ΔR CORRECTION VALUES FOR THE NORTHERN INDIAN OCEAN

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ABSTRACT. Apparent marine radiocarbon ages are reported for the northern Indian Ocean region for the pre-nuclear period, based on measurements made in seven mollusk shells collected between 1930 and 1954. The conventional ^{14}C ages of these shells range from 693 ± 44 to 434 ± 51 BP in the Arabian Sea and 511 ± 34 to 408 ± 51 BP in the Bay of Bengal. These ages correspond to mean ΔR correction values of 163 ± 30 yr for the northern Arabian Sea, 11 ± 35 yr for the eastern Bay of Bengal (Andaman Sea) and 32 ± 20 yr for the southern Bay of Bengal. Contrasting reservoir ages for these two basins are most likely due to differences in their thermocline ventilation rates.

INTRODUCTION

The most common method for determining ages of marine sediments is radiocarbon dating of fossil calcareous tests of surface dwelling foraminifers and is frequently employed in high-resolution paleoclimate studies of the Late Quaternary period. The ^{14}C ages of marine fossils are on the average 400 years older than contemporary terrestrial wood, since the reservoir (seawater) from which these foraminifers derive carbon has lower $^{14}C/^{12}C$ ratios compared to the atmosphere, due to mixing with deeper ^{14}C depleted water. Considerable spatial variability is seen in the apparent ^{14}C ages of marine calcareous shells due to variations in the regional ocean circulation patterns. For a given region (s) at any given time (t), the difference between the regional marine ^{14}C age $R_s(t)$ and the global model marine ^{14}C age $R_g(t)$, is given by ΔR(s) (Stuiver and Braziunas 1993). The ΔR value accounts for regional deviations, necessary for calibrating ^{14}C ages of marine samples (Stuiver et al. 1986, 1993, 1998a) and is assumed to be approximately constant for a given region. This offset in the regional marine ^{14}C ages from the global modeled mean can be determined from ^{14}C dating of: 1) marine calcareous shells of known age from the pre-nuclear era, 2) growth bands in corals of pre-nuclear era, or 3) wood and marine shell pairs collected from same stratigraphic horizon.

The northern Indian Ocean region is an area of considerable interest to study the monsoon variations in southern Asia and Africa during the Quaternary period. The Arabian Sea and the Bay of Bengal sediments are archives of such climatic variations. The margin sediments, in particular, can record past monsoon variations with high temporal resolution (von Rad et al. 1999; Sarkar et al. 2000). Such studies obviously require a reliable ^{14}C chronology. Unfortunately, data on the ^{14}C reservoir ages for this part of the ocean are very meager. The present work is the first attempt to determine pre-nuclear $\Delta^{14}C$ and ΔR correction values for the northern Indian Ocean region, from ^{14}C measurements of archived marine shells. Here we report ΔR values for the northern Arabian Sea, the northern and southern Bay of Bengal and for the Andaman Sea, based on ^{14}C measurements made on seven marine mollusk samples, collected between 1930 and 1954. The ΔR values derived from ^{14}C measurements in annual bands of corals that grew between 1949 and 1954 in the Gulf of Kutch reported earlier (Chakraborty 1993; Bhushan et al. 1994) are also discussed.

MATERIALS AND METHODS

The bivalve shells from Stewart Sound and Chilika Lake (Figure 1) were collected during 1935 and 1954, respectively, and procured from the archives of Zoological Survey of India (ZSI), Calcutta for ^{14}C measurements. Bivalve and gastropod samples from Port Okha, Dwarka and Rameswaram were

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obtained from different shell collectors. The coral *Favia speciosa* was collected from the Gulf of Kutch in June 1990. It was dated by identifying its annual growth bands using X-radiography, and sub-sampled for ^{14}C measurements (Chakraborty 1993). The bivalve and gastropod samples were initially washed free of surface contamination with distilled water. They were then rinsed in 0.1N HNO_3 and sonified in distilled water in an ultrasonic bath to dislodge surface organic coatings. The outer layers of the shells were etched off by dipping them in 2N HCl for about 2 minutes, to remove surface calcareous contaminants. They were then washed thoroughly with de-ionized water and oven dried. Before analysis, the shells were finely powdered in an agate mortar and homogenized. About 25–30 g of powdered samples were used for each analysis. For the two coral samples, two to three consecutive annual growth bands identified by X-radiograph were combined to get sufficient material for analysis (Chakraborty 1993). The powdered sample was hydrolyzed in a vacuum system using dilute (30% v/v) H_3PO_4 and the CO_2 liberated was converted to benzene using TASK Benzene Synthesizer. The benzene samples were assayed for ^{14}C using Packard 2250C liquid scintillation counter in low level count mode (Bhushan et al. 1994). An aliquot of CO_2 collected during the hydrolysis stage was analyzed for $\delta^{13}C$ measurement using PDZ Europa Geo 20–20 mass spectrometer. The 1-σ precisions for $\Delta^{14}C$ and $\delta^{13}C$ measurements are ±5‰ and ±0.05‰, respectively.

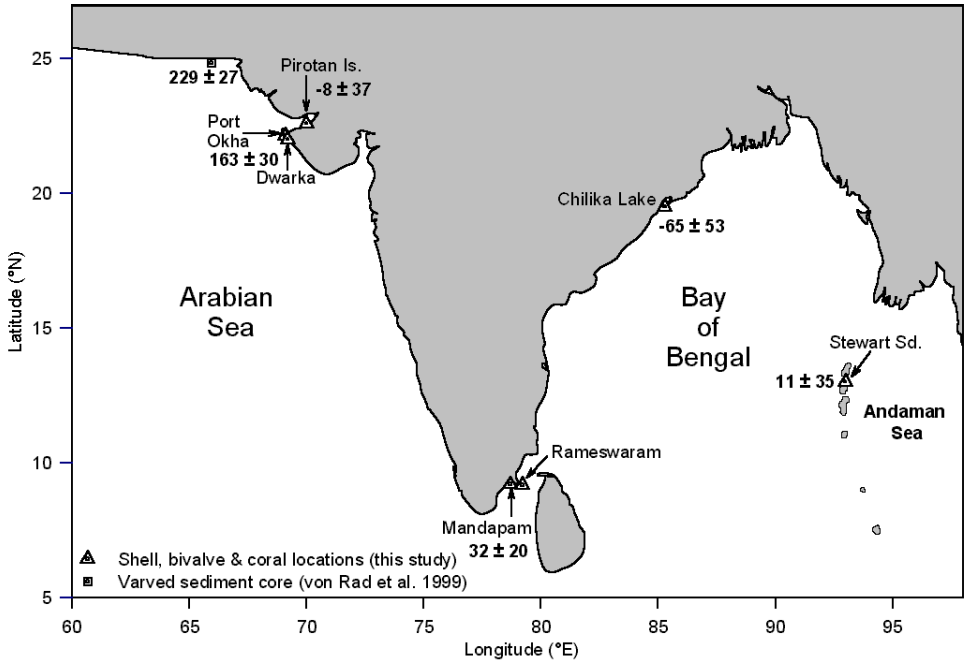

Figure 1 Sampling sites from the northern Indian Ocean. Pooled mean ΔR values in years (±1 σ) are given for each region.

RESULTS

The results of ^{14}C measurements of the shell samples are given in Table 1. The ^{14}C ages [$R_s(t)$] are reported following the conventions of Stuiver and Polach (1977). The modeled global marine ^{14}C ages [$R_g(t)$] are from Stuiver et al. (1998b), reported for decadal samples. The ΔR values are obtained as difference between $R_s(t)$ and $R_g(t)$. Errors quoted on $\Delta^{14}C$, $R_s(t)$ and ΔR are 1σ. The

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Table 1 Results of ^{14}C analyses in archived pre-bomb marine shells and corals from the northern Indian Ocean[a]

Sample code (PRLCH-)	Species[b]	Sample location		Year of collection or growth (t)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)	Conventional ^{14}C age (BP)		ΔR (years) $=R_s(t) - R_g(t)$
		Site	Lat., Long.				$R_s(t)$	$R_g(t)$	
Arabian Sea coasts									
319	*Turbobrunneus sp.*(g)	Port Okha, Gujarat	22°28′N, 69°05′E	1953	2.18	–83 ± 5	693 ± 44	473 ± 13	220 ± 46
543	*Turbobrunneus* sp.(g)	Dwarka, Gujarat	22°16′N, 68°57′E	1952	2.36	–72 ± 4	598 ± 35	473 ± 13	125 ± 37
542	*Conus monule* (g)	Dwarka, Gujarat	22°16′N, 68°57′E	1952	2.08	–173 ± 3	1524 ± 30[c]	—	—
541	*Nerita oryzorcem* (g)	Dwarka, Gujarat	22°16′N, 68°57′E	1952	3.39	–116 ± 4	988 ± 37[c]	—	—
339	*Architectonica* sp. (g)	Dwarka, Gujarat	22°16′N, 68°57′E	1952	1.66	–141 ± 4	1219 ± 38[c]	—	—
340	*Nassarius* sp. (g)	Dwarka, Gujarat	22°16′N, 68°57′E	1952	—[d]	–126 ± 4	1080 ± 37[c]	—	—
87	*Favia speciosa* (c)	Pirotan Is., Gulf of Kutch	22°36′N, 70°E	1952–1954	–0.65	–53 ± 6[e]	434 ± 51	473 ± 13	–39 ± 53
88	*Favia speciosa* (c)	Pirotan Is., Gulf of Kutch	22°36′N, 70°E	1949–1951	–0.79	–60 ± 6[e]	497 ± 51	473 ± 13	24 ± 53
Bay of Bengal coasts									
320	*Marcia pinguis* (g)	Chilika Lake, Orissa	19°43′N, 85°37′E	1954	0.76	–50 ± 6	408 ± 51	473 ± 13	–65 ± 53
539	*Asaphis deflavata* (b)	Stewart Sd., N. Andaman	13°01′N, 92°58′E	1935	0.98	–55 ± 4	469 ± 34	458 ± 4	11 ± 35
545	*Cyprea* sp. (g)	Rameswaram, Tamilnadu	9°15′N, 79°29′E	1930	2.02	–56 ± 4	483 ± 34	458 ± 4	25 ± 35
544	*Cyprea* sp. (g)	Rameswaram, Tamilnadu	9°15′N, 79°29′E	1949	2.42	–60 ± 4	498 ± 34	465 ± 7	33 ± 35
526	*Cyprea* sp. (g)	Mandapam, Tamilnadu	9°12′N, 78°42′E	1953	2.36	–62 ± 4	511 ± 34	473 ± 13	38 ± 36

[a]$\Delta^{14}C$ and conventional ^{14}C ages are defined by Stuiver and Polach (1977), normalized for isotopic fractionation to –25‰. Conventional ^{14}C ages are calculated relative to AD 1950 using the Libby half-life. $\Delta^{14}C$ values are corrected for ^{14}C decay between the calendar year of the sample collection or sample growth (t) and AD 1950.

[b]b=bivalve, g=gastropod, c=coral.

[c]Not used for ΔR calculation. See text for details.

[d]$\delta^{13}C$ not measured. 2‰ assumed (mean value of other similar samples).

[e]From Bhushan et al. (1994)

results are also summarized in Figure 1, where the ΔR values quoted are error weighted pooled mean for a given region.

DISCUSSION

Arabian Sea

Two samples of *Turbobrunneus* collected from Port Okha and Dwarka from the northern margin of the Arabian Sea (see Figure 1), yielded mean ^{14}C age of 635 ± 27 BP (1 σ), corresponding to mean ΔR of 163 ± 30 yr (1 σ). In the northeastern Arabian Sea, vertical mixing is favored by 1) seasonal upwelling during southwest monsoon, and 2) convective processes associated with winter cooling (Madhupratap et al. 1996). The apparent ^{14}C ages in the Arabian Sea are higher than that of the modeled world ocean, due to upwelling induced mixing with deeper ^{14}C-depleted water. From accelerator mass spectrometry (AMS) ^{14}C measurements of planktonic foraminifers in varved sediments off Pakistan, von Rad et al. (1999) estimated a local reservoir age of 640 yr for the Northern Arabian Sea. This is based on ^{14}C ages of 664 ± 25 BP and 705 ± 23 BP for varves deposited in 1926 and 1898 AD, respectively. This core was collected from a location about 300 km northwest of our sampling site at Port Okha (Figure 1). The above ages correspond to ΔR values of 208 ± 25 and 248 ± 24 yr, respectively, with a regional mean of 229 ± 27 yr (1 σ) (Reimer and Reimer 2001).

The coral *Favia speciosa* collected from the Pirotan Island within the Gulf of Kutch gives mean ΔR of −8 ± 37 yr for the two coral bands, which is significantly younger than the open Arabian Sea samples. The average water depth of the gulf is less than 30 m (Chakraborty et al. 1994). The lower ^{14}C age in the gulf compared to the open Arabian Sea appears to reflect faster equilibration time for the shallow gulf, with respect to atmospheric CO_2 exchange. Even in the post-bomb era during late 1970s, the Gulf of Kutch recorded much higher level of ^{14}C than the open Arabian Sea. The $\Delta^{14}C$ of dissolved inorganic carbon (DIC) in the mixed layer at the GEOSECS station 416 in the northern Arabian Sea was 59 ± 4‰ during 1978 (Stuiver and Ostlund 1983), while the mean $\Delta^{14}C$ for the Pirotan Island coral sample for the year 1975 and 1978 is 112 ± 7‰ (Chakraborty 1993). Four samples of gastropod collected from Dwarka yielded much older ^{14}C ages, between 989 and 1524 BP (Table 1), and have been excluded from ΔR calculations. The beaches of Port Okha and Dwarka in the western Gujarat from where these samples were collected are composed of calcareous sediments derived from Late Quaternary miliolite limestone and old coral reefs. The $^{230}Th/^{234}U$ ages of these miliolite limestones range from ~30 to ~235 ka (Somayajulu 1993). The coral reefs from this region fall in two groups, one around 6 ka and the other between 118 to 176 ka (Somayajulu et al. 1985). Thus higher ages of the four gastropod samples from Dwarka are possibly due to incorporation of dead carbonate in their shells (Dye 1994).

Bay of Bengal

The three samples from Tamilnadu were collected from the shallow Palk Bay area (water depth <100 m), yielded an average ^{14}C age of 497 ± 20 BP, corresponding to mean ΔR of 32 ± 20 yr. The ^{14}C age of the sample collected from Stewart Sound in the Andaman Sea is 469 ± 34 BP corresponding to ΔR of 11 ± 35 yr. This is statistically indistinguishable from that of the Palk Bay samples. The ^{14}C age of the sample from Chilika Lake, a shallow lagoonal lake in the northern Bay of Bengal is 408 ± 51 BP, the youngest compared to all the northern Indian Ocean samples analyzed in this study (Table 1).

The Bay of Bengal receives large amount of fresh water from the north, by seven major rivers (Milliman and Meade 1983), resulting in steep gradients of the isopycnal surfaces within the top 200 m.

This greatly reduces the vertical mixing rate, preventing advection of deeper ^{14}C depleted water. As a result, relatively younger reservoir ages compared to the Arabian Sea are likely to be observed in this basin. However riverine DIC depleted in ^{14}C will tend to counteract this effect (Little 1993). The ^{14}C age of the Chilika Lake is slightly younger than that obtained for the southern Bay of Bengal region. Younger ^{14}C reservoir ages in enclosed shallow lagoons are expected because of absence of upwelling of deeper ^{14}C depleted waters and faster equilibration rate with the atmosphere. This is similar to the case for the Pirotan Island coral in the shallow Gulf of Kutch. More measurements from the northern Bay of Bengal are needed to ascertain its reservoir age.

CONCLUSIONS

This is the first attempt to determine ΔR correction values for the two northern Indian Ocean basins, the Arabian Sea and the Bay of Bengal, from apparent ^{14}C ages of marine shells and corals formed prior to the nuclear era. The northern Arabian Sea has the mean ΔR of 163 ± 30 yr. For the enclosed Gulf of Kutch the ΔR is −8 ± 37 yr obtained from ^{14}C measurements in annual coral bands. The surface seawaters of the Bay of Bengal has younger apparent ^{14}C age than that of the Arabian Sea, with ΔR values of 11 ± 35 yr for the Andaman Sea and 32 ± 20 yr for the southern Bay of Bengal. The lowest ΔR of −65 ± 53 yr is obtained for the Chilika Lake, a shallow lagoon in the northern Bay of Bengal.

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