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MARINE RESERVOIR AGE CORRECTION FOR THE ANDAMAN BASIN

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ABSTRACT. Marine reservoir age is an important component for correction in radiocarbon (^{14}C) dating of marine and coastal samples. ^{14}C concentration in pre-bomb marine samples of known age are used to derive marine reservoir age of a region. Annually banded coral from Landfall island in the northern Andaman has been analyzed for its ^{14}C concentration during the pre-bomb period 1948–1951. ^{14}C age and reservoir effect (ΔR) are reported for these pre-bomb coral samples from the northern Andaman region. The mean ^{14}C age of 331 ± 61 yr BP was obtained for the period 1948–1951 with an average reservoir age correction of –138 ± 61 yr. This reservoir age correction is lowest reported from the northern Indian Ocean. ΔR value of the northern Andaman and the Bay of Bengal appears lower than that of southern Andaman. The ΔR values obtained using mollusk shells and coral from the Andaman region shows large variability. The lower reservoir age correction for the Landfall Island situated in the northern part of the Andaman archipelago, could result due to freshwater flux and reduced upwelling in the region.

KEYWORDS: Andaman basin, coral, marine reservoir age, radiocarbon.

INTRODUCTION

Radiocarbon (^{14}C) is primarily produced in the atmosphere by interaction between cosmic rays and atmospheric nitrogen. ^{14}C in the atmosphere reacts with oxygen to form carbon dioxide and then enters the biosphere and hydrosphere. It reaches the ocean mainly through air–sea CO_2 exchange process (Alves et al. 2018; Bhushan et al. 2000; Dutta and Bhushan 2012). ^{14}C concentration of dissolved inorganic carbon in surface seawater depends on ^{14}C concentration of the atmosphere and oceanic subsurface waters. Since ocean subsurface waters remain isolated from the atmosphere for hundreds of years before shoaling up, its ^{14}C concentration is generally lower than atmospheric ^{14}C concentration. Combination of air–sea CO_2 exchange, and upwelling reduces the ^{14}C activity of the surface ocean reservoir as compared to that of the atmosphere, leading to reservoir effect (Stuiver and Polach 1977; Alves et al. 2018). This causes an offset between ^{14}C age of marine samples and corresponding atmospheric age, and this offset is called the reservoir age (R) (Stuiver and Braziunas 1993). The varying intensity of air–sea CO_2 exchange, upwelling and horizontal or lateral advection, results in different reservoir ages of surface ocean across the globe. Variation of regional R from the global average R value is called reservoir effect correction (ΔR). Using marine calibration curve, the ^{14}C age corresponding to calendar year of sample growth or collection provides the global average R value for that time. Mathematically, subtracting this global average R value from measured ^{14}C age of marine sample yields ΔR (Stuiver and Braziunas 1993; Reimer and Reimer 2017; Alves et al. 2018). ΔR values are applied to ^{14}C age of marine samples before calibration to correct for local reservoir effect. As reservoir age varies due to ocean circulation, upwelling and freshwater flux, apart from reservoir age correction it also helps in understanding the oceanography of the region. In the northern Indian Ocean, ΔR values observed for the Bay of Bengal region are lower compared to those for the Arabian Sea (Dutta et al. 2001). Intense upwelling in the Arabian Sea during monsoon leads to higher ΔR values (Southon et al. 2002), whereas relatively lower ΔR values in the Bay of Bengal (Dutta et al. 2001) is due to highly stratified surface water which impedes vertical mixing (Thadathil et al. 2007; Sijinkumar

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et al. 2016). Andaman basin situated on the eastern side of the Bay of Bengal receives large amount of freshwater from rivers.

Several scientific investigations in the Andaman region used ^{14}C ages focusing on diverse subjects like past monsoonal variability (Rashid et al. 2007; Achyutan et al. 2014; Ali et al. 2015; Ota et al. 2017; Kumar et al. 2018; Bhushan et al. 2019b), past salinity changes (Sijinkumar et al. 2016), deformational history of Andaman Islands (Rajendran et al. 2008; Kunz et al. 2010; Awasthi et al. 2013), past volcanic activity (Awasthi et al. 2010), past sea-level changes (Scheffers et al. 2012), past tsunami deposits (Jankaew et al. 2008) and archeological history (Cooper 1993) of the region. However, there are limited reservoir age estimates available from the region (Dutta et al. 2001; Southon et al. 2002). In order to constrain the reservoir effect and understand the oceanography of the region, more pre-bomb ^{14}C values from this region are required. Corals are good marine archive recording the past ^{14}C changes in DIC of seawater (Druffel and Linick 1978; Hideshima et al. 2001; Grumet et al. 2002; Dang et al. 2004; Druffel et al. 2008). In this study, annually banded *Porites* coral core drilled from the Landfall Island from the northern Andaman has been analyzed for its ^{14}C composition. The pre-bomb ^{14}C value between 1948 and 1951 obtained from the coral has been used to estimate the reservoir age correction of the Andaman basin.

MATERIALS AND METHODS

In March 2018, a 126-cm-long coral core was collected from a live *Porites* sp. colony from Landfall Island (13º39′N, 93º02′E) situated in the northern Andaman using an underwater coral driller. The coral core was cut into 8-mm-thick slices. X-radiograph of the coral slice shows annual density banding (Figure 1). The coral core slices were treated with 10% H_2O_2 solution and then cleaned with Milli-Q in ultrasonic bath to remove organics from coral skeleton. After cleaning, the slices were dried at 60ºC. The clean and dried slices were drilled for stable isotope and ^{14}C analysis using micro-driller. Chronology of the annual bands were assigned using stable isotopic composition of the skeleton. The $\delta^{18}O$ and $\delta^{13}C$ values of drilled coral sample show good seasonality, which is also observed in another *Porites* coral core from Andaman region (Rixen et al. 2011). The distance between consecutive maxima of $\delta^{18}O$ was considered as one year. Top most band was assigned year of sample collection i.e. 2018, and the last analysed band corresponds to year 1948. About 10 mg of drilled coral carbonate powder samples along with new oxalic acid standard (NIST Oxalic Acid, SRM 4990C, HOxII), inter-comparison sample VIRI-R (Scott et al. 2010) and in-house coral standard (PRL-C) were converted to graphite using automated graphitization equipment (AGE3) (Wacker et al. 2010, 2013). Oxalic acid standard (HOxII) is the primary standard used for normalizing sample ^{14}C content, whereas VIRI-R was used as a check standard. The graphitized samples and standards were pressed into targets and measured at PRL Accelerator Mass Spectrometer facility (PRL-AURiS; Bhushan et al. 2019a, 2019b). Each target was measured for 10 cycles of 10,000 ^{14}C counts, with total of at least 100,000 ^{14}C counts. VIRI-R standard yielded ^{14}C value of 74.6 ± 1.0 pMC, which is close to the consensus value of 73.338 ± 0.037 pMC, affirming the accuracy of the measurement. To determine the reservoir age of the region where the coral was growing, ^{14}C concentration of six samples corresponding to period between 1948 and 1951 were analyzed.

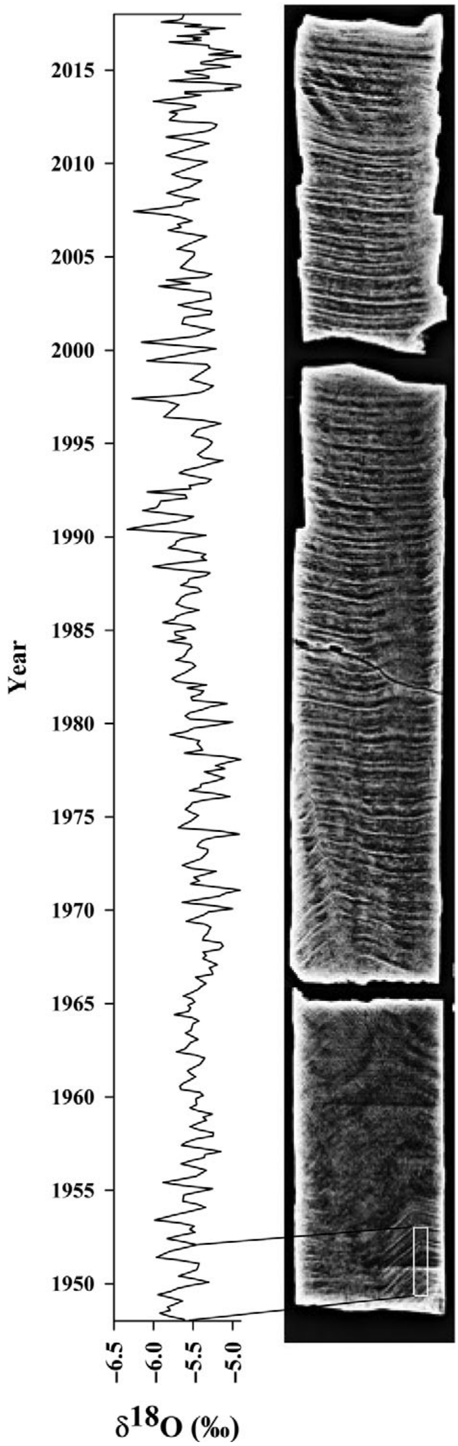

Figure 1 X-radiograph of Landfall coral showing annual density banding along with its $\delta^{18}O$ composition. White box is the marked area of samples between 1948 and 1951.

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Table 1 Results of ^{14}C analysis of Landfall coral skeleton between 1948–1951.

Year (AD)	$\Delta^{14}C$ (‰)	$\Delta^{14}C$ (Suess corrected) (‰)	^{14}C age (yr BP)	Model ^{14}C age (yr BP)	ΔR (yr)
1948	–38 ± 8	–29 ± 9	313 ± 67	469 ± 23	–156 ± 71
1948	–32 ± 8	–23 ± 9	263 ± 66	469 ± 23	–206 ± 70
1949	–39 ± 8	–30 ± 9	321 ± 67	469 ± 23	–148 ± 71
1950	–54 ± 8	–45 ± 9	446 ± 68	469 ± 23	–23 ± 72
1951	–41 ± 8	–32 ± 9	335 ±67	469 ± 23	–134 ± 71
1951	–38 ± 8	–29 ± 9	310 ± 67	469 ± 23	–159 ± 71
Average	–40	–31	331		–138
Std dev	7	7	61		61

RESULTS AND DISCUSSION

Results of ^{14}C measurement are summarized in Table 1, where $\Delta^{14}C$ (‰) and ^{14}C age (yr BP) were calculated using measured $^{14}C/^{12}C$ and $^{13}C/^{12}C$ ratios. The results have been reported following conventions of Stuiver and Polach (1977). Calculated $\Delta^{14}C$ are corrected for fractionation and age between year of measurement and growth of coral band. As samples belong to 20th century, Suess correction of –9 ± 3‰ is applied only to $\Delta^{14}C$ values of corals (Southon et al. 2002). Model ^{14}C age is derived from Marine13 calibration curve, which uses IntCal13 curve and ocean–atmosphere box diffusion model to obtain global marine surface ocean curve for 0 to 10.5 cal kBP (Reimer et al. 2013). The model ^{14}C age used here for period 1948–1951 is 469 ± 23 yr BP. ΔR values are calculated by subtracting model ^{14}C age from conventional ^{14}C age of the coral samples. Dutta et al. (2001) and Southon et al. (2002) did not use Suess corrected $\Delta^{14}C$ value to calculate the ΔR values. Although, Southon et al. (2002) reported Suess corrected $\Delta^{14}C$ values, but the ΔR values were calculated without Suess correction. Thus, to maintain uniformity and ease for comparison, ΔR values were calculated without Suess correction.

Errors quoted for $\Delta^{14}C$, ^{14}C age and ΔR are one sigma. The $\Delta^{14}C$ value for Landfall coral sample ranges from –32 ‰ to –54‰ with mean value of –40 ± 7‰ (mean ± SD, n = 6) between 1948 and 1951. The Suess-corrected $\Delta^{14}C$ value averages around –31 ± 7‰. Between 1948 and 1951, ΔR value recorded by the Landfall coral ranges between –23 to –206 yr. The $\chi 2$ test was carried out to test the variability in our coral ΔR values. It is observed that $\chi 2/(n{-}1)$ is less than 1, suggesting that the measurement errors explain the coral ΔR variability and no additional uncertainty is required when calculating the average ΔR (Mangerud et al. 2006). The observed changes in ^{14}C values of coral could result from local oceanographic conditions. Reservoir correction, calculated using Marine13-derived model age, for Chilika lake in the northern Bay of Bengal (Dutta et al. 2001) equals to –61 ± 61 yr. As it is the only reservoir correction value available from the region, it is assumed to be representative of the northern Bay of Bengal. This value is lower than observed ΔR value of –23 ± 76 yr in the year 1950 for the Landfall coral, suggesting lateral mixing of surface waters from the northern Bay of Bengal may not result in such change in ΔR value. This suggests that the observed variation in coral ^{14}C values could have resulted from either vertical mixing or lateral transport from the southern Andaman region. The mean ΔR value of Landfall coral is calculated to be –138 ± 61 yr. In absence of any other ΔR value reported from the northern Andaman, the obtained mean value of –138 ± 61 yr can be applied on ^{14}C dates for the northern Andaman region for reservoir correction. Previously, Dutta et al. (2001) and Southon et al. (2002) had reported ^{14}C values of bivalve (*Asaphis deflavata*) and gastropod (*Thais* sp.) shell from the Andaman region. Bivalve shell from the Stewart Sound in the northern Andaman gave $\Delta^{14}C$ value of –55 ± 4‰ (Dutta et al. 2001), and gastropod shell from the Nicobar Island showed $\Delta^{14}C$ value of –53.6 ± 7.7‰ (Southon et al. 2002). The $\Delta^{14}C$ values from Landfall coral are higher when compared to the Stewart Sound and Nicobar Island samples.

The ΔR values calculated from the reported $\Delta^{14}C$ of calcareous shells from the Stewart Sound and Nicobar Island is 12 and 30 yr, respectively (Table 2). Both these values are higher than ΔR value of the Landfall coral. It is interesting to note that even the highest ΔR value recorded by Landfall coral is lower than that of Andaman mollusk shells. The model ages used for reservoir age calculation for each sample are different as the year of growth or collection for these samples varies from 1913 to 1951. The model age ranges from 448 to 469 yr BP. The observed differences in ΔR value of samples are result of either species specific ^{14}C activity or oceanic processes like upwelling and circulation or both.

Feeding habits and habitats of mollusks can have effects on their ^{14}C records. Species-dependent ^{14}C activity can result in variable ΔR values for the same region (Dye 1994; Forman and Polyak 1997; Hogg et al. 1997; Petchey et al. 2012). Bivalves can be suspension feeders or deposit feeders. Some bivalves engage in deposit feeding depending on their local conditions (Petchey et al. 2004). Thus, bivalves feeding on detritus of old limestone can result in high ^{14}C ages. Petchey et al. (2004) analyzed marine shells from the Coral Sea and the Solomon Sea region, and they found mollusk (*Asaphis violascens*) collected from an area dominated by calcareous bedrock yielded high ΔR values. Unlike bivalves, *Thais* sp. is a carnivorous predator. The ^{14}C content of these gastropod may not represent seawater DIC ^{14}C content, as their ^{14}C content depends on the carbon reservoir of their prey (Hua 2015). Lindauer et al. (2017) had also observed influence of food resource and habitat on the ΔR of bivalve and gastropod from Gulf of Oman region. Therefore, enriched values in mollusk (*Asaphis deflavata, Thais* sp.) from Andaman could be due to species specific ^{14}C activity. Apart from species difference, the sample location can also be one of the reasons behind observed differences in ΔR value from Andaman region.

The Landfall Island is in the northern part of Andaman archipelago, which receives large flux of fresh riverine water. Salinity in the Andaman basin increases southwards (Babu and Sastry 1976) and reservoir age correction also shows increasing value with locations further south in the Andaman basin away from freshwater region. During winters, southern Andaman sea is influenced by flows from the Malacca strait originating from the South China Sea (Raju et al. 1981). The average ΔR value reported for the South China Sea is –3 ± 50 yr (Dang et al. 2004). During summer monsoon, Southwest Monsoon Current flows eastward south of Sri Lanka to bring saltier Arabian Sea waters into the Bay of Bengal (Schott et al. 2009). Southon et al. (2002) reported ΔR values of 127 yr for the Sri Lankan region. During the same period (summer), southern Andaman (around 10-degree channel) receives strong influx of surface currents from the Bay of Bengal side (Kiran 2017), which could bring ΔR enriched waters to the southern Andaman. These surface currents in summer and winter season could lead to the observed high ΔR values in the southern Andaman. Whereas, the northern Andaman region receives freshwater flux from rivers leading to stratification of surface waters, which inhibits vertical mixing and contributes to the lower reservoir age of the region. By comparing previously reported ΔR values with Landfall coral value, it is

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Table 2 Reservoir age correction (ΔR) values of pre-bomb marine samples from Andaman Basin.

	Sample (b = bivalve, c = coral, g = gastropod)	Site	Lat., long.	Year of collection/ growth	$\Delta^{14}C$ (‰)	^{14}C age (yr BP)	Model ^{14}C age (yr BP)	ΔR (^{14}C yr)
This study	*Porites* sp. (c)	Landfall Island	13º39′N, 93º02′E	1948–1951	–40 ± 7	331 ± 61	469 ± 23	–138 ± 61
Dutta et al. (2001)	*Asaphis deflavata* (b)	Stewart Sound	13º01′N, 92º58′E	1935	–55 ± 4	469 ± 40	457 ± 23	12 ± 46
Southon et al. (2002)	*Thais* sp. (g)	Nicobar Islands	9ºN, 94ºE	1913	–53.6 ± 7.7	478 ± 65	448 ± 23	30 ± 69

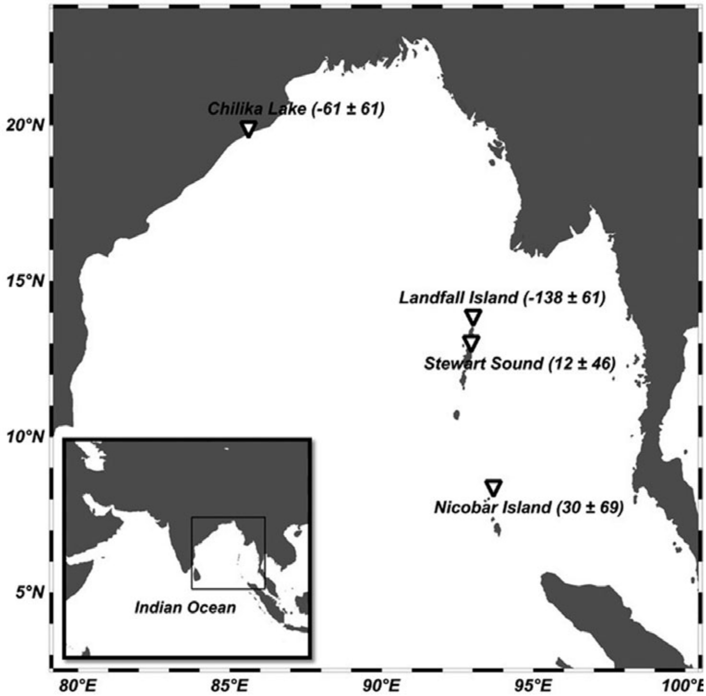

Figure 2 Map of northeastern Indian Ocean with reservoir age correction values from Landfall Island (this study), Chilika lake, Stewart sound (Dutta et al. 2001) and Nicobar Island (Southon et al. 2002). (Inset: study location marked by rectangle in northern Indian Ocean.)

observed that there exists significantly large variation in ΔR values from the Andaman Sea derived from coral and mollusk shells (Dutta et al. 2001; Southon et al. 2002) (Figure 2). Reservoir age correction values from the northern Andaman Sea and the Bay of Bengal are lower as compared to the southern Andaman Sea. These variations in reservoir age corrections need to be accounted while correcting ^{14}C dates of marine samples for reservoir age of the region.

CONCLUSION

A *Porites* coral core from Landfall Island in the northern Andaman basin was analyzed for its ^{14}C concentrations. The Δ^{14}C values of coral for the period 1948–1951 varies between –32 to –54‰. The mean ΔR value obtained for this period from the Landfall coral is –138 ± 61 yr, which is lowest reported for the northern Indian Ocean. The ΔR values reported from the Andaman basin shows large variations, wherein southern Andaman ΔR value is higher than that of the northern Andaman and Bay of Bengal. As the northern Andaman basin receives more freshwater flux as compared to the southern Andaman, such differences in reservoir age could be observed. However, difference in ΔR values due to species dependent ^{14}C variability cannot be ruled out. More pre-bomb samples need to be analyzed to better estimate reservoir age and its variation with time in the Andaman basin.

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