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RELICT FAUNAL TESTIMONY FOR SEA-LEVEL FLUCTUATIONS OFF MYANMAR (BURMA)

RAJANI PANCHANG[a,*], RAJIV NIGAM[a], G. V. RAVI PRASAD[b], G. RAJAGOPALAN[b], D. K. RAY[b] and U. KO YI HLA[c]

[a]MICROPALAEONTOLOGY LAB., GEOLOGICAL OCEANOGRAPHY DIVISION, NATIONAL INSTITUTE OF OCEANOGRAPHY, GOA 403 004, INDIA
[b]INSTITUTE OF PHYSICS, SACHIVALAYA MARG, BHUBANESWAR, ORISSA 751 005, INDIA
[c]DEPARTMENT OF GEOLOGY, UNIVERSITY OF MAWLAMYINE, MYANMAR 12012
*E-mail: prajani@nio.org

ABSTRACT

The distribution and ecological significance of the relict benthic foraminiferal assemblage found in the study area off Myanmar is discussed here. Of the 126 surface sediments studied for foraminiferal content, relict foraminiferal assemblage comprising the genera *Operculina-Amphistegina-Calcarina-Alveolinella-Heterostegina* were encountered at 22 different locations nearly parallel to the west coast of Myanmar. Soft coral sclerites, coral rubble and calcareous algae were found associated with this assemblage. These signatures confirm the existence of fossil patch reefs in the region, which were never reported before. A conceptual framework is proposed to explain the proliferation of coral patches at different depths during different times in the geological past. Radiocarbon AMS dating of 7 select samples representing different depths revealed different ages at different depths. To derive a sea-level curve, the sea level was assigned to 17.5 m above the depth of finding the relict fauna as deciphered from soft coral assemblage. On the basis of the faunal ecology and chronology, for the first time a sea level curve for the past 16,000 radiocarbon years is proposed for the west coast of Myanmar. This study suggests an episodic sea-level rise in the region. A comparison of this sea level curve with the ones proposed for the East and West coasts of India indicates that in addition to the global Holocene sea level rise, tectonic vertical displacement is the cause of the destruction of the soft coral patches off west coast of Myanmar.

Keywords: Relict Foraminifera, soft coral sclerites, AMS dates, sea level, subsidence, Myanmar

INTRODUCTION

The Bay of Bengal has always been the least understood water mass in the Indian Ocean, particularly towards its east, with very few studies carried out along the west coast of Myanmar and the Andaman Sea. Thus, the 'India-Myanmar Joint Oceanographic Studies' were initiated by the Ministry of External Affairs, Government of India, with active support from the Department of Ocean Development (DOD) and Council of Scientific and Industrial Research (CSIR), to understand this region better. Global climate change has become synonymous with global warming, of which sea level rise is the most dreaded consequence. At the direct risk of assured inundation are the coastal low-lying regions all over the globe which are most populated. Thus, the estimation of past, present and thereby future sea-level fluctuations remains a major challenge to palaeoclimatologists. The results brought out by the IGCP Project 61 demonstrated that determination of a single sea-level curve of global applicability was an illusory task. Thus, the need was felt for individual regions to be studied for local sea-level histories considering all local influencing factors (Pirazzoli, 1991; Stanley, 1995). Several attempts have been made to reconstruct past sea levels in regions adjoining the study area, namely West Coast of India (Bruckner, 1989; Merh, 1992; Hashimi *et al.*, 1995; Rao *et al.*, 1996; Vora *et al.*, 1996; Mazumder, 2005), East Coast of India (Vaz, 1996 and 2000; Vaz and Bannerjee, 1997; Banerjee, 2000; Rana *et al.*, 2007), Thailand – (Sinaskul, 1992) and South China Sea (Yim *et al.*, 2006). However, the coast of Myanmar had remained unexplored in terms of signatures of high resolution sea-level history before the present study. Being a promising basin in terms of petroleum and natural gas reserves as well as a tectonically active margin, the study area faces far reaching consequences of sea-level fluctuations. Thus, the present results not only form baseline data for future workers but are also very promising for the academia and industry alike.

The marine protists, Foraminifera, have been chosen as a proxy to meet our objectives because of their dual utility. First, their sensitivity to slight changes in their environment and extensive preservation potential make them useful in palaeoclimatic analysis. Secondly, their distribution is indicative of the various physical, chemical, biological and geological processes pertaining to the study area. The objective of this paper is to present foraminiferal evidence supported by other relict coral fauna and AMS ^{14}C dates for sea level fluctuations along the west coast of Myanmar.

REGIONAL SETTING

The Coast of Myanmar can be divided into two significant physiographic divisions; the western Rakhine Coast opening into the Bay of Bengal and the southern Ayeyarwady delta (former Irrawaddy), Gulf of Martaban and the Mergui platform into the Andaman Sea. The Andaman-Nicobar Ridge, which is a part of the northern segment of the Sunda subduction zone, separates the Andaman Sea, from the Bay of Bengal. The western margin along the Sunda Trench is an oblique convergence continental and arc margin. The sedimentary cover over the subducting plate is very thick because of the Bengal Fan (Curray *et al.*, 2003), and the 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 (Curray, 2005). The outer shelf in the Gulf of Martaban has a rough topography and is characterized by features such as pinnacles, highs, and valleys, buried channels and scarps. The sediments in the outer-shelf of the Ayeyarwady is constituted by >80% relict sands (Rao *et al.*, 2005). A complex system of N-S trending dextral strike slip faults runs through the Ayeyarwady shelf and the Gulf of Martaban, the most promi-

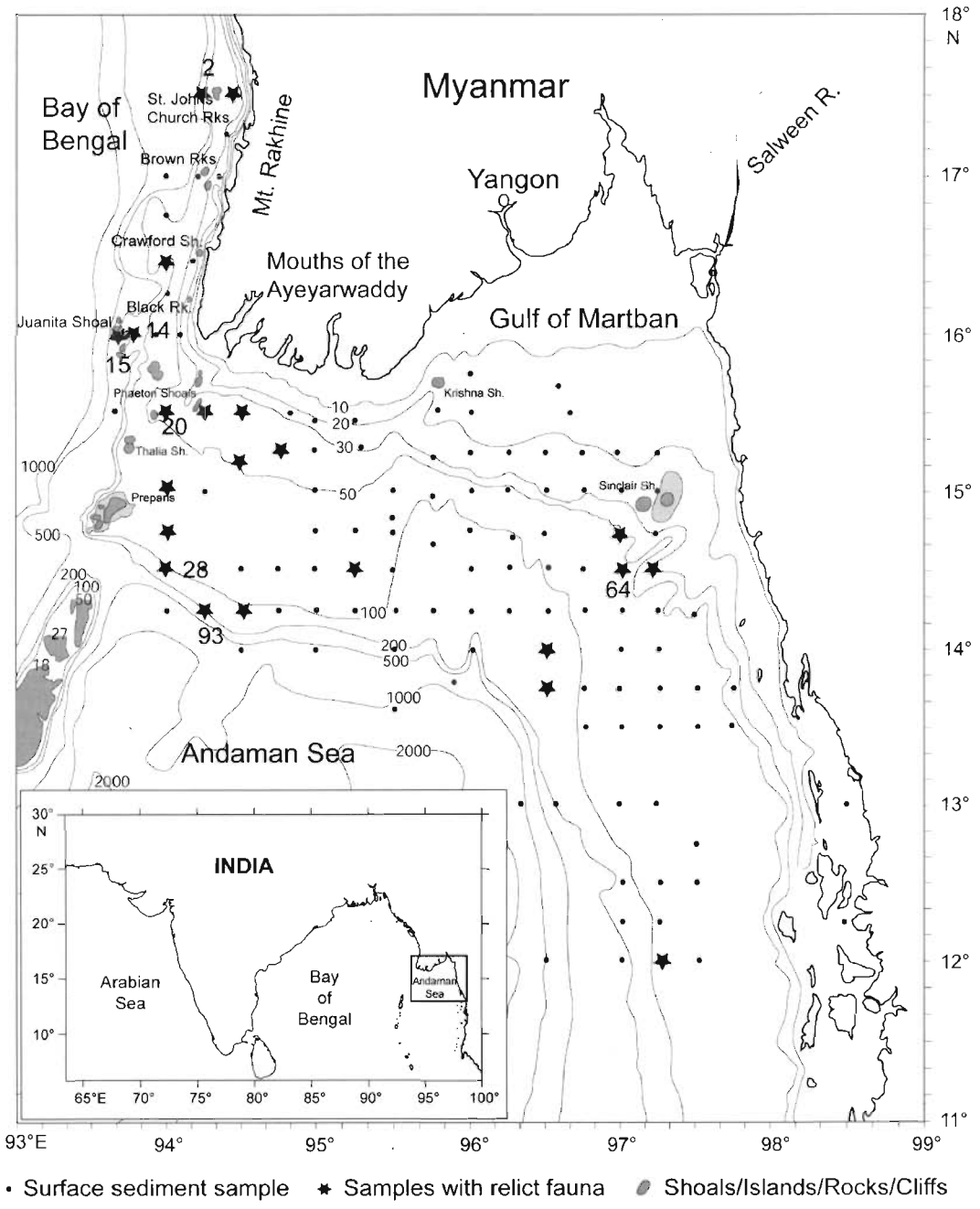

Fig. 1. Location map of the study area showing the sampling stations. Table 1 should be followed for precise depth of each station. Contours filled with shades of grey indicate submerged islands and shoals. The stations accompanied by station numbers indicate the locations at which AMS dates have been procured.

nent being the Sagaing Fault System that extends southwards to join the Central Andaman Rift (Kamesh Raju *et al.*, 2004). Coral reefs are only found away from the river delta and mainly around islands along the southern coast near the Thai border, particularly in the Mergui Archipelago. This string of over 800 islands has not been studied properly since the 1800s (IUCN/UNEP 1988). Recently, Spalding (2001) reported around 97 scleratinian coral species and 67 hermatypic coral genera from these islands.

MATERIALS AND METHODS

In April 2002, 126 grab samples (surface sediments, top 2 cm) were collected (Fig.1) on board ORV Sagar Kanya. Of these, 22 samples contained relict Foraminifera (discussed later), which form the basis for the present investigations. Echo-sounding data was acquired along the cruise track with Elac deep sea echo sounder operating at 12 kHz.

For foraminiferal investigations, ~15 g of sediment sample was first kept in the oven for drying overnight at 60° C. The dried samples were then soaked in water for a day. To disperse the lumps of clay in the samples, sodium hexametaphosphate was added and kept for a day. Then hydrogen peroxide was added and kept overnight to remove the organic matter. Finally, the samples were washed through a 63μm sieve using a

shower with a low water pressure to prevent foraminiferal test breakage. The sand fraction thus obtained was dried and examined for the total (living + dead) foraminiferal assemblage.

The sand fractions of 22 samples contained relict foraminifera along with soft coral sclerites, coral debris, coralline algae and coarse coral sand. Those foraminiferal specimens that looked quite different to the normal Recent benthic Foraminifera were termed 'relict'. Following the criteria defined by Murray (1973), they could be identified by their dull lustre, yellowish to grey colour and slightly broken to abraded surfaces, with identifying features intact. Their appearance indicated their relict nature suggesting that they have been lying on the surface of the ocean bottom, without being buried under sediments. The details regarding the sediment texture and percentage abundance of relict fauna in these 22 samples is tabulated in Table 1. Specimens of the relict foraminiferal assemblage from seven samples were dated at the Institute of Physics, Bhubaneswar using accelerator mass spectrometry (AMS) technique. 10-15% of sand fraction comprised of soft coral sclerites, which were also identified.

RESULTS

The 22 samples with relict Foraminifera have a depth range of 29-160m, but their spatial distribution is dispersed and discontinuous (Fig. 1). The relict foraminiferal assemblage mainly comprises *"Alveolinella, Operculina, Amphistegina, Calcarina, and Heterostegina"* (Fig. 2a-e). A complete list of the relict faunal species is presented in Table 2 which commonly comprises 'larger foraminiferal species', characteristic of coral reef environments.

The stations with relict foraminiferal assemblage also showed the presence of some other relict fauna. This comprised of soft coral sclerites (Fig. 3a), solitary caryophyllids (Fig. 3b and c), coralline algae (Fig. 3d) coral debris and coarse coral sand. The soft coral sclerites found in these samples belong to soft coral assemblage *"Siphonogorgia, Chironephthya, Subergorgia, Acalycigorgia* and *Ctenocella"* assemblage (Fig. 4a-e).

The relict fauna occurs as discontinuous patches at variable depths along the sampling tract. Even the water depth at which this relict fauna appears is variable. The details of AMS ^{14}C dates obtained on the 7 samples are tabulated in Table 3.

Table 1: Details of sediment texture and relict foraminiferal abundance in samples containing relict fauna. Depths mentioned have been recorded using echo-sounder, onboard during sample collection.

Sample No.	Depth (m)	Sediment Texture	Percentage abundance of Relict foraminifera
SK-175/2	137	Clayey Silty Sand	84%
SK-175/3	49	Clayey Silty Sand	39%
SK-175/9	132	Sandy Silty Clay	7%
SK-175/14	160	Sand	11%
SK-175/15	29	Sand	36%
SK-175/20	33	Sand	82%
SK-175/21	32	Sand	45%
SK-175/22	37	Clayey Sand	13%
SK-175/24	35	Sand-Silt-Clay	30%
SK-175/25	47	Clayey Sand	15%
SK-175/27	70	Clayey Sand	22%
SK-175/28	76	Sand-Silt-Clay	15%
SK-175/29	105	Sand	22%
SK-175/61	40	Sand-Silt-Clay	2%
SK-175/63	35	Sand	40%
SK-175/64	52	Sand	70%
SK-175/75	73	Sand	15%
SK-175/92	97	Sand	63%
SK-175/93	122	Sand	40%
SK-175/102	110	Sand	35%
SK-175/103	138	Sand	5%
SK-175/127	92	Sand	8%

Table 2: List of species constituting the relict foraminiferal assemblage in the study area; species have been listed alphabetically and classified on the basis of their abundance. The larger foraminiferal species is indicated by an asterix.

Occurrence	Species
Abundant:	*Alveolinella quoii**
	*Alveolinella Sp.**
	*Amphistegina bicirculata**
	*Amphistegina papillosa**
	*Amphistegina radiata**
	*Calcarina hispida**
	*Calcarina spengleri**
	*Gypsina vesicularis**
	*Heterostegina operculinoides**
	*Heterostegina sub-orbicularis**
	*Nummulites cummingi**
	*Operculina ammonoides**
	*Operculina granulosa**
	*Operculina heterosteginoides**
	*Parasorites orbitolitoides**
	*Planorbulinella acervalis**
	*Planorbulinella larvata**
Common:	*Asterorotalia dentata*
	Cycloforina semiplicata
	Elphidium crispum
	Elphidium macelliforme
	*Peneroplis pertusus**
	Quinqueloculina elongata
	Quinqueloculina kerimatica
	Quinqueloculina laevigata
	Quinqueloculina parkeri
	Quinqueloculina partschii
	Quinqueloculina rariformis
	Rotalidium annectens
	Septotextularia rugosa
	Siphogenerina raphanus
	Siphogenerina transversus
	*Sphaerogypsina globulus**
	Textularia pseudocarinata
Rare:	*Cornunuspiroides compressa* Amma*
	Coscinospira hemprichii Ehrenberg 1840*
	Hauerina elongata
	Pseudohauerina ornatissima
	*Siphoniferoides siphoniferus**
	*Spincterules anaglyptus**
	Spiroloculina subimpressa

DISCUSSION

Three groups of organisms are responsible for the construction of coral reefs. Besides scleratinian-corals and coralline algae, the Foraminifera are extremely abundant in coral reef environments. The coral reef environments are known for prolific development of algal symbiont-bearing Foraminifera. However, the foraminiferal assemblage of a coral reef ecosystem is distinctive as they grow to large sizes, in some cases reaching a few centimetres (Hohenegger, 1996), commonly termed

Table 3: Details of surface samples dated and AMS ^{14}C dates obtained.

Geographic Location		Sample Number	Depth of Sample (m)	^{14}C age (yr. BP)	Calibrated age
Lat. °N	Long. °E				
17°29'	94°15'	SK-175/2	137	9,968 (±130)	8,969 (±183) BC
16°00'	93°73'	SK-175/14	160	13,840 (±150)	13,840 (±273) BC
16°00'	93°68'	SK-175/15	29	996 (±95)	1,376 (±71) AD
15°49'	94°00'	SK-175/20	33	2,997 (±85)	825 (±101) BC
14°74'	93°99'	SK-175/28	76	7,354 (±100)	5,855 (±105) BC
14°50'	97°00'	SK-175/64	52	3,394 (±110)	1,276 (±150) BC
14°25'	94°26'	SK-175/93	122	11,567 (±100)	11,092 (±95) BC

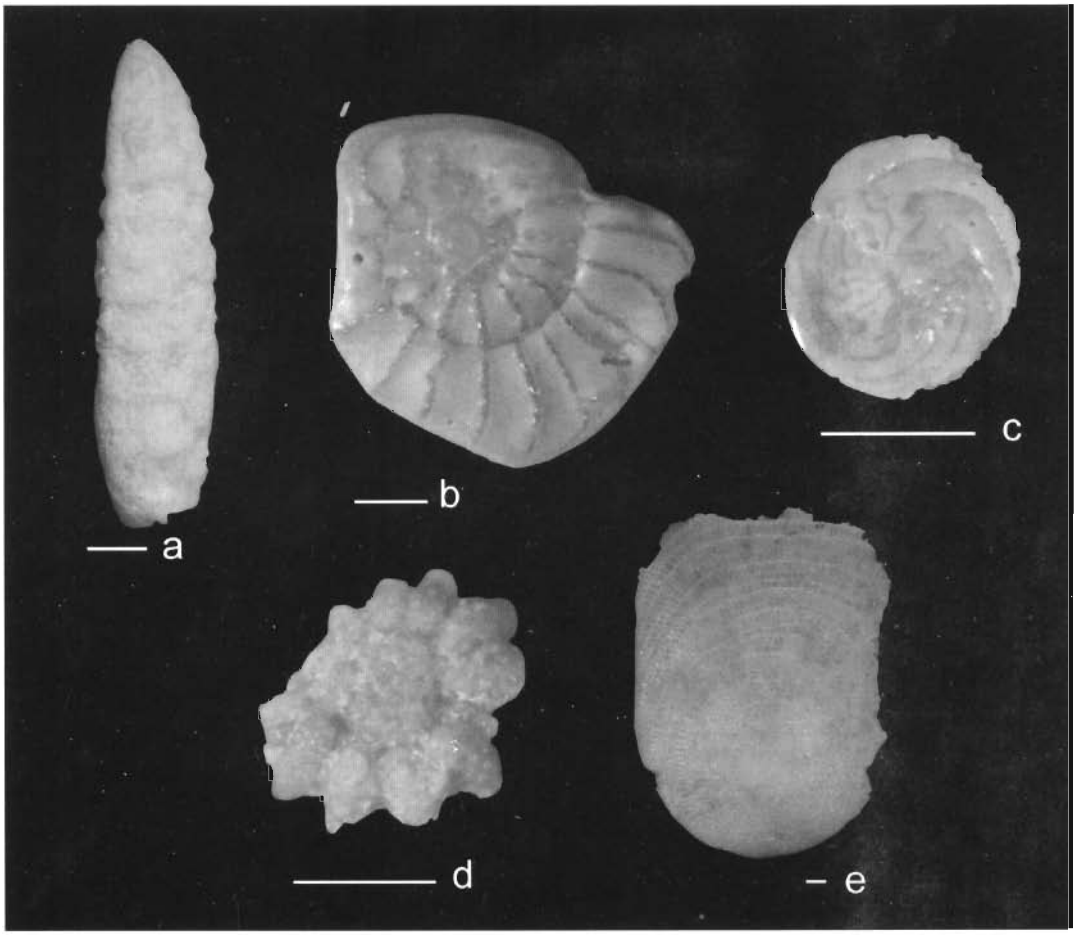

Fig. 2. Relict larger foraminiferal assemblage encountered along the west coast of Myanmar (present study): a. *Alveolinella*, b. *Operculina*, c. *Amphistegina*, d. *Calcarina*, e. *Heterostegina* (Scale Bar = 2000 μm).

"Larger Foraminifera". The larger foraminiferal assemblage in the present study comprising *"Alveolinella, Operculina, Amphistegina, Calcarina, Heterostegina"* (Fig. 2a-e), is reported to inhabit modern reefs (Cockey *et al.*, 1996; Hallock, 2000; Hart and Kaesler, 1986; Hohenegger et al, 1999; Langer and Lipps, 2003; Saraswati, 2002; Venee-Peyre, 1985). But those Foraminifera found in present study are 'relict' as indicated by their dull, earthy lustre, grey to brown colour, and ageing, biofouling and deterioration of the tests over the time. They are interpreted to indicate the presence of former reefs in the study area.

Another important observation is that these relict Foraminiferal tests show no indications of transport or reworking such as fracturing, breakage, polishing, rounding abrasion, secondary replacement of test material or obliteration of identifying features. This eliminates the possibility of their being transported from another location.

Secondly, a similar relict reef-foraminiferal assemblage (*Alveolinella, Amphistegina, Operculina*) indicative of coral reefs has been encountered at a comparable depth range of 90-135m along the west coast of India (Mazumder, 2005). Mazumder has suggested the occurrence of a palaeo-reef off the coast of Goa, dated to 11,000 years ago. He reinforces the postulation by Vora *et al.* (1996) who using East-West echo-sounding profiles along the length of the West coast confirmed the existence of a North-South trending palaeo-reef

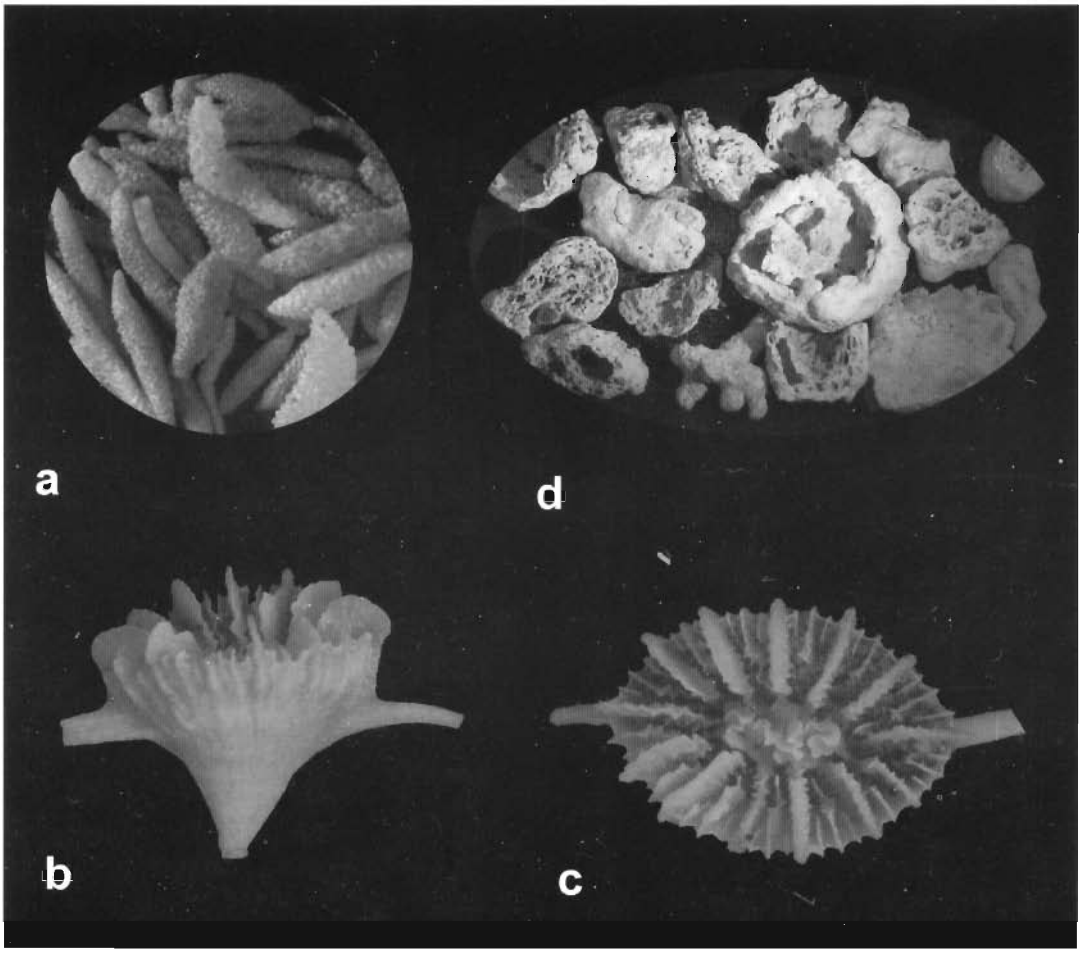

Fig. 3. Associated coral fauna; a. Microphotograph showing bulk sclerites (25x); b. side view of a caryophyllid specimen (7x); c. top view of the same caryophyllid specimen; d. Coral rubble and debris; transverse sections of a few specimens show the concentric growth of coralline algae.

parallel to the West-coast of India. Furthermore, both studies argue that the postulated reef was destroyed during the Holocene sea-level rise.

A comparison of echo-sounding records in the two areas only enhanced the degree of similarity along the two coastlines. The echograms obtained along E-W profiles off Rakhine coast of Myanmar exhibited 'peaks' and 'pinnacles' (Fig. 5a) at several locations (Eg. Station 2, 9, 13, 14, 15, 20, 28) comparable to those obtained by Vora *et al.* (1996) along the West coast of India (Fig. 5b) and interpreted as palaeo-reefs.

The existence of palaeo-reefs is further indicated by the abundant occurrence of soft coral sclerites. Most soft corals form "spicules" in their soft tissues (endoskeleton) which get preserved as fossils. The soft corals are an extremely diverse group and show variation in distribution based on their depth preferences. The sclerites are typical to different species and thus can be used in identifying the soft coral species that produced them (Van Alstyne *et al.*, 1992; Gosliner *et al.*, 1996). In the present study, the sclerites were identified to belong to the *"Siphonogorgia, Chironephthya, Subergorgia, Acalycigorgia and Ctenocella"* assemblage (Fig. 4a-e). These genera of soft corals prefer hard rocky substrates and are restricted to shallow depths (maximum 32 m).They are common inhabitants of the Indo-Pacific coral reefs and occur on reef slopes, barrier walls and other vertical surfaces (Gosliner *et al.*, 1996).

Based on the relict larger Foraminifera, the echo-sounding records, soft coral sclerites, calcareous algae and coral debris in the samples along the west coast of Myanmar, it is logical to postulate the existence of a palaeo-reef parallel to much of the coast of Myanmar. We further discuss why the relict fauna occurs in patches and at variable depths.

The Indian Naval Hydrographic Chart No.41 (published in 1979 by the National Hydrographic Office, Dehra Dun, India) was referred for an overview of the bathymetry in the region. The Rakhine coast slopes abruptly and the shelf is extremely narrow. But towards the south, the Ayeyarwady deltaic sediments extend far into the sea, giving rise to a gentle slope. A series of topographic highs, with rather small aerial extent can be noticed at certain locations. From North to South these can be identified as St. John's or Church Rocks (35 m water depth), Brown Rocks (40 m), Hnget-taung Kyun (20 m), Crawford Shoal (25 m), Black Rocks (23 m), Juanita Shoal with a surrounding group (29-58 m), Phaeton shoals (6-23 m), Thalia Shoal (18-44 m) and groups of shoals within the Preparis Channel. All these shoals are shown in grey in Figure 1. Similar small shoals also occur in the outer shelf parallel to the deltaic coastline to the south. Most of these are also the sites where the relict fauna occurs. The outer

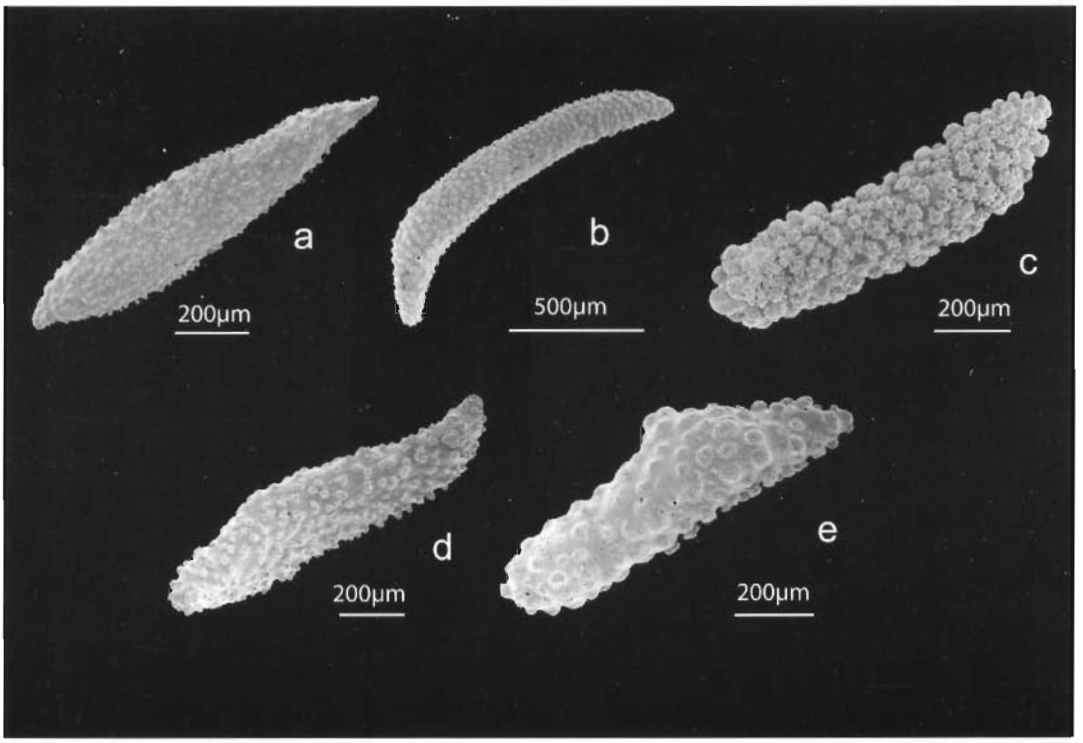

Fig. 4. Sclerites of the soft coral assemblage encountered during the present study; a. *Siphonogorgia*, b. *Chironephthya*, c. *Subergorgia*, d. *Acalycigorgia and* e. *Ctenocella* (Scale Bar = 2000 µm).

shelf has been reported as a zone of non-deposition, starved of modern fine-grained sediments (Rao *et al.*, 2005). Based on the presence of relict Foraminifera in this region, Rudolfo (1969) suggested that the outer relict shelf sands were probably deposited during the Holocene transgression. The exposure of the relict sands near the Ayeyarwady River mouths points to the lack of cross shelf transport of the river sediments. The suspended sediment concentration and the sediment distribution pattern show that most of the river discharge is transported eastward along the coast into the Gulf of Martaban (Ramaswamy *et al.*, 2004).

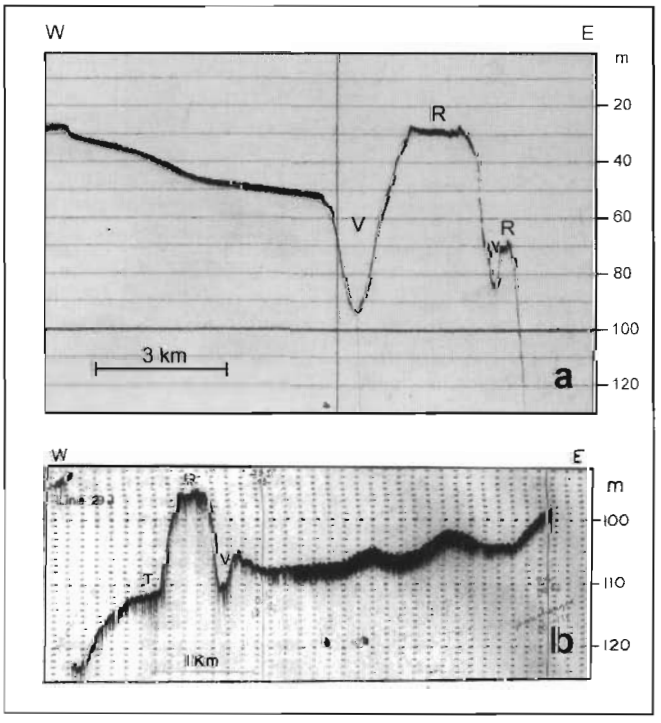

Fig. 5. Comparison between E-W echograms obtained along the west coast of a. Myanmar (station 14 and 15 in the present study) and b. India (Vora *et al.*, 1996).

The echograms (eg. Fig. 5a) show 'pinnacles' only across the shoaling sites; in between two such locations the seafloor depicted by the echogram is flat. The echo-sounding data and bathymetry thus portray that the ocean bottom at such locations is exceptionally steeply sloping and giving rise to small submerged islands or groups of islands which are restricted in aerial extent. The chain of islands between Myanmar and the Andaman-Nicobar Archipelago are well known, though they have been hardly studied. But the small cliffs / islands / shoals close to the coastline of Myanmar are inconspicuous and seem to be neglected as they do not fall into the purview of extensive navigation. In view of the foregoing, the occurrence and distribution of the relict fauna in the study area can be explained with the help of a schematic diagram (Fig. 6) as follows:

The flat relieves have been sites of sediment accumulation whereas the pinnacles, formed due to tectonic accretion (Bender, 1983; Brunnschweiler, 1974; Subramanian, 2005) obviously have escaped sedimentation. It has been reported that corals do not develop without a stable substratum to attach and optimum depth-light conditions (Fox, 2001; The Coral Reef Alliance, 2004). Given the conditions, the corals found these so-called 'submerged islands' ideal sites to nucleate and grow. This explains the intermittent absence of relict coral reef fauna along the tract. It is a well known fact that the sea level has been lower than the present quite a few times in the geological past (Hashimi *et al.*, 1995). After each standstill the sea level has risen in episodes, sometimes gradually and sometimes rapidly. Thus we postulate that the relict

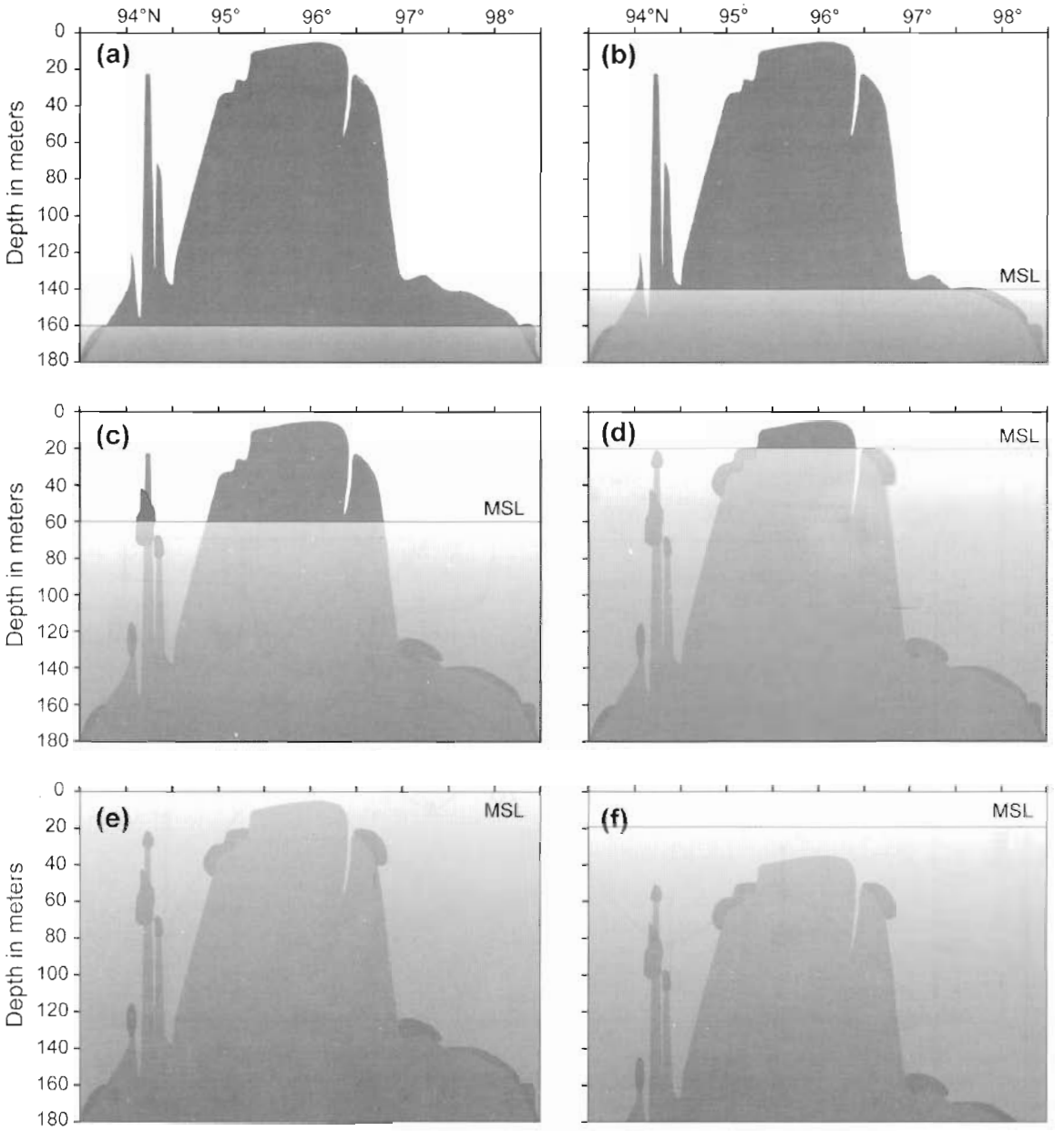

Fig. 6. Schematic explaining the proliferation of coral patches at different depths and different times in the geological past. The green patches depict live coral and the red patches depict dead coral. (a) Coral colonies develop at depths with optimum light on hard substratum and hard ground. (b) When sea level rises, those which can adapt continue to prolifer while those which cannot die out. (c and d) Corals continue to opportunistically nucleate; however cannot cope up with steep slopes and rapid sea level rise. (e) In the present study, coral fauna also occuring at shallow depths are relict, representing dead coral. This could be attributed either to eustatic sea level rise or (f) This could be a result of tectonic subsidence in the region.

fauna at different depths suggest the colonization of corals during different sea stands and thus would show different ages.

PROPOSITION OF A REGIONAL SEA LEVEL CURVE

So as to establish the depth to age relationship of these samples, specimens of the relict foraminiferal assemblage from seven stations representing different depths were identified for ^{14}C AMS dating. The details about the samples dated and the dates obtained have been presented in Table 3. As no reservoir age exists for the Ayeyarwady shelf, those previously used for the Andaman region, i.e. ΔR value 12 (±34) years, reported for Stewart Sound (13°N 93°E), North Andaman (Dutta *et al.*, 2001) has been used to calibrate all samples. The conventional radiocarbon ages were calibrated using the Marine-04 dataset by Hughen *et al.* (2004) as used by the online version of the standard radiocarbon calibration program CALIB 5.0.2 (Stuiver and Reimer, 1993). The calibrated ages were plotted against the depth at which the samples were collected. Based on the average of the depth preference of the different soft coral species (Fig. 7), 17.5 m is taken as the common depth and added to the depth at which the relict fauna occurs. The error bars used in Fig. 8, however, account for a variation from 5-30 m, i.e. ±12.5 m from

	Depth distribution in m.					
Name of Soft Coral Species	**0-5m**	**6-10**	**11-15**	**16-20**	**20-25**	**25-30**
Siphonogorgia godeffroyi Kolliker, 1874						
Chironephthya cf. macrospiculata Thomson & Henderson, 1906						
Subergorgia suberosa (Pallas, 1766)						
Acalycigorgia sp.						
Ctenocella (Ellisella) sp.						

Fig. 7. The ecological depth preferences of soft coral assemblage that existed in the study area is shaded in grey. The diagonal-line shading represents the depth zone where all the genera seem to have co-existed. Thus considering their occurrence from 6-30 m, 17.5 m is used as the average height to which the past sea-level has been assigned.

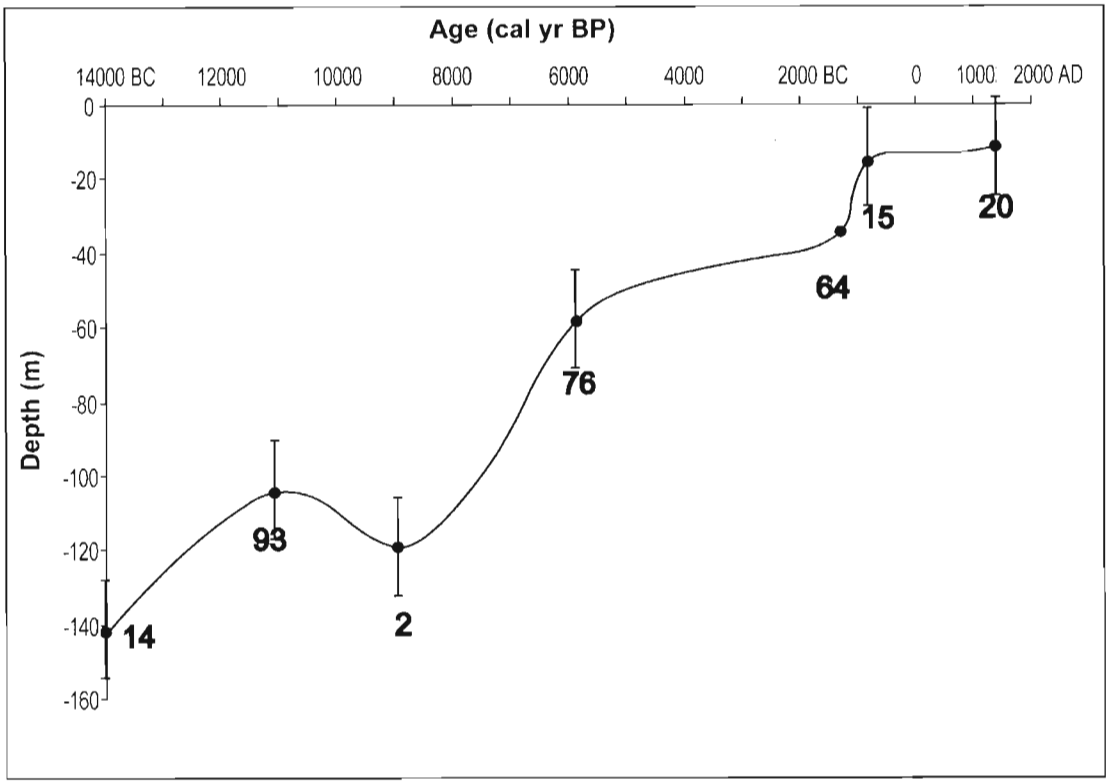

Fig. 8. Sea Level Curve proposed for the West Coast of Myanmar based on the ecology of the soft coral assemblage (sample numbers indicated with corresponding numbers) and ^{14}C dates of relict foraminiferal assemblage.

the assigned sea level. Thus, considering the coral ecology in the region, the sea level curve (Fig. 8) for the west coast of Myanmar has been constructed.

COMPARISON WITH OTHER SEA-LEVEL CURVES

The sea level curve proposed for the study area shows significant differences from other global and regional sea level curves published before (Fig. 9). Many global sea level curves (Waelbroeck *et al.*, 2002; Stanley, 1995; Toushingham and Peltier, 1991) and the one that was proposed for Barbados (Fairbanks, 1989) all indicate the sea level to be at ~110 m below present MSL ~16,000 yr. BP. However, present study shows that the sea level was at ~140 m below present MSL in the study area at the same time. The curve has similar shifts throughout the 16,000-year record.

However, it is worth noticing that at 13,000 yr. BP the sea level in the study area is comparable with the regional sea level at Barbados and the global sea level proposed by Stanley (1995). Along the east coast of India, between ~14,500 and ~12,500 yr. BP the sea level was reported to be 110 m (Vaz, 1996) and 100 m (Mohan Rao and Rao, 1994) below present MSL, respectively. In the study area the sea level was at -115 m 14,000 yr. BP and at 100 m and -100 m at 13,000 yr. BP. These levels thus seem very close to being comparable. When the west coast of India was experiencing a prolonged sea stand between 11,500 and 10,000 yr. BP (Hashimi *et al.*, 1995), the west coast of Myanmar seems to have undergone significant subsidence, after which the sea level rose as reported globally, except maintaining a level ~30m lower than elsewhere. Another major subsidence event is recorded at ~3,000 to 2,800 yr. BP after which the sea level gradually attained the present level.

Though the general rising trend of the sea level in the study

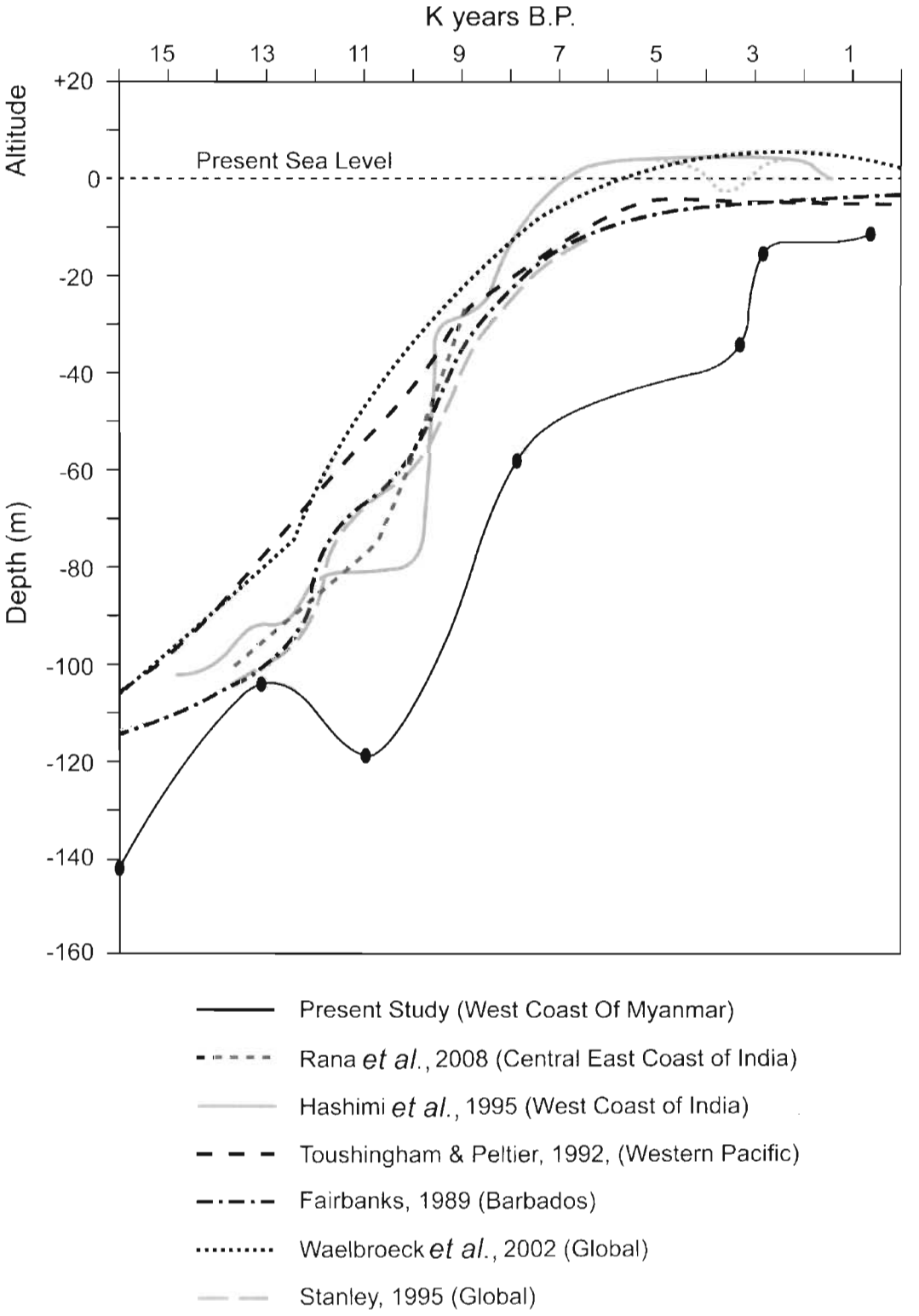

Fig. 9. Figure showing comparison of the sea level curve proposed for the west coast of Myanmar with previously published sea level curves.

area can be correlated with the Holocene sea level rise, the destruction of the coral patches along the west coast of Myanmar cannot be entirely due to the same. Sea level rise apart from eustasy is also largely dependent on rates of sedimentation and the tectonic setting of the area. The present study indicates that in addition to the global Holocene sea level rise, the subsidence of the region west coast off Myanmar seems to have led to destruction of patch coral reefs in this region.

CONCLUSIONS

Most of the studies on the tectonic evolution of the Andaman basin consider time scales of millions of years and

propose the opening of the basin along numerous but small fault systems. However, the vertical tectonic component of displacement, especially during the late Pleistocene-Holocene, has a direct bearing on the local sea levels of Myanmar. The present study demonstrates the utility of ^{14}C AMS dating of relict coral reef Foraminifera in deciphering changing sea levels along the west coast of Myanmar and proposing a local sea level curve. Limitation if any, in this study remains the lack of dredge samples and thus interpretations had to be made based on grab samples.

Neither has work been done along the west coast of Myanmar to understand the fluctuating sea levels nor have any such events been dated. This work offers a baseline data for future workers to pursue this line of research. In order to refine the present preliminary curve proposed, more surface and subsurface samples covering the entire Holocene period needs to be collected in order to generate more data as well as dates.

Coral colonies have only been known far from the deltaic environments and south of Myanmar, close to the Thai border. This study provides numerous evidences for the existence of Late Pleistocene-Holocene soft corals, along the west coast of Myanmar which have been destructed due to sea level rise.

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REFERENCES

Banerjee, P.K. 2000. Holocene and Late Pleistocene relative sea level fluctuations along the east coast of India. *Marine Geology*, **167** : 243-260.

Bender, F. 1983. Geology of Burma. (Eds. Bender, F., Jacobshagen, V., de Jong, J.D. and Lutig, G.), Gebruder Borntraeger, Berlin, Stuttgart.

Bruckner, H. 1989. Late Quaternary shorelines in India, In: Late Quaternary Sea Level Correlation and applications (Eds. Schott, D.B., Pirazzoli, P.A., Honig, C.A.), Kluver Dordrecht, pp. 169-194.

Brunnschweiler, R. O. 1974. Indoburman ranges-Data for Orogenic studies, In: Mesozoic-Cenozoic Orogenic Belts (Ed. Spencer, A.M.). *Journal of the Geological Society of London Special Publication*, **4**: 279-299.

Cockey, E. M., Hallock, P. M. and Lidz, B. H. 1996. Decadal-scale changes in benthic foraminiferal assemblages off Key Largo, Florida. *Coral Reefs* **15** : 237-248.

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

Curray, J. R. 2005. Tectonics and history of the Andaman Sea region. *Journal of Asian Earth Sciences*, **25** : 187–232.

Dutta, K., Bhushan, R. and Somayajulu, B. L. K. 2001. ^{14}C reservoir ages and ÄR correction values for the northern Indian Ocean. *Radiocarbon*, **43** : 483–488.

Fairbanks, R.G. 1989. Glacio-eustatic sea level record 0-17,000 years before present: influence of glacial melting rates on Younger Dryas event and deep ocean circulation. *Nature*, **342** : 637-642.

Fox, H.E. 2001. Enhancing reef recovery at Komodo National Park, Indonesia: A proposal for coral reef rehabilitation at ecologically significant scales. http://www.komodonationalpark.org/downloads/CorRehabProp.PDF

Gosliner, T. M., Behrens, D. W. and Williams, G. C. 1996. Coral Reef Animals of the Indo-Pacific. Sea Challengers, Monterey, California, pp. 314.

Hallock, P. 2000. Larger Foraminifera as indicators of coral-reef vitality. *Environmental Micropalaentology*, **15** : 121-150.

Hart, A.M. and Kaesler, R.L. 1986. Temporal changes in Holocene lagoonal assemblages of Foraminifera from Northeastern Yucatan Peninsula, Mexico. *Journal of Foraminiferal Research*, **16**(2) : 98-109.

Hashimi, N. H., Nigam, R., Nair, R. R. and Rajgopalan, G. 1995. Holocene sea level fluctuations on the Western Indian continental margin: An update. *Journal of the Geological Society of India*, 46 : 157-162.

Hohenegger, J. 1996. Larger foraminifera as important calcium-carbonate producers in coral reef environments and constituting the main components of the carbonate beach sands: Examples from Ryukyu archipelago. In: Proceedings of FORAMS'98- International symposium on Foraminifera. Monterrey, Mexico. http://www.okinawa-conference.unibonn.dc/Hohenegger.html

Hohenegger, J., Yordanova, E., Nakano, Y. and Tatzreiter, F. 1999. Habitats of larger Foraminifera at the upper reef slope of Sesoko Island, Okinawa, Japan. *Marine Micropalaeontology*, **36**(2) : 109-168.

Hughen, K. A., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Bertrand, C ., Blackwell, P. G., Buck, C. E., Burr, G., Cutler, K. B., Damon, P. E., Edwards, R. L., Fairbanks, R. G., Friedrich, M., Guilderson, T. P., Kromer, B., McCormac, F. G., Manning, S., Ramsey, C. B., Reimer, P. J., Reimer, R. W., Remmele, S., Southon, J. R., Stuiver, M., Talamo, S., Taylor, F. W., van der Plicht, J. and Weyhenmeyer, C. E. 2004. Marine04 Marine Radiocarbon Age Callibration, -0-26 Cal Kyr BP. *Radiocarbon*, **46** : 1059-1086.

IUCN/UNEP, 1988. Coral reefs of the world, Vols. 1-3. IUCN, Gland, Switzerland and Cambridge, U.K./UNEP, Nairobi, Kenya.

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

Langer, M.R. and Lipps, J.H. 2003. Foraminiferal distribution and diversity, Madang Reef and Lagoon, Papua New Guinea. *Coral Reefs*, **22** : 102-132.

Mazumder, A. 2005. Paleoclimatic reconstruction through the study of foraminifera in marine sediments off Central west coast of India. *Unpublished Ph.D. thesis*, Goa University.

Merh, S.S. 1992. Quaternary sea level changes along Indian Coasts. *Proceedings of the Indian National Science Academy*, **58** : 461-472.

Murray, J. W. 1973, Distribution and Ecology of Living Benthic Foraminiferids: Heinemann Educational Books, London, 274 p.

Pirazzoli, P.A. 1991. World Atlas of Holocene Sea-Level Changes. Elsevier, Amsterdam.

Ramaswamy, V., Rao, P. S., Rao, K. H., Swe Thwin, N. Srinivasa Rao and Raiker, V. 2004. Tidal influence on suspended sediment distribution and dispersal in the northern Andaman Sea and Gulf of

Martaban. *Marine Geology,* **208** : 33–42.

Rana S.S., Nigam, R. and Panchang, R. 2007. "Relict benthic foraminifera in surface sediments off Central East Coast of India as indicator of sea level changes". *Indian Journal of Marine Sciences*, **36**(4) : 355-360.

Mohana Rao, K. and Rao, T.C.S. 1994. Holocene sea levels of Vishakhapatnam shelf, East coast of India. *Journal of Geological Society of India*, **44** : 685- 689.

Rao, V.P., Veerayya, M., Thamban, M. and Wagle, B.G. 1996. Evidences of Late Quaternary neo-tectonic activity and sea level changes along the western continental margin of India. *Current Science,* **71**: 213-219.

Rao, P. S., Ramaswamy, V. and Swe Thwin, 2005. Sediment texture, distribution and transport on the Irrawaddy continental shelf, Andaman Sea. *Marine Geology*, **216** : 239-247.

Rodolfo, K. S. 1969. Sediments of the Andaman Basin, Northeastern Indian Ocean. *Marine Geology,* **7** : 371–402.

Saraswati, P.K. 2002. Growth and habitat of some Recent Miliolid Foraminifera. *Current Science*, **82**(1) : 81-84.

Sinsakul, S. 1992. Evidence of Quaternary sea level changes in the coastal areas of Thailand: a review. *Journal of Southeast Asian Earth Sciences*, **7**(1) : 23-37.

Spalding, M.D., Ravilious, C. and Green, E.P. 2001. World Atlas of Coral Reefs. University of California Press, Berkeley, USA.

Stanley, D.J. 1995. A global sea-level curve for the late Quaternary: the impossible dream? *Marine Geology*, **125** : 1-6.

Stuiver, M. and Reimer, P. J. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C Age calibration program. *Radiocarbon,* **35**(1) : 215-230.

Subramanian, K.S. 2005. The Sunda Trench and the Andaman-Nicobar Islands. *Journal of the Geological Society of India,* **66** : 255.

The Coral Reef Alliance, 2004. What corals need most. http://www.coralreefalliance.org/aboutcoralreefs/coralneeds.html

Toushingham, A. M. and Peltier, W. R. 1991. ICE-3G: A new model of late Pleistocene deglaciafion based upon geophysical predictions of post-glacial sea level change, *Journal of Geophysical Research*, **96** : 4497-4523.

Van Alstyne, K., Wylie, C.R., Paul, V. J. and Meyer, K. 1992. Anti-predator defenses in tropical pacific soft corals (Coelenterata: Alcyonacea). I. Sclerites as defenses against generalist carnivorous fishes. *Bulletin of Biology*, **182** : 231-240.

Vaz, G.G. 1996. Relict coral reef and evidence of Pre-Holocene sea level stand off Mahabalipuram, Bay of Bengal. *Current Science,* **71**(3) : 240-242.

Vaz, G.G. 2000. Age of relict coral reef from the continental shelf off Karaikal, Bay of Bengal: Evidence of Last Glacial Maximum. *Current Science*, **79**(2) : 228-230.

Vaz, G.G. and Banerjee, P.K. 1997. Middle and late Holocene sea level changes in and around Pulicat Lagoon, Bay of Bengal, India. *Marine Geology,* **138** : 261-271.

Venee-Peyre, M.T. 1985. The study of the Living Foraminiferan Distribution in the Lagoon of the high volcanic island of Moorea (French Polynesia). *Proceedings of the 5th International Coral Reef Congress*, Tahita, **5** : 227-232.

Vora, K.H., Wagle, B.G., Veerayya, M., Almeida, F. and Karisiddaiah, S.M. 1996. 1300 Km. Long late Pleistocene-Holocene shelf edge barrier system along the western continental shelf of India: Occurrence and significance. *Marine Geology*, **134** : 145-162.

Waelbroeck, C., Labeyrie, L., Michel, E., Duplessy, J.C., McManus, J.F., Lambeck, K., Balbon, E. and Labracherie, M. 2002. Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records. *Quaternary Science Reviews,* **21** : 295-305.

Yim, W.W.S., Huang, G., Fontugne, M.R., Hale, R.E., Paterne, M., Pirazzoli, P.A. and Ridley T.W.N. 2006. Postglacial sea-level changes in the northern South China Sea continental shelf: Evidence for a post-8200 calendar yr BP meltwater pulse. *Quaternary International,* **145–146** : 55–67.

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