Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Asian Earth Sciences 25 (2005) 187–232
Journal of Asian Earth Sciences
www.elsevier.com/locate/jaes

Tectonics and history of the Andaman Sea region

Joseph R. Curray*

Scripps Institution of Oceanography, La Jolla, CA 92093-0220, USA

Received 20 May 2004; revised 25 August 2004; accepted 1 September 2004

Abstract

The Andaman Sea is an active backarc basin lying above and behind the Sunda subduction zone where convergence between the overriding Southeast Asian plate and the subducting Australian plate is highly oblique. The effect of the oblique convergence has been formation of a sliver plate between the subduction zone and a complex right-lateral fault system. The late Paleocene collision of Greater India and Asia with approximately normal convergence started clockwise rotation and bending of the northern and western Sunda Arc. The initial sliver fault, which probably started in the Eocene, extended through the outer arc ridge offshore from Sumatra, through the present region of the Andaman Sea into the Sagaing Fault. With more oblique convergence due to the rotation, the rate of strike-slip motion increased and a series of extensional basins opened obliquely by the combination of backarc extension and the strike-slip motion. These basins in sequence are the Mergui Basin starting at ∼32 Ma, the conjoined Alcock and Sewell Rises starting at ∼23 Ma, East Basin separating the rises from the foot of the continental slope starting at ∼15 Ma; and finally at ∼4 Ma, the present plate edge was formed, Alcock and Sewell Rises were separated by formation of the Central Andaman Basin, and the faulting moved onshore from the Mentawai Fault to the Sumatra Fault System bisecting Sumatra.

Keywords: Andaman Sea; Backarc Basin; Oblique Convergence; Subduction; Myanmar; Sumatra

1. Introduction

The Andaman Sea (Figs. 1 and 2) is a complex backarc extensional basin that differs from most other such basins in that it is west facing and that it was formed by transtension. The Andaman Sea lies along a highly oblique convergent margin between the northeastern moving Australian and/or Indian plate and the nearly stationary Eurasian or Southeast Asian plate. As the Greater Indian continental mass converged on the southeastern Asian margin, it caused clockwise rotation of the subduction zone and increase in the obliquity to the point that transtension along a sliver fault has resulted in oblique rhombochasm-like opening of the Andaman Sea during the Neogene.

The tectonics and geological history of the Andaman Sea cannot be separated from the tectonics and geological histories of Myanmar (Burma) on the north, the Andaman and Nicobar Islands part of the accretionary prism on the western side of the Andaman Sea, and Sumatra on the south. The descriptions and discussion to follow will, therefore, include consideration of Sumatra and western and central Myanmar. The continental crust and pre-Neogene rocks of the Malay Peninsula and the Shan Plateau of Myanmar are directly involved in the tectonics where they have been rifted and thinned to form the Mergui Basin in the southeastern part of the Andaman Sea.

1.1. Previous exploration and investigation

An early sighting of the Andaman and Nicobar Islands by a western explorer is attributed to Marco Polo in 1298, allegedly on his return to Europe by sea. He wrote ‘Angamanain is a very long island…’, and then went on to describe the unsavory nature of the aboriginal inhabitants of both the Andaman Islands (Angamanain) and Nicobar Islands (Necuveran), descriptions that were subsequently shown to be untrue or greatly exaggerated (Mukerjee, 2003).

* Tel.: +1 858 534 3299; fax: +1 858 534 0784.
E-mail address: jcurray@ucsd.edu.

1367-9120/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jseaes.2004.09.001

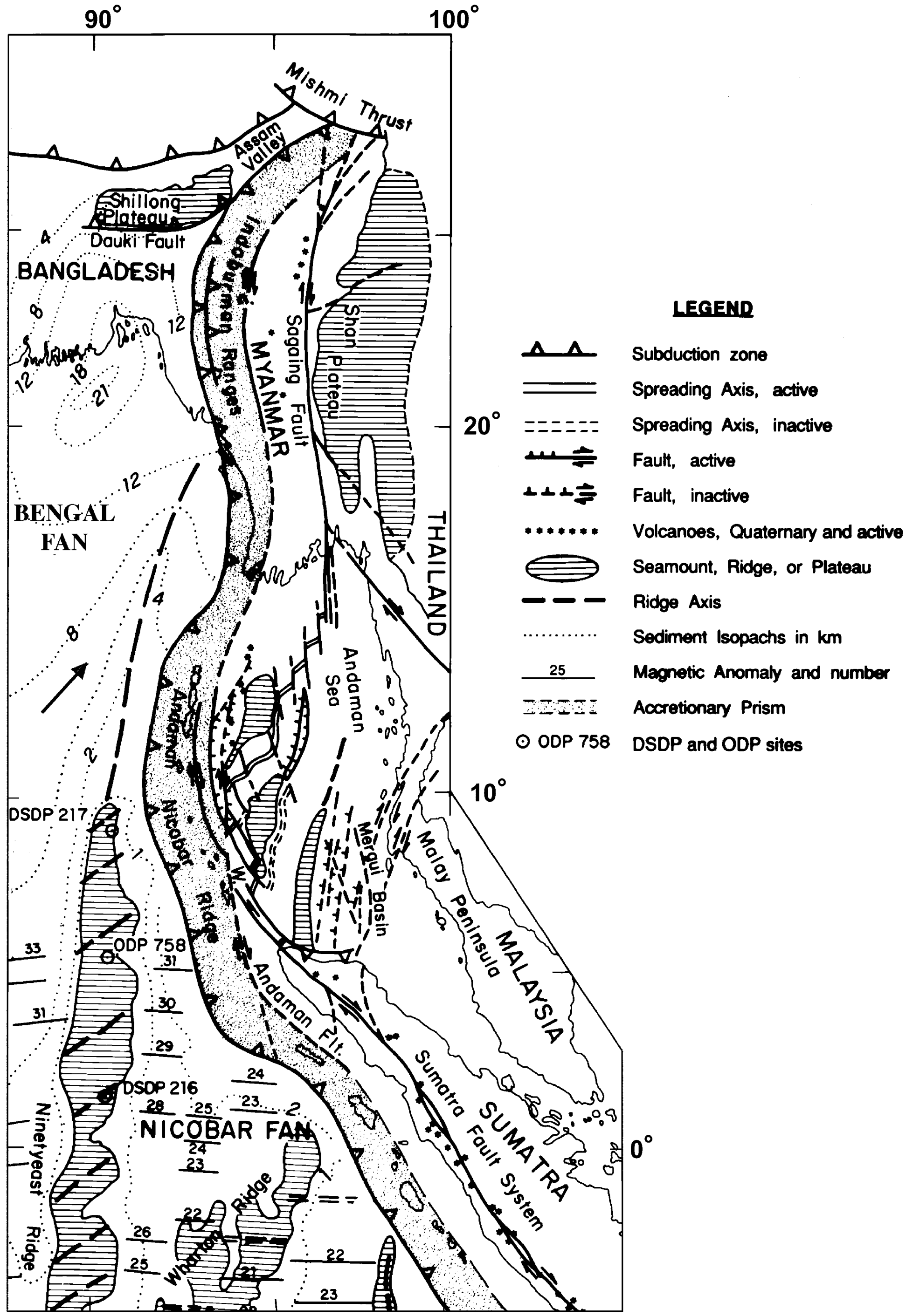

Fig. 1. Tectonic map of part of the northeastern Indian Ocean. Modified from Curray (1991).

Whether these comments were from his personal observations or taken from earlier Persian accounts, Marco Polo brought them to Europe.

The first organized oceanographic and marine biological investigations of the Andaman Sea were by Alcock (1902). Sewell (1925), Director of the Zoological Survey of India, did further oceanographic and geographic surveys. Rodolfo (1969a,b) named Alcock and Sewell Seamounts, later designated rises, after these two pioneers. Earlier workers had, however, made observations of Barren Island (about 12°N, Figs. 1, 2 and 4), the only active subaerial volcano and on the adjacent Andaman and Nicobar Islands and the Malay Peninsula. The first recorded observation of Barren Island by a western explorer was by Van Linschoten (1595). Mallet (1895) 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 whom Port Blair on South

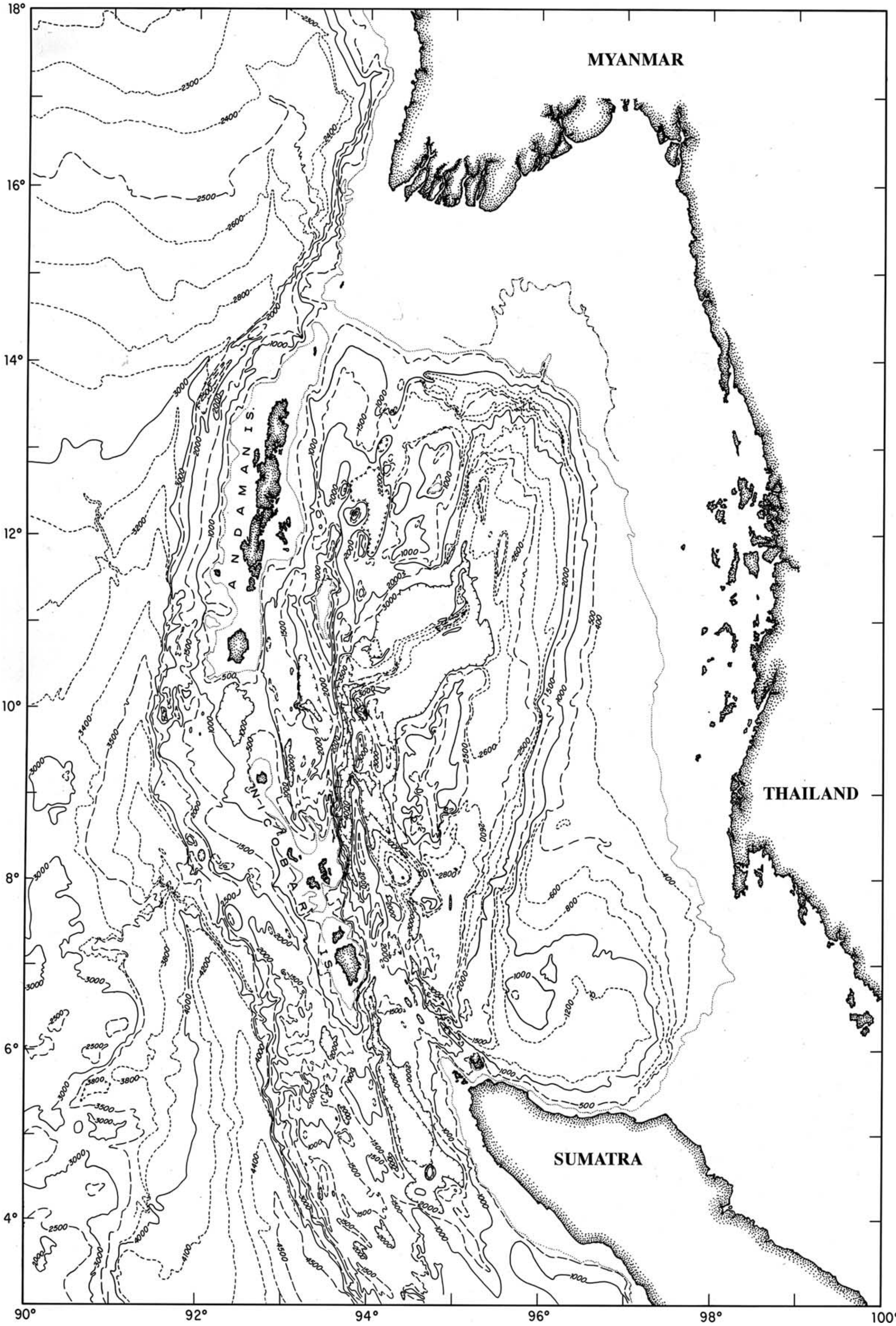

Fig. 2. Bathymetry of the Andaman Sea and part of the adjacent Indian Ocean, in corrected meters.

Andaman Island was named. The other subaerial volcano, Narcondam Island, is inactive or dormant.

The earliest known geological mention in the western literature of Myanmar (Burma) was by Fitch (1599) who traveled from Syria to Burma. Cox (1799a,b) described the hand-dug oil wells on the Yenangyaung anticline in the Central Burma basin, although there are reports of a Chinese traveler who reported oil workings at Yenangyaung in the 13th century. Suess (1904) divided Myanmar into three zones (Fig. 1): (1) The Western Indoburman Ranges; (2) The Central Tertiary Burma Basin; (3) The Eastern Zone Shan Plateau. Classic descriptions of the geology of Burma were published by Pascoe (1912), Chhibber (1934) and many other publications of the Geological Survey of India (GSI), as summarized by Goosens (1978).

Consideration of the geology and origin of the Andaman–Nicobar Ridge started with Rink (1847), who 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. Hochstetter (1869) pointed out that the same ridge extended southward as the outer arc ridge off Sumatra and Java. Sewell (1925) suggested that 'the Andaman–Nicobar Ridge has drifted toward the west away from the mainland, and has thus formed a pronounced curve with its apex in the region of Little Andaman Island'. Wegener was probably the first author to postulate a rift origin of the Andaman Sea in one of the early editions of his book 'Die Entstehung der Kontinente und Ozeane', starting in 1915. In the 1966 edition of the translation of his 1929 edition (Wegener, 1966), he compared Lawson's (1921) analysis of the San Andreas Fault of California and the opening of the Gulf of California with opening of the Andaman Sea. He says (p. 201) of the Andaman Sea 'We may perhaps assume here that the vast compression of the Himalaya put the Indochina chains in tension along their length, that under this stress the Sumatra chain was torn at the northern end of that island and that the northern part of the chain (Arakan) was, and still is, being pulled northwards like a rope's end into the great compression'.

Post-World War II work in the Andaman Sea, Burma and Sumatra which contributes to understanding the Andaman Sea includes important papers by Brunnschweiler (1966, 1974), Peter et al. (1966), Weeks et al. (1967), Aung Khin and Kyaw Win (1968, 1969), Rodolfo (1969a,b), Frerichs (1971), Mitchell and McKerrow (1975), Paul and Lian (1975), Mitchell (1976, 1981, 1985), Curray et al. (1979, 1982), Bender (1983), Chatterjee (1984), Roy and Chopra (1987), Mukhopadyay (1984, 1992), Polachan and Racey (1994), Acharyya (1994, 1997, 1998), Sieh and Natawidjaja (2000), Genrich et al. (2000) and many others. However, not all Indian syntheses agree with the plate tectonic interpretations presented in this paper. Rodolfo (1969a) was the first modern worker to fully understand the rifting and extensional opening of the Andaman Sea.

Newer information is gradually coming into public availability with excellent work in progress by Indian and French scientists and oil and gas exploration studies. Many of the irresolvable problems encountered in the present paper with the limited data available will eventually be resolved with these new sources of information, but many conclusions and interpretations in the present paper must for now remain speculation based on limited data.

My colleagues and I started publishing on the tectonics and history of the Andaman Sea in 1979 (Curray et al. 1979), including analysis of sea floor spreading magnetic anomalies for most of the Andaman Sea, which we had interpreted back to 11 Ma. Later, we extended that to 13 Ma. Several years ago, however, I carefully reviewed our anomaly interpretations and at first concluded that none prior to about 3 Ma were correct. More recently, we (S. Cande, personal communication, 2003) concluded that even those last 3 my anomaly identifications were not valid. We then concluded that anomalies could be identified back to 4 Ma for the Central Andaman Basin (Fig. 4).

While in the final stages of preparation of this manuscript, a long-awaited analysis of excellent closely spaced swath mapping and magnetic surveys of the Central Andaman Basin (Fig. 4) was published by Raju et al. (2004). I have now revised my discussion of our limited magnetic data in the Central Andaman Basin and have accepted their interpretation of the magnetic anomalies. Raju et al. (2004) agreed with our conclusion that the Central Andaman Basin has opened 118 km in about the last 4 my. Unfortunately, those authors misread our earlier publications that stated that the entire Andaman Sea had opened up to 460 km in the last 11 my. Instead they attributed our 11 my time to just the central most recent 118 km of opening. This opening history will be reviewed in Sections 6 and 7 in this paper.

1.2. Sources of data

Most of the ship tracks (Fig. 3) on which this study is based are from ships of the Scripps Institution of Oceanography, run between 1968 and 1979. In addition, some useful information has come from the cruises of R/V Pioneer and R/V Oceanographer from the US Coast and Geodetic Survey in 1964 and 1967, a few lines of the Lamont-Doherty Geological Observatory and several lines to which I was given access by oil companies. The data utilized include magnetics, gravity, 3.5 kHz bottom-penetrating ($\sim$100 m maximum) echo sounder and airgun seismic reflection profiling, mainly analog, but with some multichannel digital seismic reflection data. For most of our analog seismic reflection surveys, data were collected with two different sweep times and filter settings: a slower sweep, generally five seconds, filtered to 20–60 Hz; and a faster sweep, generally 2 s, filtered to 50–150 Hz for higher

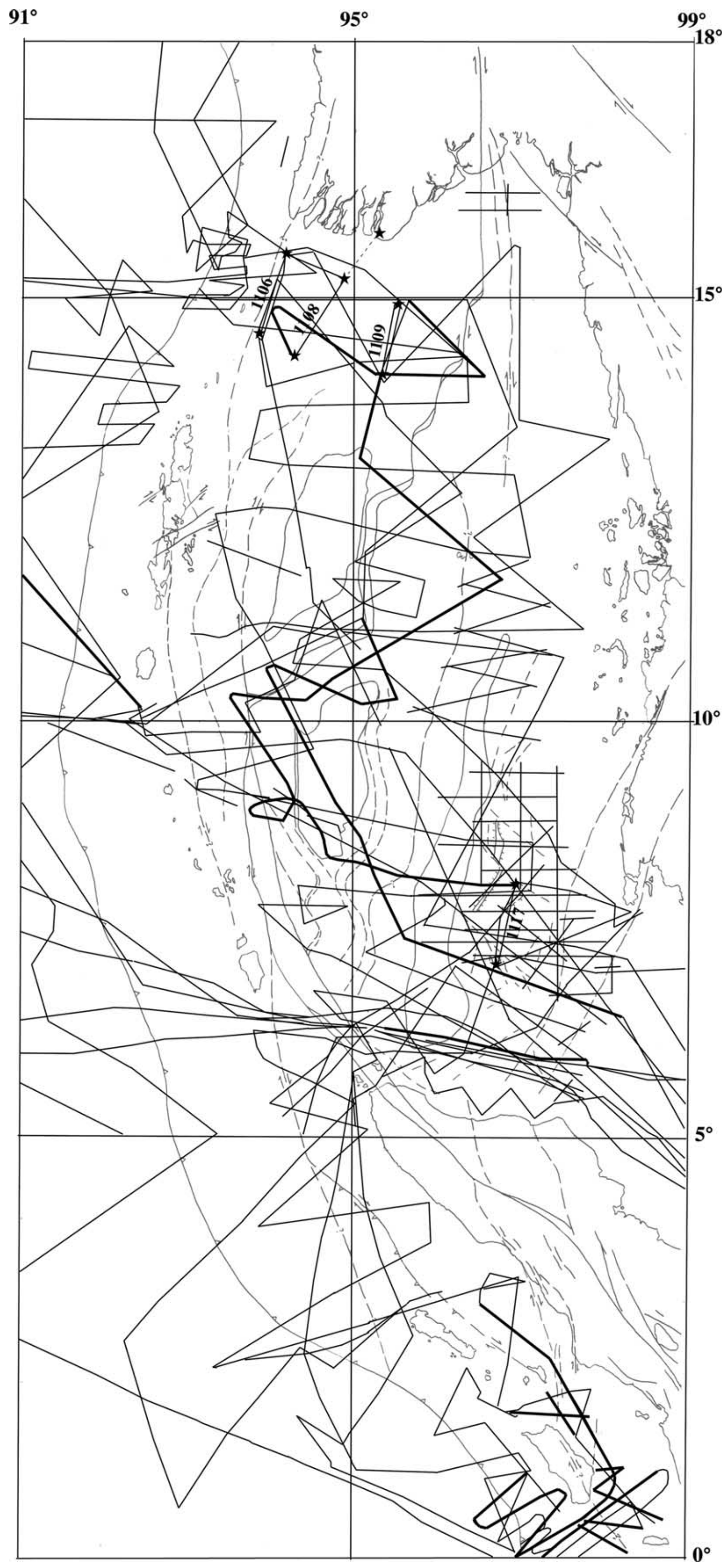

Fig. 3. Geophysical ship tracks available for this study, shown overlain on a partial tectonic map of Fig. 4. Bathymetry of Fig. 3 is based on many more tracks than shown here. Stars indicate ends of reversed seismic refraction lines. Heavy lines are SIO multichannel lines.

resolution. Swath-mapping bathymetry equipment was not available to us at the time of our surveys.

Some of the 134 seismic refraction and wide-angle seismic reflection stations involved single expendable sonobuoys; some were run with successive sonobuoys at intervals. All utilized air guns as a source, and about a third of the stations also utilized explosives as a source. Four of the refraction stations (Fig. 3) utilized moored telemetering hydrophones at each end of a reversed line as well as successively launched sonobuoys in between. The three lines on the Myanmar continental shelf were run in collaboration with geophysicists from the Myanma Oil Corporation, the Myanmar national petroleum company. A 24 channel analog receiving array was set up on the landward end. One of our technicians worked on shore with the oil company crew placing the geophones and synchronizing the shot timing by radio with our ship. A geophysicist from Myanma worked aboard our ship, which acted as both a shooting ship and receiving ship, while the time-synchronized signals were also received at the shore station. A geophysicist and a geologist from Myanma listed in the Acknowledgements at the end of this paper came to Scripps following the cruise to participate in analyzing the results.

Our bathymetric chart (Fig. 2) is based on many additional ship tracks, positions of which were adjusted to agree with the satellite-positioned lines of our own surveys. Our bathymetric and reflection profiles commonly exhibit a vertical exaggeration averaging about 10×. I have compared the bathymetry of Fig. 2 with bathymetry calculated from satellite altimetry (Smith and Sandwell, 1997) and conclude that while bathymetry from satellite measurements is useful for general trends, it is not satisfactory for understanding complex tectonic features.

2. Morphological and tectonic features of the Andaman Sea region

The major tectonic elements of the northeastern Bay of Bengal and the adjacent parts of Southeast Asia are shown in Fig. 1. The Indian and Australian plates are converging on the Eurasian or Southeast Asian plate in a northeasterly direction along the Himalayan front at the north and the Sunda Trench. The margin along the western Sunda Trench is an oblique convergence continental and arc margin. The sedimentary cover on the subducting plate is very thick because of the Bengal Fan (Curray et al., 2003), and sediments and ocean crust have been accreted and uplifted into the Indoburman Ranges, the Andaman–Nicobar Ridge and the outer arc ridge off Sumatra and Java. The sediments thin over the Ninetyeast Ridge, which is commonly interpreted as a hotspot trace (see, for example, Curray et al. (1982)), with NE–SW en echelon ridges on top. The bathymetric trench extends continuously from east of Java westward and northward to where it is overwhelmed by sediment of the Bengal Fan, and the surface trace of the subduction zone rises out of the depths onto land as the thrust faults of eastern Bangladesh, eastern India, western Myanmar and the southeastern edge of the Assam Valley (Fig. 1). The accretionary prism forms an entire mountain range, the Indoburman Ranges.

A tectonic map of the Andaman Sea region is shown in Fig. 4, extending from the Malay Peninsula on the east side to the Bay of Bengal sea floor on the west side, and from southern Myanmar in the north to northern Sumatra in the south. The free air gravity and seismicity for the same area are shown in Figs. 5 and 6, overlain on a simplified tectonic map. The overall basic structure, the tectonic elements, and the geology of the Andaman Sea region (Figs. 1 and 4) will be described in terms of extensions of the zones defined by Suess (1904) for Myanmar, consisting of: (1) The western zone extending from the Indoburman Ranges southward into the Andaman–Nicobar Ridge and to the outer arc ridge off Sumatra; (2) The Tertiary central Basin of Myanmar extending southward into the central basin of the Andaman Sea and the hydrocarbon rich backarc basins of Sumatra; (3) The Shan Plateau of Myanmar of mainly Mesozoic and Paleozoic continental rocks extending southward to the Malay Peninsula.

Fig. 4 shows the tectonic elements judged to be the most important, including topographic or subsurface highs, volcanoes, faults judged to be active, faults judged to be inactive, active and abandoned spreading axes and locations of important dredge or rock sampling sites. Discussion of most of these features follows.

3. Outer arc—Andaman–Nicobar Ridge

The Andaman–Nicobar Ridge is the part of the outer arc ridge of the northern segment of the Sunda subduction zone lying seaward of the Andaman Sea. As the accretionary prism of the subduction zone, its basic simplified structure is an imbricate stack of eastward-dipping fault slices and folds, with Cretaceous ophiolites and older deep sea sedimentary rocks lying generally at the top and on the eastern side of the pile, and progressively younger Neogene sedimentary rocks at the western side and bottom of the pile immediately above the trench. This imbricate stack is capped with Neogene sediments deposited on top and on the seaward face of the older rocks of the stack.

The stratigraphy of the Andaman Islands was first described in some detail by Oldham (1885), of the GSI, who mentions the fragmentary observations of others, including Rink (1847), Hochstetter (1869) and Ball (1870) in the Nicobar Islands, and some other early explorers in the Andaman Islands. Oldham divided the section into two basic formations, the Port Blair and the Archipelago Series. The Port Blair series consists principally of firm gray sandstone and interbedded gray shales, with minor amounts of coaly matter, conglomerate and limestone. The sandstone is the characteristic rock of the series. He also, however, noted the presence of some red and green jasper beds, serpentine and

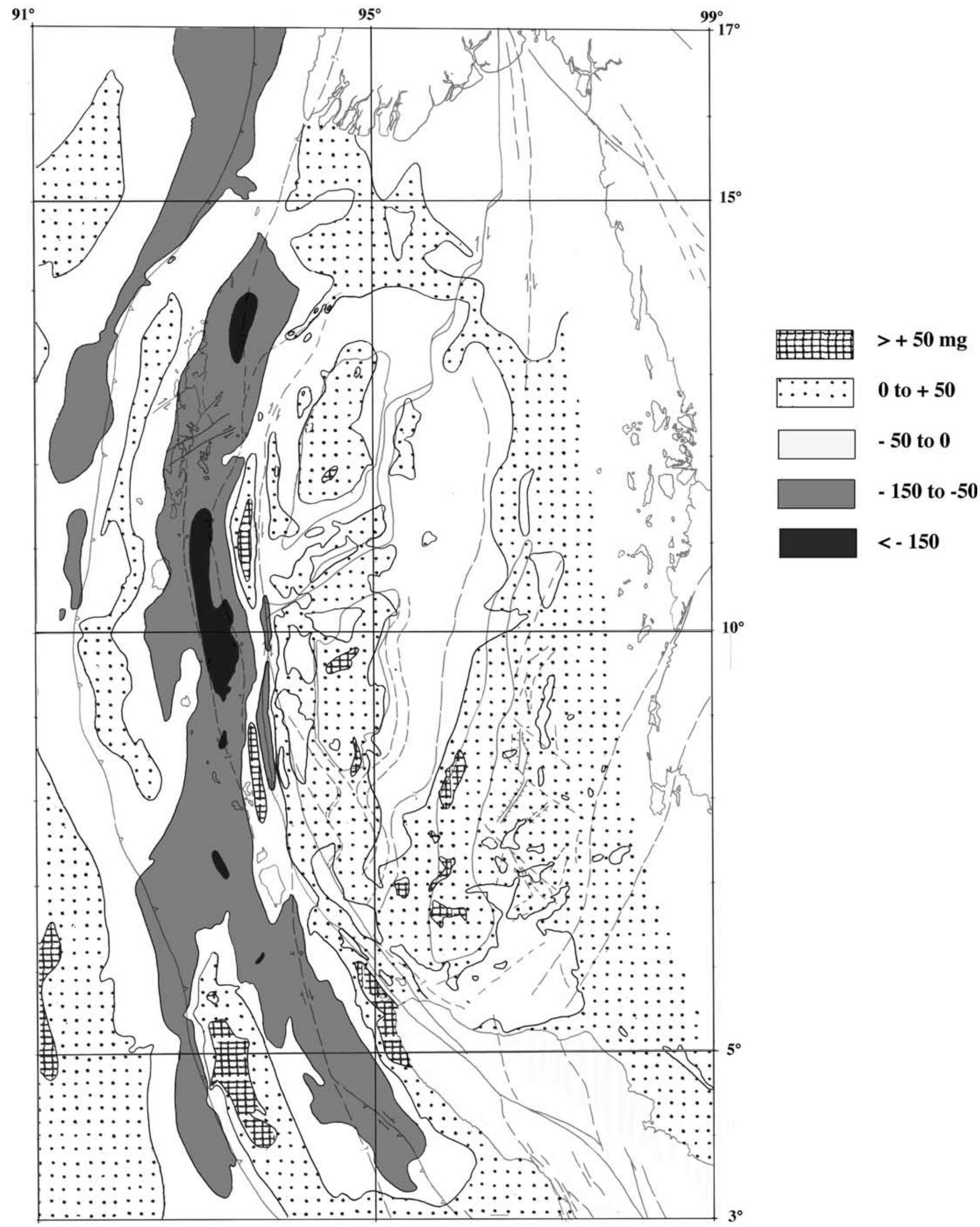

Fig. 5. Free air gravity, composite from shipboard measurements and satellite measurements, overlain on partial tectonic map.

volcanic beds, but he could not determine whether or not they were older than the sandstones and shales. The younger Archipelago Series, the capping on the imbricate stack, consist typically of soft limestones formed of coral and shell sand, soft calcareous sandstones and soft white clays.

Further contributions and more detailed work were done by other GSI geologists, e.g. Tipper (1911), Gee (1927) and Jacob (1954). The stratigraphy was revised and new names were given to some of the units in a series of papers by Karunakaran et al. (1964a,b,c, 1968a,b, 1975). For example, the Port Blair formation was redefined as the Andaman Flysch, and some other new formation names have been introduced. More recently, GSI geologists Chatterjee (1967, 1984), Parthasarathy (1984), Roy et al. (1988), Bandopadhyay and Ghosh (1998), Acharyya et al. (1990), Acharyya et al. (1997, 1998), Acharyya (1997), Chakraborty and Pal (2001) and Chakraborty et al. (1999, 2002) have published excellent new descriptions and facies interpretations, some of which I will follow in the subsequent discussions.

More recently, after much of this discussion had been written, a new paper by Pal et al. (2003) appeared in

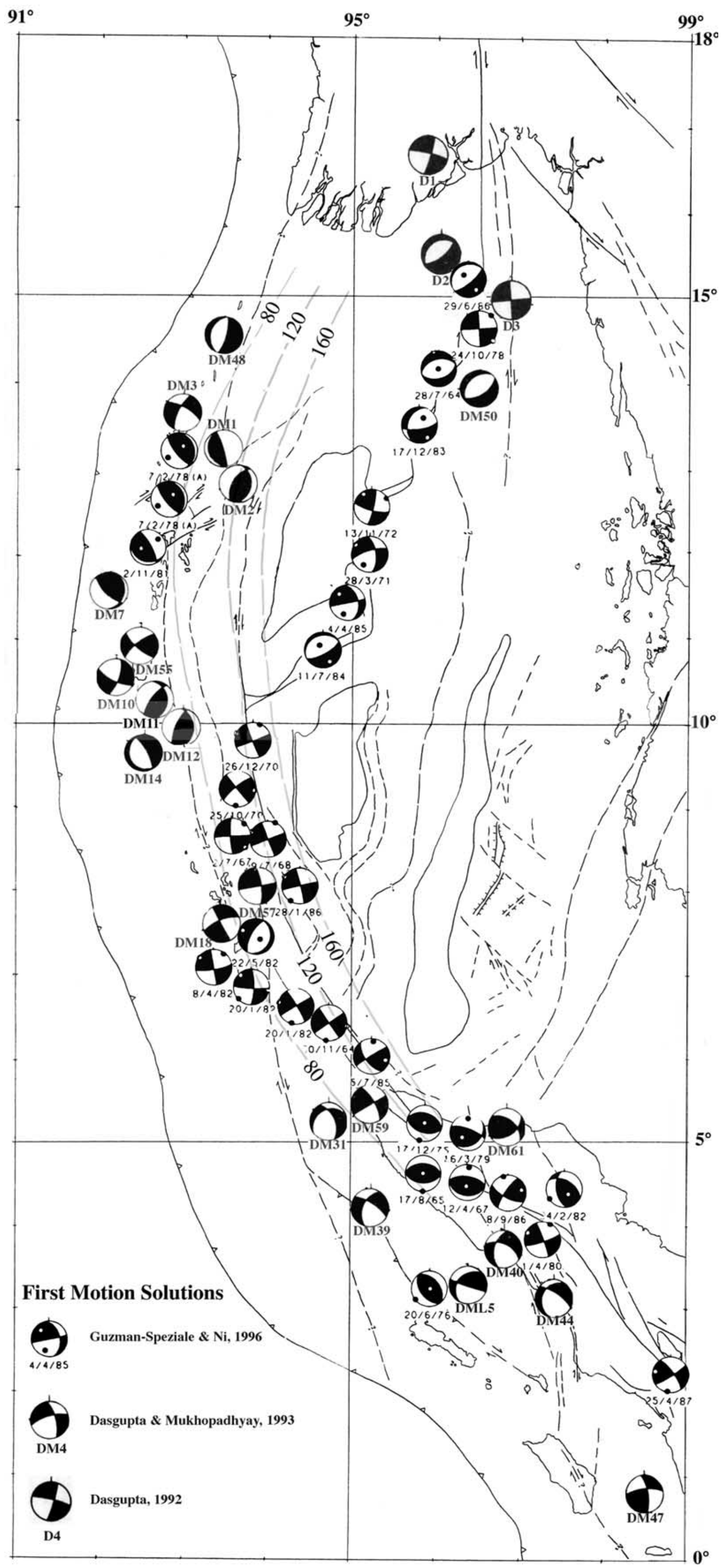

Fig. 6. Earthquake first motions solutions from the upper plate, from Guzmán–Speziale and Ni (1996) and Dasgupta (1992). Depth to Benioff, from Guzmán-Speziale and Ni (1996). Overlain on partial tectonic map.

the literature with excellent descriptions, analyses and interpretations. The following discussion is based in part on that newer paper.

Geologists from the Oil and Natural Gas Commission (ONGC) continued using the older GSI system of stratigraphy for their drilling and seismic work, with approximately the same units, with some of the original Oldham names for the formations. See, for example, Chatterjee (1967), Roy (1983, 1986), Misra and Roy (1984) and others. Ananthanarayanan et al. (1981) correlated the seismic, drilling and outcrop stratigraphy, by designating Seismic Sequences correlating with the formations. Subdivision of the Archipelago Group has been proposed by a series of papers by Srinivasan (see, for example, Srinivasan and Azmi (1979) and Srinivasan (1979, 1986)).

The generalized stratigraphy of the Andaman–Nicobar Ridge is shown in Table 1, with both the newer and older (in italics) formation and group names. The notations ‘M Seismic Horizon?’ and ‘P Seismic Horizon?’ in the right hand column refer to seismic horizons identified in the Bengal Fan sedimentary section, described in Curray et al. (2003).

In evaluating this stratigraphic column, it should be kept in mind that all observations have been made on either drill cores or cuttings or on outcrops of an accretionary complex, described by many of the authors as melange. The outcrops are furthermore only on the exposed island sections, much of which is described as humid jungle. Thus, the sections may be incompletely represented, and some of the rocks sampled in drilling do not crop out anywhere on land. And certainly, the facies shown in seismic reflection records from low on the western slope of the ridge do not crop out on land.

The final difficulty in attempting a general description of the stratigraphy and environments of deposition, the most difficult to reconcile, is very different interpretations of the environments of deposition. For example, the sedimentary rocks of the Archipelago Series have been interpreted by many to have been deposited mainly in shallow marine conditions, while others, including M.S. Srinivasan, of

Table 1
Stratigraphy of the Andaman–Nicobar Ridge

Age	Lithostratigraphic Units		Lithology	Facies	Seismic Units
Pleistocene 0 - 1.95 Ma	Nicobar Series	Shampenian	Shell limestone	Upper bathyal to shelf, to beach in Holocene, ca. 500 to 0 m or shallow marine?	SS 4
Late Pliocene 3.7 - 1.95 Ma		Taipian	Silty mudstone, limestone	Middle bathyal, ca. 500 - 2500 m or shallow marine?	SS 3
Early Pliocene 5-3.7 Ma		Sawaian	Mudstone, silty-mudstone, limestone	Lower bathyal to abyssal, ca. 2500 - 4000 m or shallow marine?	
Late Miocene 10 - 5 Ma	Archipelago Series	Neillian	Mudstone, silty-mudstone, limestone	Middle to lower bathyal, ca. 500 - 3500 m or shallow marine?	M Seismic Horizon?
Middle Miocene 16 - 10 Ma		Havelockian	Mudstone, silty-mudstone, limestone	Lower bathyal, ca. 2500 - 3000m or shallow marine?	
		Ongeian	Mudstone, limestone	Lower bathyal, ca. 2500 - 3000 m or shallow marine?	
		Inglisian	Creamish yellow calcareous chalk and marl	Lower bathyal, ca. 2500 - 3800 m or shallow marine?	SS 2
Early Miocene 25 - 16 Ma		Jarawaian	Creamish yellow calcareous chalk and limestone	Lower bathyal, ca. 3000 m or shallow marine?	
		Andamanian	Grey sandy limestone, white siliceous chalk and silt	Middle bathyal, ca. 500 - 3000 m or shallow marine?	
Upper Eocene to Oligocene ca. 45 - 25 Ma	Andaman Flysch Group *(Port Blair Group)*		Graded beds of sandstone and shale, with mainly southerly-directed flow.	Bengal Fan turbidites with some slope basin deposits	
Upper Cretaceous to Middle/Upper Eocene ca. 70 - 45 Ma	Mithakhari Group *(Baratang and Port Meadow Groups)*	Namunagarh Formation	Conglomerate, sandstone, siltstone, limestone and shale, grading upward into Andaman Flysch.	Small isolated trench-slope basins to paralic	SS 1
		Lipa Black Shale	Dark gray to black splintery shale, with local gypsum, pyrite, coal and mud cracks.	Shallow to sub-aerial	P Seismic Horizon?
Mesozoic to Eocene?	Ophiolite		Pillow basalts, serpentinites, ultramafic rocks, associated with radiolarian cherts and other sedimentary rocks.	Open ocean ophiolites	P Seismic Horizon?
Proterozoic ?	Older Sediments		Tectonic slices of deformed continental metamorphic rocks.	Fragments from pre-subduction continental margin	

Banaras Hindu University, interpret some of the same rocks as products of deposition in deep water (see Table 1). It would not be unreasonable, in view of the nature of the sampling, to conclude that both are present. For example, geologists who sampled the subaerially exposed sections of Archipelago rocks would have seen mainly the shallow water facies. These different facies should perhaps have been given different formation names, but they were not.

All of the rocks are the products of a subduction zone region. Possible environments of accumulation include the open ocean floor, the trench, slope basins on the landward slope of the trench and the top of an outer arc ridge. In addition, some of the older deposits could have originated on a pre-subduction passive continental margin, and olistostromes are common because the slopes above subduction zones are frequently steep and are disturbed by earthquakes. The consensus opinions of the environments and ages of the units are listed in Table 1.

Composites of line drawings of seismic reflection lines of portions of the outer arc ridge distributed southward down the Andaman–Nicobar Ridge from offshore Myanmar to northern Sumatra are illustrated in Figs. 8a–d. Tracks of seismic reflection records in the line drawings are shown in Fig. 7. Most of these sections do not cross the entire ridge of the Andaman and Nicobar Islands; they mainly show the landward trench slope from the floor of the Bay of Bengal to the top of the slope offshore from the islands. The principle passes through the ridge between the islands (Figs. 2, 4 and 7) are the 'Great Channel' north of Sumatra at about 6–7°N, the 'Ten Degree Channel' and 'Preparis Channels North and South', which lie south of the southwest tip of Myanmar. Several sections have been adapted from Roy (1983, 1992) and Roy and Chopra (1987).

Many of the sections clearly show folding of the sea floor Bengal Fan sediments, increasing from north to south, caused by convergence of the Australian (or Indian) Plate with the accretionary prism, especially in Fig. 8a, b and d in the central and southern parts of the area. The direction of plate convergence is much more oblique in the northern sector, Fig. 8a, and in fact is almost entirely transverse or strike slip. Where the direction of convergence is less oblique, sediments of the fan are wrinkled up into folds as they approach the base of the accretionary prism. These folds are then uplifted and progressively underthrust by new folds forming at the base of the slope. The folds form slope basins, some of which appear to be tilted landward (e.g. T 24–25. Fig. 8a; and T 55–56 and T 57–58, Fig. 8b). Eastward tilting of Car Nicobar has also been reported (Tipper, 1911).

Sections T 22–23 and T 24–25 (Fig. 8a) are adjacent to the location of a dredge sample, C-29, collected on our first cruise to the area on Circe Expedition in 1968. Frances Parker (personal communication, 1968) determined by micropaleontology that the shales in the sample are Miocene in age and of deep-water origin. This, stratigraphically, would be in the Archipelago Series. Younger rocks are being thrust into the slope below the level of this sample.

Several of the sections and parts of the area have mid-level plateaus, especially in the northern sector (Figs. 8a and b). The significance is not clear, but could possibly represent a change in rate or direction of convergence at some time in the Neogene.

The sections that cross over the top of the ridge are T 36–37,C–F–G in Fig. 8a, and all of the sections in Fig. 8c and d. Section T 36–37, C–F–G shows only a suggestion of folds over the ridge and eastward dips into the forearc basin. Sections Roy, S.K., Roy, T.K.-9, Roy and Chopra in Fig. 8c and Roy, T.K.-16 in Fig. 8d were interpreted to show eastward-dipping reverse or thrust faults all across the ridge and into the forearc basin lying to the east. In addition, they show the Neogene section, the Archipelago Series, both on the top of the ridge and starting westward down the landward slope of the trench. These sedimentary rocks were apparently deposited both in a shallow environment on top of the ridge and as deeper facies of the slope and slope basins, explaining the variation in interpretations of environment already mentioned.

Section Roy and Chopra in Fig. 8c and Sections M 8–9 and E 42–43 in Fig. 8d show the West Andaman Fault (WAF), which has also been called the Invisible Bank Fault. Sections AND-1 and Roy and Chopra in Fig. 8c and T 5–7 in Fig. 8d show the Eastern Margin Fault (EMF).

The 'Older Sediments', Table 1, are perhaps fragments derived from rocks of the continental margin that existed prior to the initiation of subduction in this sector of southern Asia. Offshore, ophiolites, i.e. ocean floor basalts and the associated pelagic sediments, formed as the floor of the Tethys Sea that lay between India and Asia. I believe that subduction along this margin started in the Cretaceous with the separation of India from its former Gondwana neighbors. The Lipa formation of shallow water to paralic sediments may have been deposited on the pre-subduction continental margin. The Namunagarh sediments appear to have been deposited in a range of environments that range from paralic to deeper trench slope basins.

Most authors agree that the Andaman Flysch or Port Blair Formation sandstones and shales are turbidities. We have interpreted them as sediments of the Bengal Fan (Curray et al., 1979; and subsequent papers). Newer work by Pal et al. (2003), however, attributes the Andaman Flysch mainly to a forearc basin environment, barred from deposition of turbidities from the Bengal Fan by the outer arc ridge. They suggest the possibility of the Irrawaddy (Ayeyarwady) Delta as a source of these sediments. They have described outcrops of Andaman Flysch on both sides of the top of the Andaman Islands in approximately the locations of some of the sections of Fig. 8c and d. To be forearc sediments from Myanmar, long distance transport down the axis of a forearc basin would be required. Also, if they are forearc deposits, the source of this thick (3000 m?) section could hardly have been from islands on the outer arc

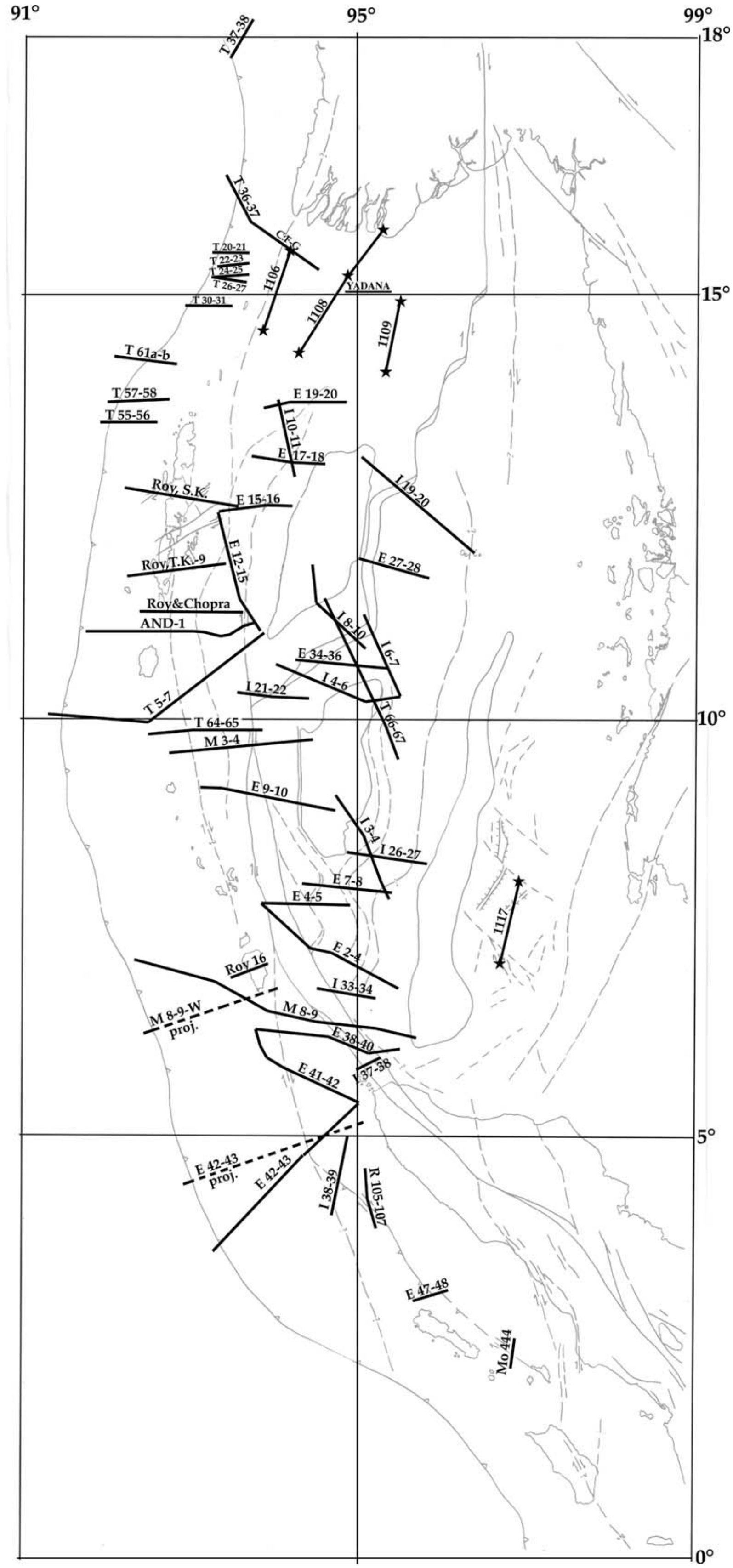

Fig. 7. Locations of line drawings of seismic reflection records in Figs. 8, 10, 11, and 12. Approximate location is shown for the Yadana line (Fig. 9), from Win Maw and Myint Kyi (1998).

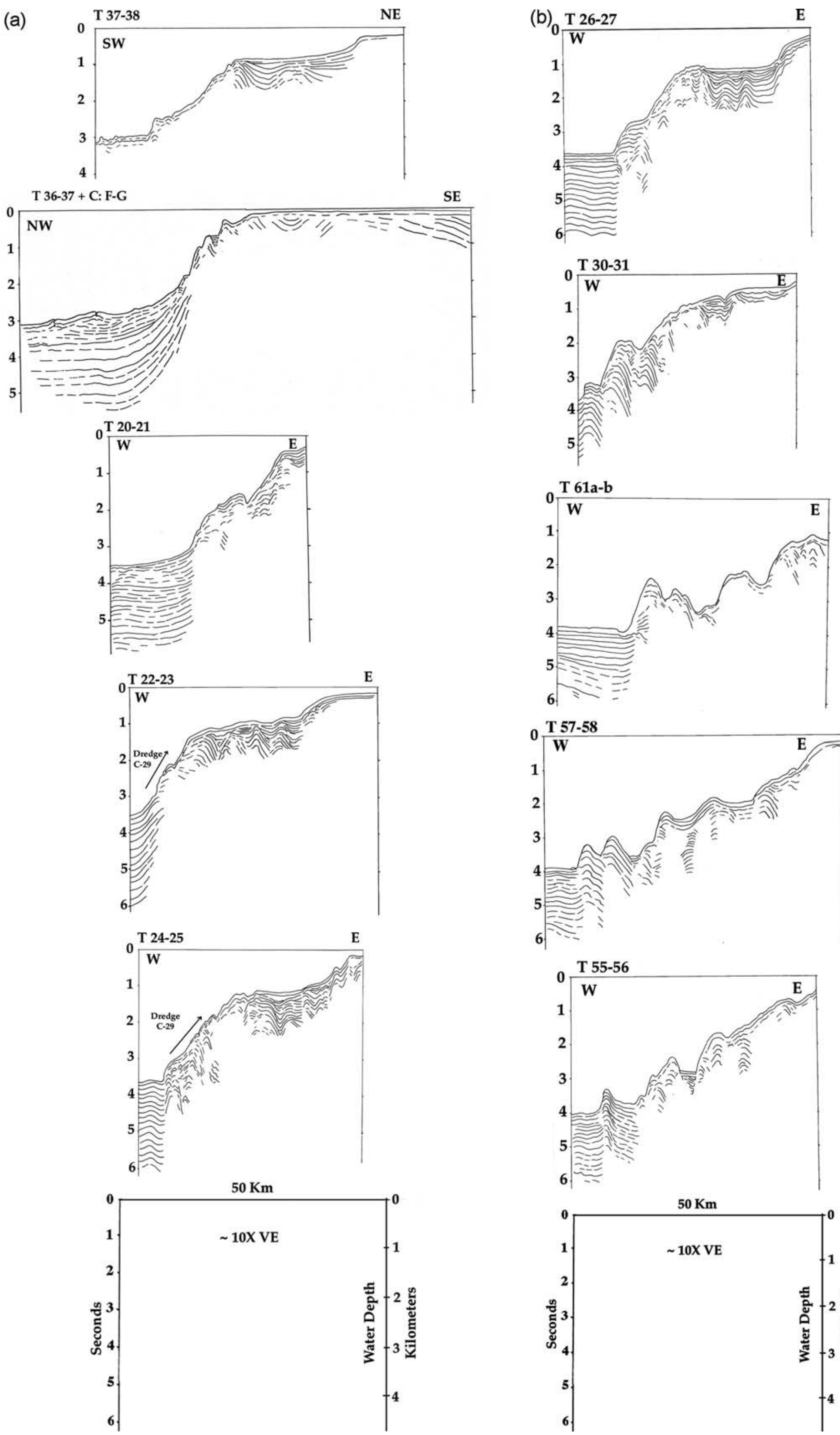

Fig. 8. (a–d) Line drawings of seismic reflection records of the Andaman–Nicobar Ridge and the Bay of Bengal continental slope. The base of the slope is within the Sunda Trench from T 30–31 southward. North of this point, about 15°N, the trench is filled with sediments of the Bengal Fan and from Myanmar. See Fig. 7 for locations. Sections M 8–9W and E 42–43 are compressed as if projected to lines normal to the structural trends, shown in Fig. 7 as dashed lines, to illustrate changes in width of the outer arc ridge.

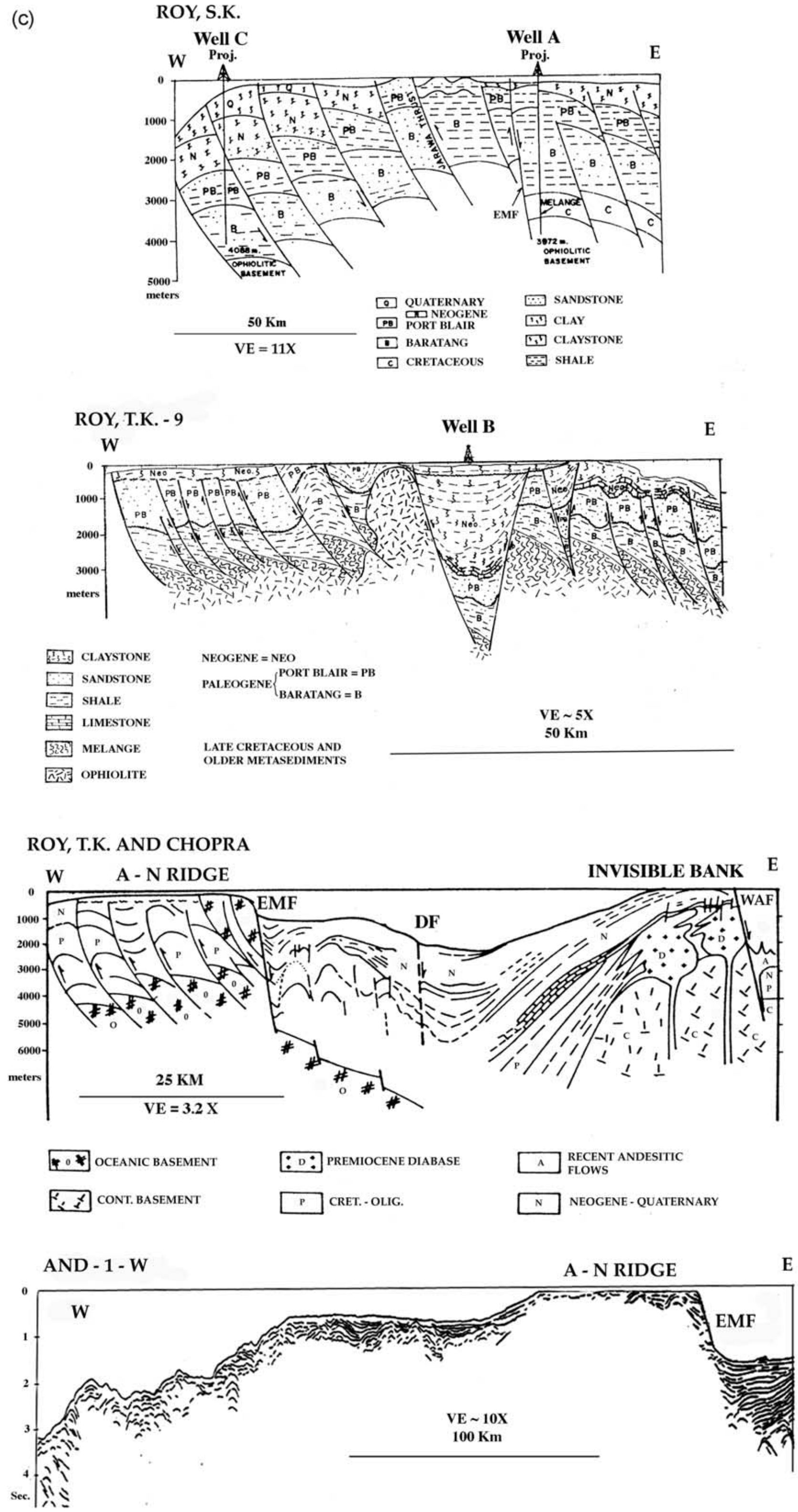

Fig. 8 (*continued*)

ridge that are very limited in size. The seismic sections of Fig. 8, moreover, show undeniable evidence of folding and uplift of Bengal Fan sediments at the base of this slope, so the interpretation that the Andaman Flysch is at least mainly Bengal Fan sediment will be used in this paper. Future provenance work of comparing Oligocene Andaman Flysch with Oligocene samples not yet recovered by drilling in the Bay of Bengal may resolve this problem.

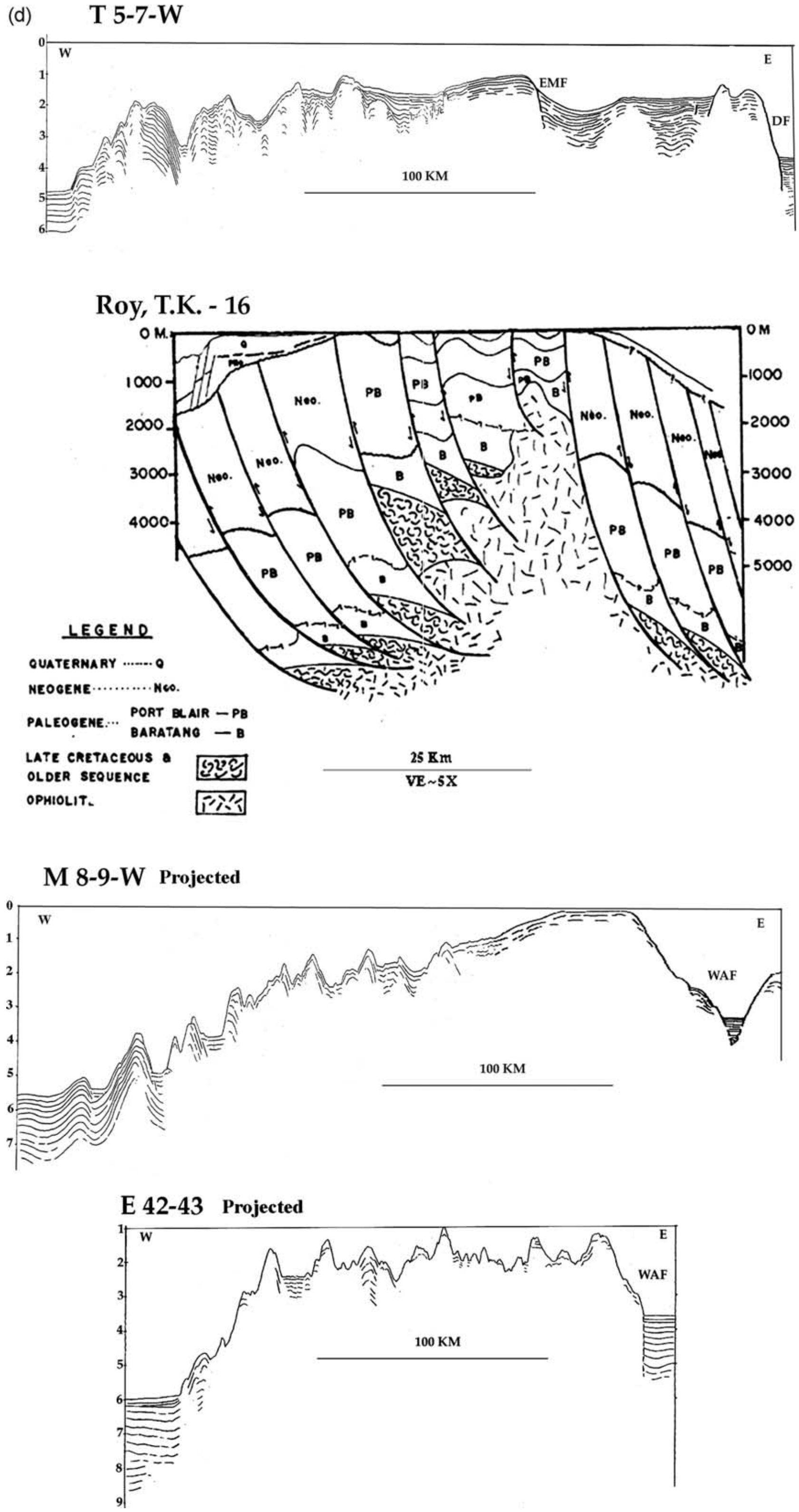

Fig. 8 (*continued*)

The Archipelago Series was interpreted as shallow marine, with water depths from 0 to 25 m by Roy (1983), and as deep water to neritic or outer neritic by Srinivasan (1986). In Table 1, the environmental interpretations of Srinivasan (1986) are shown first, followed by the alternative option. I conclude that the major part of the sedimentary rock is probably the facies as interpreted by Srinivasan, but suggest that shallow facies are also present, considering the sampling problems discussed previously and the complexities of simultaneous deposition of sediments both on top of a accretionary prism and farther on down the slope and in slope basins.

The outer arc ridge is characterized by a strong negative free air gravity anomaly (Fig. 5), indicating an excess of relatively low-density sediment in the accretionary complex. Invisible Bank (~11°N, 93°E), part of the forearc basin, on the other hand, is a rather high positive anomaly (Fig. 5) because, as has been shown by Roy and Chopra (1987) (Fig. 8c), it is underlain by uplifted volcanics and/or intrusives. This may also explain the high positive anomaly at about 8°N, 93°E, east of Camorta Island (Fig. 4).

The first motion solutions for earthquakes on the upper Southeast Asia or Burma Plate within the Andaman–Nicobar Ridge (Fig. 6) are generally easily explained. Some, for example, suggest normal or reverse faults with a strike of about SE–ESE, as one might expect in this environment. A few suggest right-lateral strike-slip faulting approximately parallel to the arc and parallel to the similar solutions along the trend of the West Andaman Fault which lies within the central part of the Andaman Sea. Some of these may indicate continued strike-slip activity along the Eastern Margin or Diligent Faults, the boundary between the outer arc ridge and the central basin. A few others show 'nodal planes oriented NNW–SSE characterizing the deformation in the forearc region. The depths of these events suggest that they were located within the upper plate…and suggests that the sedimentary forearc is being deformed by the convergence [between the Indian and Southeast Asian plates]' (Guzmán-Speziale and Ni, 1996, p. 72). Normal faulting is occurring in the Central Andaman Basin and in the area of short spreading axes at about 14°N; and right-lateral strike-slip faulting is occurring along the transform segments east of Alcock Rise.

What is the nature of the crust underlying the outer arc ridge? Kieckhefer et al. (1981) concluded that the outer arc ridge off Sumatra is probably underlain by melange, including ultramafic rocks, or by continental crust. In Myanmar, in contrast, Mitchell (1989), Acharyya (1994, 1998) and Hutchison (1989) all conclude that the Indoburman Ranges are underlain by continental crust.

I have one reversed seismic refraction line over the Andaman–Nicobar Ridge, Line 1106, offshore from the Indoburman Ranges (Figs. 3, 7 and 9a). The section for Line 1106 had records from six buoy receivers. The thin water layer is ignored in these sections. A thick sedimentary rock section showed a range of velocities between about 2.8 and 3.3 km/s, but most of the solutions were not very good because of rather steep southerly dips, as shown in the reflection records. Some of this sedimentary section may be deltaic sediment from Ayeyarwady (Irrawaddy) River and other rivers, and some may be melange of uplifted sedimentary rocks. The variation in velocities in this thick layer shows somewhat more of the higher velocities of 3.5 km/s in the north, with the section of lower velocity 2.8 km/s thickening toward the continental slope to the south. The basement velocities of 6.3–6.9 km/s are suggestive of oceanic crust.

4. The central basin

This is the part of the Andaman Sea region where the action has occurred during the Neogene, where the strike-slip sliver faulting and transtensional extension have occurred. The major tectonic parts of this province are the forearc basin, the magmatic arc and the backarc basin. The forearc Basin in this discussion includes West Basin, Invisible Bank, and the other banks farther to the south. The magmatic arc discussion will be limited to the few known or suspected volcanic features in the Andaman Sea, the known volcanic line in Myanmar and the shelf lying in between. The backarc region will include Alcock and Sewell Rises, East Basin, the shelf and basins to the north and east and the small basin between the rises, the Central Andaman Basin (Fig. 4).

4.1. The forearc basin: West Basin, Invisible Bank and West Sewell Ridge

The dividing line between the outer arc ridge and the forearc basin is the Diligent Fault (DF) in the central and northern parts of the area (Fig. 4). It is shown in some of the sections in Fig. 8c and d, as are the Eastern Margin Fault (EMF; Roy, 1983) and the West Andaman Fault (WAF; Curray et al., 1979). The Eastern Margin and Diligent Faults are apparently normal faults, although there may both at times in the past and today possibly have been some dextral strike-slip motion (Fig. 6). No seismicity north of about 9° can convincingly be associated with these faults, but at about 7°N earthquake DM 18 (Dasgupta and Mukhopadhyay, 1993) and earthquakes 8/4/82 and 20/1/82 (Guzmán-Speziale and Ni, 1996) could possibly lie along these faults (Fig. 6). South of there the right-lateral strike-slip motions are probably associated with the West Andaman Fault. North of the Andaman Islands the Diligent Fault is shown questionably connected with the Kabaw Fault of Myanmar (Hla Maung, 1987) to form the eastern margin of the Indoburman Ranges. A splay may be the Cocos Fault (Fig. 4 and sections E 19–20 and I 10–11, Fig. 8a). To the south, the Diligent Fault can be traced questionably to the Nicobar Islands (Chatterjee, 1984). Off Northern Sumatra, the back of the outer arc ridge lies along the trace of the West Andaman Fault, behind Tuba Ridge, and in line with what has been called the Mentawei Fault (Diament et al., 1992) behind the islands off Sumatra. In this paper, the name West Andaman Fault will be applied to this fault to as far south as the apparent offset by the Battee Fault at 2°N, following the earlier definition (Curray et al., 1979; Curray, 1989, 1991). The name Mentawei Fault will be restricted to southeast of the Battee Fault.

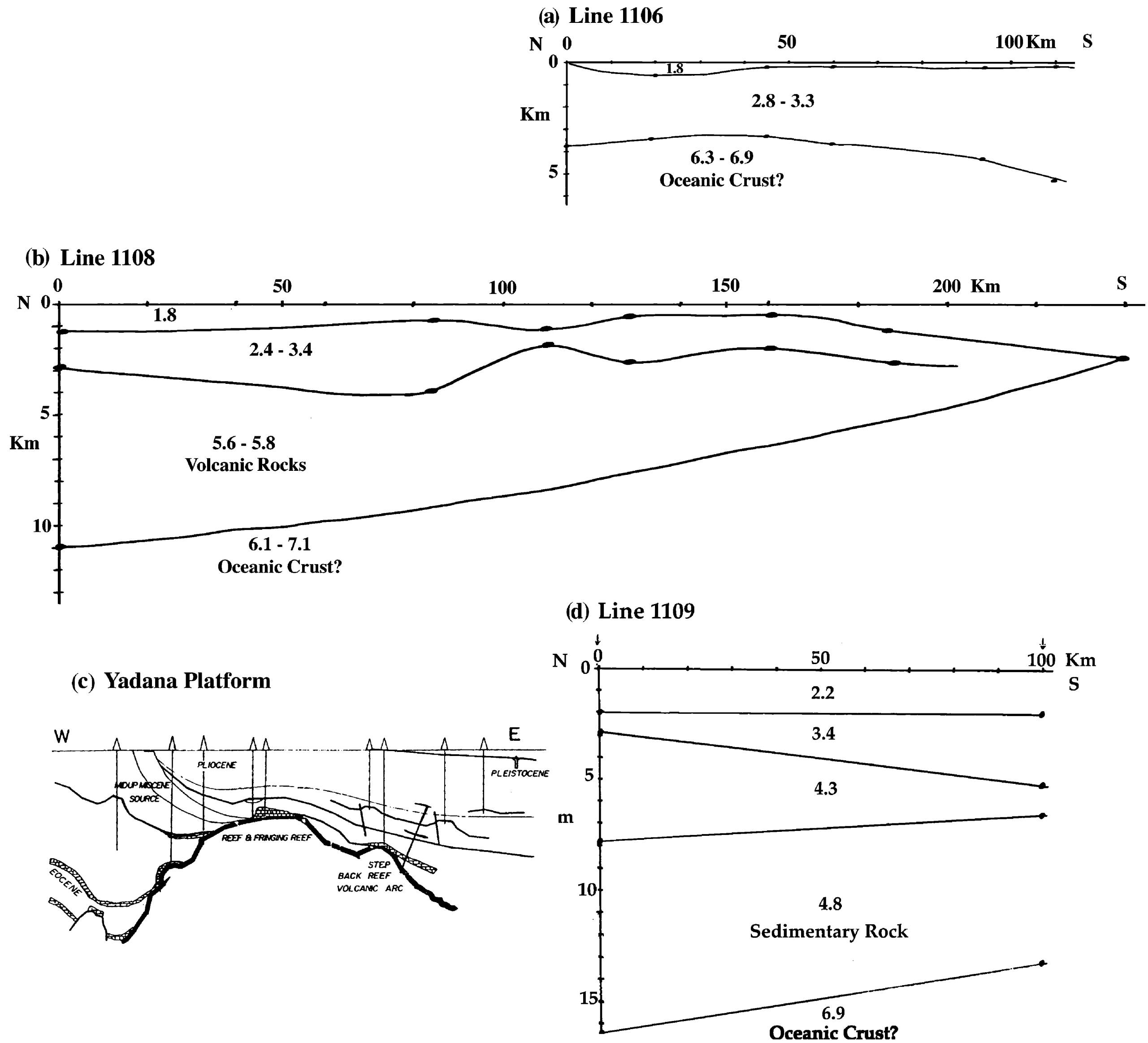

Fig. 9. Simplified plots of reversed refraction lines on the northern shelf off Myanmar (Figs. 3 and 7). Buoy stations indicated by small arrows. Buoys at ends of lines and some intermediate buoys and were anchored; other buoys were expendable. Northern station in line 1108 was land station with 24 channels (Ama Village, Fig. 4). The water layer, less than 200 m, is ignored in the sections. Line drawing of the Yadana line (Fig. 9c) is adapted from Win Maw and Myint Kyi (1998). The scales are unknown.

West Basin is a gently south-sloping plain of sediment from the continental slope at the north ponded against cuestas of the Cocos Fault, the volcanic seamounts of Barren and Narcondam Islands, some apparently volcanic seamounts and the northwest side of Alcock Rise. Unfortunately, I have no refraction data using explosives to establish the sediment thickness in this basin, but an airgun refraction line shows a velocity of only 2.14 km/s at a depth of 1.51 km beneath the sea floor. This is suggestive of young Tertiary sediment and a rather thick total section.

Invisible Bank is a cuesta formed by the West Andaman Fault (Figs. 4, 8c and d and 10). Fig. 10a–c shows section line drawings aligned along the WAF proceeding from north to south. It is not apparent where the WAF is in the northern section, E 19–20, and its northern end may be south of there. These two northern sections do, however, show a different cuesta behind a fault that I have named the Cocos Fault. The possible significance of this cuesta is discussed in Section 6.

Invisible Bank is a distinct cuesta formed by the WAF as far south as E 9–10, Fig. 10b at about 9°N. South of there the WAF forms the back of the outer arc ridge and the outside flank of the forearc basin. See M 8–9, Fig. 10b and the other sections farther south and east. Southeast of the bend in the WAF at about 4.5°N the right-lateral motion of the WAF has a component of convergence, that has formed Tuba Ridge (Figs. 4 and 10c). It cannot be definitively determined from the reflection records whether this convergence is still occurring today or is older.

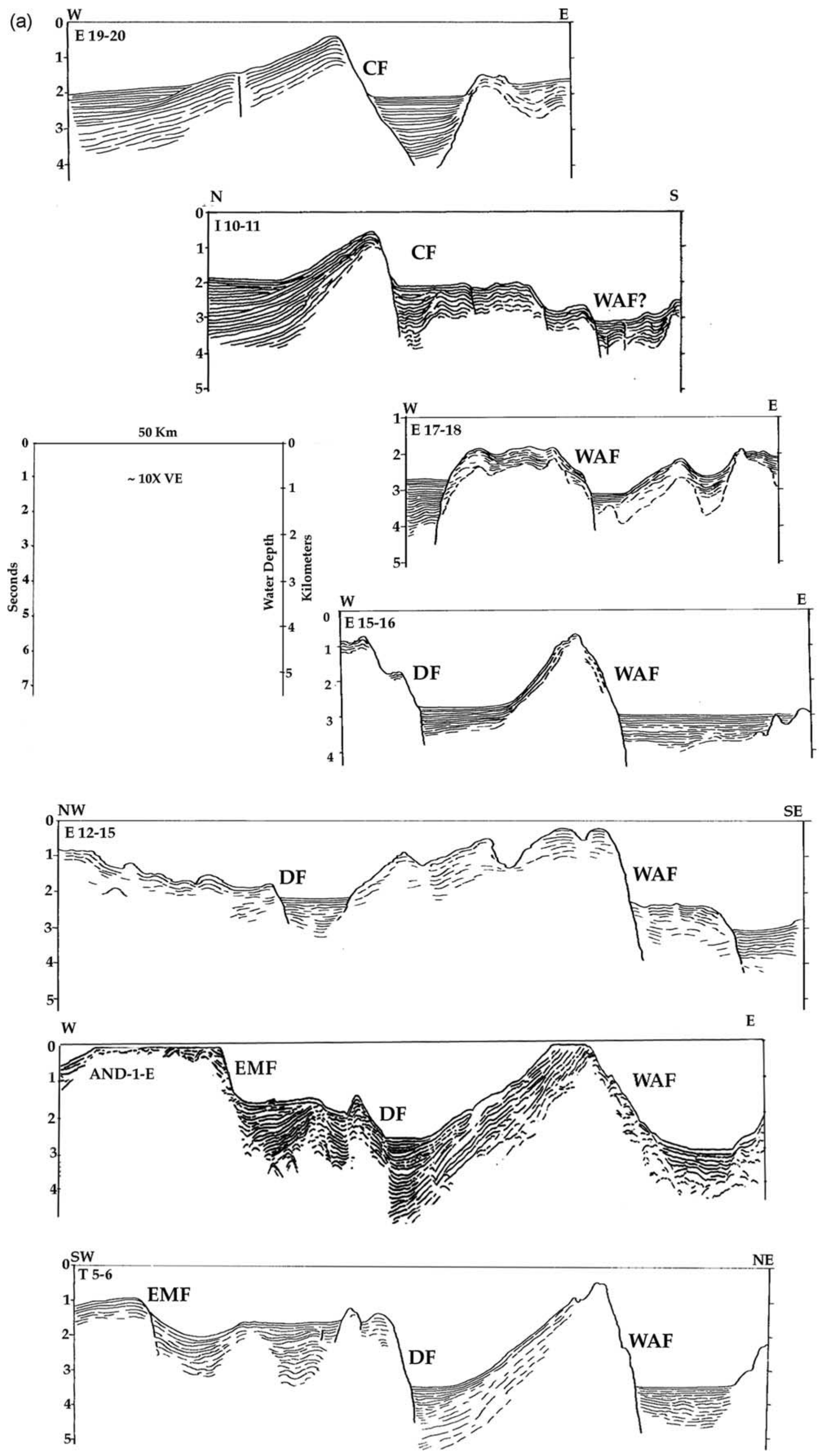

Fig. 10. (a–c) Line drawings of seismic reflection records aligned along the trace of the West Andaman Fault (WAF). See Fig. 7 for locations and caption Fig. 4 for abbreviations.

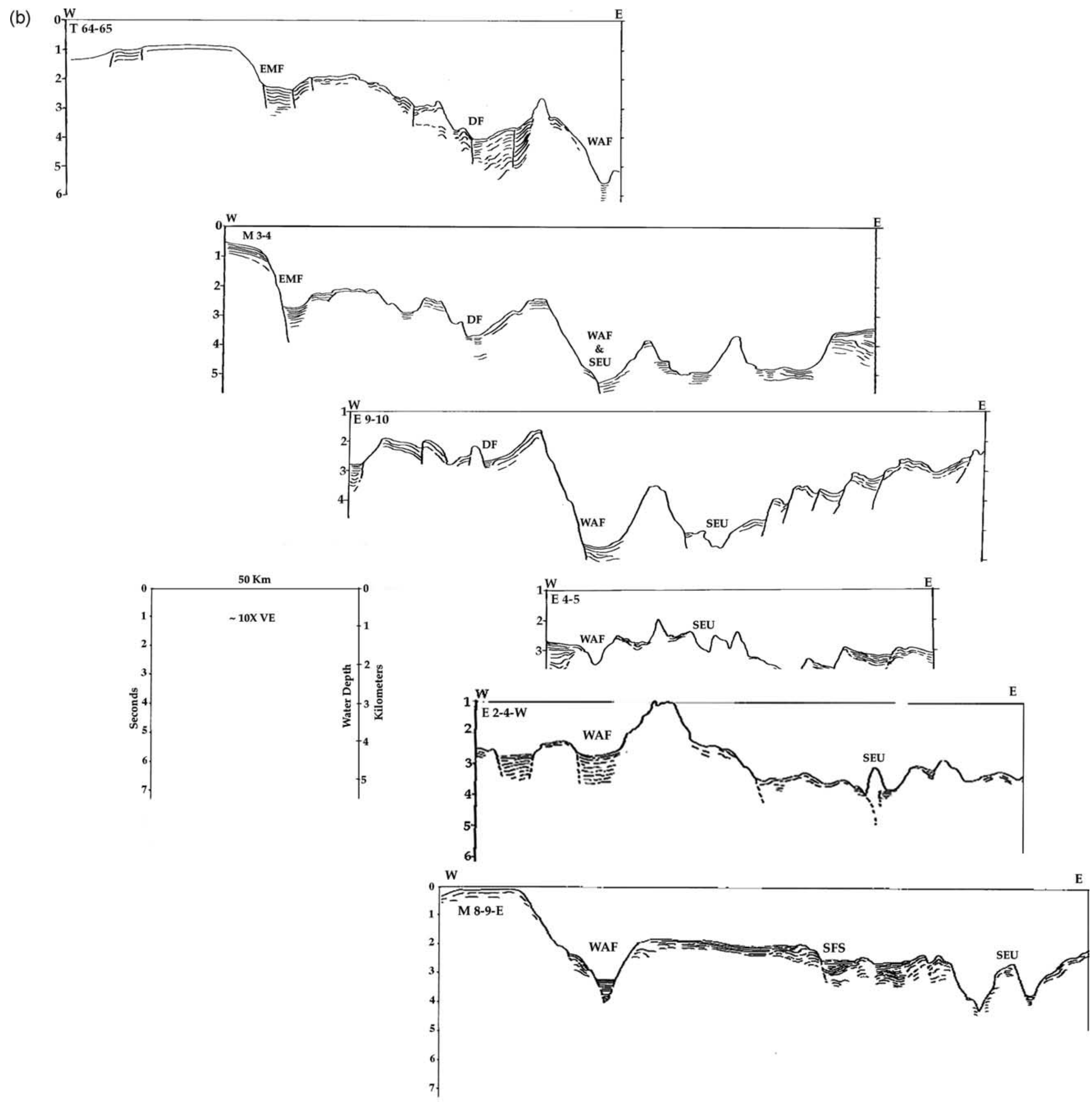

Fig. 10 (*continued*)

Roy and Chopra (1987) report that drilling near the crest of Invisible Ridge encountered thick lava flows below 1100 m of middle Miocene sedimentary rocks. Frerichs (1971) reports that dredge sample ***8*** (∼9°N, Fig. 4) contained radiolarian shale of post-early late Miocene age, ∼10 my, which was uplifted about 2000 m since deposition. Dredge sample ***12*** (∼11.5°N) was late lower Miocene calcarenite and calcilutite, ∼17 my, uplifted about 400 m since deposition; and dredge sample ***13*** (∼12°N) was late upper Miocene, ∼6 my, uplifted more than 500 m. These sediments are probably forearc basin sediments, and the West Andaman Fault probably formed the cuesta within the past 6 my.

The nature and rocks of the somewhat discontinuous West Sewell Ridge (WSR, Fig. 4) are not known. The North Sumatra Ridge (NSR, Fig. 4) is probably underlain by the continental crust of Sumatra.

4.2. The volcanic arc

The volcanic arc of the Andaman Sea lies between the active volcanic arc on Java and Sumatra and the extinct or dormant arc in Myanmar. The last volcanic activity of Mount Popa, Myanmar, ∼21°N, is believed to have been sub-Recent (Chhibber, 1934; Bender, 1983; Stephenson and Marshall, 1984). Chhibber reported local legend of an

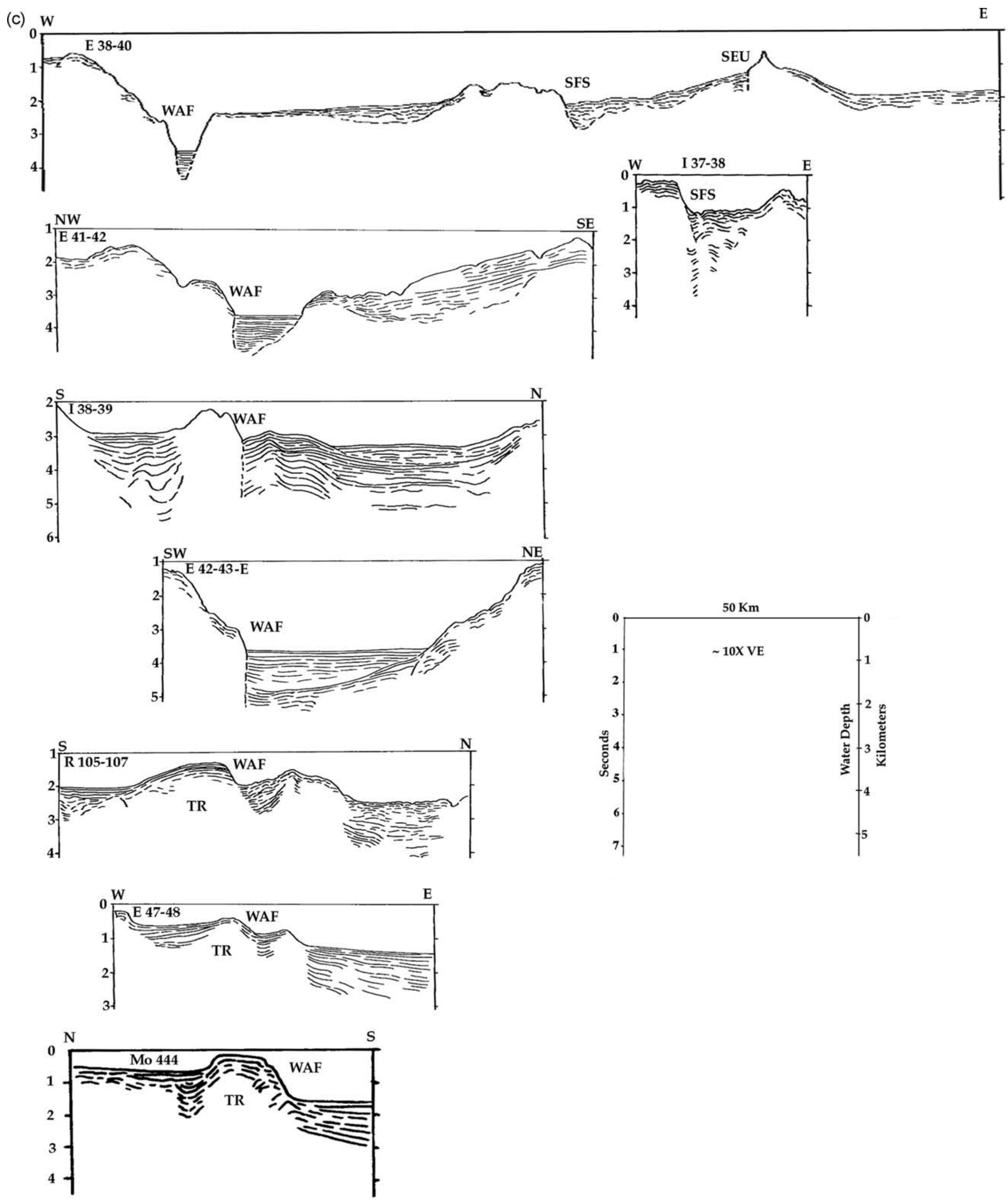

Fig. 10 (*continued*)

eruption about 2500 years ago, but could find no firm evidence. The other volcanic centers along this line in central Myanmar are also probably extinct or dormant. Stephenson and Marshall (1984) describe the volcanics at Popa as high K calcalkaline latites, rhyodacites and ignimbrites overlain by basalt and basaltic andesite.

The reversed refraction Line 1108 (Figs. 3, 7 and 9b) is in line with the volcanic arc between Narcondam and Barren volcanic islands and the volcanic area of Mount Popa near 21°N in Myanmar. The thin water layer is ignored in the sections. The thick section of velocity 5.6–5.8 km/s is interpreted as volcanic rock, overlying probable oceanic crust of 6.1–7.1 km/s. Note that the northern end of the line lies at Ama Village on the Myanmar coastline.

Two volcanic islands (Bhattacharya et al., 1993) lie in the northern Andaman Sea (Fig. 4), Barren Island, which is still active, and Narcondam Island, which may be dormant. Barren showed some activity as recently as 1994. Andesite, dacite and basalt have been reported. Other sea floor features that may be volcanic in origin are shown in Fig. 4. The next definitely volcanic features are Wey and Brueh Islands off the north tip of Sumatra, approximately 400 km farther south, approximately the total amount of opening suggested for the entire Andaman Sea in Sections 6 and 7.

4.3. Backarc basin: Alcock and Sewell Rises, Central Andaman Basin and East Basin

The backarc region of the Andaman Sea (Fig. 4), a part of the central basin of the Andaman Basin, includes Alcock and Sewell Rises, the Central Andaman Basin between the two rises, East Basin and some other smaller topographic features of unknown character. It also includes part of the present plate edge between the Burma platelet and the Eurasian or Southeast Asian plate (Figs. 10a–c) and it includes a segment of what I interpret as an abandoned plate edge (Fig. 11).

Alcock and Sewell Rises were named Alcock and Sewell Seamounts by Rodolfo (1969a). They were renamed Alcock and Sewell Rises in the GEBCO Gazetteer of Undersea Features Names in November 2003, and will be referred to by those names in this paper. Neither feature is well surveyed bathymetrically, and they are shown with somewhat generalized contours in Fig. 2. The margins adjoining the Central Andaman Basin and spreading axis, Fig. 4, are however well enough known to suggest their reassembly (Section 6 of this paper) into a single rise prior to opening of this small basin. Both rises show a suggestion of northeast–southwest trending top surface features, approximately parallel to the trend of the spreading axis in the basin. The western margins of both rises appear to be faults, which align with each other in a reassembly.

The northern end of Alcock Rise is uncertain, as indicated in Fig. 4. Line drawing of a multichannel reflection line is shown in Fig. 9c, adapted from Win Maw and Myint Kyi (1998). Unfortunately, neither the scales nor the exact location were indicated in the original paper, so the location indicated in Fig. 7 is only approximate. The line does, however, show a ridge that might represent the northern end of Alcock Rise, or the connection with the Bago Yoma, as discussed later in Section 6.3.

Rodolfo (1969a) describes rocks from dredge sample ***14*** in the northern part of Alcock Rise ($\sim$13°N, Fig. 4) as 'large tabular slabs of massive unaltered intergranular augite basalt'. Unfortunately, the samples from this dredge haul collected from R/V Pioneer in 1964 are lost, and cannot be located for further analysis and dating. In 1977, my colleagues and I sampled rocks in dredge haul ***17*** from an escarpment at 900–1250 m from the southern part of Alcock ($\sim$11.5°N, Fig. 4). J.W. Hawkins (personal communication, 1982) described the rocks as 'moderately fractionated tholeitic basalts'. In 1993, two samples were dated by K–Ar as 19.8 ± 0.7 and 20.5 ± 1.0 my by Geochron Laboratories, Cambridge, MA.

Refraction/reflection Line 1109 (Figs. 3, 7 and 9d) lies north of the axis of thickest sediment accumulation in the Andaman Sea, and has a sedimentary rock section of high velocity between 14 and over 16 km thick. The high velocities are similar to deeply buried high sediment velocities beneath the Bengal Fan (Curray et al., 2003). Another possibility is that this section is mixed well-lithified sediments and volcanics. The basement velocity of 6.9 km/s is probably oceanic crust. The section could possibly be even thicker farther to the east in the center of the Gulf of Mottama (formerly the Gulf of Martaban) (Fig. 4).

East Basin has a section of flat ponded sediment at least 4.6 km thick. I have one especially good refraction line where the 'Oc' symbol is shown at about 9°10′N in Fig. 4. Basement is definitely oceanic, with a velocity of 6.7 km/s. The layers beneath the sea floor in this side solution, weighted least squares fit layer solution are: a sediment layer of 1.8 km/s, 1.0 km thick; a sediment layer of 3.4 km/s, 3.6 km thick; a layer of probable volcanic rock of 5.8 km/s and 2.7 km thick; all overlying oceanic basement of 6.7 km/s velocity.

The edge of continental crust is shown in Fig. 4 as interpreted from all available lines of evidence: gravity, magnetics, seismic reflection and refraction data and bathymetry. It is at best an approximation. The lower continental slope above this line is marked with listric block faulting down to the west or NW, as suggested in Fig. 11, Section I 19–20 and Fig. 12, sections I 3–4, I 26–27, E 7–8, E 2–4 and I 33–34.

The sliver plate between the Sunda subduction zone on the west and the Sagaing Fault in Myanmar, a plate edge in the Andaman Sea and the Sumatra Fault System (SFS) on the east was named the Burma Plate by Curray et al. (1979), but has been given various other names by later workers. The present plate edge (Fig. 4) is the Sagaing Fault in Myanmar, passing into the system of short spreading axes and transform faults down to the longer spreading axis at about 11°N, then southward on the WAF, SEU and SFS into the SFS which runs the length of Sumatra to the Sunda Strait.

Locations of major earthquakes in Myanmar were plotted by Chhibber (1934) along the now-known trend of the Sagaing Fault. The fault (Fig. 13) was recognized as separate from the Shan Scarp Fault which forms the edge of the Shan Plateau by Dey (1968). Win Swe (1972, 1981) recognized right-lateral offsets at Sagaing, near Mandalay. Mitchell (1977) referred to this fault as the Hninzee–Sagaing Fault and attributed in excess of 300 km of offset to it. Curray et al. (1982) suggested that the total offset might be as much as 460 km. Ba Than Haq (personal communication, 1986) observed offset of a Permo-Triassic limestone

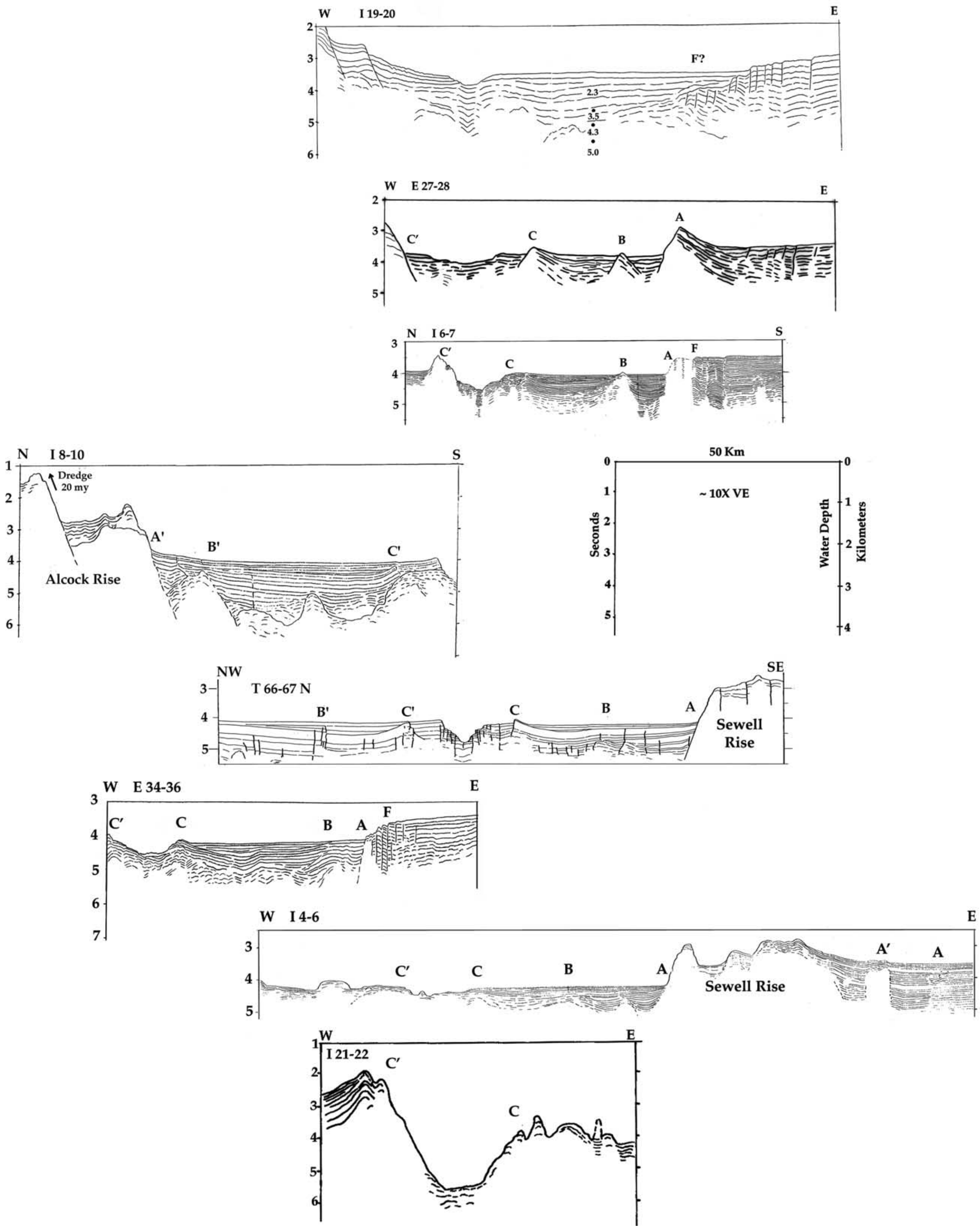

Fig. 11. Line drawings of seismic reflection records of the plate edge east of Alcock Rise and in the Central Andaman Basin.

of 444 km across the fault; and Hla Maung (1987) estimated between 425 and 460 km from river offsets. Another opinion was published by Myint Thein et al. (1981), stating that the Mayathein metamorphics 26 km north of Sagaing were continuous until late Oligocene or early Miocene and are now offset 203 km.

Guzmán-Speziale and Ni (1993) calculated rates of opening of the Central Andaman Basin and offset along

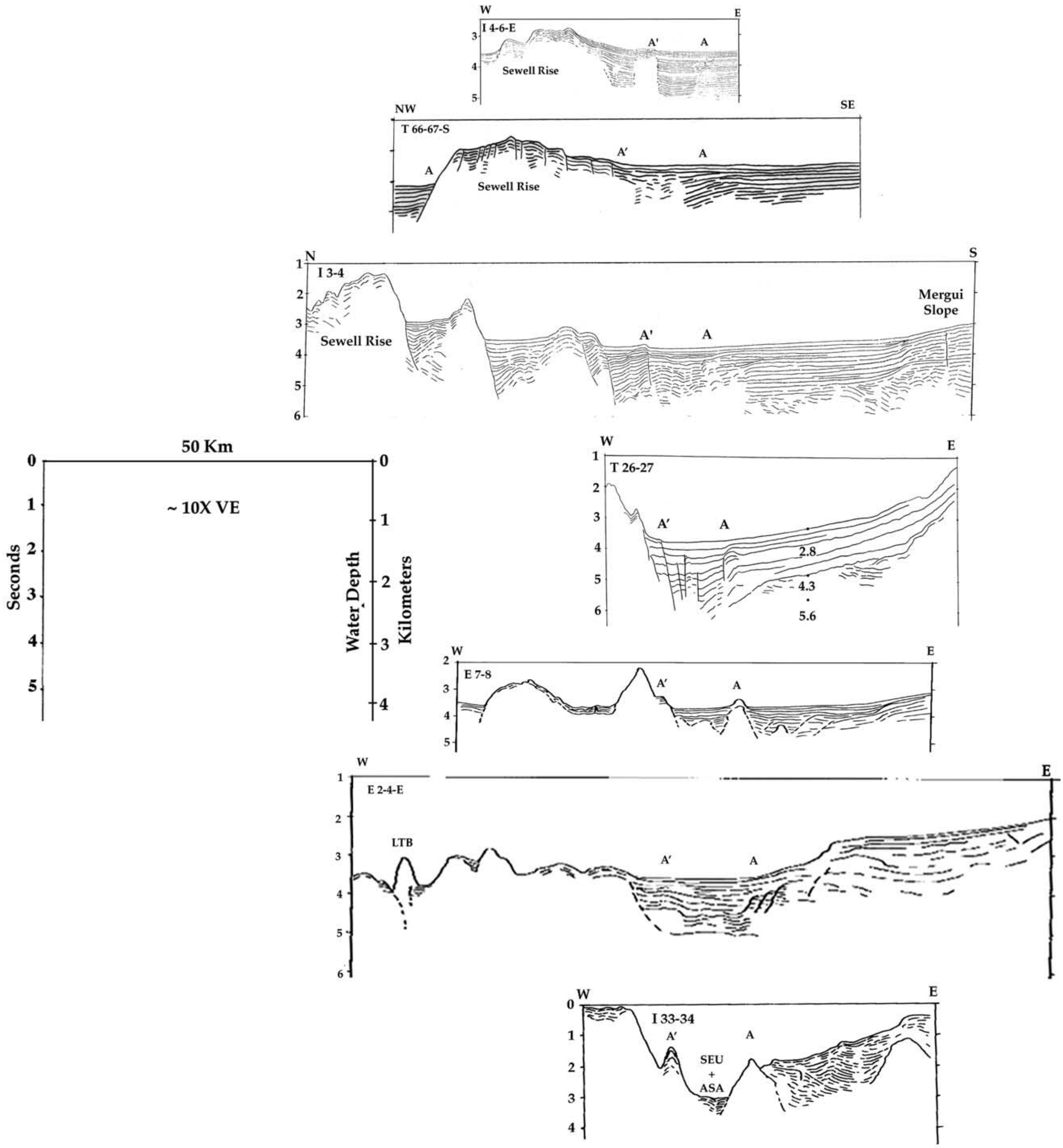

Fig. 12. Line drawings of seismic reflection records of the abandoned plate edge spreading axes and short segments of transform fault in the southern Andaman Sea east of Sewell Rise.

the Sagaing Fault from earthquake seismic moments. Using earthquakes from 1964 to 1986, they obtained rates of only 0.5 and 5 mm/yr, respectively. Using earthquakes back to 1908, they obtained a rate of 57 mm/yr for the Sagaing Fault. They suggested that opening of the Central Andaman Basin might be partly aseismic. Vigny et al. (2003) conducted field work in Myanmar and GPS surveys across the Sagaing Fault and Shan Scarp Fault zones and concluded that the Sagaing Fault motion today is <20 mm/yr of the total of 35 mm/yr of the India/Sundaland (Eurasia or Southeast Asia) strike-slip motion. The remainder of the motion is accommodated by distribution of deformation over a wide zone.

The Sagaing Fault appears to splay southward into two or three faults at about the point of intersection with the Three Pagodas Fault (TPF) at 17°N (Fig. 4). One of these trends may be the Shan Scarp Fault (SSF).

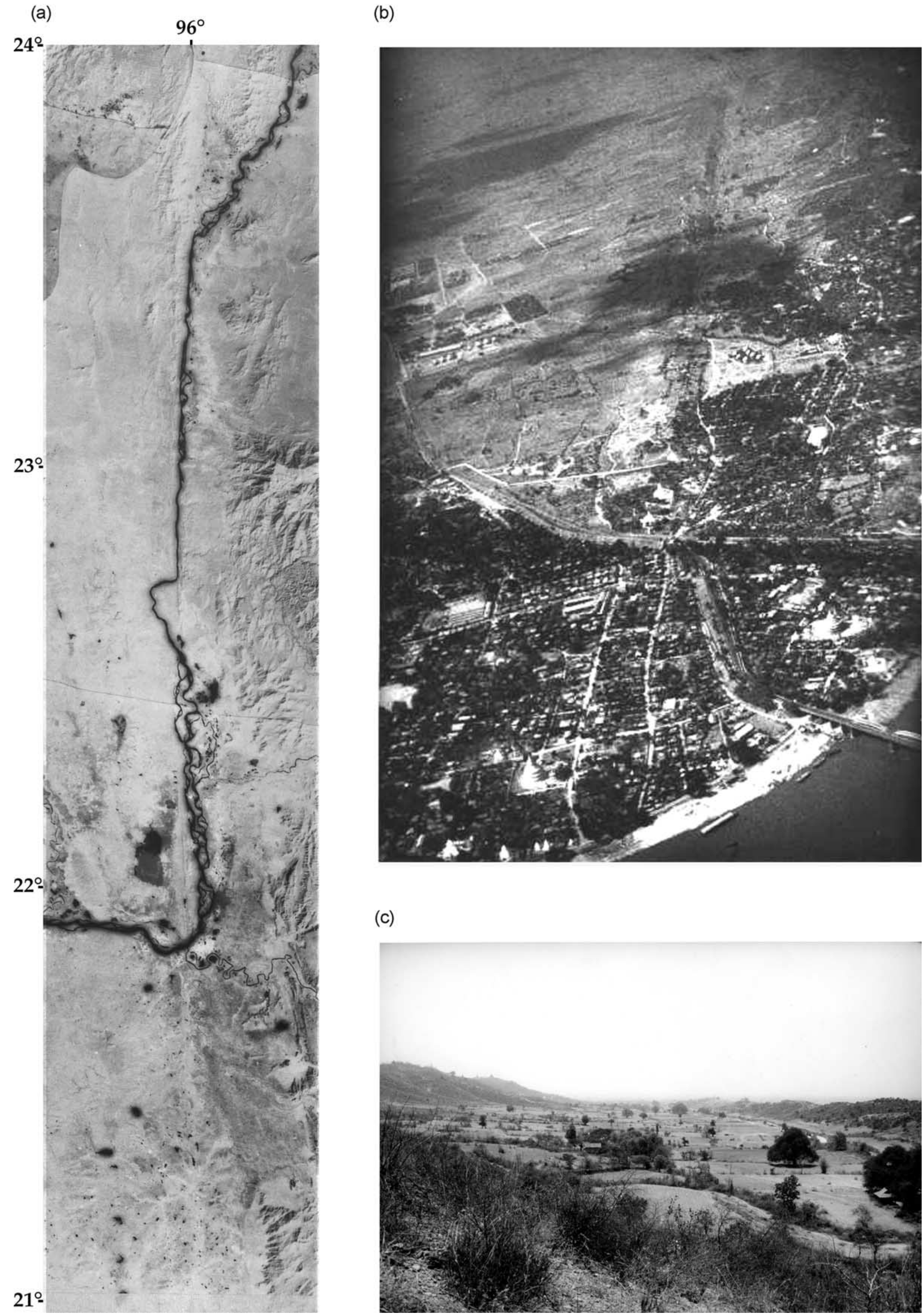

Fig. 13. Photographs of the Sagaing Fault. (a) Landsat photo mosaic. Ayeyawardy River joins the fault rift at 23°35′N and leaves it at 21°50′N at the town of Sagaing. (b) Low altitude oblique photo of Sagaing, the Sagaing Bridge and the fault rift. (c) Rift valley looking northward at Sagaing. Note temples on the ridge to the left.

A complex extensional fault system is seen in reflection surveys on the shelf. Fig. 4 shows an overly simplified pattern of short spreading axes and transform faults running off the continental slope into the Andaman Sea basin. This is based on seismicity (Fig. 6) as well as reflection evidence. The bathymetric and reflection record evidence is very good off the slope at the northernmost longer segment of spreading axis at about 13°N. Section I 19–20 (Fig. 11) shows a crossing of this spreading axis. This line shows the faulted eastern margin of Alcock Rise, it shows the present spreading axis, and it shows higher sediment velocities down to at least 2 km below the sea floor.

Section E 27–28 (Fig. 11) shows four upturned margins of the plate edge: C′, C, B and A. Edges C and C′ are arranged symmetrically outside of the present or youngest axis, as they are in other sections farther south and west. The older ridges, A and B are proportionately farther away from the present rift valley. These edges can be traced and correlated in the bathymetry and reflection records (Fig. 4) southward to the major NE–SW trending spreading axis in the Central Andaman Basin at 10.2–11°N (Fig. 11); and correlations of A and A′ are interpreted southward along the abandoned plate edge to as far as 7°N (Fig. 12).

These upturned edges were earlier interpreted as time lines in the opening of the central basin (Curray et al., 1979), and considered as indicating either episodic spreading or episodic deposition. We favored the latter explanation and suggested that a correlation should exist with fluctuations of sea level. See Section 6.

The plate edge delineated in Fig. 4, where it is a valley south of the continental slope, slopes continuously to the south and west to about 10°30′N and 94°25′E, indicating that during the last period of lowered sea level, turbidity currents flowed through this rift valley as a turbidity current channel until the river mouth supply had retreated too far across the shelf for much sediment to reach the canyon. Several other probable turbidity current channels are also indicated in Fig. 4 running down the slope to join this major channel. Thus, this valley is at the same time a rift valley of a spreading axis, in places a plate edge, which is mainly transform motion and a turbidity current channel. Again, analogous with the Bengal Fan, the valley below the submarine canyon cut into the Gulf of Mattama continental slope was filled during the decreased turbidity current activity of rising sea level. Just as in the Bengal Fan, the fan valleys farther down the fan are left open and inactive, and are relict conduits from the large turbidity currents of low stands of sea level.

The present rift valley in the Central Andaman Basin (Fig. 14) ranges from about 6 to almost 20 km in width and is typically 400–600 m deep. These are deeper and wider than fan valleys of the Bengal Fan, perhaps in part because of their dual role as spreading axes and in part because it is probably the only channel for all of the sediments coming from the combined Ayeyarwady (Irrawaddy), Sittoung (Sittang) and Thanlwin (Salween) Rivers.

It is not entirely clear why the former edges of the transform—spreading axis plate edge are upturned, but it is perhaps partly a subsidence effect and partly a result of natural levee deposition from the turbidity currents.

The oldest former plate edge delineated, F in sections I 6–7 and E 34–35, Fig. 11, and in Fig. 4, forms the western edge of the northern part of East Basin and the boundary between East Basin and the Central Andaman Basin. Typical crossings of F show a change of level of about 350–400 m. It lies very close to A, which appears to be the northwestern margin of Sewell Rise; A′ is the southeastern margin of Alcock Rise. If F represents the time of initiation of spreading in the Central Andaman Basin (CAB), it might be present in some of the faulting above the level of the CAB on the flanks of the rises and in some of the faulting on the east side of Alcock Rise. It may not represent much of a time hiatus. Difference in level across F is interpreted as differential subsidence of the younger sea floor.

Sediment thicknesses in the Central Andaman Basin range from essentially zero in the southwestern part of the basin to almost two km in the outer edges of the northeastern end near the bend in the plate edge to about

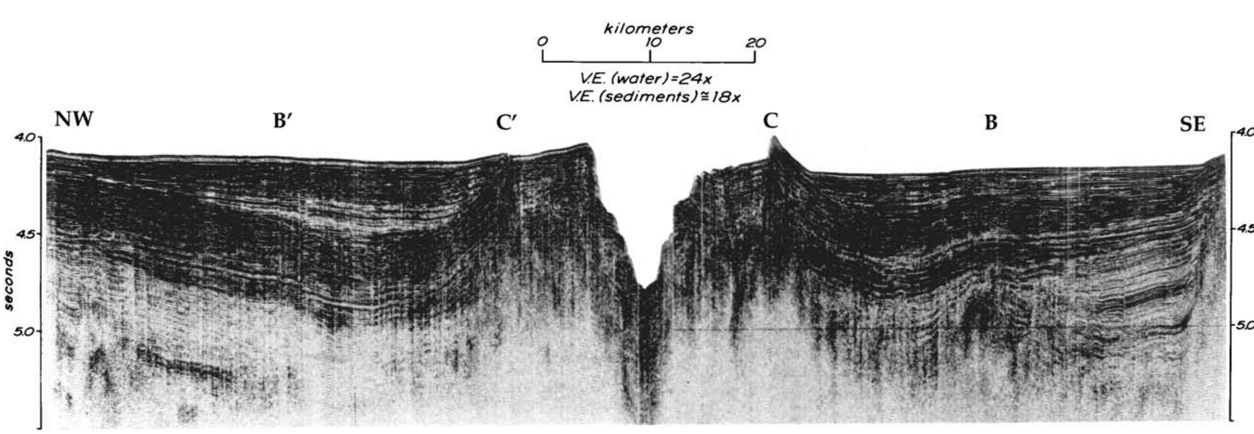

Fig. 14. Photograph of single-channel seismic reflection profile across the Central Andaman Basin spreading axis, line T 66–67. The older upturned edges are labeled.

north–south, as based on refraction data using both explosive and airgun sources and airgun wide-angle reflection data. Unfortunately, our data are insufficient to isopach the sediments.

Oceanic magnetic anomalies have been recognized in the southwestern part of the Central Andaman Basin where the sediment section is thin. These are discussed in Section 6.

Study of seismic reflection sections and seismicity suggests that the West Andaman Fault is inactive from its northern termination to where it intersects with the spreading axis at about 10.2°N (Fig. 4), south of line T 5–7 (Fig. 10a). From that point of intersection, it is active and constitutes the sliver plate edge to where the Seulimeum (SEU) Fault and/or the SFS then form the plate edge in Sumatra. The more active strand of the SFS in Aceh Province at the northwestern corner of Sumatra is what Sieh and Natawidjaja (2000) call the Seulimeum segment, abandoning the former name of Lam Teuba Baro (Bennett et al., 1981).

A possible abandoned plate edge is shown in Figs. 4 and 12 along the eastern margin of Sewell Rise. The margins of this spreading axis—transform system are correlated with plate margins A—A′ bordering the active plate edge farther north. This plate edge was presumably abandoned some millions of years ago, and the rift valley depression is filled. These are discussed in Section 6 of opening history, as are possible correlations of the old rift valley margins A–A′, B–B′, C–C′ with the chronology of sea level fluctuations.

5. Eastern zone of continental crust

Following the Suess (1904) subdivision, the eastern zone is the continental crust of the Shan Plateau in Myanmar and the Malay Peninsula and continental margin in the eastern Andaman Sea. This is basically the SIBUMASU Block of Metcalfe (1984) and Acharyya (1994). It includes Siam, Burma, Malaysia and Sumatra, and consists mainly of Paleozoic and Mesozoic rocks overlying continental crust.

The western margin of the Shan Plateau is generally interpreted to be an old suture, and is assumed to be along a fault known as the Shan Scarp Fault (Aung Khin et al., 1970; Mitchell, 1989) or the Central Burma Suture (Acharyya, 1998). The origin of the margin in the Andaman Sea is presumed to be an extensional margin formed by opening of the Andaman Sea along a back arc fault line, as outlined in Section 6 of this paper. Several of our reflection lines suggest down-to-basin listric faulting beneath this continental slope, as mentioned previously. Faulting on the shelf is also important in some of the areas of commercial wells drilled on this continental shelf, such as the Yetagun Field at about 13°N, 97°E and also in some of the seismic lines illustrated by Win Maw and Myint Kyi (1998).

The Mergui Basin (Fig. 4) is an offshore extension of the North Sumatra Basin. It is a backarc basin formed by rifting, transtension and thinning of continental crust, starting in Early Oligocene. The very simplified rifting structure is shown in Fig. 4. It is discussed and illustrated in much more detail in papers by Harding (1985), Polachan and Racey (1994) and Andreason et al. (1997). The basic simplified structure is a sag basin formed by graben and half-graben extensional faulting. The structural components (Fig. 4) are the Mergui Ridge, the West Mergui sub-basin, the Central Horst, the East Mergui sub-basin, the Ranong Ridge and the Ranong Trough. Extension was in an E–W to ESE–WNW direction, but dextral sliver faulting turns this extension direction to NW–SE, as explained in Section 7.

A simplified stratigraphy (Table 2) of the North Sumatra Basin and the Mergui Basin is adapted primarily from Polachan and Racey (1994) and Andreason et al. (1997). Lateral facies changes are important between the sub-basins of the Mergui Basin and the North Sumatra Basin, and both North Sumatra and Mergui Basin names are listed in Table 2. Fig. 15 shows profiles from reflection and refraction data, respectively, in a line in the East Mergui sub-basin (Figs. 3 and 7). The subsurface high at Well W9 B1 is the small horst located to the east and southeast of the Central Horst. My interpretation of these sections and velocities is that the 3.1–4.9 km/s velocity is Tertiary sedimentary rock, that the 4.9–5.7 km/s layer is probably Mesozoic or Paleozoic rock, that the 6.4 km/s layer (Fig. 15b) is continental intrusive and metamorphic rock, and that the 7.9 km/s horizon is the Moho.

The first marine incursion into the area was in Eocene, when early continent–continent hard collision was occurring between the Indian continental mass and Southeast Asia. Extension of continental crust occurred mainly during the Oligocene. This brought about rapid subsidence that continued through early Miocene. Subsidence slowed, and the grabens and half-grabens filled almost to sea level. The chronology of this extension and relationship to other opening events in the Andaman Sea are discussed in Sections 6.5 and 7.

The Ranong and Khlong Marui Faults (Fig. 4) may have been right lateral following early collision and reversed to left lateral during the Miocene with accelerated clockwise rotation of the region (Lee and Lawver, 1995).

6. Tectonic history of the Andaman Sea

Several scenarios and mechanisms of opening of the Andaman Sea have been published, including Wegener (1966), Rodolfo (1969a), Mitchell (1976), Curray et al. (1979, 1982), Hla Maung (1983), Bender (1983), Mukhopadyay (1984), Curray (1989), and many other papers. Some of these scenarios and chronologies were based in part on the erroneous interpretations previously mentioned of magnetic anomalies in the Central Andaman Basin. In this paper, a revised interpretation is presented of the opening history based on new interpretations of the magnetic anomalies, some dated rocks and the literature published on commercial drilling in the Mergui Basin and

Table 2
Mergui Basin and North Sumatra tectonics and deposition

Stratigraphic Age	Age my	Sequence Name	Thickness of Sediments m.	Environment of Deposition and Lithology	Tectonics and Deposition
Plio-Pleistocene	0 - 5	Takua Pa	300 to max. 3400	Outer Neritic (deep shelf) to Bathyal	Regression followed by transgression.
Late Miocene	5 - 11	Takua Pa Thalang Keutapang	to 1400	Estuarine/coastal from south to deep marine, including turbidites.	Transgression/subsidence.
Middle Miocene	11 - 15	Trang Surin Baong	to 800	Fluvial, deltaic and shallow marine from N and SE to bathyal mudstones.	Transgression/subsidence followed by regression.
Early Miocene	15 - 22	Tai Kantang Payang Peutu Belumai	to 2100	Maximum transgression. Patch and pinnacle reefs and deep marls and shales. Fluvial-deltaic sandstones from the N. Restricted marine to bathyal.	Rapid subsidence, sea level rise and transgression followed by regression and major unconformity.
Early Miocene Oligocene	22 - 36	Yala Ranong Bampo Bruksah	to 4600	Basal fanglomerates. deltas from the N. Restricted marine basins.	Sea level rise and subsidence during crustal extension.
Eocene	36 - 49			Shallow marine limestone and dolomite.	Stable with clockwise rotation.
Pre-Tertiary	> 49			Accreted melange of Permo-Carboniferous to Cretaceous schist, phyllite, quartzite, limestone, dolomite. Late Cretaceous granites.	

the Gulf of Mottama (see Fig. 4). Unfortunately, our seismic reflection records are not of sufficient power, penetration and resolution to enable much direct correlation with these exploration wells.

Simplified magnetic anomaly data adapted from Raju et al. (2004) in the Central Andaman Basin are shown in Fig. 16. Anomalies J, 2 and 2A are shown symmetrically arranged around a rift valley segment. These identifications are based on the Indian close spaced pattern of magnetic lines and on other data from NGDC, which are mainly our Scripps lines. The correlation we made from our limited data (S. Cande, personal communication, 2003) suggested a half-rate of 15 mm/yr, or opening of the Central Andaman Basin 118 km in 4 my, but it was not truly compelling. Raju et al. (2004) propose a half-rate of 8 mm/yr until sometime between anomalies 2 and 2A and then an increase in half-rate to 19 mm/yr. They tentatively identify anomaly 3 off the corner of Sewell Rise, but we were not able to identify this anomaly in our data. Their conclusion is the same as ours, that the Central Andaman Basin opened about 118 km in about 4 my.

Also shown in Fig. 16 are the locations of upturned edges A, A$''$, B, B$''$ C, C$'$ and F–F$'$. Lineation F probably lies along lineation A, within the escarpments bordering the Central Andaman Basin, and represents the time of initial rifting across the Alcock/Sewell combined Rises. Our explanation of these upturned edges (Curray et al., 1979) is that spreading was continuous and at an approximately constant rate, but that influx of sediment transported by turbidity currents into this basin was episodic with fluctuations in Plio-Pleistocene sea level. During periods of lowered sea level, sediments poured off the shelf down the canyons and gullies cut into the shelf edge and slope (Fig. 2) as massive turbidity currents. Then, during the rise of sea level as the river mouths retreated from the shelf edge, the sediment supply was greatly reduced and the fan valleys or turbidity current channels were filled. This is analogous to what happened with Quaternary sea level fluctuations on the Bengal Fan (Curray et al., 2003) and other submarine fans. This is the Andaman Submarine Fan, extending from the continental slope of the Gulf of Mattama southward to East Basin, with a more recently opened segment in the Central Andaman Basin (Fig. 4).

A and A$'$ and probably also the lineation F appear to be ~4 my. At a half-spreading rate of 19 mm/yr. B and B$'$ would be ~1.7 my; and C and C$'$ would be ~630,000 years. The outer edges of the rift valley (Fig. 14) would be about 260,000 years; the inner 'terrace' within the rift valley would be about 130,000 years and the narrow bottom of the inner rift would be about 66,000 years. The 66,000, 130,000, 260,000 and 630,000 year times very roughly occur in sea level lows in the climate curve by Imbrie et al. (1984) and Mitchell (1985) and the 1.7 my dates occurs very approximately during a low stand shown by Haq et al. (1987), but these correlations are not very good. This would imply that the large turbidity currents of lowered sea level scoured the channels and subsequent smaller turbidity currents have backfilled the open channels.

Several dredge samples of rocks and cores sampled during the 1964 Pioneer Expedition were dated

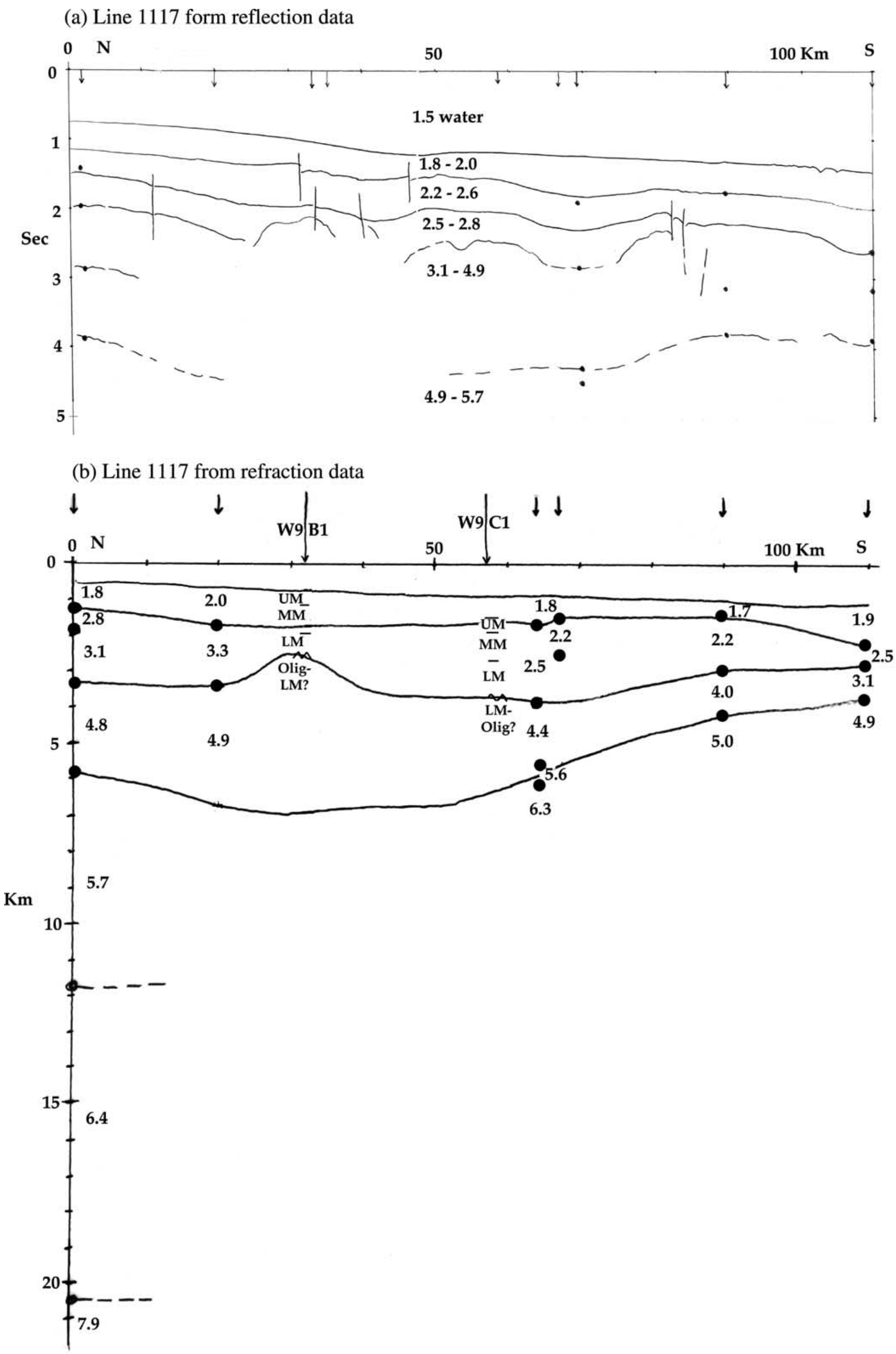

Fig. 15. North–south line 1117 in Mergui Basin (see Figs. 3 and 4). Buoy locations indicated by small arrows. (a) Section from reflection data, with velocity data from refraction and wide-angle reflection. (b) Section from refraction data.

stratigraphically by Frerichs (1971). These are located in Fig. 4 and are listed in the caption. Of especial value are some of the core samples of Neogene sediments with Frerichs' estimates of amount of uplift from their original depositional depth. Dredge sample ***17***, ∼11°40′N, 94°3′E, from 950 to 1250 m is from an escarpment near the south flank of Alcock Rise. Two samples, described by J.W. Hawkins (personal communication, 1982) as moderately

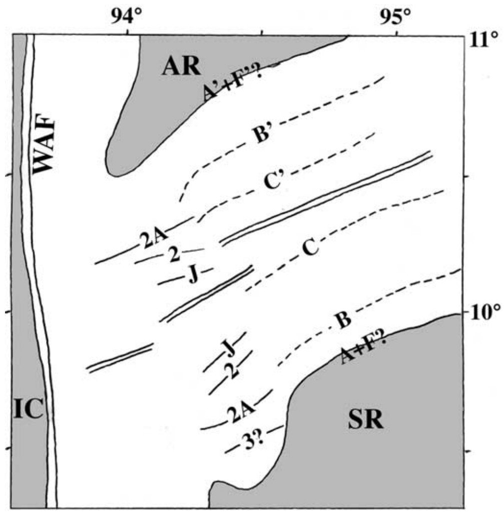

Fig. 16. Mergui Basin magnetic anomalies, simplified from Raju et al. (2004). Anomalies J, 2 and 2A are labeled. Rift margins B′, C′, C and B are shown, as are Alcock and Sewell Rises, Invisible Cuesta and the West Andaman Fault. Double lines indicate the three segments of spreading rift identified by Raju et al. (2004).

fractionated tholeitic basalts, dated by at 19.8 ± 0.7 and 20.5 ± 1.0 my.

Not all of the tectonic elements shown in Fig. 4 are active today, and an effort was made to distinguish between active and inactive elements. The elements judged to be active today are shown separately in Fig. 17. They include the two strands of the SFS, the main strand coming out of northwest Sumatra and the more active Seulimeum Fault (SEU) (Bennett et al., 1981; Sieh and Natawidjaja, 2000), the WAF from its intersection with the SFS to the western end of the Central Andaman Basin, the spreading axis in the Central Andaman Basin and the complex spreading axis-transform system extending northward from the eastern end of the Central Andaman Basin to where the Sagaing Fault comes offshore from Myanmar. The Eastern Margin and Diligent Faults (Fig. 4) are probably inactive, but this cannot be determined for sure.

As shown by the magnetic anomalies, the present full rate of spreading in the Central Andaman Basin (Raju et al., 2004) is about 38 mm/yr. This rate compares with the estimate of about 25 mm/yr for the SFS and SEU in northwestern Sumatra (Sieh and Natawidjaja, 2000; Genrich et al., 2000; Prawwirodirdjo et al., 2000). Sieh and Natawidjaja (2000) suggest that only the SEU at the northwest tip of Sumatra has been active for the last 100,000 years. The consensus of opinion of these workers in Sumatra is that the rate decreases to 10–20 mm/yr toward the southeast by either stretching of the sliver on the southwest side of the fault or by take-up of motion by other faults. These estimates of slip rate also compare with estimates for the Sagaing Fault. As mentioned previously, Vigny et al. (2003) have shown that less than 20 mm/yr of the total plate motion of 35 mm/yr occurs along the Sagaing Fault. They suggest that the remainder is accommodated by distribution of deformation over a wide zone. A wide zone of deformation must also exist along the SFS. These rates will be further compared in Sections 6.1 and 7.

The subduction zone of the Sunda Trench is active. Reflection records from the slope above the filled trench in Fig. 8a and b, sections T 24–25 and southward, show deformation of young sediments of the Bengal Fan low on the slope. North of T 24–25 the slope is depositional, probably from the large input of sediment from the Myanmar rivers and coastline, but a component of convergence probably still exists all the way up the Myanmar part of the arc, although this is controversial (see, for example, Satabala (1998) and Guzmán-Speziale and Ni (2000)).

Vectors are shown at several points along the trench axis (Fig. 17). The rate of convergence between the Indian and Eurasian (or Southeast Asian) plates is in dispute today. Estimates from GPS observations (Holt et al., 2000) differ from the earlier IN-EU-NUVEL-1A of DeMets et al. (1994). The vectors in Fig. 17 are therefore only approximate, and are shown only to illustrate that convergence appears to occur all along this segment of the trench because of the spreading in the Andaman Sea. Vectors AE represent the Australian plate with respect to the Eurasian or Southeast Asian plate; vectors AB represent Australia with respect to the Burma sliver plate; vectors AT represent the component of convergence normal to the trend of the trench, and vectors BE represent Burma with respect to Eurasia. Vectors are shown for the spreading across the Central Andaman Basin.

The vectors at 2°N are adapted from McCaffrey et al. (2000) who calculated vector AB as the slip vector from earthquakes. They found that vector BE is about 1/3 less than the total trench-parallel vector and interpreted this to mean that the additional strike-slip motion occurs between the SFS and the trench. This is analogous to Vigny et al. (2003) conclusion that some of the total plate motion occurs in a wide zone between the Sagaing Fault and the plate edge. This implies that there are many unmapped faults active within the Andaman and Nicobar accretionary complex.

I do not have access to slip vectors for the 7.5 and 15.5°N locations, so some assumptions have been made in attempting to show AB and BE. The rationalization behind these assumptions will be explained in Section 6.1, and at that time we will return to consideration of Fig. 17.

Opening of the Andaman Sea has occurred during the convergence of India and Asia since Paleogene time. The history of convergence and collision have been thoroughly discussed in the literature. This discussion will follow the chronology by Lee and Lawver (1995); an adaptation of their convergence curves is shown in Fig. 18. Some events in the Andaman Sea history appear to correlate with events in these convergence curves, while others do not. The stages of the opening of the Andaman Sea to be discussed below are summarized in Table 3.

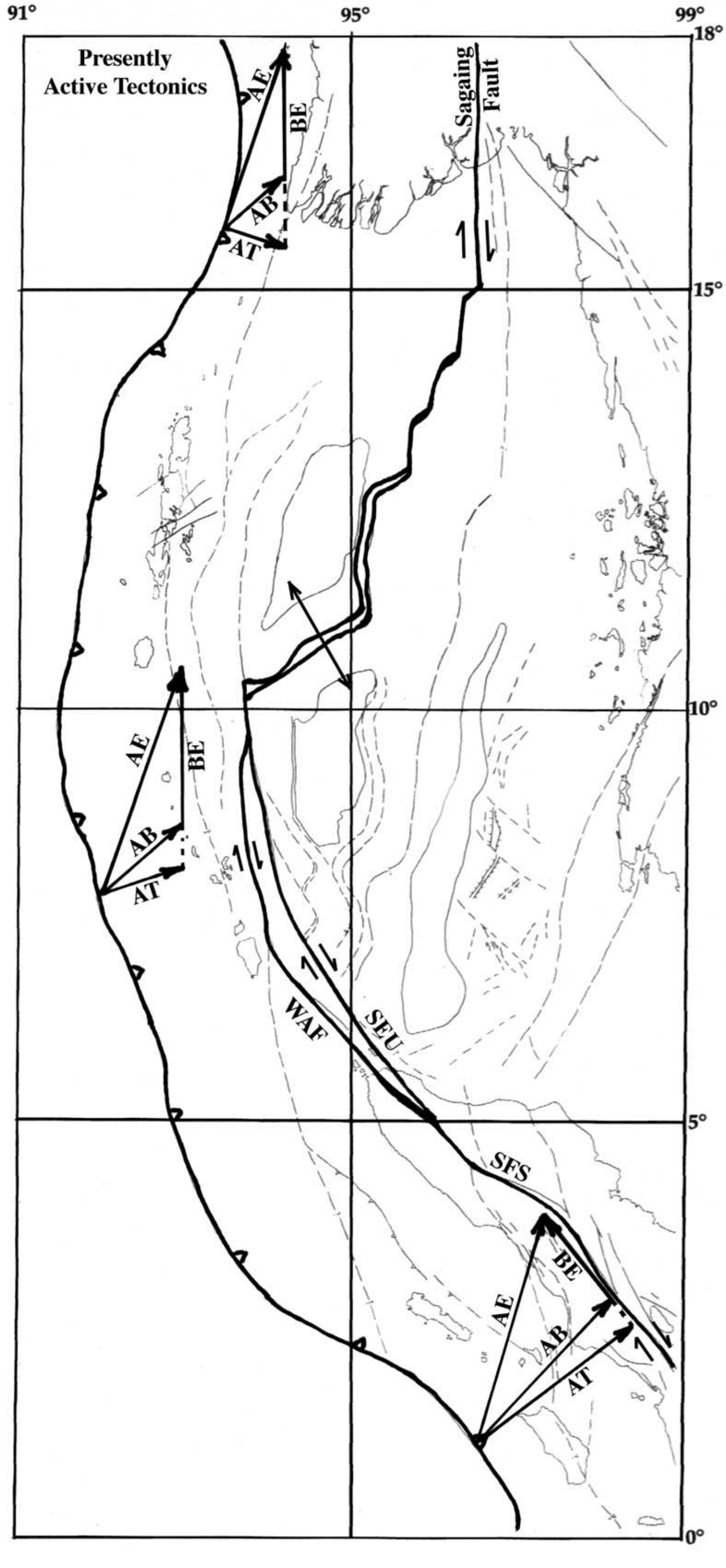

Fig. 17. Presently active tectonic elements. Edge between the Eurasian and the Burma sliver plate is the Sagaing Fault, the spreading axis in the Central Andaman Basin, the West Andaman (WAF) and Seuliman (SEU) Faults to the Sumatra Fault System (SFS). Vectors: AE, Australian plate with respect to Eurasia plate; AB, Australia with respect to Burma plate; BE, Burma plate with respect to Eurasia; AT, Australia with respect to the alignment of the trench or trace of the subduction zone, to demonstrate that while highly oblique, subduction is occurring all along this trench axis. Full rate of separation normal to the CAB spreading axis is currently about 38 mm/yr. Derivation of vectors explained in text.

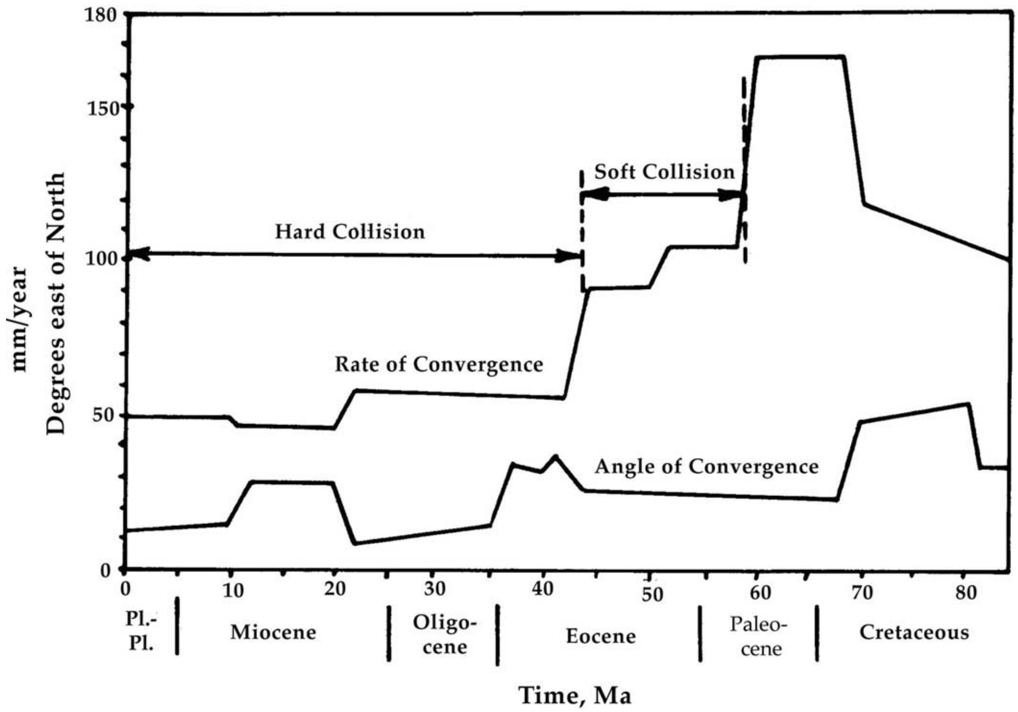

Fig. 18. Rate and direction of convergence between India and Asia. Modified from Lee and Lawver (1995).

Notice the reverse or thrust fault first motion solutions near the north coast of Sumatra in Fig. 6. In an earlier attempt at a history and tectonic scenario for the Andaman Sea (Curray et al., 1979), we suggested that a splay of the active West Andaman Fault might bend around the coastline with a component of convergence. Our seismic reflection lines do not show any such fault, nor does the land mapping, and those thrusting mechanisms remain a mystery.

No definitive paleomagnetic data have been collected in the Burma Block. Richter et al. (1993) and Richter and Fuller (1996) reported CW rotation of the Shan Plateau between Late Cretaceous and Late Oligocene, but Richter et al. (1999) reported 30–40° CCW rotation of peninsular Malaysia between late Eocene and late Miocene. The consensus of opinion based on tectonic considerations, however, is that CW rotation of the western Sunda Arc, the Burma Block to southwestern Sumatra, occurred during the Tertiary (e.g. Curray and Moore (1974), Ninkovich (1976), Tapponnier et al. (1982), Mitchell (1989), Lee and Lawver (1995), Varga (1997) and many others). The reconstructions in Figs. 19–23 show somewhat more rotation than Lee and Lawver (1995) showed, on the assumption of deep indentation by India into the Asian margin by the collision and extrusion of the Indochina block. Tapponnier et al. (1986) and Alam et al. (2003) suggested a linear pre-collision south Asian continental margin trending about 120–300° between the Gulf of Oman and Sumatra. Using this as the original alignment, I have assumed about 60° of rotation since initial 'soft collision' about 59–60 Ma, and rotation has been prorated in the reconstructions to follow: about 44° since 44 Ma, 32° since 32 Ma, etc.

The Andaman Sea has opened by extension in a series of stages that are reconstructed below, going backward in time. The process started some time after the collision of Greater India with the southeastern Asian margin, which was the locus of the zone beneath which the Tethys sea floor was subducted. This subduction zone is believed to have been active at least by Cretaceous time when the Gondwana continent was breaking up. Table 4 is a summary of the spreading history, as will be explained.

6.1. Reconstruction to 4 Ma (Fig. 19) and tectonics of 0–4 Ma

The tectonic action of the past 4 my was opening of the Central Andaman Basin across the spreading axis shown in Fig. 4 and comparable right-lateral offset along the transforms to the north and south, the Sagaing, West Andaman, Seuliman, and Sumatra Fault Systems. The opening of the CAB is estimated at 118 km in a direction of ca. 335° relative to the Eurasian, Southeast Asian or Sundaland block, at an average rate of about 30 mm/yr, starting at 16 mm/yr and then speeding up to 38 mm/yr at about 2–2.5 Ma (Raju et al., 2004). Although 4 Ma was a time of reorganization of the tectonics, with a plate edge jump from the east flank of Sewell Rise to the Central Andaman Basin and the West Andaman Fault, it shows no correlation with convergence between India and Asia and the overall tectonics of the Indian Ocean (Fig. 18).

The turbidity current channel occupying the plate edge rift is believed to have continued along the east side of Sewell Rise prior to opening of the CAB, to as far south

Table 3
Andaman Sea spreading history

Age	Event	Total Rotation*	Spreading Direction*	Spreading Amount km	Spreading Rate mm/yr.	North Component km	North Velocity mm/yr	West Component km	West Velocity mm/yr	Tectonics
ca. 4 to 0 Ma Early Pliocene to Present	Open Central Andaman Basin	4°	ca. 335°	ca.118	38 30 16	107	27	50	12	Plate edge jump from East Basin abandoned spreading axis to West Andaman Fault, central Andaman Rift, and SEU and SFS Faults.
ca. 15 to 4 Ma End Early Miocene to Early Pliocene	Open East Basin	16°	ca. 335°	ca. 100	9	91	8	42	4	Move contiguous Alcock and Sewell Rises away from edge of continental crust. Start jump from West Andaman and Mentawei Faults to Sumatra Fault System and Batee Fault.
ca. 23 to 15 Ma Early Miocene	Form Alcock and Sewell Rises	23°	ca. 322°	ca. 120	15	95	12	74	9	Backarc extension by creation of contiguous Alcock and Sewell Rises and Bago Yoma. Rapid subsidence of Mergui Basin and deposition of deep marine shale. Continuous Sagaing and West Andaman Faults. Ranong and Khlong Marui Faults change to left lateral.
ca. 32 to 23 Ma Early Oligocene to Early Miocene	Form Mergui Basin	32°	ca. 310°	ca. 60	7	39	4	46	5	Rift extension of continental crust, thinning it by $\beta \sim 1.5$. Deposition of fluvial, deltaic and shallow marine sediments. Continuous Sagaing, West Andaman and Old West Andaman sliver faults. Ranong and Khlong Marui Faults right lateral.
ca. 44 to 32 Ma Middle Eocene to Early Oligocene	"Hard" collision of India with Asia	44°								Rotate Burma, Sumatra and Sibumasu blocks. Form Sagaing-West Andaman splinter Fault at about end of period, ca. 32 Ma.
ca. 59 Ma	"Soft collision" India and Asia.	59°								Start of rotation of northern Sunda Arc.
Totals and Averages			327° Vector Sum	389 Vector Sum	12	332	10	212	7	

[a] Directions relative to present north.

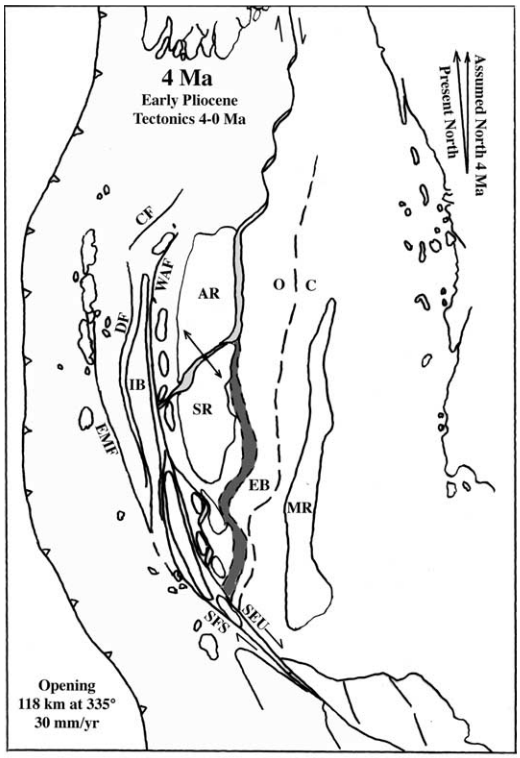

Fig. 19

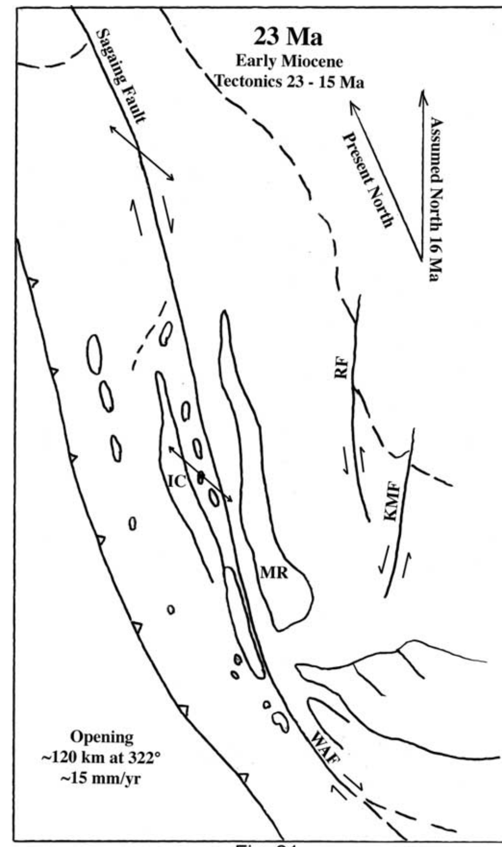

Fig. 21

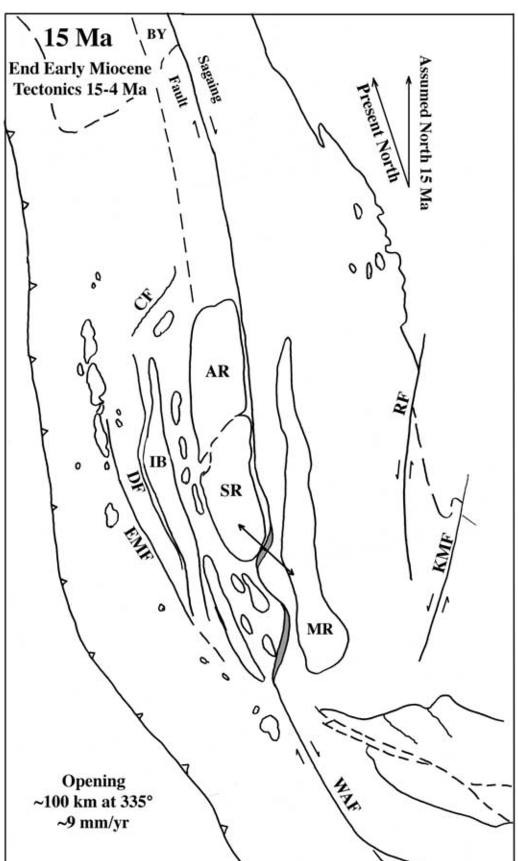

Fig. 20

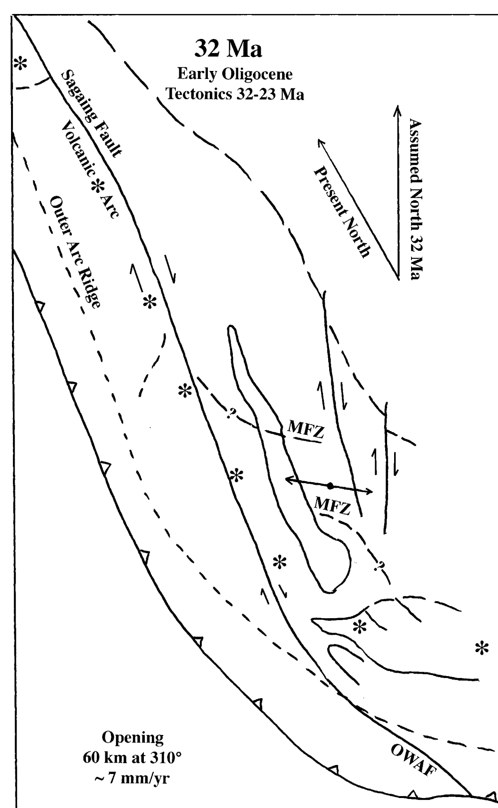

Fig. 22

as the intersection with the Seuliman Fault, although differential subsidence and later deposition have made the channel shoaler south of the northeast corner of Sewell Rise than it is farther north. The continuous gradient southward has not been preserved. The rifting of the CAB and the jump in the plate edge apparently initiated the subsidence now shown across lineation F of 350–400 m.

This reconstruction was made by fitting Alcock and Sewell Rises together along their margins, which are lines A′ and A, respectively, in Fig. 4. This brings the abandoned plate edge A–A′ from east of Sewell Rise approximately into line with the present rift valley A–A′ east of Alcock Rise. It also brings the western flanks of the two rises approximately into alignment, suggesting a fault or rift origin.

The West Andaman Fault was probably active all along its trend. From the west end of the Central Andaman Basin rift to its northern end, it may have been primarily a reverse fault forming the Invisible Bank Cuesta and uplifting older forearc basin sediments, while from this point south it also served as a strike-slip transform fault to northwest Sumatra. Dredged sediments (Fig. 4) were uplifted 400–2000 m above their depths of deposition in the forearc basin during this period (Frerichs, 1971; Rodolfo, 1969a). Invisible Bank continues as a cuesta to about the southern end of Sewell Rise (Line E 9–10, Fig. 10b). The Eastern Margin (EMF) and Diligent (DF) Faults were probably also active during this period.

The Cocos Fault (sections E 19–20 and I 10–11, Fig. 10a) created a cuesta, also suggesting a reverse fault. Since both the Cocos and West Andaman Faults were probably active during this period, a component of compression may have existed northwest of Alcock Rise as a result of the extension forming the rises, to be discussed in Section 6.2.

Fig. 19 shows faulting in northwestern Sumatra along both the Seuliman and Sumatra Fault System alignments although Sieh and Natawidjaja (2000) suggest that the Seuliman Fault did not start until about 2 Ma. They also suggest that the main strand of the fault (SFS in Fig. 19) has not been active for the past 100,000 years. Our offshore reflection records suggest that the SFS strand is currently inactive and that the SEU fault is the active strand (Fig. 10b, sections E 2–4W and M 8–9E; and Fig. 10c sections E 38–40 and I 37–38).

Sieh and Natawidjaja (2000) suggest that the Sumatra Fault System in northwestern Sumatra may be no older that 4 my and perhaps only 2 my in the remainder of Sumatra. They show a progressive shoreward or northeastward migration of the fault system with time, from offshore to onshore. This reinforces our belief that the West Andaman Fault represents an earlier sliver fault off northwest Sumatra running into the Mentawei Fault at the intersection with the Battee Fault. Our reflection lines off Sumatra suggest that the Mentawei Fault is not active today. Even earlier, from as early as Eocene until about early Miocene, we believe that the WAF ran across the outer arc ridge as the Old West Andaman Fault (OWAF; Fig. 4). Replumaz and Tapponnier (2003) speculated that a fault they named the Nicobar Fault runs where we had previously published the location of the West Andaman Fault and continuing across the accretionary prism where we show the OWAF, but they calculate that it has been active at a rate of 24 mm/yr during the past 5 my. We see no evidence for current activity of this fault, nor is its trend apparent in the seismicity, in the bathymetry or in the complex structures in the reflection profiles across the accretionary wedge.

Fitch (1972) introduced the concept of partitioning of motion in oblique subduction: that the lateral component is frequently taken up by an arc-parallel sliver fault and that the normal component represents subduction. Backarc extension can similarly be expressed as components, as in the case of the opening of the Central Andaman Basin with northward, arc-parallel sliver faulting by the Sagaing–West Andaman–Sumatra Fault System, and arc normal extension. In the CAB with spreading about 335° relative to present north at an average rate of 30 mm/yr, the northward component would be 27 mm/yr and the westward component relative to the eastern Andaman Sea would be about 12 mm/yr. In Table 3, each separate period of opening is expressed as an arc-normal and an arc-parallel component.

Fig. 19. Reconstruction at ca. 4 Ma. Plate edge after 4 Ma was same as Fig. 17, shown in light shading. Plate edge prior to the realignment of 4 Ma, shown in darker shading, was Sagaing Fault, abandoned spreading axis/transform complex east of Sewell Rise (SR), to SEU and SFS Faults in Sumatra. Farther southeast in Sumatra, Sieh and Natawidjaja (2000) suggest that the Sumatra Fault System did not move onshore until about 4 Ma, and that displacement was taken up by extension in the outer arc ridge seaward of the Battee Fault. AR, Alcock Rise; SR, Sewell Rise; EB, East Basin; MR, Mergui Ridge; IB, Invisible Bank. Other features are the same as in Fig. 4, but whether they were active cannot be established, e.g. Cocos Fault (CF), Eastern Margin Fault (EMF), Diligent Fault (DF) and West Andaman Fault west of Alcock Rise. Opening from 4 my to present was about 118 km at 335°.

Fig. 20. Reconstruction at about 15 Ma, made by closing East Basin and moving Alcock (AR) and Sewell (SR) Rises against the presumed edge of continental crust off the Mergui Ridge (MR) and continental slope to the north and rotating the region 15° CCW. BY, Bago Yoma. Other abbreviations as in Fig. 4. Opening during this period was about 100 km at 335° relative to present north.

Fig. 21. Reconstruction at about 23 Ma, made by closing Alcock and Sewell Rises and rotating region another 7° CCW. Opening during this period was about 120 km at 322°.

Fig. 22. Reconstruction at about 32 Ma, made by closing Mergui Basin and rotating region another 9° CCW. Opening during this period was about 60 km at 310°.

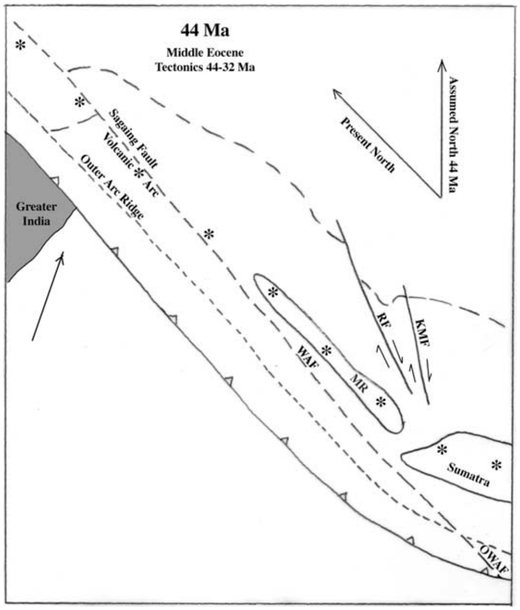

Fig. 23. Reconstruction at about 44 Ma, made by rotating region another 12° CCW and bending the arc at northwest Sumatra.

I had previously considered sliver faulting of the Burma Platelet in terms of rigid plate tectonics, with a pole of rotation at about 24°N, 125°E, assuming that the Sagaing and Sumatra Fault Systems are transforms and the Central Andaman Basin points toward this pole (Curray et al., 1979; Curray, 1989). It is clear now, as shown by McCaffrey (1991) and McCaffrey et al. (2000), that the sliver plate should not be considered to be rigid. By the Fitch concept (1972), the arc-parallel component of the oblique convergence is a function of the obliquity of convergence. Around the Sunda Arc, where convergence is normal to the arc, there is no arc-parallel component, and hence no sliver faulting. This point lies near the Sunda Strait between Sumatra and Java (Fig. 1), where the Sumatra Fault System terminates. Adjacent to the Andaman Sea, the convergence direction between the Australian and Eurasian (or Southeast Asian) plates is approximately parallel to the arc, and without the component of opening of the Andaman Sea there would be no subduction—only lateral motion.

In plotting the vectors for the 15.5 and 7.5°N locations in Fig. 17, it has been assumed that the vector BE, the motion of the Burma sliver plate relative to the Eurasian (or Southeast Asian) plate is N–S parallel to the Sagaing Fault, rather than oblique and parallel to opening of the Central Andaman Basin. Approximate vectors AB, Australia with respect to the Burma platelet, are estimated from the earlier calculations assuming a rigid Burma plate and by assuming that about 1/3 of the arc-parallel motion is absorbed in the forearc region, as McCaffrey et al. (2000) have shown. So magnitudes of strike-slip motion cannot therefore be calculated with any accuracy, but these vector plots demonstrate that a component of subduction exists normal to the arc. Our reflection and 3.5 kHz records also confirm that subduction is still occurring.

We have assumed that the sliver fault on the east side of the Burma sliver plate is the Sagaing Fault down to the Central Andaman Basin, the spreading axis in the Central Andaman Basin, the West Andaman Fault and the Sumatra Fault System. The rates of motion compare rather well. The plate motion is about 35 mm/yr in Myanmar, about 20 of which is on the fault itself. The northward component in the Central Andaman Basin is 27 mm/yr, and the estimates in Sumatra decrease from 25 mm/yr in the northwest to 10–20 mm/yr in the southeast, and may be greater if there is a wide zone of deformation between the fault and the trench axis.

6.2. Reconstruction to 15 Ma and tectonics of 15–4 Ma

Fig. 20 is a reconstruction of the Andaman Sea region at about 15 Ma. This was prepared by moving the contiguous Alcock and Sewell Rises against the edge of continental crust of Fig. 4, thus closing East Basin by about 100 km in direction 155°. The direction of motion to close East Basin is approximated by fitting the shapes of the rises and the shape of my estimate of the edge of continental crust. Seismic reflection records show some listric faulting of both the edge of the continental crust and the margins of the rises, but I cannot judge how much extension had occurred. Hence, I postulate opening during this period in direction 335° by spreading along two or more spreading axes, in a transform spreading axis connecting the Sagaing Fault with the West Andaman and Mentawei Faults offshore from Sumatra. An average rate of opening would have been only about 9 mm/yr. Starting at about 4 Ma, the rate apparently speeded up to about 16 mm/yr, and then speeded up again to 38 mm/yr after anomaly 2A, at about 2.0–2.5 Ma (Raju et al., 2004).

The Sumatra Fault System was probably not active yet, so the Burma sliver plate at this time probably included only western Myanmar and the western Andaman Sea region. The West Andaman Fault west of Alcock and Sewell Rises was probably not active during this period; the Eastern Margin and Diligent Faults may have been active; and the possible fault line along the western margin of the contiguous and joined rises may also have been active as a normal fault. The Ranong and Khlong Marui Faults were believed to have been left lateral during this period of time (Lee and Lawver, 1995; Andreason et al., 1997).

The beginning of this tectonic period, about 15–16 Ma was the end of early Miocene. This is an important time in the stratigraphy of the Mergui Basin, a time of rapid subsidence and deposition of bathyal shales in the center of the basin, following a maximum transgression (Polachan and Racey, 1994; Andreason et al., 1997). However, it shows no relationship to the convergence across the Indian Ocean (Fig. 18).

The Bago Yoma (formerly named Pegu Yoma) low mountains are shown in this figure, and are discussed in Section 6.3.

6.3. Reconstruction to 23 Ma and tectonics of 23–15 Ma

Fig. 21 is a reconstruction of the region at about 23 Ma. It was made by removing the contiguous Alcock and Sewell Rises and displacing the western sliver plate about 120 km toward 142°, relative to present north. The direction of motion to close up the space of the rises is judged by the structural grain of the tops of the rises. Hence, spreading during the formation of these volcanic piles was in a direction 322° relative to present north at an average rate of about 15 mm/yr.

Two rock dredge hauls have yielded information on the petrology of Alcock Rise. Pioneer dredge ***14*** at 13°N (Rodolfo, 1969a) is a 'tabular, massive unaltered intergranular augite basalt'. No dating has been done because the samples are lost. Dredge ***17*** is a moderately fractionated tholeitic basalt (J. W. Hawkins, personal communication, 1982). Two dates are 19.8 ± 0.7 and 20.5 ± 1.0 my. Thus, this part of Alcock Rise was formed about 20 Ma. Hawkins' analyses furthermore show that it is rather typical backarc basin basalt. This was the time of the earliest backarc basin sea floor spreading the Andaman Sea.

The northern limit of Alcock Rise is unknown; our seismic data are not adequate to resolve this, as is indicated in Fig. 4. Thus, the question is how far did the extension to form the rises continue to the north? The suggested solution shown in Figs. 20 and 21 is that it extended north about as far as the bulge in the Sunda subduction zone extends, or to at least 17°N, north of the present Myanmar shoreline. This assumes that the Sunda subduction zone and trench were approximately linear or a smooth curve between northern Sumatra and central Myanmar, rather than showing a pronounced bulge as it does today. A possibility is that this Alcock–Sewell extension continued into the Bago Yoma low mountain region in the southeastern part of the central basin of Myanmar (see Fig. 20) immediately west of the Sagaing Fault, to perhaps 19–20°N. The ridge in the Yadana section (Fig. 9c) might represent the connection between Alcock Rise and the Bago Yoma.

Rocks cropping out in the Bago Yoma are early to late Miocene. This region started subsiding in early Miocene and deposition in the Bago Yomas was in a long narrow north–south trough (Aung Khin and Kyaw Win, 1968, p. 246), compatible with the suggestion that this basin opened by rifting during this period. Pivnik et al. (1998) report that this area was subject to Miocene NNW-directed extension, followed by ENE-directed compression. This compression could be related to the suggested compression NW of Alcock Rise from 4 to 0 Ma, although the direction is wrong.

Seismic refraction line 1109 (Fig. 9d) shows a great thickness of sediment and high velocity sedimentary rock, over 16 km at its northern end, overlying apparent oceanic crust. These high velocity sediments are analogous with the deeply buried high velocity older sediments beneath the northern Bengal Fan, which have been interpreted by consideration of temperature and pressure conditions to be low grade greenschist facies metasediments (Curray, 1991). This is also compatible with the interpretation that extension occurred in this area while Alcock and Sewell Rises were forming. Volcanic filling of the extended backarc region occurred in the Alcock–Sewell region and the flood of sediment from the large rivers of Myanmar buried and filled the northern continuation in the Bago Yoma and shelf area.

Prior to 23 Ma, the Sagaing Fault apparently connected directly in line with the West Andaman Fault passing offshore west of the tip of Sumatra and perhaps connected southeastward with the Mentawei Fault. The Battee Fault, a splay of the Sumatra Fault System, was probably not active yet because the Sumatra Fault had not yet formed in Sumatra. The Samalanga Sipokok Fault in northern Sumatra (Fig. 4) became active in the Oligocene (Cameron et al., 1983; Keats et al., 1981) and might have continued as the Batee Fault, but the time of first activity of the Batee Fault is not known. The Ranong and Khlong Marui Faults were probably actively cutting the Malay Peninsula and are believed to have reversed from right lateral to left lateral at about this time (Lee and Lawver, 1995).

More rotation, 23°, is suggested than in the previous period. This time of 23 Ma was a time of change in convergence direction and rate between India and Asia (Fig. 18). The rate of convergence decreased from about 60 mm/yr to less than 50 mm/yr, and the direction of convergence turned more eastward, from about 010 to 025°. This was also perhaps the time of first emergence of the top of the Andaman–Nicobar Ridge above sea level, as documented by the shallow water facies of the Archipelago Series.

6.4. Reconstruction to 32 Ma and tectonics from 32 to 23 Ma

Fig. 22 is a reconstruction to early Oligocene, about 32 Ma. It was made by closing the extended continental crust in the Mergui Basin and the North Sumatra Basin. The direction of closing is determined by the trends of the normal faults in the basin. The pole of rotation for opening these basins is generally assumed to lie close to the north because the basin terminates in a point somewhere on the Myanmar shelf between about 12 and 14°N.

Fig. 15 shows the refraction line and a line drawing of the reflection line in the Mergui Basin with average velocities for each unit. The stratigraphy of two exploration wells is projected into the refraction line. At the north end of the line an arrival with 7.9 km/s velocity is interpreted as mantle at

Table 4
Correlation of chronology of events

India-Asia Convergence Fig. 18	Myanmar Irrrawaddy Delta	Andaman Nicobar Ridge Table 1	Spreading History Table 3	Mergui N. Sumatra Basins Table 2	Sumatra Fault System	Geologic Time Scale
			Central		SFS on	Quater-
	Irrawaddy	Nicobar	Andaman	Takua Pa	Land	nary
~50 mm/yr	Group	Series	Basin			
~015°	Fluvial	----5 my----	---4 my---	----5 my----	---4 my---	---5 my---
	Delta					Late
			East Basin	Keutapang		Miocene
--10-12 my--	--~10 my--					--10 my--
		Archipelago			WAF &	Middle
	Upper	Series			Mentawei	Miocene
~50 mm/yr	Burman		--15 my---	----15 my---	Faults	--16 my--
~030°	Limestone		Alcock	Peutu		Early
			Sewell	Payang		Miocene
	--~20 my--		Rises			
--20-22 my--	Middle	---- 23 my---	--23 my---	----22 my---	-----?-----	--25 my--
	Burman		Mergui			
	Neritic to	Andaman	Basin	Ranong		
	Deltaic	Flysch	Opens	Bampo	OWAF	Oligocene
10-20 mm/yr	--~30 my---		---32 my--			
010°-030°	Lower		Sliver			
	Burman		Faulting	----36 my---		--36 my--
	Shallow		Arc			
	Marine		Rotation		-----?-----	
	Clastics &					Eocene
---44 my---	Tuff	----45 my----	--44 my---			
Hard				Shallow		
Collision		Mithakhari		Limestone		
90-100		Group				
mm/yr						--54 my--
025°						Paleocene
---59 my---			---59 my--			
Soft						
Collision						--66 my--
~165 mm/yr		----70 my---		---------------		Cretaceous
~025°		Ophiolite				
		Mesozoic?		Pre-Tertiary		

		Proterozoic?				
		Sediment				

about 20 km depth. On the assumption that the original thickness of sedimentary rock plus continental crust was about 30 km, this suggests extension and $\beta = 1.5$, i.e. thinning from 30 to 20 km by extension and increasing the width of the basin to 1.5 times its original width (McKenzie, 1978).

Extension, and rapid subsidence in the Mergui Basin are postulated to have occurred in the Oligocene and early Miocene (Polachan and Racey, 1994; Andreason et al., 1997; Table 2). This was the first period of opening of the Andaman Sea, for approximately 60 km in a direction 310°, at a rate of about 7 mm/yr. The plate edge is believed to have been the Sagaing Fault, extending the length of the Andaman Sea at that time and connecting with the West Andaman Fault and what is called here the OWAF which crosses the outer arc ridge/accretionary prism to the Sunda Trench off Sumatra (Figs. 4 and 21).

6.5. Reconstruction to 44 Ma and tectonics from 44 to 32 Ma

Fig. 23 is a reconstruction to the end of middle Eocene, about 44 Ma. This was the time of hard continent–continent collision between India and continental Asia (Fig. 18). Initial collision occurred earlier, probably early Eocene, about 59 Ma, but convergence continued at about 100 mm/yr for about 15 my before the rate of convergence reduced to about 60 mm/yr (Fig. 18; Lee and Lawver, 1995). During all of this time clockwise rotation of this region continued, and perhaps some bending of the SIBUMASU block (Siam, Burma, Malay Peninsula, and Sumatra) between Sumatra and the southern Andaman Sea. Fig. 23 was drawn on this assumption, so the bend in the trend of the magmatic arc was decreased, and the Andaman Sea and Myanmar are shown more nearly in line with the trend of Sumatra.

The Greater Indian subcontinent had collided with the subduction zone and had started the clockwise bending of this northern part of the Sunda Arc. The sliver fault, the combined Sagaing and West Andaman Faults, perhaps started in middle to late Eocene, as suggested by Tankard et al. (1998) after some rotation had already occurred and the convergence direction was more oblique.

As shown in Table 3, the vector sum of the different periods of opening of the Andaman Sea is about 389 km in a direction 327° relative to present north.

7. Discussion of geological history and tectonics

Reconstructions of the several stages in the opening history of the Andaman Sea have been presented going backwards in time because that is the way the reconstructions were made. Let us now summarize that history moving forward in time (Table 4).

India separated from Australia and Antarctica in eastern Gondwanaland in the Cretaceous and started its spectacular flight northward. The precise time of this separation is irrelevant, but subduction along the eastern Asian margin had started by at least that time. Before the departure of India from Australia and Antarctica, the South Tibet, Burma and SIBUMASU Blocks had already spun off northward and had docked against Asia. Prior to initiation of the subduction system, this could have been a passive continental margin, the source of some of the older sediments found in Myanmar and the Andaman–Nicobar Ridge.

The northeastern corner of ‘Greater India’ hit this subduction zone at about 59 Ma (Klootwijk et al., 1992; Table 4), the so-called ‘soft collision’, and India underwent some counter clockwise rotation from about 59 to 55 Ma, at which time the suture was completely closed. During this time and until about 44 Ma, India was indenting the Asian margin and rotating the subduction zone in a clockwise direction. With this rotation the direction of convergence became increasingly more oblique. Finally, probably in the middle to late Eocene, about 44 Ma, a sliver fault formed, the forerunner of the Old West Andaman, West Andaman and Sagaing Fault systems (Fig. 23). Right-lateral motion started on the Khlong Marui and Ranong Faults at about this same time (Lee and Lawver, 1995) prior to the opening of the Mergui Basin during the Oligocene. Also active from the Late Oligocene were the Lhokseumawe-Lopok Kutacane Fault (Cameron et al., 1983) and the Samalanga Sipokok Fault (Keats et al., 1981; Cameron et al., 1983; Fig. 4). They could have been the southern ends of the Ranong and Khlong Marui Faults, respectively. With extension of the Mergui Basin starting in late Oligocene, the Mergui Faults, north and south (Fig. 4 and 22), could have terminated these connections. The northern strand of the Mergui Fault may have crossed the Mergui Ridge as a splay of the Sagaing Fault (Fig. 22). The Mergui Ridge was probably part of the original volcanic arc (Fig. 23).

By early Miocene, about 23 Ma (Fig. 21), the plate convergence was oblique enough that extension and backarc sea floor spreading moved westward to the sliver fault running approximately along the magmatic arc, which had by that time migrated westward. This sea floor spreading and creation of oceanic crust formed the rock masses comprising Alcock and Sewell Rises and possibly opened the southern Bago Yoma Basin. The dates on rocks from Alcock are early Miocene. With abandonment of extension in the Mergui Basin area, rapid subsidence occurred and the shallow water deposits of the late Oligocene were buried by deeper water facies.

With continuing rotation of the arc, the direction of extension relative to present north (Table 3 and Figs. 21 and 22) became more northerly, from 310 to 335°, between 32 and 15 Ma and stabilized thereafter at 335°.

At the end of early Miocene, about 15–16 Ma, a major change occurred in the Mergui Basin with an unconformity and deposition of dark gray to black shales of the Baong, Trang and Surin Formations over the carbonate sediments of the Peutu, Tai, Katang and Payang formations. At this time the conjoined Alcock and Sewell Rises started rifting away from the edge of continental crust forming East Basin (Fig. 4). And finally at about 4 Ma, the plate edge migrated again to cut Alcock and Sewell apart, and the present plate edge between the Southeast Asian and the Burma Sliver Blocks was formed.

The interpreted timing of tectonic events of the different parts of the system is compared in Table 4. We cannot determine whether these times of change were gradual and the tectonic events described overlapped, or whether these times were sharp events. Although some of the events appear to correlate from region to region within the Andaman Sea, we must bear in mind that the times in the spreading history, Table 3, and the middle column in Table 4, were estimated in part from the better-dated tectonic events in the Mergui Basin. Nevertheless, there are some apparent correlations. Major stratigraphic changes occurred on the Andaman–Nicobar Ridge and in the Mergui Basin at about 4–5 Ma, the time rifting began separating Alcock and Sewell Rises and the time the Sumatra Fault System moved onto land (Sieh and Natawidjaja, 2000). Compression and uplift of the older forearc basin had commenced approximately 6 Ma. Stratigraphic changes occurred at about 20–23 my in the Irrawaddy Delta, the Mergui Basin and in the sediments accreted on the Andaman–Nicobar Ridge. This is the time of a major unconformity in the Indoburman Ranges and on the Andaman–Nicobar Ridge (Acharyya et al., 1990). The time of ‘hard’ India–Asia collision, about 44 my, is about the age of the oldest Andaman Flysch on the A–N Ridge.

During this history of extension, northward motion of the sliver plate occurred as a result of the oblique convergence, and westward extension occurred, a result of the component of normal convergence like other backarc extensional basins. The relative northwest motion of the block west of the sliver fault was oblique, a resultant vector of the normal extension and the north–south sliver faulting. Total offset of the Sagaing Fault during this spreading history should be just the northward component, 332 km, rather than the vector sum of the sliver block of 389 km toward 327°. These reconstructions, therefore, predict total offset of the Sagaing Fault as somewhere between the extremes previously published of 203 and 460 km.

The direction and magnitude of opening of each of these stages depends on an estimate of the direction of tectonic trends or opening lines within the basin or ridge. Each was explained during the descriptions of these stages. An error of a few degrees of direction in each could amount to tens of kilometers in amount of opening because of the shapes of the features. Thus, the possible error, although indeterminate, could amount to tens of kilometers.

The strike-slip fault rate, vector BE in Fig. 17, varies with the obliquity of plate convergence, from more oblique in the north to less oblique off Sumatra. Estimates of the rates of the Sagaing Fault and Sumatra Fault System appear to confirm this. Vigny et al. (2003) estimate total strike-slip plate motion in Myanmar as 35 mm/yr, with <20 mm/yr along the Sagaing Fault itself. Our estimate of N–S motion in the Central Andaman Basin is 27 mm/yr (Table 3). Sieh and Natawidjaja (2000) and Genrich et al. (2000) estimate 25 mm/yr at northwest Sumatra, decreasing to 10–20 mm/yr in southeast Sumatra.

The E–W component of opening of the Central Andaman Basin (Table 3) at the present time is 12 mm/yr. This compares with the rate of convergence between the Andaman Islands and mainland eastern India of 15 mm/yr reported by Paul et al. (2001) from GPS surveys.

The rates of spreading or opening in the Andaman Sea appear to range widely (Table 3) from Oligocene to the present from about 7 to 38 mm/yr. Fluctuations occur, and the apparent increase is not uniform. With increasing rotation of the trend of the arc from about 120–300° to N–S, the obliquity of the convergence increased, so the rate of sliver faulting should also increase. The reversals in spreading rate are undoubtedly misinterpretations in directions and amounts of opening during each stage and misinterpretations in the times.

The outer arc ridge, the combined Andaman–Nicobar and Mentawei Ridges, varies in width, as measured by the distance from the subduction zone to the islands or crest of the ridge. It ranges from 80 km at Preparis Island at 15°N, to 95 km off the Andaman Islands, to a maximum of 150 km at Great Nicobar, to 85 km at Similue and Nias (Figs. 1, 2 and 4). It thins rapidly southeast of where the OWAF crosses the ridge. If the OWAF has always been right lateral, one would expect the ridge to be a more constant width and one would not expect the sharp bend in the trench axis and subduction zone at 2°N. This bend suggests the interesting possibility that the OWAF was initially left lateral. Pivnik et al. (1998) have considered the possibility of initial left-lateral motion on the Sagaing Fault in Myanmar because of possible movement of the Burma Block during the collision process.

At about 42 Ma, the direction of convergence between India and Asia was about 38° (Fig. 18), and the perpendicular to the alignment of a straight linear arc would have been about 038° by the rate of rotation we have assumed. This would have been normal convergence. Furthermore, if the arc were bending, as we speculated in discussion of the period 44–32 Ma, east of that point the lateral component would have been left lateral; west and NW of that point would have been right lateral. Thus, the ancestral OWAF could possibly have been left lateral for a period of time.

As stated earlier, many of the interpretations and conclusions of this paper are speculative based on limited data. Much remains to be done within the Andaman Sea and in the adjacent land areas to resolve some of this speculation. We need more rock sampling, analysis, dating and stratigraphic analysis. Further definitive magnetic surveys are needed. More seismic refraction and/or deeper penetration multichannel seismic reflection are needed. Correlation of exploration seismic reflection data with hydrocarbon exploration wells is already possible, but needs to be expanded into the deeper water areas where such exploration drilling has not and will not be extended. The bathymetry is exceedingly complex, and detailed swath mapping and detailed high resolution seismic reflection surveys will be required to understand it and the tectonics.

Finally, a recent paper by Clark et al. (2004) considers river capture and changes in drainage patterns in eastern Asia as a result mainly of Miocene (?) uplift in eastern Tibet. They raise the possibility that the Salween (Thanlwin) River had captured drainage that previously had run into the South China Sea through the Red River. Subsequently, the Irrawaddy (Ayeyarwady) River captured drainage of the Tsangpo River, and even later the Brahmaputra River captured the Tsangpo drainage and the Irrawaddy (Ayeyarwady) drainage was limited to northern Myanmar. These drainage changes would be reflected in amount and provenance of sediment coming into the Andaman Sea in this late to post-Miocene time. It also raises the possibility that studies of provenance of the sedimentary record in cores from the Andaman Sea could help to establish the timing of these changes, if the source areas show differences in mineralogy.

8. Conclusions

1. The Andaman Sea is an active backarc extensional basin lying above and behind the Sunda subduction zone where convergence is highly oblique.
2. The Andaman Sea opened during the Cenozoic by a succession of extensional episodes.
3. During each extensional episode backarc extension normal to the trend of the subduction zone combined

with strike-slip faulting of a sliver plate, first formed probably in the Eocene, to result in oblique opening.

4. During the Cenozoic collision of India with Asia, the alignment of the Sunda subduction zone gradually rotated in a clockwise direction.
5. With this rotation, obliquity increased and the opening scenario shows an apparent increase in the rate of strike-slip motion.

Acknowledgements

I have many colleagues to thank for sharing in the collection, analysis and interpretation of the information in this paper. Dave Moore and Frans Emmel were my close colleagues who contributed especially significantly through the early years of this study, as did Larry Lawver (magnetics), Bob Kieckhefer, Russ Raitt and Marilee Henry (seismic refraction work), Perry Crampton, Paul ONeil, Aung Tin U, Hla Tin, Aung Min and our other colleagues who worked with us at sea. More recently, I have been especially assisted by Bob Kieckhefer, Steve Cande, Hla Maung and Kerry Sieh. Funding for the work at sea and early years of analysis was provided by the Office of Naval Research and the National Science Foundation. Dave Moore, Dick Murphy and Kelvin Rodolfo made careful, thoughtful reviews of an early version of this paper and made many excellent suggestions for improvement. Responsibility for all interpretations and opinions is mine.

References

Acharyya, S.K., 1994. Accretion of Indo-Australian Gondwanic blocks along Peri-Indian collision margins. Ninth International Gondwana Symposium, Hyderabad, India 1994, pp. 1029–1049.

Acharyya, S.K., 1997. Stratigraphy and tectonic history reconstruction of the India–Burma–Andaman mobile belt. Indian Journal of Geology 69, 211–234.

Acharyya, S.K., 1998. Break-up of the greater Indo-Australian continent and accretion of blocks framing south and east Asia. Journal of Geodynamics 26, 149–170.

Acharyya, S.K., Ray, K.K., Sengupta, S., 1990. Tectonics of the ophiolite belt from Naga Hills and Andaman Islands, India. Proceedings Indian Academy Science (Earth Planetary Science) 99, 187–199.

Alam, M., Alam, M.M., Curray, J.R., Chowdhury, M.L.R., Gani, M.R., 2003. An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history. Sedimentary Geology 155, 179–208.

Alcock, A.W., 1902. A Naturalist in Indian Seas. John Murray Publishing Company, London, p. 328.

Ananthanarayanan, P.V., Ramdev, C.M., Murti, K.V.S., 1981. Andaman Island Arc. Workshop on Geological Interpretation of Geophysical Data. Institute of Petroleum Exploration, Oil and Natural Gas Commission, Dehra Dun, India, p. 8

Andreason, M.W., Mudfor, B., St Onge, J.E., 1997. Geologic evolution and petroleum system of the Thailand Andaman Sea basins. Indonesian Petroleum Association. Proceedings of the Petroleum Systems of SE Asia and Australasia, May 1997, IPA97-OR-44 1997.

Aung Khin, Kyaw Win, 1968. Preliminary studies of the paleogeography of Burma during the Cenozoic. Union of Burma Journal of Science and Technology 1, 241–251.

Aung Khin, Kyaw Win, 1969. Geology and hydrocarbon prospects of the Burma Tertiary geosyncline. Union of Burma Journal of Science and Technology 2, 53–81.

Aung Khin, Aung Tin U., Aung Soe, Khin Han, 1970. A study on the gravity indication of the Shan Scarp fault. Union of Burma Journal of Science and Technology 3, 91–113.

Ball, V., 1870. Notes on the geology of the vicinity of Port Blair, Andaman Islands. Journal Asiatic Society of Bengal 39, 231–239.

Bandopadhyay, P.C., Ghosh, M., 1998. Facies, petrology and depositional environment of the Tertiary sedimentary rocks, around Port Blair, South Andaman. Journal Geological Society of India 52, 53–66.

Bhattacharya, A., Reddy, C.S.S., Srivastav, S.K., 1993. Remote sensing for active volcano monitoring in barren Island, India. Ninth Thematic Conference on Geologic Remote sensing, Pasadena, California, pp 993–1003.

Bender, F., 1983. Geology of Burma. Borntraeger, Berlin, p. 260.

Bennett, J.D., Bridge, D.McC., Cameron, N.R., Djunudden, A., Ghazali, S.A., Jeffery, D.H., Keats, W., Rock, N.M.S., Thompson, S.J., Whandoyo, R., 1981. Geologic Map of the Banda Aceh Quadrangle, North Sumatra. Geologic Map. Geological Research and Development Centre, Bandung, Indonesia, p. 19.

Brunnschweiler, R.O., 1966. On the geology of the Indoburman Ranges. Geological Society Australia Journal 13, 127–194.

Brunnschweiler, R.O., 1974. Indoburman Ranges. In: Spencer, A.M. (Ed.), Mesozoic–Cenozoic Orogenic Belts Geological Society London, Special Publication 4, pp. 279–299.

Cameron, N.R., Bennett, J.D., Bridge, D.McC., Clarke, M.C.G., Djunuddin, A., Ghazali, S.A., Harahap, H., Jeffery, D.H., Keats, W., Ngabito, H., Rocks, N.M.S., Thompson, S.J., 1983. The Geology of the Takengon Quadrangle, Sumatra. Geological Map. Geological Research and Development Centre, Bandung, Indonesia, p. 26.

Chakraborty, P.P., Pal, T., 2001. Anatomy of a forearc submarine fan: Upper Eocene–Oligocene Andaman Flysch Group, Andaman Islands, India. Gondwana Research 4, 477–486.

Chakraborty, P.P., Pal, T., Gupta, T.D., Gupta, K.S., 1999. Facies pattern and depositional motif in an immature trench-slope basin, Eocene Mithakhari Group, Middle Andaman Island, India. Journal Geological Society India 53, 271–284.

Chakraborty, P.P., Mukhopadhyay, B., Pal, T., Gupta, T.D., 2002. Statistical appraisal of bed thickness patterns in turbidite successions, Andaman Flysch Group, Andaman Islands, India. Journal of Asian Earth Sciences 21, 189–196.

Chatterjee, P.K., 1967. Geology of the main islands of the Andaman Sea. Proceedings Symposium on Upper Mantle Project, Geophysical Research Board, National Geophysical Research Institute, Hyderabad, India, pp. 348–360.

Chatterjee, P.K., 1984. The Invisible Bank fault and geotectonics of the Andaman Nicobar Islands. Quarterly Journal Geological Mineral Metallurgical Society India 56, 28–40.

Chhibber, H.L., 1934. The Geology of Burma. McMillan and Co, London, p. 530.

Clark, M.K., Schoenbohm, L.M., Royden, L.H., Whipple, K.X., Whipple, K.X., Burchfiel, B.C., Tang, W., Wang, E., Chen, L., 2004. Surface uplift, tectonics, and erosion of eastern Tibet from large-scale drainage patterns. Tectonics 23 (TC1006), 1–20.

Cox, H., 1799a. An account of the petroleum wells in the Burmha Dominions, extracted from a journal of a voyage from Ranghong up in the river Erai-wuddey to Amarapoorah to the present capital of the Burmha empire. Philosophical Magazine 9, 226–234.

Cox, H., 1799b. An account of the petroleum wells in the Burmha Dominions, extracted from a journal of a voyage from Ranghong up in the river Erai-wuddey to Amarapoorah to the present capital of the Burmha empire. Asiatic Research 6, 127–136.

Curray, J.R., 1989. The Sunda Arc: a model for oblique plate convergence, Netherlands. Journal of Sea Research 24, 131–140.

Curray, J.R., 1991. Possible greenschist metamorphism at the base of a 22 km sediment section, Bay of Bengal. Geology 19, 1097–1100.

Curray, J.R., Moore, D.G., 1974. Sedimentary and tectonic processes in Bengal deep-sea fan and geosyncline. In: Burk, C.A., Drake, C.L. (Eds.), The Geology of Continental Margins. Springer, New York, pp. 617–628.

Curray, J.R., Moore, D.G., Lawver, L.A., Emmel, F.J., Raitt, R.W., Henry, M., Kieckhefer, R., 1979. Tectonics of the Andaman Sea and Burma. In: Watkins, J., Montadert, L., Dickerson, P.W. (Eds.), Geological and Geophysical Investigations of Continental Margins American Association Petroleum Geologists, Memoir 29, pp. 189–198.

Curray, J.R., Emmel, F.J., Moore, D.G., Raitt, R.W., 1982. Structure, tectonics and geological history of the northeastern Indian Ocean. In: Nairn, A.E.M., Stehli, F.G. (Eds.), The Ocean Basins and Margins. The Indian Ocean, vol. 6. Plenum Press, New York, pp. 399–450.

Curray, J.R., Emmel, F.J., Moore, D.G., 2003. The Bengal Fan: morphology, geometry, stratigraphy, history and processes. Marine and Petroleum Geology 19, 1191–1223.

Dasgupta, S., 1992. Seismotectonics and stress distribution in the Andaman plate. Memoir Geological Society of India 23, 319–334.

Dasgupta, S., Mukhopadhyay, M., 1993. Seismicity and plate deformation below the Andaman arc, northeastern Indian Ocean. Tectonophysics 225, 529–542.

DeMets, C., Gordon, R.G., Argus, D.F., Stein, S., 1994. Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions. Geophysical Research Letters 21, 2191–2194.

Dey, B.P., 1968. Aerial photo interpretation of a major lineament in the Yamethin–Pyawbwe quadrangle. Union of Burma Journal Science and Technology 1, 431–443.

Diament, M., Harjono, H., Karta, K., Deplus, C., Dahrin, M., Zen Jr.., M.T., Gérard, M., Lassai, O., Martin, A., Malod, J., 1992. Mentawei fault zone off Sumatra: a new key to the geodynamics of western Indonesia. Geology 20, 259–262.

Fitch, R., 1599. The voyage of M. Ralph Fitch, marchant of London…. Hakluyt's Principal Navigation 2, 250–268.

Fitch, T.J., 1972. Plate convergence, transcurrent faults and internal deformation adjacent to Southeast Asia and the western Pacific. Journal Geophysical Research 77, 4432–4462.

Frerichs, W.E., 1971. Paleobathymetric trends of Neogene foraminiferal assemblages and sea floor tectonism in the Andaman Sea area. Marine Geology 11, 159–173.

Gee, F.R., 1927. The Geology of the Andaman and Nicobar Islands, with special reference to Middle Andaman Island. Records of the Geological Survey of India LIX, 208–232.

Genrich, J.F., Bock, Y., McCaffrey, R., Prawirodirjo, L., Stevens, C.W., Puntodewo, S.S.O., Subarya, C., Wdowinski, S., 2000. Distribution of slip at the northern Sumatran fault system. Journal of Geophysical Research 105, 28,327–28,341.

Goosens, P.J., 1978. Earth sciences bibliography of Burma, Yunan and Andaman Islands, Third Regional Conference on Geology and Mineral Resources of Southeast Asia, Bangkok, Thailand.

Guzmán-Speziale, M., Ni, J., 1993. The opening of the Andaman Sea. Geophysical Research Letters 20, 2949–2952.

Guzmán-Speziale, M., Ni, J., 1996. Seismicity and active tectonics of the western Sunda Arc. In: An Yin, Harrison, M.T. (Eds.), The Tectonic Evolution of Asia. Cambridge University Press, Cambridge, pp. 63–84.

Guzmán-Speziale, M., Ni, J., 2000. Comment on 'Subduction in the Indo-Burman region: is it still active?' by S.P. Satyabala. Geophysical Research Letters 27, 1065–1066.

Haq, B.U., Hardenbol, J., Vail, P.R., 1987. Chronology of fluctuating sea levels since the Triassic. Science 235, 1156–1167.

Harding, T.P., 1985. Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion. American Association of Petroleum Geologists, Bulletin 69, 582–600.

Hla Maung, 1983. A new reconstruction of Southeast Asia and Gondwanaland: its relation to mantle plumes or hotspots. SEAPEX Proceedings VI, 66–70.

Hla Maung, 1987. Transcurrent movements in the Burma–Andaman Sea region. Geology 15, 911–912.

Hochstetter, F. von, 1869. Geology and physical geography of Nicobar Islands. Records Geological Survey of India 2 (Pt 3).

Holt, W.E., Chamot-Rooke, N., Le Pichon, X., Haines, A.J., Shen-Tu, B., Ren, J., 1918. Velocity field in Asia inferred from Quaternary fault slip rates and global positioning system observations. Journal of Geophysical Research 105, 19,185–19,209.

Hutchison, C.S., 1989. Geological Evolution of South-East Asia. Clarendon Press, London, p. 368.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., Shackleton, N.J., 1984. The orbital theory of Pleistocene climate: support from a revised chronology of the marine $\delta^{18}O$ record. In: Berger, A., Imbrie, J., Hays, J., Kukla, G., Saltzman (Eds.), Milankovitch and Climate. D. Riedel, Boston, pp. 269–305.

Jacob, K., 1954. The occurrence of radiolarian cherts in association with ultrabasic intrusives in the Andaman Islands, and its significance in sedimentary tectonics. Records Geological Survey India 83 (Pt 2).

Karunakaran, C., Ray, K.K., Saha, S.S., 1964a. A new probe into the tectonic history of the Andaman and Nicobar Islands. Reports of the 22nd International Geologic Congress, New Delhi, India IV, 507–515.

Karunakaran, C., Pawde, M.B., Raina, V.K., Ray, K.K., Saha, S., 1964b. Geology of South Andaman Island, India. Reports of the 22nd International Geologic Congress, New Delhi, India. XI, 79–100.

Karunakaran, C., Ray, K.K., Saha, S.S., 1964c. Sedimentary environment of the formation of Andaman Flysch, Andaman Islands, India. Reports of the 22nd International Geologic Congress, New Delhi, India XV, 226–232.

Karunakaran, C., Ray, K.K., Saha, S.S., 1968a. A revision of the stratigraphy of Andaman and Nicobar Islands, India. Bulletin of the National Institute of Sciences of India 38, 436–441.

Karunakaran, C., Ray, K.K., Saha, S.S., 1968b. Tertiary sedimentation in the Andaman–Nicobar geosyncline. Journal Geological Society of India 9, 32–39.

Karunakaran, C., Ray, K.K., Sen, C.R., Saha, S.S., Sakar, S.K., 1975. Geology of Great Nicobar Island. Geological Society of India Journal 16, 135–142.

Keats, W., Cameron, N.R., Djunuddin, A., Ghazali, S.A., Harahap, H., Kartawa, W., Ngabito, H., Rock, N.M.S., Thompson, S.J., Whandoyo, R., 1981. The Geology of the Lhokseumawe Quadrangle, Sumatra, Geological Research and Development Centre, Bandung, Indonesia. Geological Map, p. 13.

Kieckhefer, R.M., Moore, G.F., Emmel, F.J., 1981. Crustal structure of the Sunda forearc region west of central Sumatra from gravity data. Journal of Geophysical Research 86, 7003–7012.

Klootwijk, C.T., Gec, J.S., Peirce, J.W., Smith, G.M., McFadden, P.L., 1992. An early India–Asia contact: Paleomagnetic constraints from Ninetyeast Ridge, ODP Leg 121. Geology 20, 395–398.

Lawson, A.C., 1921. The mobility of the Coast Ranges of California. University of California Publications in Geology 12, 431–473.

Lee, T.T., Lawver, L.A., 1995. Cenozoic plate reconstruction of Southeast Asia. Tectonophysics 251, 85–138.

Mallet, F.R., 1895. Some early allusions to Barren Island, with a few remarks thereon. Records Geologic Survey India 28, 22–34.

McCaffrey, R., 1991. Slip vectors and stretching of the Sumatran fore arc. Geology 19, 881–884.

McCaffrey, R., Zwick, P.C., Bock, Y., Prawirdirdjo, L., Genrich, J.F., Stevens, C.W., Puntodewo, S.S.O., Subarya, C., 2000. Journal of Geophysical Research 105, 28,363–28,376.

McKenzie, D., 1978. Some remarks on the development of basins. Earth and Planetary Science 40, 25–32.

Metcalfe, I., 1984. Late Paleozoic paleogeography of SE Asia: some stratigraphic paleontological and paleomagnetic constraints, Fifth Regional Congress Geology Mineral Resources. SE Asia, Kuala Lumpur Abstr. 20.

Misra, P.C., Roy, T.K., 1984. Exploration in Andaman forearc basin its evaluation, facies trend and prospects—a review. Fifth Offshore Southeast Asia, Singapore, 4.66–4.83.

Mitchell, A.H.G., 1977. Tectonic settings for emplacement of southeast Asian tin granites. Geological Society of Malaysia, Bulletin 6, 123–140.

Mitchell, A.H.G., 1981. Phanerozoic plate boundaries in mainland SE Asia, the Himalayas and Tibet. Journal Geologic Society London 138, 109–122.

Mitchell, A.H.G., 1985. Collision-related fore-arc and back-arc evolution of the northern Sunda Arc. Tectonophysics 116, 323–334.

Mitchell, A.H.G., 1989. The Shan Plateau and western Burma: Mesozoic–Cenozoic plate boundaries and correlations with Tibet. In: Sengor, A.M.C. (Ed.), Tectonic Evolution of the Tethyan Region. Kluwer Academic Publishers, Dordrecht, pp. 567–583.

Mitchell, A.H.G., McKerrow, W.S., 1975. Analogous evolution of the Burma orogen and the Scottish Caledonides. Geological Society of America Bulletin 86, 305–315.

Mukerjee, M., 2003. The Land of Naked People. Houghton Mifflin Company, Boston, New York, p. 268.

Mukhopadyay, M., 1984. Seismotectonics of subduction and back-arc rifting under the Andaman Sea. Tectonophysics 108, 229–239.

Mukhopadyay, M., 1992. On earthquake focal mechanism studies for the Burmese arc. Current Science 62, 72–85.

Myint Thein, Kyaw Tint, Aye Ko Aung, 1981. On the lateral displacement of the Sagaing Fault. Georeports 1, 1. University of Mandalay, Burma.

Ninkovich, D., 1976. Late Cenozoic clockwise rotation of Sumatra. Earth Planetary Science Letters 29, 269–275.

Oldham, R.D., 1885. Notes on the geology of the Andaman Islands. Records Geological Survey India 18 (Pt 3).

Pal, T., Chakraborty, P.P., Gupta, T.D., Singh, C.D., 2003. Geodynamic evolution of the outer-arc–forearc belt in the Andaman Islands, the central part of the Burma–Java subduction complex. Geological Magazine 140, 289–307.

Parthasarathy, T.N., 1984. The conglomerates of Middle Andaman and their geologic significance. Journal Geological Society India 25, 94–101.

Pascoe, E.H., 1912. The oil-fields of Burma. Memoirs of the Geological Survey of India, XL, 1, 1–269.

Paul, D.D., Lian, H.M., 1975. Offshore basins of southwest Asia—Bay of Bengal to South Sea. In: Proceedings of the Ninth World Petroleum Congress, Tokyo, vol. 3, pp. 1107–121.

Paul, J., Bürgemann, R., Gaur, V.K., Bilham, R., Larson, K.M., Ananda, M.B., Jade, S., Mukal, M., Anupama, T.S., Satyal, G., Kumar, D., 2001. The motion and active deformation of India. Geophysical Research Letters 28, 647–650.

Peter, G., Weeks, L.A., Burns, R.E., 1966. A reconnaissance geophysical survey in the Andaman Sea and across the Andaman–Nicobar Island arc. Journal of Geophysical Research 71, 495–509.

Pivnik, D.A., Nahm, J., Tucker, R.S., Smith, G.O., Nyein, K., Nyunt, N., Maung, P.H., 1998. Polyphase deformation in a fore-arc/back-arc basin, Salin subbasin, Myanmar (Burma). American Association of Petroleum Geologists Bulletin 82, 1837–1856.

Polachan, S., Racey, A., 1994. Stratigraphy of the Mergui Basin, Andaman Sea: implications for petroleum exploration. Journal of Petroleum Geology 17, 373–406.

Prawirodirdjo, L., Bock, Y., Genrich, J.F., 2000. One century of tectonic deformation along the Sumatran fault from triangulation and global positioning system surveys. Journal of Geophysical Research 105, 28,343–28,361.

Raju, K.A.K., Ramprasad, T., Rao, P.S., Rao, B.R., Varghese, J., 2004. New insights into the tectonic evolution of the Andaman basin, northeast Indian Ocean. Earth and Planetary Science Letters 221, 145–162.

Replumaz, A., Tapponnier, P., 2003. Reconstruction of the deformed collision zone between India and Asia by backward motion of lithospheric blocks. Journal of Geophysical Research 108, ETG 1-1-24.

Richter, B., Fuller, M., 1996. Paleomagnetism of the Sibumasu and Indochina blocks: implications for the extrusion tectonic model. In: Hall, R., Blundell, E. (Eds.), Tectonic Evolution for Southeast Asia Geological Society Special Publication No. 106, pp. 203–224.

Richter, B., Fuller, M., Schmidtke, E., Tin Myint, U., Tin Ngwe, U., Mya Win, U., Bunapas, S., 1993. Paleomagnetic results from Thailand and Myanmar: implications for the interpretation of tectonic rotations in Southeast Asia. Journal of Southeast Asian Earth Sciences 8, 247–255.

Richter, B., Schmidtke, E., Fuller, M., Harbury, N., Samsudin, A.R., 1999. Paleomagnetism of peninsular Malaysia. Journal of Asian Earth Sciences 17, 477–519.

Rink, P.H., 1847. Die Nikobar Inseln. Eine Geographische Skizze, mit speciieller Berüksichtigung der Geognosie, Kopenhagen. Translated Selections, Records Government India LXXVII, 540.

Rodolfo, K.S., 1969a. Bathymetry and marine geology of the Andaman basin, and tectonic implications for Southeast Asia. Geological Society of America Bulletin 80, 1203–1230.

Rodolfo, K.S., 1969b. Sediments of the Andaman basin, northeastern Indian Ocean. Marine Geology 7, 371–402.

Roy, T.K., 1983. Geology and hydrocarbon prospects of Andaman–Nicobar basin. In: Bhandari, L.L. (Ed.), Petroliferous Basins of India Petroleum Asia Journal, pp. 37–50.

Roy, T.K., 1986. Petroleum prospects of the frontal fold belt and subduction complex associated with the Indian plate boundary in the northeast. Proceedings of the Southeast Petroleum Exploration Society VII, 192–212.

Roy, S.K., 1992. Accretionary prism in Andaman forearc. Geological Survey India Special Publication 29, 273–278.

Roy, T.K., Chopra, N.N., 1987. Wrench faulting in Andaman forearc basin, India. Proceedings Offshore Technology Conference 19, 393–404.

Roy, D.K., Acharyya, S.K., Ray, K.K., Lahri, T.C., Sen, M.K., 1988. Nature of occurrence, age, and depositional environment of the oceanic pelagic sediments associated with the ophiolite assemblage, South Andaman Islands, India. Indian Minerals 42, 31–56.

Satabala, S.P., 1998. Subduction in the Indo-Burman region: is it still active?. Geophysical Research Letters 25, 3189–3192.

Sewell, R.B.S., 1925. The geography of the Andaman Sea basin. Asiatic Society of Bengal 9, 1–26.

Sieh, K., Natawidjaja, D., 2000. Neotectonics of the Sumatran fault, Indonesia. Journal of Geophysical Research 105, 28,295–28,326.

Smith, W.H.F., Sandwell, D.T., 1997. Global seafloor topography from satellite altimetry and ship depth soundings. Science 277, 1956–1962.

Srinivasan, M.S., 1979. Geology and mineral resources of the Andaman and Nicobar Islands, Andaman Nicobar Information 1978–1979. Government Printing Office, Port Blair.

Srinivasan, M.S., 1986. Neogene reference sections of Andaman–Nicobar: their bearing on volcanism, sea-floor tectonism and global sea-level changes. In: Ghose, N.C., Varadarajan, S. (Eds.), Ophiolites and Indian Plate Margin, pp. 295–308.

Srinivasan, M.S., Azmi, R.J., 1979. Correlation of late Cenozoic marine sections in Andaman–Nicobar, northern Indian Ocean and the equatorial Pacific. Journal of Paleontology 53, 1401–1415.

Stephenson, D., Marshall, T.R., 1984. The petrology and mineralogy of Mt. Popa and the nature of the late-Cenozoic Burma volcanic arc. Journal Geological Society of London 141, 747–762.

Suess, E., 1904. The Face of the Earth, vol. 5. Clarendon Press, Oxford.

Tankard, A.J., Balkwill, H.R., Mehra, A., Aung Din, 1998. Tertiary wrench fault tectonics and sedimentation in the central basin of Burma. American Association of Petroleum Geologists Bulletin 78, 1165, (Abstr.).

Tapponnier, P., Peltzer, G., Le Dain, A.Y., Armijo, R., Cobbold, P., 1982. Propagating extrusion tectonics in Asia: new insights from simple experiments with plasticine. Geology 10, 611–616.

Tapponnier, P., Peltzer, G., Armijo, R., 1986. On the mechanics of the collision between India and Asia, In: Coward, M., and Ries, A.C. (Eds), Collision Tectonics, Geological Special Publication No. 19, pp. 115–157

Tipper, G.H., 1911. The geology of the Andaman Islands. Memoir Geological Survey India 35, 195–216.

Van Linschoten, V.J.H., 1595. Itinerario Voyage ofte Schipvaert, Van Jan Huygen Van Lindschoten naer ooste ofte Portugaels Indien, Amstelredam.

Varga, R.J., 1997. Burma. In: Moores, E.M., Fairbridge, R.W. (Eds.), Encyclopedia of European and Asian Regional Geology. Chapman and Hall, London, pp. 109–121.

Vigny, C., Socquet, A., Rangin, C., Chamot-Rooke, N., Pubellier, M., Bouin, M.-N., Bertrand, G., Becker, M., 2003. Present-day crustal deformation around Sagaing Fault, Myanmar. Journal of Geophysical Research 108, ETG 6-1-10.

Weeks, L.A., Harbison, R.N., Peter, G., 1967. Island arc system in the Andaman Sea. American Association of Petroleum Geologists Bulletin 51, 1803–1815.

Wegener, A., 1966. The Origin of Continents and Oceans. Dover Publications, New York, p. 246.

Win Maw, Myint Kyi, 1998. Prospecting the Moattama/Tanintharyi Shelf of Myanmar, Proceedings, Gas Habitats of SE Asia and Australian Conference. Indonesian Petroleum Association.

Win Swe, 1972. Strike-slip faulting in central belt of Burma (abs). In: Haile, N.S. (Ed.), Regional Conference on the Geology of Southeast Asia, Kuala Lumpur, Malaysia Annex to Newsletter No. 34, p. 59.

Win Swe, 1981. A major strike-slip fault in Burma. Contributions to Burmese Geology 1, 63–72.

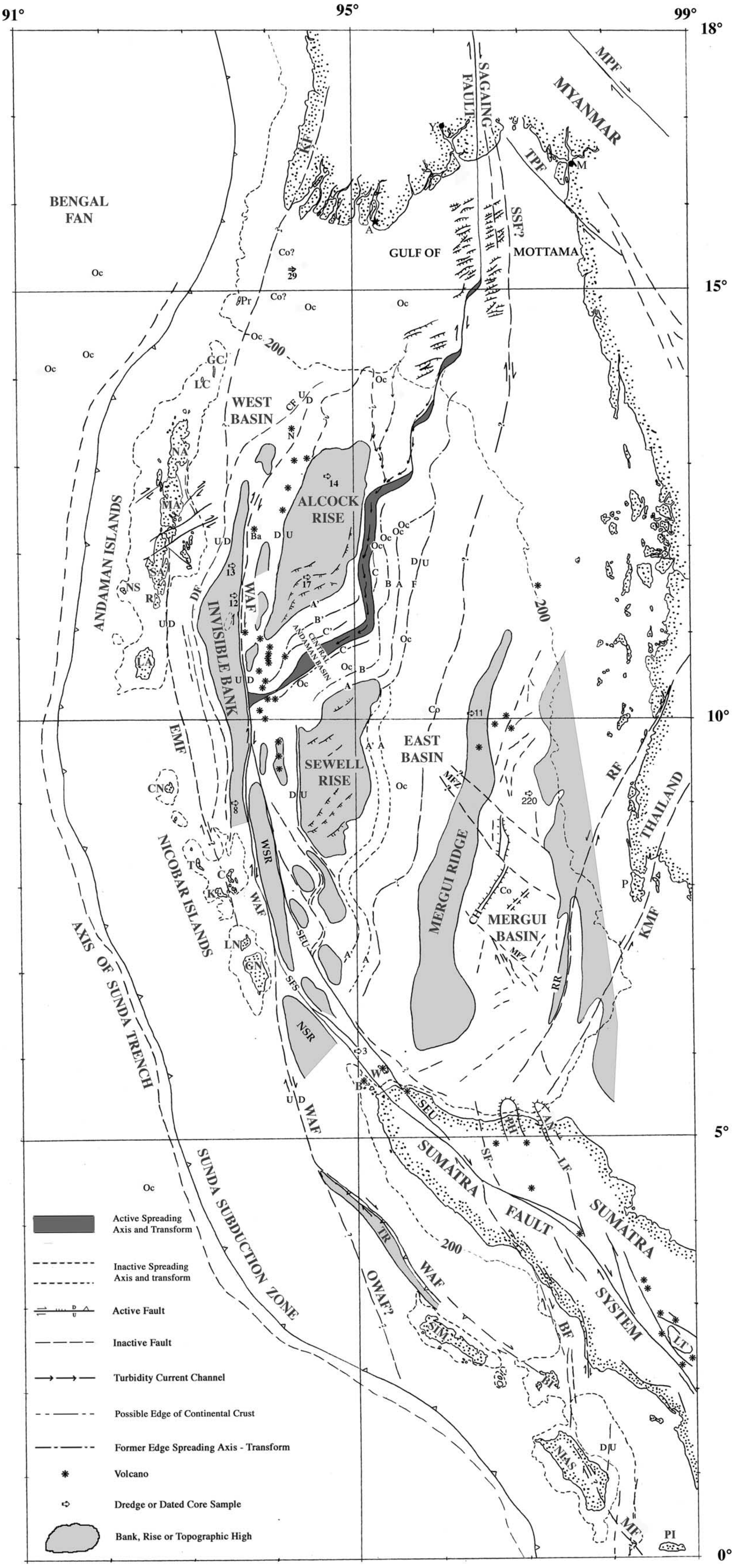

Fig. 4. Tectonic map of the Andaman Sea and adjacent southern Myanmar and northern Sumatra. Abbreviations for this and subsequent figures: A is Ama Village, AN is Arun High, B is Brueh Island, Ba is Barren Island, BF is Battee Fault, BI is Banyak Islands, C is Camorta Island, CF is Cocos Fault, CH is Central Horst, CN is Car Nicobar Island, Co is continental crust refraction determination, DF is Diligent Fault, EMF is Eastern Margin Fault, EP is Elephant Point, GC is Great Cocos Island, GN is Great Nicobar Island, K is Katchall Island, KF is Kabaw Fault, KMF is Khlong Marui Fault, LA is Little Andaman Island, LC is Little Cocos Island, LF is Lhokseumawe-Lopok Kutacane Fault, LN is Little Nicobar Island, LT is Lake Toba, M is Mawlamyine (Moulmein), MA is Middle Andaman Island, MF is Mentawei Fault, MFZ is Mergui Fault, MPF is Mae Ping Fault, N is Narcondam Island, NA is North Andaman Island, NS is North Sentinal Island, NSR is North Sumatra Ridge, Oc is oceanic crust refraction determination, OWAF is Old West Andaman Fault, P is Phuket Island, PH is Peusangan High, PI is Pini Island, Pr is Preparis Island, R is Rutland Island, RF is Ranong Fault, RR is Ranong Ridge, SA is South Andaman Island, SEU is Seulimeum strand of SFS, SF is Samalanga Sipokok Fault, SFS is Sumatra Fault System, SIM is Simeuleu Island, SSF is Shan Scarp Fault, T is Terressa Island, TPF is Three Pagodas Fault, TR is Tuba Ridge, W is Weh Island, WAF is West Andaman Fault, WSR is West Sewell Ridge, Y is Yangon (Rangoon). Dredge and dated core samples: ***17***, dredge I-17, moderately fractionated tholeitic basalt (J.W. Hawkins, personal communication ~11.5°N, deepth ~900–1250 m, dates 19.8 ± 0.7, 20.5 ± 1.0 my; ***29***, dredge C-29, Miocene deep-water shale (F.L. Parker, personal communication, 1968), depth ~1350–2100 m; The following from Frerichs (1967) and Rodolfo (1969a,b): ***3***, altered hypersthene augite basalt, ~11°N; ***8***, radiolarite shale, post-early late Miocene, ~10 my, uplifted > 2000 m, plus altered extrusive rock ~9°N; ***11***, unaltered vesicular basalt from a 120 m pinnacle on the shelf, ~1.5–2 my, ~10°N; ***12***, late lower Miocene calcarenite and calcilutite, ~17 my, uplifted ~400 m, ~11.5°N; ***13***, late upper Miocene calcarenite and calcilutite, ~6 my, uplifted > 500 m, ~12°N; ***14***, tabular, massive unaltered intergranular augite basalt, undated; ***220***, core of early Pliocene shale, ~5 my, subsided > 100 m, ~13°N.