka. Based on ^{40}Ar-^{39}Ar dating Streck et al. (2011)

reported two dates of 33 ±70 ka and 32 ± 88 ka (2σ) for two lava samples form Barren Island, however very high analytical uncertainties make this unusable. The eruptions on Narcondam Island are found to be much older with two samples plateau ages of 548 ± 22 ka and 707 ± 170 ka (Streck et al., 2011). Based on these data the authors suggest that the cone building activity on the volcano is younger than 700 ka.

Narcondam Volcano

The Narcondam Volcano forms a small island, ~ 3.5 km across and 710 m high. On the basis of depth contours of the office of Naval Research (2002) the submarine and subaerial volumes of the island are 95 km^3 and 4 km^3 respectively. The latest eruption of the volcano is believed to have occurred in Holocene but one of the subaerial lava flows has been dated to as old as 550 ka (Streak et al., 2011). The Narcondam volcanics are represented by i) porphyritic dacite, ii) amphibole–andesite and iii) andesite. Dacite contains plagioclase, hornblende, biotite and quartz with minor apatite as phenocrysts set in a groundmass comprising plagioclase, hornblende, opaque minerals (magnetite, ilmenite) and glass (Pal et al., 2007). These workers report presence of amphibole, plagioclase and cummingtonite as phenocrysts as well as groundmass phases along with minor quartz and apatite in amphibole-andesites. In contrast, in andesite, calcic plagioclase, olivine, orthopyroxene (hypersthene, bronzite) and clinopyroxene (augite, diopside) represent both phenocrysts and groundmass phases.

Pal et al. (2007) reported the lavas of Narcondam Island are andesite to dacite that display the evidence for interplay of two types of magmas. They suggested the lavas are mixing product of rhyolitic and basaltic magmas. Streck et al. (2011) suggested based on primitive mantle normalized trace element contents the Narcondam lavas are subduction

origin magmas which show typical signature depletions of Nb, Ta and Ti and enrichments in K and Pb, with lesser enrichment of Sr. They also stated the higher Sr and Pb isotopic values of Narcondam lavas are due to crustal contamination.

Barren Island Volcano

The first recorded observation of Barren Island was by Van Lineshooter in 1595 that hasn't mentioned the volcanic character of this island and reported it as one of many emergent islands within the Andaman Sea. First volcanic behaviour of this island was reported by Lieutenant Colebrook in 1787 after he noticed column of smoke ascending from the summit (Shanker et al., 2001). The geologists who had established the basic stratigraphic framework by early survey of this island were Mallet (1895) and Ball (1888) from Geological Survey of India (GSI). They reviewed the history of observations of eruption of Barren Island and reported that, the first known landing on the island by a westerner was by Captain Archibald Blair in 1789, after which Port Blair on South Andaman Island has been named (Curray, 2005). The first short petrography studies were published in 1924 by Washington, who collected five samples from GSI. He identified those samples as basalt and augite bearing andesite (Shanker et al., 2001). Halder (1989, 1991) and Halder et al (1992a, b, c, 1994, 1999) described petrology, chemistry of the recent volcanics and eruptive history of the volcano.

Apart from geological studies, geophysical studies were also done in and around Barren Island. Dasgupta and Mukhopadhyay (1993) mapped this island using seismic methods and described the tectonic framework of the island and its delineation by a set of faults, such as the west Andaman fault connecting to the semangko faults in Sumatra. Banarjee et al. (1998) carried out magnetic measurements and ocean-

bottom magnetometer surveys around Barren Island after a volcanic eruption in 1991. From the spectral analysis of magnetic data, the depth obtained to the Curie isotherm is about 3–5 km on the eastern side of Barren Island, whereas on the western side it falls sharply to 12 km. suggesting a high heat flow on the eastern side of Barren Island associated with volcanism. They believed that such a sharp difference in the heat flow could be related to a structural barrier aligned in the north-south direction that prevented volcanic material flowing towards the west. The worker also suggested that there existed a partial melting zone at a depth of 17-27 km.

Since ground monitoring is difficult on the Barren Island Volcano because of its rough terrain, geophysicists used Remote Sensing Temporal Monitoring (RSTM) tool for monitoring the volcanism. First remote sensing on the island was done by Bhattacharya et al (1993), who reported the changing size and position of erupting vents, identified westward flow of lava on digitally enhanced TM images, delineated and mapped lava flows of different eruptive phases of 1991 eruptions. He also reported that the 1991 volcanic activity started around March 25, 1991 and appeared to end by late December 1991. On the basis of nearly 20 TM imagery acquired in between 1986-1993, Reddy and Bhattacharya (1997) carried out comparative studies of pre- and post-eruptions landforms on Barren Island. He reported four significant aspects of the volcano which were brought out by TM images viz. : i) geomorphic changes in the form of a newly formed crater, which is 500 m across, ii) seaward extension of the land due to the deposition of the recent lava flows, iii) regrowth of vegetation burnt due to the eruption seen clearly (in bluish tint) on the southern flanks of volcano, and iv) delineation of recent lava flows (erupted in 1991) based on their sharp tonal contrast with the older flows. The 1991 lava flows have lighter tones on the FCC image (RGB=7, 5, 4)

whereas the older flows erupted during 1789-1803 (second episode) have distinct darker tones on all the pre-eruption images. Based on these observations and in conjunction with the geochemical analyses on lava samples Halder et al. (1992) it can be inferred that the recent flows are mostly basaltic andesites, whereas the older flows are high alumina olivine tholeiites.

As a part of the present study we have carried out field observations on Barren Island and reported several new features including new lava flows. We also have prepared a new geological map of the island, which is more accurate then the existing ones. Detailed descriptions of these studies are given in a separate chapter called the "volcanological studies of Barren Island" (Chapter 3).

2.2 Structure of the Andaman and Nicobar Islands

The Andaman and Nicobar ridge is the main feature of the Andaman forearc, which is the result of oblique subduction of Indian plate beneath the Burmese plate. The main elements of the forearc are the accretionary prism and outer arc ridge, a series of forearc basins and major N–S faults. The accretionary prism is an imbricate stack of fault slices and folds consisting of ophiolites and sediments (Roy, 1983). The western, outer slope of the accretionary prism is very steep, rising from depths of 1500–2000 m within a distance of 30 km. There is a difference in the short wavelength morphology between the western and eastern portions of the accretionary prism. The outer portion consists of a series of faulted anticlines and synclines with amplitudes of a few 100 to ~ 1000 m and widths of 5–15 km resulting from ongoing deformation of the sediments (Curray, 2005). The inner portion is smoother with lower slopes and forms a strong backstop. The width of the deforming portion of the accretionary prism narrows from 80 to 100 km in the south to about 40 km between 10°

N and 11°30′ N. It remains at about 40 km to ~ 14°40′ N. North of there, the inner trench wall becomes a single steep slope up to the Myanmar shelf (Bilham, 2005). The eastern edge of the outer arc ridge is fault bounded and north of the Nicobar Islands, a forearc basin is located immediately to the east. A deep gravity low with very steep gradients lies directly over the forearc basin (Cochran, 2010). The West Andaman Fault (WAF) and/or the Seulimeum strand of the Sumatra Fault System form the boundary between the Burma and Sunda plates south of the Andaman spreading centre. The WAF is the most prominent morphologic feature of the Andaman Sea and divides the sea into a shallow forearc and a deeper backarc region (Curray et al., 1979). The Diligent Fault runs through the forearc basin east of Little Andaman Island (Fig 2.3). Although it has the general appearance of a normal fault, multichannel seismic data show that it is a compressional feature that probably resulted from deformation of the hanging wall of the Eastern Margin Fault (Kamesh Raju et al., 2004). This could occur if the forearc basins were formed by subduction erosion of the underlying crust rather than by east–west extension (Cochran, 2010). Andaman forearc is a zone of high compressional stress and high seismicity and the mud volcanoes of the forearc are a result of such activities. In the present study we have studied these features to understand their origin and relationship to the fluid activity in the forearc region.

2.3 Mud Volcanoes of the Andaman Islands

Mud volcanoes are very small volcano like geological features that ooze out mud, water and hydrocarbon gases at a much lower temperature (30-40°C) than the real volcanoes. The diameter of mud volcanoes ranges from a few centimeters to several meters.

Although mud volcanoes are observed all over the globe, they are predominantly found in areas of tectonic compression like the subduction zones, and are usually associated with hydrocarbon deposits (Kopf, 2002).

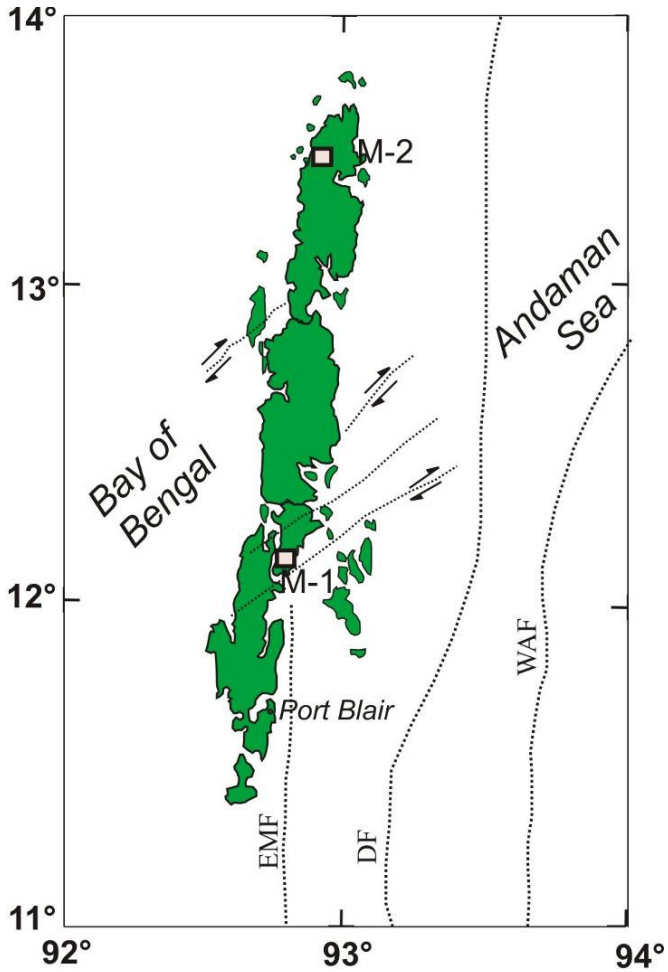

Fig. 2.3 Location of mud volcanoes in Andaman Islands and major fault systems in the Andaman Sea (M-1: Middle Andaman and M-2 North Andaman; EMF: East Margin Fault, DF: Dilligent Fault, WAF: West Andaman Fault).

Mud volcanoes of accretionary prisms that tap fluids and clay rich sediments of the slab at shallow levels (2-4 km) can reveal a lot about the subducting material prior to its journey into the mantle. The detailed structure of the mud volcano is largely unknown; however, Kopf (2002) made attempts to describe various features associated with these. The

main structure of a mud volcano consists of the fluid source with a feeder channel above and a complex system of fractures and dykes filled with mud through which fluid-sediment-rock clast mixture erupts out to Earth's surface to form the mud volcano (Fig 2.4).

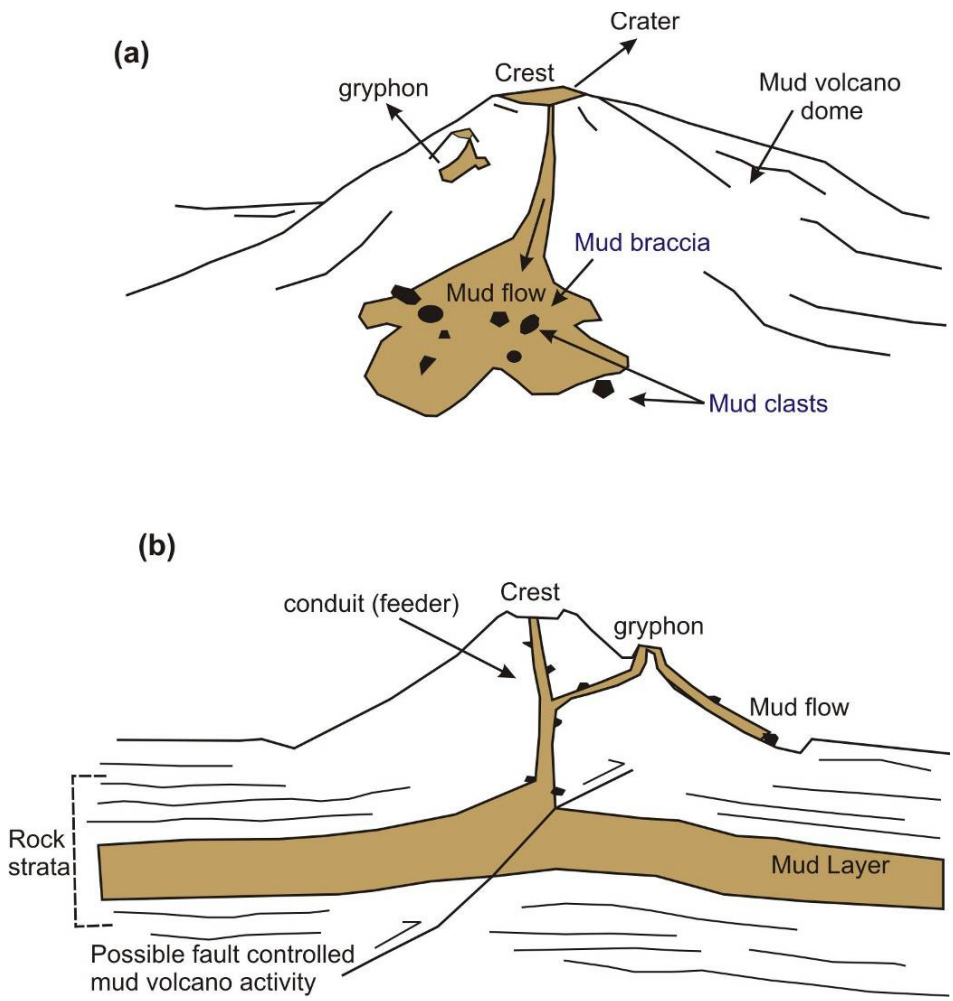

Fig. 2.4 Schematic diagrams of a cone shaped mud volcano with its various components (after Koef, 2002) a) a general surficial view; b) a cross sectional view

The solid material that gets expelled through mud volcanoes along with fluids is known as 'mud breccia, which is made up of rock fragments embedded in mud matrix. These clasts are a very complex mixture of

material from the rock sequences through which mud volcanoes have erupted.

Several active mud volcanoes have been reported in the Andaman and Nicobar Islands (Dimitrov 2002) and these represent mud expulsion in a compressional regime. A majority of these are reported from the Baratang Island of the Middle Andaman, and from Diglipur Island in the North Andaman (Fig. 2.3). These mud volcanoes are located along fault zones trending mainly in N-S direction. The N-S aligned faults are part of the imbricated thrust sheets that dip eastward, parallel to trench of the subduction zone. The diapiric ascent of fine sediments through these faults is believed to be due to post-Eocene compressional forces resulting from overthrusting (Badve et al., 1984; Ling et al., 1995). These thrust faults provide the pathways for the material in the accretionary wedge to come up through the mud volcanoes. These faults are probably the continuation of East Margin Fault (Curray, 2005) further north or the Jarawa Thrust Fault (Fig 2.3). On the basis of our observations we have prepared two mud volcano regions (Fig. 2.5a, c) and a blow up of the Middle Andaman mud volcano zone (Fig. 2.5b)

Very Limited work exists on the mud volcanoes and a majority of these are mainly on microfossils which are present in mud breccia. The prime objectives of these studies were to explore hydrocarbon reservoir in this area as mud volcanoes are believed to be indicators of potential reservoir of hydrocarbon.

Various workers (Badve et al., 1984; Rajshekhar, 1985, 1989, 1992; Jafar, 1985 Jafar, et al., 1989a; Ling et al., 1995) have reported foraminiferas, coccoliths and radiolarian, of age ranging between Late Cretaceous to Miocene, from these mud volcanoes. Apart from these studies one

interesting work has been done by Achyuthan and Eastoe (1999) in Jarawa creek mud volcanoes, Baratang Island where they report volcanic glass and sulphide nodules in the mud breccia and on the basis of sulphur isotope composition of the mud, brines, and nodules they suggest that there have been a large influx of groundwater into the system prior to its eruption.

Andaman mud volcanoes eject sediments and rocks of various shapes, compositions and ages that may have came from greater depths. We examined the rock clasts and sediment that are ejected from these mud volcanoes and found that along with pillow lava and sediments from the underlying sedimentary formations it also brought out plenty of organic matters- possibly related to deep petroleum systems. In the breccia we observed at least seven types of lithoclasts viz.: i) serpentinites - derived from Ophiolite Group, ii) limestones, iii) shales iv) siltstones, v) sandstones; vi) pillow basalts, and vii) quartz bearing rocks. These rock clasts provide important information about the type and composition of rocks in deep-seated formations through which eruption of the mud volcanoes have occurred. As we know the water plays an important role in subduction zone magmatism (Jarrard 2003), therefore study the mud water throw some light on the role of dewatering processes of Andaman forearc region and their influence on overall fluid of Andaman subduction zone. To characterize these fluids we took up a geochemical investigation of the gases and water erupting out of these mud volcanoes. Fig. 2.6 shows various field observations on these mud volcanoes.

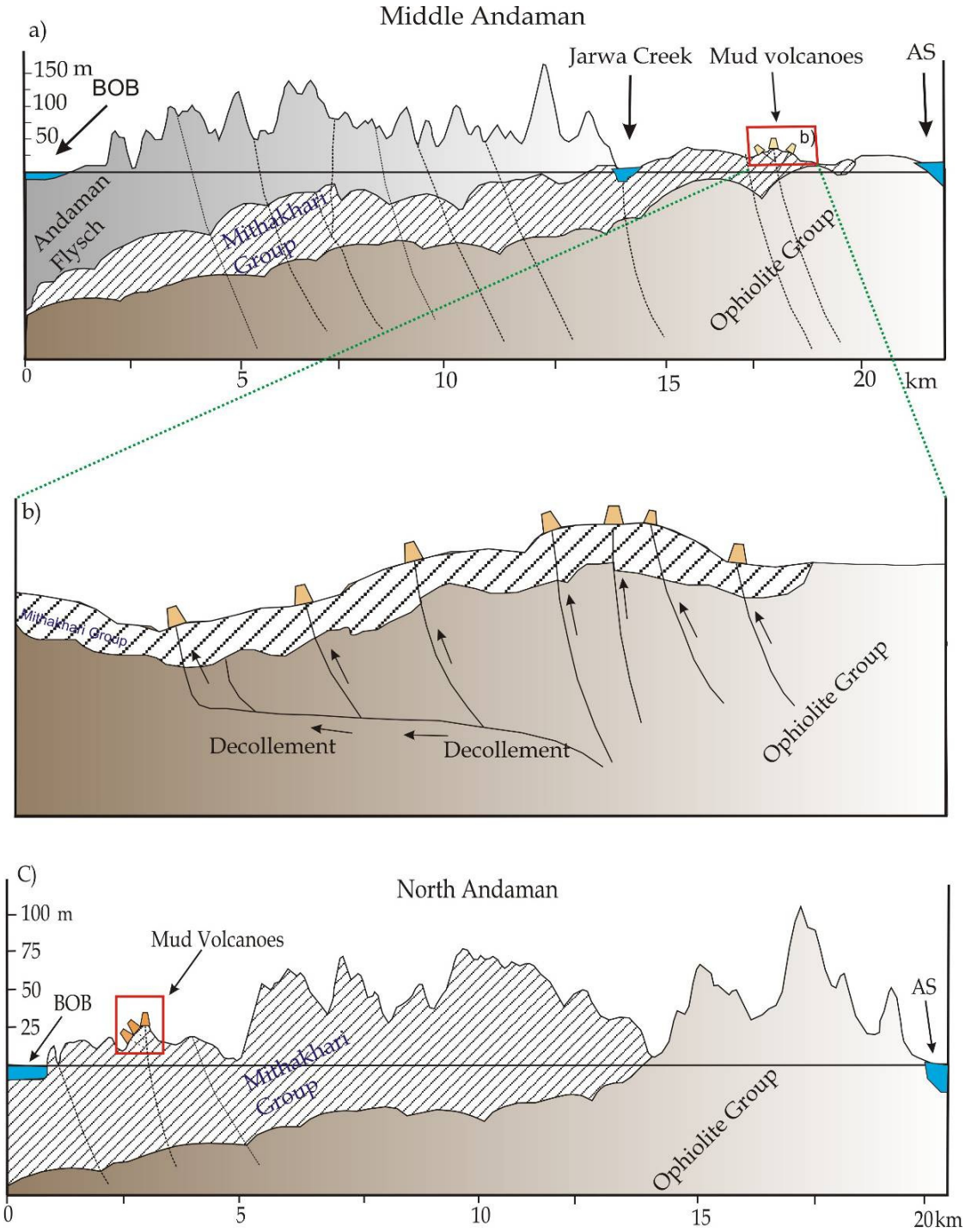

Fig. 2.5 Cross-sectional views of mud volcanoes of Middle and South Andaman Islands, based on author's identification and interpretation. a) Middle Andaman, b) Blow up of rectangular area in (a). c) North Andaman. BOB: Bay of Bengal, AS : Andaman Sea.

Fig 2.6 Field photographs of mud volcanoes from Andaman Islands a) active mud volcano cone at Jal Tekari, Shyamnagar, Diglipur, North Andaman b) active mud volcano oozing out mud water and hydrocarbon, gases Baratang Island, Middle Andaman c) mud breccia containing fine mud and rock clasts d) the rock clast contains pillow basalts oozing during explosive eruption e) showing gas bubble coming out continuously f) Field of active mud volcanoes destroyed all the plants, Baratang Island Middle Andaman