Structural Imprints of Andaman Accretionary Prism and Its Tectonic Relation with Ophiolite Belt of Indo-Burma Ranges

Tapan Pal

Abstract In Andaman subduction complex Indian plate is subducting towards east below Burma plate. In this subduction complex an accretionary prism comprising of Upper Cretaceous ophiolite and Eocene sediments is exposed in Andaman Islands. Map pattern and the field distribution show dismembered ophiolites occurring in different N-S trending thrust slices where the western slices have low dip (8°–10°) and the eastern slices have steep dip (65°–70°) towards east. Besides, few N-S trending back thrust and E-W trending out of sequence thrust have affected the disposition of the litho units. Oligocene-Miocene forearc sediments are exposed on both side of the accretionary prism. Eocene sediments deposited in trench slope basin have very irregular fold geometry which is due to changes to the basin floor topography during its upliftment along with ophiolite. The forearc sediments showing proximal to distal fan facies have regular fold geometry with N-S striking axial plane and very low plunge (18°–25°) either north or south. Based on the field disposition it is suggested that on land emplacement of Andaman ophiolite took place after the deposition of Oligocene-Miocene sediments. The forearc sediment was deformed during on-land emplacement of the accretionary prism. Similarity in petrographic character, age of the ophiolite, occurrence in an accretionary prism and field disposition suggest that both the ophiolite bodies of Andaman and Naga Hills of Indo Burma Ranges (IBR) represent Neotethyan crust. The ophiolites with Neotethyan crust situated in western belt of IBR have also similarity with the ophiolites of Eastern belt of IBR and on-land emplacement of IBR ophiolites took place during India-Asia/Burma plate collision in Late Miocene time.

Keywords Andaman accretionary prism · Deformation · Ophiolite belt · Indi-Burma ranges

---

T. Pal (✉)
Geological Survey of India, North Eastern Region, Shillong 793003, India

T. K. Biswal et al. (eds.), *Structural Geometry of Mobile Belts of the Indian Subcontinent*,
Society of Earth Scientists Series,
https://doi.org/10.1007/978-3-030-40593-9_5

1 Introduction

The Andaman Islands, lying in the central part of the 5000 km long Burma–Andaman–Java subduction complex, displays different tectonic elements of subduction zone. Here the Indian plate is subducting below Burma plate with easterly dipping subduction. The closure of Tethyan Sea was the outcome of India–Asia collision. The Indus–Yarlung Tsangpo suture zone (ITYSZ) display the remnants of the once extensive Mesozoic–age Tethyan Ocean. Along the northeastern margin of the Indian plate ophiolitic rocks and associated rocks of ITYSZ continue sweeps in a clock wise direction around the eastern Himalaya syntaxis and turns towards southward along Indo Burma ranges to the Andaman Sea. This suture zone is traceable through SE Tibet into Myanmar and is offset by the dextral strike slip fault known as Sagaing fault which shows Miocene to recent displacement (e.g., Morley and Searle 2017). The Neotethyan boundary follows a trend of ophiolite occurrences, lying east of present day plate boundary, running from Indo Burma ranges (IBR) to southwards in Andaman islands (Acharyya 2007; Searle et al. 2007; Baxter et al. 2011; Sloan et al. 2017). The IBR mountain ranges lies beyond the eastern extremity of Indian continental crust and thus did not develop due to continent-continent collision (e.g., Aitchison et al. 2019). Within India the IBR runs through SE Arunachal Pradesh, Nagaland, Manipur and Mizoram. The IBR is interpreted as a part of extensive accretionary prism beneath which subduction is still continuing, and the Burma arc situated to the western edge of Burma microplate collides with northeastern Indian passive margin (Steckler et al. 2008, 2016; Sloan et al. 2017). At present the trench around the Andaman islands, known as Java trench, is to the West of the main Andaman Islands and the Java trench has little expression in the gravity field (20 mgal) towards Burma but stronger signatures (100 mgal) towards south in Nicobar Islands (Mukhopadhyay and Dasgupta 1988). Seismic data from the Andaman Islands and Andaman Sea also indicates a Benioff zone dipping 40°–55° towards the east and record epicentres at 200 km focal depth (e.g., Mukhopadhyay and Dasgupta 1988).

The Andaman group of Islands represent mainly Cretaceous-Eocene accretionary prism and Oligocene–Miocene forearc sediments. In the east of Islands, Quaternary magmatic arcs, known as dormant Narcondam and active Barren volcanoes are present. In the accretionary prism besides Eocene trench sediments, dismembered ophiolite thrust slices are present in the central to eastern part of the islands.

Many works have been done on petrology and tectonics of Andaman ophiolite and depositional environment of the Tertiary outerarc and forearc sediments but the structural attributes of this belt have not been dealt comprehensively. In this review work, map pattern, field features, structural elements, petrological characters of ophiolite and associated Tertiary sediments have been dealt together to understand the Andaman accretionary prism in the background of subduction tectonics. In many literatures Andaman ophiolite belt has been correlated with ophiolite of IBR (e.g., Acharyya 2007, 2010). But detailed field and petrological attributes of those ophiolite belts were not discussed during correlation. Here detailed features of accretionary prism setting of Andaman ophiolite belt have been dealt for tectonic correlation of Andaman ophiolite belt with the ophiolite belts of Indo Burma Ranges.

2 Geological Setting

Andaman Islands being a part of an accretionary prism comprises of (a) numerous north–south-trending slices of upper Cretaceous ophiolites and (b) Tertiary sedimentary rocks (Fig. 1). The disposition of ophiolite along with sediments have been described by many (Karunakaran et al. 1967; Ray 1982; Pal et al. 2003; Pal 2011; Ghosh et al. 2013, 2017; Bhattacharya et al. 2013). Although slices are dismembered in nature, all the members ophiolite stratigraphy along with sole metamorphic are exposed in Andaman Islands. The thrust slices of ophiolite as a coherent bodies, run several kilometers in the eastern part and small, isolated klippes in the western part of the island chain. The different members of ophiolite bodies occur mainly in eastern part of the North-, Middle- and South Andaman Islands (Fig. 1a–c). The mantle section representing mainly peridotites along with few dunite pods and rare chromitite pods occurs in large volume in Middle and North Andaman and Rutland islands whereas cumulate, intrusives and extrusives dominate in South Andaman Island (Pal and Bhattacharya 2016). The cumulate section is represented mainly by dunite-lherzolite-wehrlite-pyroxenite-gabbro, intrusive unit is represented by plagiogranite-diorite-dolerite dykes, and extrusives are represented by massive to pillowed tholeiitic basalt and boninite-andesite-dacite of calc alkaline suite (Pal. 2011). The field disposition of the ophiolite along with sediments shows characters of accretionary prism (Pal et al. 2003; Bhattacharya et al. 2013). In South Andaman, largest ophiolite slice with 300–750 m thickness runs in kilometer scale. Radiolarian chert interlayered with basalt gives Cretaceous–Palaeocene an upper age limit of ophiolite (Roy et al. 1988) whereas the palgiogranite gives a radiometric age ~95 Ma (Pedersen et al. 2010; Sarma et al. 2010).

Tectonic slices of ophiolitic rocks are interleaved with Middle to Late Eocene trench slope sediments (c. 1.4 km thick) (Ray 1982; Chakraborty et al. 1999). Eocene sediments cover a large span ranging from conglomerate to sandstone to shale where the clasts are derived mainly from ophiolitic rocks. Pyroclastic sediments has also been reported from Eocene sediments (e.g., Bandopadhyay and Carter 2017). A thick pile (c. 3 km thick) of Late Eocene to Oligocene turbidite forearc sediments occur above the ophiolite–Eocene-sediments sequence (Ray 1982; Chakraborty and Pal 2001). Within forearc regime turbidite display proximal to mid fan to distal fan facies (Chakraborty and Pal 2001). Miocene forearc sediments occur mainly in the Archipelago Group of Islands and are not in direct contact with any of the ophiolite slices. These sediments have huge volcanic inputs and consist of subaqueous pyroclastic rocks and siliciclastic turbidites in the lower part and carbonate turbidites in the upper part (Pal et al. 2005). Besides these lithounits of the Andaman and Nicobar islands two quaternary volcanoes, named as Barren and Narcondam volcanos located within Andaman Sea represent sub-aerial volcano in the inner volcanic arc chain. The active Barren volcano throughout its evolutionary history is erupting basaltic magma (Pal et al. 2010). Oldest age of the Narcondam lava has been reported as 1-5-1.8 Ma (Ray et al. 2015). The dormant Narcondam Volcano dacite-andesite domal volcano (Pal et al. 2007; Pal and Bhattacharya 2011). Oldest age of this lava has been reported as 1.8 and 3.5 Ma (Bhutani et al. 2014).

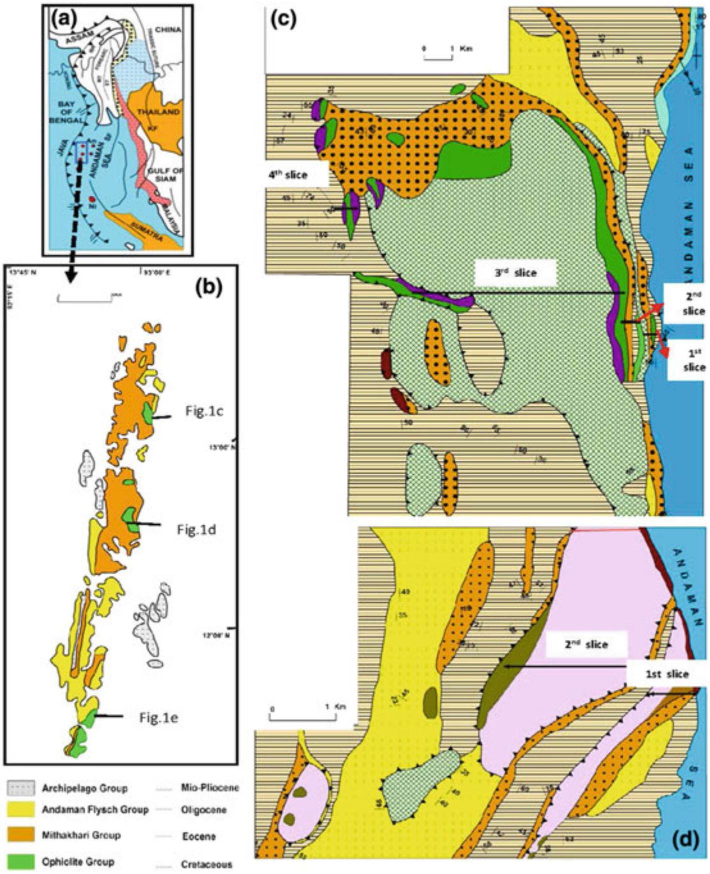

Fig. 1 **a** Regional tectonic framework of SE Asia after Mitchell (1986). **b** Generalized geological map of Andaman Islands showing distribution of the ophiolite and Tertiary sedimentary units with their stratigraphic relationship. (**c**, **d**, **e**) Geological map of part of North, Middle and South Andaman respectively (modified after Pal and Bhattacharya 2016) showing disposition of different ophiolite thrust slices and distribution of Tertiary sediments, four major thrust slices are demarcated in map. An, Andaman Island; ET, Eastern Trough; IBR, Indo Burma ranges; Ni, Nicobar Island; SF, Sagaing Fault; WT, western trough; open circles, Mogok Belt; crosses, Early Tertiary tin–granite belt

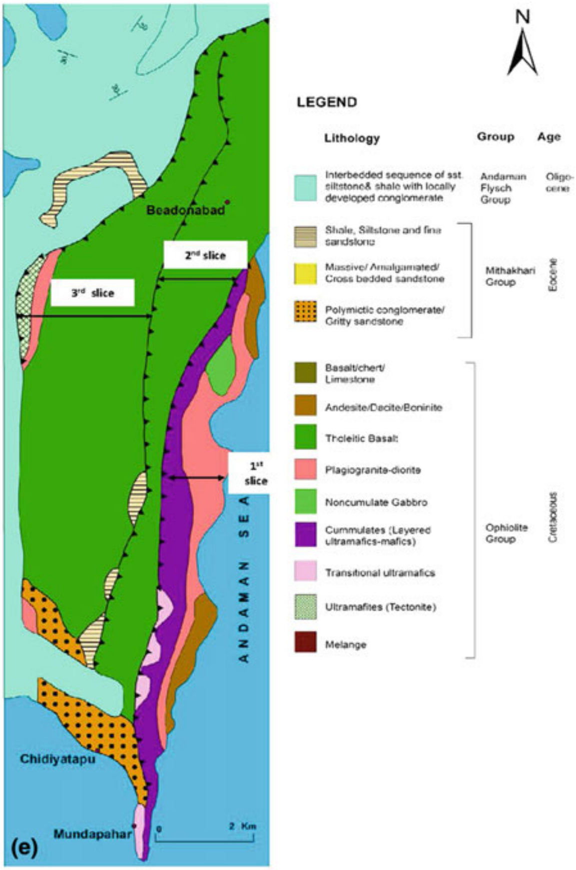

Fig. 1 (continued)

3 Deformation Structures of Andaman Accretionary Prism

3.1 Folds

Both Eocene trench slope basin and Oligocene–Mio-Pliocene forearc sediments show mesoscopic folds. In Eocene sediments folds are in general open cylindrical with low (29° towards 50°) to moderate (52° towards 240°) plunge with axial planes are inclined to vertical. The different generations could not be deciphered from the isolated fold exposures. On the other hand folds in Oligocene sediments are open with a low plunge either towards south or north (25° towards 224°), in Korang nala, Middle Andaman, 18° towards 185°, in Kalipur beach, North Andaman (22° towards 32°, in Shadipur, South Andaman). In general Oligocene sediments in eastern part of the islands record overturned sequence whereas the Oligocene sediments in the western side of the islands show steeply dipping normal bed sequence. Detailed study on the correlation of both the Oligocene sedimentary sequence has not been reported.

Eocene sediments do not show any consistent axial orientation and no cylindrical fold axis could be deciphered from the wide scatter of the S-poles in stereoeplot (Pal et al. 2003). The Oligocene sediments however, define a prominent girdle in E-W with a low plunge either towards north or south. The Miocene forearc sediments show very regular fold geometry with a low plunge, e.g., in Havelock island mesocopic folds show a 15° to the south. In the western part of Andaman Islands the forearc Oligocene sediments show normal sequence whereas in the eastern part of the Islands those forearc sediments in general show steeply dipping overturned beds.

3.2 Thrust

The Cretaceous ophiolite sitting over the Eocene sediments have thrust contact (Fig. 2a, b). Due to lack of good exposures, extensive alteration in the contact zone recognition of thrust features in field and measurement of thrust plane are difficult. In major cases the distribution of the lithounis helps to identify the thrust plane. Mylonitic rocks, silicified zone, brecciation, development of slicken side and dragging of beds also help to recognize thrusts in the field. The dip direction is postulated from the younging direction of the ophiolite section and dip amount is estimated from the geological cross section. Several N-S trending thrust planes with easterly dip have affected the area. Normally in the map, contact of Eocene sediments and ophiolite units are marked as thrust plane. Besides, thrust plane is also passing within ophiolitic members. In general dip of thrust gradually increases from west to east of the area and thrust in the western part have low dip (8°–10°) and in the eastern

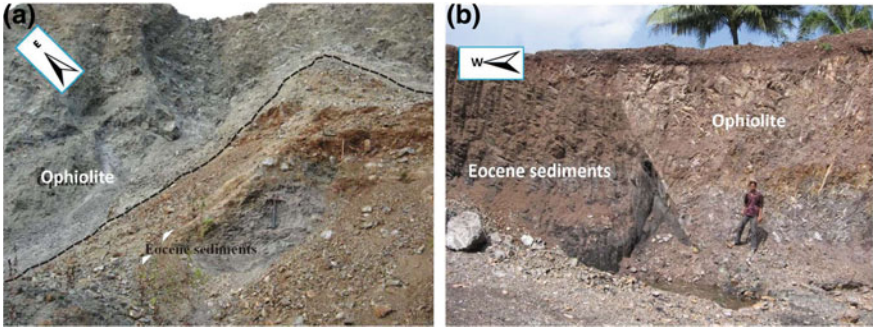

Fig. 2 Field photograph showing thrust contact of Eocene sediments and ophiolite exposed in South Andaman, **a** gently dipping thrust, exposed in Badmashpahar area, south Andaman, nature of the contact is thrust, dipping 25° towards East, here mantle lherzolite is occurring above Eocene sediments, gouge has also developed at the contact and **b** steeply dipping thrust, exposed in Bimlitan quarry section, South Andaman where basalt is in thrust contact with shale, bed attitude could not be measured, thrust is dipping 65° (modified) towards east

part of the ophiolite belt it has steep dip (65°–70°). Besides easterly dipping thrust few westerly dipping but N-S trending back thrust are also reported in Middle and North Andamans (Pal et al. 2003). A few ‘out of sequence’ thrust trending E-W is also recorded in North Andaman. The brittle and ductile nature of spatially different thrust is common. In general western thrust has ductile behavior whereas thrust in eastern part depicts brittle behavior. Foliations, wavy shear surfaces, anastomosing shearplanes, shear lenses in basalt is commonly found in thrust contact of the western part. The different ophiolite slices occur in different structural levels and are emplaced by thrust which are mainly imbricated. The geological maps of the north, middle and South Andaman Islands show in general four major thrust slices of ophiolites (Fig. 1a–c). In the eastern part of North Andaman repetition of ophiolite members may be due to thrust imbrications. Tectonic overlap also resulted omission of sediments in between ophiolite bodies.

3.3 Strike-Slip/Normal Faults

In many parts of the Andaman Islands N-S normal faults affect the disposition of litho units of Cretaceous ophiolites-Eocene sediments and Oligocene-Miocene sediments. A number of N-S trending normal and E-W trending strike slip faults have also affected the entire Andaman Islands.

4 Discussion

4.1 Evolution of Andaman Accretionary Prism

4.1.1 Thrust Emplacement of Ophiolite

The disposition of different thrusts and faults could be explained by accretionary prism model of Plat (1986). This is wedged shaped prism resting over the subducting slab. It is approximated that ophiolite slices are scrapped off from the slab. But the geochemistry of the Andaman ophiolite shows SSZ character formed in forearc condition (Pal and Bhattacharya 2016). A convincing mechanism is still not available to explain the formation of accretionary prism involving SSZ (forearc) ophiolites. The model of Whattam and Stern (2011) explains emplacement of forearc lithosphere over the subducting slab. During progressive subduction either buoyant crust or sea mount of the subducting slab jams the subduction and gradually forearc lithosphere emplaced over the subducting slab. In Andaman Islands thick sediments over the subducting slab perhaps behaved as buoyant crust. The emplacement of the ophiolite could take place through a series of thrust planes forming an accretionary prism (Fig. 3a, b). With continued eastward subduction a new thrust will generate at the back

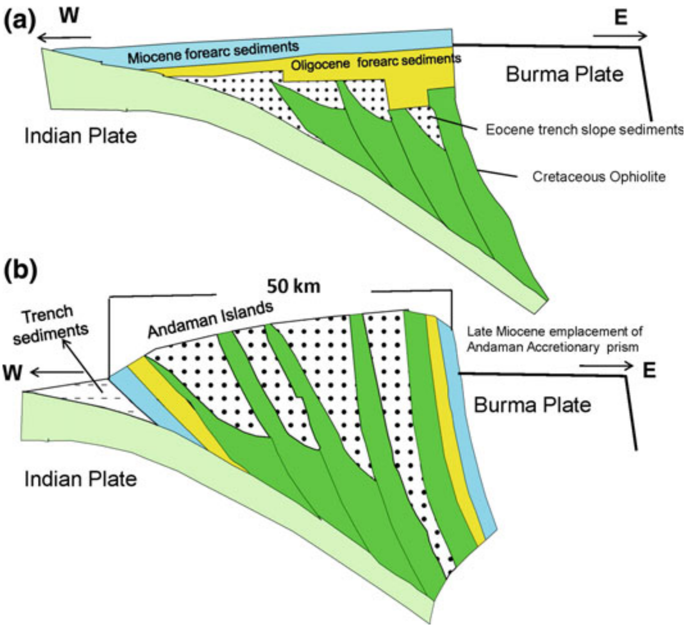

Fig. 3 A sketch diagram showing **a** the evolution of accretionary prism of ophiolite slices and Eocene trench sediments, and development of forearc basin and disposition of Oligocene-Miocene forearc sediments, **b** uplift of accretionary prism and on land emplacement of accretionary prism during Late Miocene. Forearc sediments are also deformed by thrust, disposition of forearc sediments on both side of accretionary prism is also reflected

of earlier thrust and the earlier thrust is modified and become steepened (e.g., Condie 1989). As a result of this process dip of thrust planes increased towards east. During steepening the reactivation of thrust perhaps took place in brittle regime. Accreted material lengthened the wedge resulting internal shortening. This led to "Out of sequence" and back thrusting across the earlier accretionary structures. To stabilize the wedge, sedimentation towards the rear side of wedge favoured extension and series of normal and strike slip faults developed and allowed further sedimentation in forearc basin of Andaman Island.

4.1.2 Evolution of Eocene Trench Slope Sediments

Polymictic conglomerate, sandstone, and shale comprises the Eocene sediments. This ~1.4 km thick sedimentary unit (Ray 1982) contains larger foraminifera and calcareous algae of Middle to Late Eocene age (Karunakaran et al. 1967; Roy et al. 1988). The sedimentary facies of these sediments suggest deposition of coarse detritus along with fine sediments in trench-slope basins where coarse detritus were derived from accreted ophiolite slices (Chakraborty et al. 1999). Individual small basins separated by structural highs with local sources of coarse detritus were uplifted and became part of the accretionary complex.

These sediments showing shearing effect in contact with ophiolites suggest that structural uplift during and after sedimentation and progressive uplift raised from below storm wave base to a shallow coal-depositing paralic setting (Chakraborty et al.1999). Lack of any definite fold geometry in Eocene sediments as well as the effect of superposition may be the effect of tectonically induced episodic changes to the basin floor topography during emplacement of ophiolite. Such changes may be correlated to development and growth of fault bend and fault propagation folds at the tip line of thrusts pushing up slices of ophiolite basement.

4.1.3 Evolution of Forearc Sediments

Oligocene-Miocene sediments displaying wide lateral extent of beds and development of a large-scale submarine fan and regular fold patterns deposited in forearc environment where quartz dominated turbidites were derived mainly from Irrawardy delta of Myanmar (Pal et al. 2003). During Miocene times, the inner arc probably supplied huge amounts of pyroclastic sediments in the form subaqueous pyroclastic flows and towards the end of forearc deposition, shallowing of the basin favoured carbonate deposition (Pal et al. 2005). The force resolved into margin normal and parallel components resulting strike slip movement in between accretionary complex and arc.

4.1.4 Emplacement of Ophiolite

The structural attributes show that different ophiolite slices along with Eocene sediments forms the accretionary prism where the isolated basins of Eocene sediments were uplifted along with ophiolite bodies. Again forearc sediments occur on both side of ophiolite-Eocene accretionary complex. Those sediments are steeply dipping in the eastern part of the islands and moderate to steeply dipping in the western part of the island (Fig. 3). Previously it was suggested that ophiolite were emplaced on land during late Eocene time (Pal et al. 2003; Pal and Bhattacharya 2016). In many cases the Eocene to Oligocene sediments have conformable boundary. The disposition of the forearc sediments on both side of the ophiolite-Eocene sedimentary complex, steep dip of the beds and fold pattern of the Oligocene-Miocene forearc sediments suggest that the accretionary prism uplifted to land position through thrust systems during late Miocene time (Fig. 3). Late Miocene emplacement of ophiolite could be linked with major collision time of Indian plate with Asian plate. Subduction in Andaman islands are intra oceanic and disposition of the ophiolite slices and Eocene sediments in accretionary complex and the field relationship with forearc sediments suggest autochthonous nature of the ophiolite-Eocene sediment.

4.2 *Tectonic Correlation Between Andaman Ophiolite with Other Ophiolites of IBR*

Detailed study has been done on Andaman ophiolites. But if we move further north in Indo Burma region there is diverse opinion on number of belt, age, nature of emplacement, and timing of collision of the ophiolite belt (e.g., Morley and Searle 2017). Towards South in Sumatra region continuous subduction related activity is reported from 90 to 45 Ma (Hall 2012). For Burma regions available literatures do not give a clear knowledge on the type, nature, age, mode of emplacement and the nature of underlying crust of the ophiolite. In Indo Burma region and Myanmar area two ophiolite belts are present viz. (1) Western belt ophiolite (Naga Hills- Chin Hills), (2) Eastern belt ophiolite (Fig. 4a–c). The Eastern belt ophiolite can further be divided into two: (a) Jade mines belt ophiolite (JMB ophiolite) and (b) Tagaung-Myktyina belt ophiolite (TMB ophiolite).

4.2.1 Andaman Ophiolite

It has a metamorphic sole of greenschist to amphibolites grade quartzite-phengite schist to chlorite schist to meta chert. Age of this metamorphic is still unknown. The metamorphic sole is overlain by mantle peridotites and which again is overlain by cumulates, intrusive and extrusive (Fig. 5a). Nature of ophiolite and the extensive melt-rock interaction features in the mantle rocks, geochemical characters of the mantle rocks and the geochemical behavior of the extrusives of the ophiolite suggest the suprasubduction zone character of the ophiolite (Pal 2011, Ghosh et al. 2017). Age of the Andaman ophiolite has been assigned to Upper Cretaceous (~95 Ma). On land emplacement of it took place in the form of accretionary prism possibly in late Miocene age.

4.2.2 The Naga Hills Ophiolite (NHO)

This 200 km long 15 km wide ophiolite belt runs in SE Nagaland to NE Manipur (Brunnschweiler 1966). The ophiolite units occur as thrust slices in an accretionary prism. Detailed geological map of the terrain displaying thrust slices is still not available. It has been reported that ophiolite slices are thrust upon Late Eocene trench deposit known as Disang Formation (Ghose et al. 2014). Although dismembered in nature all the units of ophiolite ranging from mantle peridotites to ultarmafic-mafic cumulate to dykes to pillowed basalt to pelagic sediments (Chert-limestone) have been reported (Acharyya 2007, 2010; Pal et al. 2014; Ghose et al. 2014; Fig. 5b). Isolated exposures of high P/T metamorphic rocks including eclogite and lawsonite bearing blueschist are also associated with ophiolites (Vidyadharan et al. 1989; Ghose et al. 2010, AO and Bhowmik 2014; Bhowmik and AO 2016). The mantle rocks show in general SSZ character (Pal et al. 2014; Ghose et al. 2014). The geochemistry of the

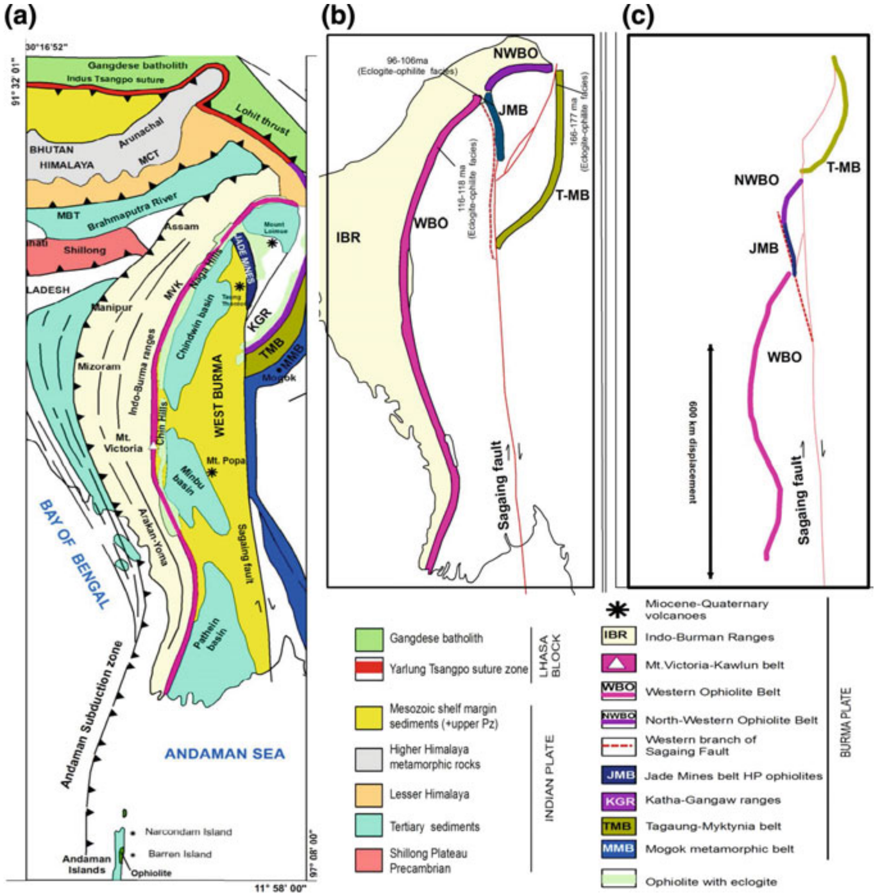

Fig. 4 **a** Geological map of SE Asia, Burma, and the Andaman Sea showing the major suture zones, faults, and terrain boundaries (after Searle et al. 2007) and distribution of eclogite ophiolite belt of Indo Burma Region (IBR) (after Morley and Searle 2017) is also reflected. **b** Present day distribution of the western belt and eastern belt ophiolites of IBR. **c** Restoration of western and eastern ophiolite belts in a single belt before the effect of Sagaing fault (**b**, **c** after Morley and Searle 2017). The reported age of the ophiolites is also shown

volcanics show a wide range from MORB to Ocean Island (OIB) and suprasubduction zone affinities (Singh et al. 2012, 2016; Kingson et al. 2017, 2019). Ophiolite records Middle to Late Jurassic fossil from chert (Baxter et al. 2011; Aitchison et al. 2019) and Early Cretaceous U/Pb date (116–118 Ma) from plagiogranite (Singh et al. 2017). Low grade metapelites and gniesses, known as Naga metamorphics, occurring in the eastern part of the ophiolite belt has Ordovician age (Aitchison et al. 2019) rather than previous report of Proterozoic age (Ghose et al. 2010). The prevalent idea is that Naga metamorphics thrust over the ophiolites during collision of Indian plate with Burma plate. But the recent field observation in Luthur-Thanemier section

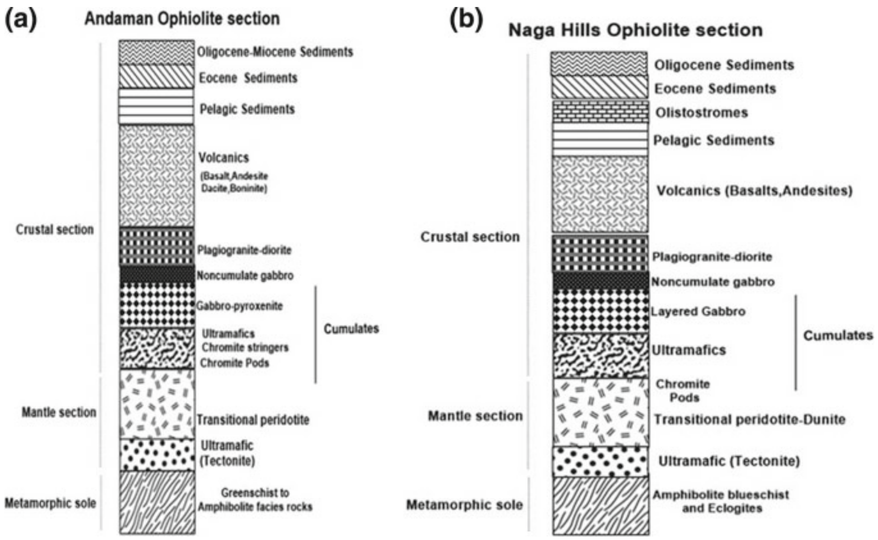

Fig. 5 A diagram showing different lithunits of ophiolite stratigraphy with metamorphic sole, **a** Andaman ophiolite (after Pal 2011; Pal et al. 2003); **b** Naga Hills ophiolite (section prepared based on the reports of different units by Acharyya 2010; Ghose et al. 2014; Pal et al. 2014; Bhowmik and Ao 2016; Singh et al. 2017 and present study)

of Nagaland by the author shows that in the eastern part of the ophiolite belt the ophiolite slices are sitting over the Naga metamorphic with westerly dipping thrust contact (back thrust) (Fig. 6). The ophiolites in the western part has thrust contact with Middle Eocene sediments with abundant olistoliths and olisotromal masses (Ghose et al. 2014). The late Eocene sediments, locally sitting directly over the ophiolites are known as Phokpur Formation records paralic facies to marine facies and these are equivalent to the coarser facies of Eocene sediments of Andaman Island (Ghose et al. 2014). The Oligocene sediments, known as Barail Group, occurring over Eocene sediments has shallow marine affinity (Ghose et al. 2014). Detailed sedimentological analysis of those sedimentary units is not available. Similar to Andaman ophiolite the Naga ophiolite has same Upper Cretaceous igneous age. It records eclogite facies metamorphic sole whereas Andaman shows low to medium P-T amphibolite facies metamorphic sole. Ghose et al. (2014), Imchen et al. (2014) suggest that Naga ophiolite is a part of accretionary prism and ophiolite shows thrust contacts with Eocene sediments. The ophiolite being a part of accretionary prism again is overlain by ophiolite derived Late Eocene–Oligocene sediments (Imchen et al. 2014). The Naga ophiolite perhaps emplaced over continental margin during Late Miocene time during major collision of Indian plate with Asian/Burma plate.

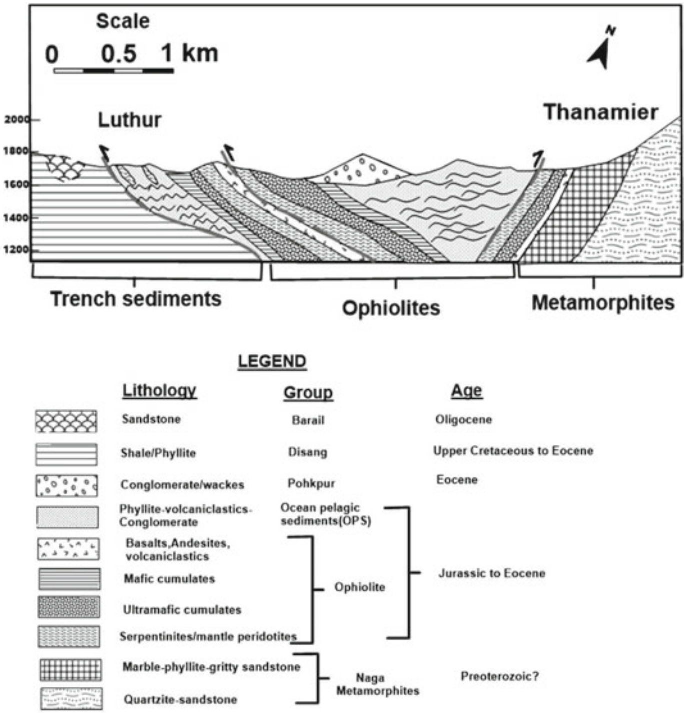

Fig. 6 A sketch showing geological section of the ophiolite exposed in Luthur (25.834° N, 94.883° E)-Thanamier (25.7773° N, 94.954° E) section of Nagaland showing easterly dipping thrust in the western part and westerly dipping back thrust where ophiolite resting over Naga metamorphics

4.2.3 Chin Hills (Mt Victoria) Ophiolite

Very little information is available for ophiolite but it comprises gabbros, dykes, pillow lavas and radiolarian chert (Socquet et al. 2002). This ophiolite belt also has eclogite facies metamorphics (e.g., Morley and Searle 2017).

4.2.4 JM Belt Ophiolite

This has high pressure eclogitic metamorphic sole represented by eclogite, and other units are poorly preserved. However, talc chlorite schist is overlain by basalt, pillowed andesite, plagiogranite and chert where the plagiogranite shows 96–106 Ma age. The metamorphic sole and age of the ophiolite are similar to the Naga ophiolite.

4.2.5 The TMB Ophiolite

It has also a metamorphic sole of chlorite and talc schists (Mitchell et al. 2007) and elcogite facies (e.g., Morley and Searle 2017). The metamorphic sole is overlain by serpentinised harzburgites, basalts and chert and the ophiolite is the host to famous Taung Ni deposit (Mitchell et al. 2007). U–Pb dating shows 166–177 Ma age (Yang and Xu 2012). This Jurassic ophiolite with SSZ character may represent either Neotethys or had a connection with Mesotethys (Yang and Xu 2012). Yui et al. (2013) however doubted about the Jurassic age and reported 77 Ma age.

The TM belt and TMB belt ophiolites are also correlated with Naga Hills ophiolite which are offset by strands of dextral Sagaing strike slip fault suggesting that it represent Neotethys rather than Mesotethys (Mitchell et al. 2012; Morley and Searle 2017). A model for a restoration of displacement by Morley and Searle (2017) suggest that the ophiolite belts in the region e.g., Naga Hills–Victoria trend, Jade Belt-, and Tagaung-Myitkyina may align into a single ophiolite belt (Fig. 4c). This single belt in that case marking the closure of Neotethys could be correlated with Indus Tsangpo suture zone of Tibet and displacement (600 km) of Sagaing fault is post-ophiolite emplacement (Morley and Searle 2017).

4.3 Nature of the Crust of Andaman and IBR

There is a diverse view on the nature of the crust below Andaman Sea. Much of the crust below East Andaman basin and Central Andaman basin is oceanic in nature (Curray 2005; Radhakrishna et al. 2008). Crustal thickness has been estimated as 30–40 km (Radhakrishna et al. 2008) which may match with the upper limit of island arc crust or accretionary prism. From regional gravity modeling, however, 25–35 km thick crust has been reported (Morley and Alvey 2015). To explain the ophiolite emplacement Acharyya (2007, 2010) suggested that ophiolite emplaced over a proto continental block. Currey, 2005 however, postulated an oceanic crust around the Andaman Islands. Based on modern seismic tomography and gravity modeling Singh et al. (2013) has reported an accretionary prism overlying lower plate oceanic crust around the islands.

Morley and Alvey (2015) suggested that Neogene oceanic crust may be restricted to Central Andaman basin whereas East Andaman basin and Alcock and Sewel rises may represent hyper-extended continental crust. Further west, the Invisible bank again represent continental crust (Roy and Chopra 1987). However Cretaceous oceanic crust in a suprasubduction zone setting exist to the west of Invisible bank (Morley 2012). Therefore a sliver of continental crust may be extended from the West Burma to further south in Andaman Sea representing Invisible Bank.

The crust of Shan plateau is being known as a part of the continental block of Sibumasu, which was derived from the Australia. Some workers also suggest that continental part of West Burma block could be part of Sibumasu (e.g., Morley and Searle 2017). West Burma was a part of SE Asia during Carboniferous to early

Permian, prior to Mesozoic and it was not a part of Indian plate origin (Sevastjanova and Hall 2016). The schists and meta sediments of the Mt Victoria is considered to represent a continental crust derived from Australia (Ridd, 2015; Rangin et al. 2013). Towards further west in the Indo Burma Ranges the ophiolite forming accretionary prism is sitting over the subducting Indian plate. The seismic signatures in northern Bay of Bengal, hoverer, is consistent with oceanic crust overlain by extremely thick and metamorphosed sediments (Curray 1991; Mitra et al. 2011). The seismically active slab extending to a depth of 160 km beneath Central Burman lowlands also confirm that continental crust cannot continue up to such great depth. Rangin et al. 2013 viewed that the Indo Burma ranges is underlain by Burma continental micro block but the interpretation of Sevastjanova and Hall (2016) is against that view. It is therefore suggested that from IBR to Andaman oceanic crust runs for the entire belt.

4.4 Volcanic Arc of Andaman and IBR Region

In Myanmar and further south in Andaman Sea a magmatic arc belt is present and in Myanmar area it is known as Wuntho-popa Arc (WPA) (Fig. 4a). The WPA shows volcanics of different age with main magmatic activity in 110–80 Ma and a subordinate stage of 70–40 Ma then in Oligocene-Miocene age (Wang et al. 2014; Mitchell et al. 2012). In the south Mt popa area the Miocene (16–13 Ma) volcanism is accompanied by Quaternary stage (<1 Ma) volcanism (Maury et al. 2004; Lee et al. 2010). This WPA continues southerly in offshore like in Barren and Narcondam Islands of Andaman Sea. The calc alkaline lavas of Narcondam volcano have a influence of the continental crust (Pal et al. 2007; Streck et al. 2011; Pal and Bhattacharya 2011). On contrary, Barren Volcano showing basaltic magmatism has no contribution from continental crust and lie on oceanic crust (Pal et al. 2010; Ray et al. 2015). Evidence of past igneous activity is also reported from Eocene sediments (Bandopadhyay 2005). The Miopliocene felsic volcanic has also been reported from the Andaman Islands (Pal et al. 2005). Subduction of Neotethys and later oceanic crust of Indian plate resulted magmatic arc and reduction of volcanic activity in WPA after 40 Ma could be linked to reduction of subduction and post collision decelarting the convergence rate (Morley and Searle 2017). The presence of the magmatic arc in the entire belt of IBR and Andaman Sea Mio Pliocene onwards with a same volcanic line suggest that the effect of subduction in IBR and Andaman area continued even after Miocene age.

5 Conclusions

The entire ophiolite belt running from Andaman to Indo Burma Ranges (IBR) has accretionary prism setup. As a part of accretionary prism the ophiolite belts running from Andaman to Chin Hills to Naga Hills, Jade mines belt have Cretaceous igneous age. Although dismembered in nature all the units of ophiolite succession are reported in Andaman and Naga hills ophiolite. Petrological attributes of the of Andaman and Naga Hills ophiolite suggest suprasubduction zone ophiolite representing forearc lithosphere. Eclogitic facies metamorphics occur as metamorphic sole in the IBR ophiolites whereas amphibolite grade metamorphic sole is present in Andaman.

Andaman ophiolite belt shows four major N-S trending east dipping thrust slices where western slices have low dip whereas eastern most slices have steep dip. In Andaman accretionary prism Eocene sediments deposited in trench slope basin and those isolated basins were also participated along the thrust uplift of the ophiolite. Subsequent to the Eocene sedimentation, Oligocene-Miocene forearc sediments deposited in the form of proximal to mid to distal fan deposits where the major source of clastics are presumed to be Irrawardy delta. The Eocene sediments display complex fold geometry whereas Oligocene-Miocene sediments show a regular fold geometry with a North-South axial plane and a low plunge. Occurrence of the forearc sediments on both side of the ophiolite-Eocene sediment complex and deformation features of forearc sediments suggest that on land emplacement of ophiolite belt took place in Late Miocene time. Field disposition of the different litho units of the Naga Hills ophiolite also suggest Late Miocene emplacement. We can guess similar situation for other ophiolite of IBR. Similarity in the age and litho logical characters of the Western belt and Eastern belt of IBR ophiolites suggest that initially there was a single ophiolite belt. Later on Sagaing strike slip fault has split that into two separate belts. Further one of the magmatic arc volcano (Mt Loimue) is situated near to Jade Mines belt which suggests that Jade Mines belt has moved down to arc zone through the Sagaing fault. The entire ophiolite belt marking the Neotethys suture probably emplaced on land during Late Miocene collision of Indian plate with Asian plate/Burma microplate.

Acknowledgements The author acknowledge helps of Annie D. Nelson, K. V. Thennuo, Rohit Gajbhiye and Ramesh Laishram of Geological Survey of India during preparation of maps, figures and finalization of the manuscript.

References

Acharyya SK (2007) Collisional emplacement history of the Naga-Andaman ophiolites and the position of the eastern Indian suture. J Asian Earth Sci 29:239–242

Acharyya SK (2010) Tectonic evolution of Indo-Burma range with special reference of Naga-Manipur Hills. Memoir Geol Soc India 75:25–43

Aitchison JC, Ao A, Bhowmik S, Clarke GL, Ireland TR, Kachovich S, Lokho K, Stojanovic D, Roeder T, Truscott N, Zhen Y, Zhou R (2019) Tectonic evolution of the western margin of the Burma microplate based on new fossil and radiometric age constraints. Tectonics (in press)

Ao A, Bhowmik (2014) Cold subduction of the Neothethys: the metamorphic record from finely banded lawsonite and epidote blueschists and associated metabasalts of the Nagaland Ophiolite in C. K. Morley & M. Searle. Downloaded from http://mem.lyellcollection.org/ at University of Colorado Boulder on February 3, 2017 Complex, India. J Metamorph Geol. https://doi.org/10.1111/jmg12096

Bandopadhyay PC (2005) Discovery of abundant pyroclasts in Namunagarh Grit, South Andaman; evidence for arc volcanism and active subduction during the Palaeogene in the Andaman area. J Asian Earth Sci 25:95–107

Bandopadhyay PC, Carter A (2017) Mithakhari deposits. In: Bandopadhyay PC, Carter A (eds) The Andaman-Nicobar accretionary ridge: geology, tectonics and hazards. Geological Society, London. Memoir 47:111–132, 235p

Baxter AT, Aitchison JC, Zyabrev SV, Ali JR (2011) Upper Jurassic radiolarians from the Naga Ophiolite, Nagaland, northeast India. Gondwana Res 20:638–644

Bhattacharya A, Pal T, Ghosh B (2013) Characterisation of the accreted ophiolite slices of Rutland Island, Andaman Sea: evolution in a suprasubduction zone setting. Ofioliti 38:121–142

Bhowmik SK, Ao A (2016) Subduction initiation in the Neo-Tethys: constraints from 687 counterclockwise P-T paths in amphibolite rocks of the Nagaland Ophiolite Complex, 688 India. J Metamorph Geol 34(1):17–44

Bhutani R, Pande K, Ray JS, Smitha RS, Awasthi N, Kumar A (2014) 40Ar-39Ar geochronology of Narcondam island volcano, Andaman-Indonesian island arc, Andaman Sea: voluminous andesitic eruption at 0.56 Ma and preservation of 1.8 Ma old plagioclase xenocrysts. Geological Society of America Abstract 46, 653

Brunnschweiler RO (1966) On the geology of the Indoburman ranges. J Geol Soc Aust 13:137–194

Chakraborty PP, Pal T (2001) Anatomy of a forearc submarine fan: Upper Eocene–Oligocene Andaman Flysch Group, Andaman Islands, India. Gondwana Res 4:477–487. https://doi.org/10.1016/s1342-937x(05)70347-6

Chakraborty PP, Pal T, Dutta Gupta T, Gupta KS (1999) Facies pattern and depositional motif in an immature trench-slope basin, Eocene Mithakhari Group, Middle Andaman, India. J Geol Soc India 53:271–284

Condie KC (1989) Plate tectonics and crustal evolution (3rd edn). Pergamon Press, 469 pp

Curray JR, Moore DG (1974) Sedimentary and tectonic processes in the Bengal deep sea fan and geosyncline. In: Burke CA, Drake CL (eds) The geology of continental margins. Springer, New York, pp 617–627

Curray JR (1991) Possible greenschist metamorphism at the base of a 22 km sediment section, Bay of Bengal. Geology 19:1097–1100

Curray JR (2005) Tectonics of the Andaman Sea region. J Asian Earth Sci 25:187–232

Ghose NC, Agrawal OP, Chatterjee N (2010) Geological and mineralogical study of 762 eclogite and glaucophane schists in the Naga Hills Ophiolite, Northeast India. Island 763 Arc 19(2):336–356

Ghose NC, Chatterjee N, Fareeduddin (2014) A Petrographic Atlas of Ophiolite, an example from the Eastern India-Asia collision zone. Springer, India, https://doi.org/10.1007/97-81-322-1569-1

Ghosh B, Bandyopadhyay D, Morishita T (2017) Andaman-Nicobar ophiolites, India: origin, evolution and emplacement. In: Bandopadhyay PC, Carter A (eds) The Andaman-Nicobar accretionary ridge: geology, tectonics and hazards. Geological Society, London, pp 95–110. Memoir 47, 235p

Ghosh B, Morishita T, Bhatta K (2013) Significance of chromian spinels from the mantle sequence of the Andaman ophiolite, India: paleogeodynamic implications. Lithos 164–167:86–96

Hall R (2012) Late Jurassic-Cenozoic reconstructions of the Indonesian region and the Indian Ocean. Tectonophysics 570–571:1–41

Imchen W, Thong GT, Pongen T (2014) Provenance, tectonic setting and age of the sediments of the Upper Disang Formation in the Phek District, Nagaland. J Asian Earth Sci 88:11–27

Karunakaran C, Ray KK, Saha SS (1967) A revision of the stratigraphy of Andaman and Nicobar islands, India. Bulletin of the National Institute of Science, India 38:436–441

Kingson O, Bhutani R, Balakrishnan S, Dash JK, Shukla AD (2019) Subduction-related Manipur Ophiolite Complex, Indo-Myanmar Ranges: elemental and isotopic record of mantle metasomatism. Geological Society, London, Special Publications, 481, doi:10.1144/SP481.9

Kingson O, Bhutani R, Dash JK, Sebastian S, Balakrishnan S (2017) Resolving the conundrum in origin of the Manipur Ophiolite Complex, Indo-Myanmar range: constraints from Nd isotopic ratios and elemental concentrations in serpentinized peridotite. Chem Geol 460:117–129

Lee H, Chung S, Yang H, Chu C, Lo C, Mitchell A (2010) Cenozoic volcanic rocks from central Myanmar: age, geochemical characteristics and geodynamic significance. AGU, Fall Meeting, San Francisco, 13–17th December, 2010, abstract

Maury RC, Pubellier M et al (2004) Quaternary calc-alkaline and alkaline volcanism in an upper-oblique convergence setting, central Myanmar and western Yunnan. Bull *Soc Géol France* 175:461–472

Mitchell AHG (1986) Ophiolite and associated rocks in four settings: relationships to subduction and collision. Tectonophysics 125:269–285

Mitchell AHG, Chung S-L, Oo Thura, Lin T-H, Hung C-H (2012) Zircon U-Pb ages in Myanmar: magmaticmetamorphic events and the closure of a neo-Tethys ocean? J Asian Earth Sci 56:1–23

Mitchell AHG, Htay MT, Htun KM, Win MN, Oo T, Hlaing T (2007) Rock relationships in the Mogok Metamorphic belt, Tatkon to Mandalay, central Myanmar. J Asian Earth Sci 29:891–910

Mitra S, Priestley K, Acton C, Gaur VK (2011) Anomalous surface wave dispersion and the enigma of 'continental-like' structure for the Bay of Bengal. J Asian Earth Sci 42:1243–1255

Morley CK, Searle M (2017) Ch-5: Regional tectonics, structure and evolution of the Andaman–Nicobar Islands from ophiolite formation and obduction to collision and back-arc spreading. In: Bandopadhyay PC, Carter A (eds) The Andaman-Nicobar accretionary ridge: geology, tectonics and hazards. Geological Society, London, Memoir 47:51–74 (235p)

Morley CK, Alvey A (2015) Is spreading prolonged, episodic or incipient in the Andaman Sea? Evidence from deepwater sedimentation. J Asian Earth Sci 98:446–456

Morley CK (2012) Late Cretaceous-Early Palaeogene tectonic development of SE Asia. Earth-Sci Rev 115:37–75

Mukhopadhyay M, Dasgupta S (1988) Deep structure and tectonics of the Burmese arc: constraints from earthquake and gravity data. Tectonophysics 149:299–322

Pal T (2011) Petrology and geochemistry of the Andaman ophiolite: melt–rock interaction in a suprasubduction-zone setting. J Geol Soc London 168:1031–1045. https://doi.org/10.1144/0016-76492009-152

Pal T, Bhattacharya A (2011) Block-and-ash flow deposit of the Narcondam Volcano: product of dacite–andesite dome collapse in the Burma-Java subduction complex. Island Arcs 20:520–534

Pal T, Bhattacharya A, Nagendran G, Yanthan NM, Singh R, Raghumani N (2014) Petrogenesis of chromites from the Manipur ophiolite belt, NE India: evidence for a supra-subduction setting prior to Indo-Myanmar collision. Mineral Petrol 108:713–726

Pal T, Bhattacharya A (2016) Evolution of Andaman ophiolite in the backdrop of Andaman-Java subduction—a comprehensive approach integrating field and Laboratory data Geological Survey of India Sp. Pub. No 105, pp 137

Pal T, Chakraborty PP, Duttagupta T, Singh CD (2003) Geodynamic evolution of an outer arc in convergent margin of active Burma-Java subduction complex, a document from Andaman islands, Bay of Bengal. Geol Mag 140:289–307

Pal T, Duttagupta T, Chakraborty PP, Dasgupta SC (2005) Pyroclastic deposits of Mio-Pliocene age in the Arakan Yoma–Andaman–Java subduction complex, Andaman Islands, Bay of Bengal, India. Geochem J 39:69–82

Pal T, Mitra SK, Sengupta S, Katari A, Bandopadhyay PC, Bhattacharya AK (2007) Dacite-andesites of Narcondam volcano in the Andaman Sea—an imprint of magma mixing in the inner arc of the Andaman-Java subduction system. J Volcanol Geoth Res 168:93–113

Pal T, Raghav SR, Bhattacharya A, Bandopadhyay PC, Mitra SK, Renjit ML, Shankar MS, Ghosh B (2010) The 2005-06 eruption of Barren Volcano, Andaman Sea: evolution of basaltic magmatism in island arc setting of Andaman-Java subduction complex. J Asian Earth Sci 39:12–23

Pedersen RB, Searle MP, Carter A, Bandopadhyay PC (2010) U-Pb zircon age of the Andaman ophiolite: implications for the beginning of subduction beneath the Andaman-Sumatra arc. J Geol Soc London 167:1105–1112. https://doi.org/10.1144/0016-76492009-151

Radhakrishna M, Lasitha S, Mukhopadhyay M (2008) Seismicity, gravity anomalies and lithospheric structure of the Andaman arc, NE Indian Ocean. Tectonophysics 460:248–262

Rangin C, Maurin T, Masson F (2013) Combined effects of Eurasia/Sunda oblique convergence and East-Tibetan crustal flow on the active tectonics of Burma. J Asian Earth Sci 76:185–194

Ray JS, Pande K, Bhutani (2015) 40Ar/39Ar geochronology of subaerial lava flows of Barren Island volcano and the deep crust beneath the Andaman Island Arc, Burma Microplate. Bull Volcanol 77:57. https://doi.org/10.1007/s00445-015-0944-9

Ray KK (1982) A review of the geology of Andaman and Nicobar islands, vol 42. Geological Survey of India Miscellaneous Publications, pp 110–125

Ridd MF (2015) Should Sibumasu be renamed Sibuma? The case for a discrete Gondwana-derived block embracing western Myanmar, Upper Peninsular Thailand and NE Sumatra. J Geol Soc London 173(2):249. https://doi.org/10.1144/jgs2015-065

Roy DK, Acharyya SK, Ray KK, Lahiri TC, Sen MK (1988) Nature of occurrence and depositional environment of the oceanic pelagic sediments associated with the ophiolite assemblage, South Andaman Island. Indian Miner 42:31–56

Roy TK, Chopra NN (1987) Wrench faulting in Andaman forearc basin, India. Proc Offshore Technol Conf 19:393–404

Sarma DS, Jafri SH, Fletcher IR, McNaughton NJ (2010) Constraints on the tectonic setting of the Andaman ophiolites, Bay of Bengal, India, from SHRIMP U–Pb zircon geochronology of plagiogranites. J Geol 118:691–697

Searle MP, Noble SR, Cottle JM, Waters DJ, Mitchell AHG, Hlaing T, Horstwood MS (2007) A tectonic evolution of the Mogok metamorphic belt, Burma (Myanmar) constrained by U-Th-Pb dating of metamorphic and magmatic rocks. Tectonics 26:1–24

Sevastjanova I, Hall R (2016) Myanmar and Asia united, Australia left behind long ago. Gondwana Res 32:24–40

Singh AK, Chung S-L, Bikramaditya RK, Lee HY (2017) New U-Pb zircon ages of plagiogranites from the Nagaland-Manipur Ophiolites, Indo-Myanmar Orogenic Belt, NE India. J Geol Soc 174(1):170–179

Singh AK, Khogenkumar S, Singh LR, Bikramaditya RK, Khuman CM, Thakur SS (2016) Evidence of Mid-ocean ridge and shallow subduction forearc magmatism in the Nagaland-Manipur ophiolites, northeast India: constraints from mineralogy and geochemistry of gabbros and associated mafic dykes. Chem Erde 76(4):605–620

Singh AK, Singh NI, Devi LD, Singh RKB (2012) Geochemistry of Mid-Ocean Ridge Mafic intrusives from the Manipur Ophiolitic Complex, Indo-Myanmar Orogenic Belt, NE India. J Geol Soc India 80(2):231–240

Sloan RA, Elliott JR, Searle MP, Morley CK (2017) In: Barber AJ, Zaw K, Crow MJ (eds) Chapter 2. Active tectonics of Myanmar and the Andaman Sea. Geological Society, London. Memoirs, pp 19–52

Socquet A, Goffé B, Pubellier M, Rangin C (2002) Le métamorphisme Tardi-Crétacé à Éocène des zones internes de la chaîne Indo-Birmane (Myanmar occidental): implications géodynamiques. Compte Rendus Geosci 334:573–580

Steckler MS, Akhter SH, Seeber L (2008) Collision of the Ganges–Brahmaputra Delta with the Burma Arc: implications for earthquake hazard. Earth Planet Sci Lett 273(3):367–378

Steckler MS, Mondal DR, Akhter SH, Seeber L, Feng L, Gale J, Howe M (2016) Locked and loading megathrust linked to active subduction beneath the Indo-Burman Ranges. Nat Geosci 9(8):615–618

Streck MJ, Ramos F, Gillam A, Haldar D, Duncan RA (2011) Thei intra-oceanic Barren Island and Narcondam arc volcanoes, Andaman Sea: implications for subduction inputs and crustal overprint of depleted mantle source. In: Ray J, Sen G, Ghosh B (eds) Topics in igneous petrology. Springer, Dordrecht, Heidelberg, pp 241–273

Vidyadharan KT, Joshi A, Ghose S, Gaur MP, Sukla R (1989) Manipur Ophiolites. Its geology, tectonic setting and metallogeny. In: Ghose NC (ed) Phanerozoic Ophiolites of India and associated monerial resources. Sumna Publishers and Distributors, Patna, pp 197–212

Wang J-G, Wu F-Y, Tan X-C, Liu C-Z (2014) Magmatic evolution of the Western Myanmar Arc documented by U-Pb and Hf isotopes in detrital zircons. Tectonophysics 612–613:97–105

Whattam SA, Stern RJ (2011) The ‘subduction-initiation rule’: a key for linking ophiolites, intra-oceanic forearcs and subduction initiation. Contributions to Mineral Petrol 162:1031–1045. https://doi.org/10.1007/s00410-011-0638-z

Yang JS, Xu ZQ (2012) Discovery of a Jurassic SSZ ophiolite in the Tagaung-Myitkyina region of Myanmar. Acta Petrol Sin 28:1710–1730

Yui T-F, Fukoyama M, Iizuka Y, Wu C-M, Wu T-W, Lious JG, Grove M (2013) Is Myanmar jadeitite of Jurassic age? A result from incompletely recrystallized inherited zircon. Lithos 160–161:268–282