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Full Length Research Paper

Environmental effects on the stable carbon and oxygen isotopic compositions and skeletal density banding pattern of Porites coral from Khang Khao Island, Thailand

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The timing of band formation and linear skeletal growth rate based on environmental changes were investigated using alizarin red S (ARS) in *Porites lutea* coral at Khang Khao Island, the Gulf of Thailand from November 10, 1999 to March 15, 2001. The X-radiograph of the vertical section of the *Porites* coral skeleton was examined and three pairs of density bandings including intermediate bandings were observed in one year, suggesting that additional factors other than sea surface temperature (SST) were associated during the process of band formation. We assumed that variation of salinity variations, nutrition/sedimentation load and light intensity may control the process of density band formation which may be influenced by the river run-off due to heavy rainfall. The coral skeleton was analyzed and measured from top to a depth of 47 mm by mass spectrometry and three cyclic changes in both oxygen and carbon isotopic values which reveal the abrupt changes of aquatic environment was observed. By using isotopic compositions, X-radiography and analyzing ARS line, the average annual growth rate of the *Porites* coral was inferred at ~17.91 mm/year. Our results demonstrate that the density bands of coral and perhaps a useful proxy of extension rate could also be a potential indicator for reconstructing the past SSTs in rain-infested areas like the upper Gulf of Thailand.

Key words: Oxygen isotopes, carbon isotopes, *Porites* coral, density bands, skeletal growth, sea surface temperature, salinity, Khang Khao, Gulf of Thailand.

INTRODUCTION

Over the past hundreds to thousands of years, massive corals with annual growth bands have been studied by many researchers as an excellent archive for the environmental history of the tropical oceans. In the early 1930's, Ma (1934) reported that the skeletal growth bands were cyclic and Knutson et al. (1972) first described the skeletal density bandings in several pacific corals by observing the X-radiography. But the timing and pattern of depositions of dense skeletal bandings in massive corals are debatable in some papers (Highsmith, 1979; Wellington and Glynn, 1983) and remained unresolved.

Oxygen isotope records in coral skeletons are correlated with the sea surface temperature (SST) and $\delta^{18}O$ of seawater that depends on the salinity in which coral grows (Dunbar and Wellington, 1981; Pätzold, 1984; Winter et al., 1991; Halley et al., 1994; Leder et al., 1996; Cohen and Hart, 1997; Al–Rousan et al., 2003). Coral $\delta^{18}O$ values are affected by seawater $\delta^{18}O$ compositions which are influenced by seasonal variations of salinity in the surface oceans (Dunbar and Wellington, 1981; Cole and Fairbanks, 1990; Gagan et al., 1994). Variations in the salinity caused by the rainfall and/or river run–off may affect the skeletal $\delta^{18}O$ which should be considered while establishing the skeletal $\delta^{18}O$–SST relationship. The variation in the skeletal carbon isotopic values ($\delta^{13}C$) indicate the seasonal changes, but the values are significantly influenced by

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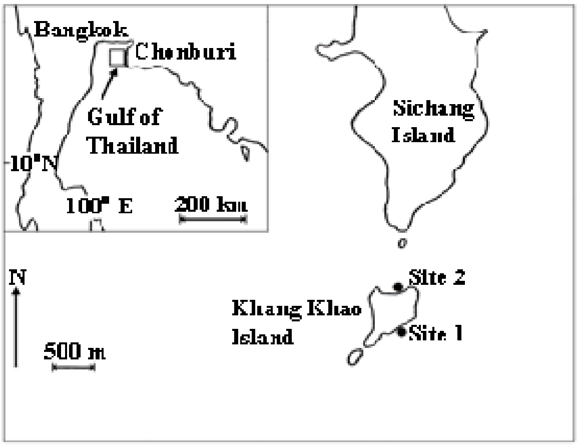

Figure 1. Map showing Khang Khao Island, Thailand. Coral sample was collected from Site 1 and seawater samples were collected from Sites 1 and 2.

metabolic activities regulated by seasonal light intensity including cloud cover (Weber and Woodhead, 1972; Muscatine et al., 1989; Gagan et al., 1994; Swart et al., 1996; Grottoli, 2000). Skeletal $\delta^{13}C$ values are often usedto understand the variations in light intensity (Grottoli, 2000).

Several studies have been performed using corals collected in Phuket Island, Thailand (Scoffin et al., 1989; Brown et al., 1990; Allison et al., 1996), but most of them are concerned with the growth performance of the corals in the open sea environment of the Andaman Sea. The present study area, around the Gulf of Thailand, is receiving a huge amount of extensive freshwater load (253×10^8 m^3 $year^{-1}$) (Menasveta et al., 1986) through river run-off. Therefore, a dramatic decrease of surface seawater salinity (Menasveta and Hongskul, 1988) during the rainy season seems to offer an opportunity to verify the controlling factor for the skeletal growth rate and density band deposition in massive corals.

In order to elucidate the effect of temperature and salinity changes on the coral extension rate, we have performed this study through calibrating the skeletal $\delta^{18}O$ values of a *Porites* coral and sea surface temperatures of the upper Gulf of Thailand using isotopic and environmental data.

METHODS

Study area

The study area (13°9′ N, 100°48′ E) is located in Khang Khao Island, the Northern Gulf of Thailand (Figure 1). This area experiences wet season from mid May to September, when the country is affected by warm and humid air and much cloud from the Indian Ocean towards Thailand causing rainfall all over the country. Abundant rainfall from early May to late September is observed in Bangkok and Chonburi regions, while a little or almost no rainfalls are observed during November to February. Air temperature was observed high during the wet season, which makes the condition rather oppressive. The dry season is from November to April when wind blows over the country from Indo–China along with dry air. For most part of the country, the hottest month is April before the onset of the southwest monsoon and cloud cover is normally less from November to March (Thai Meteorological Department, Thailand).

Sample collection

For coral staining experiment, a massive colony of *Porites lutea* was chosen at Site 1 of Khang Khao Island, Thailand (Figure 1). The specimen was stained *in situ* for one hour using alizarin-red S (ARS) on January 6, 2000 and was left as it was in the reef habitat to grow up. The coral was dislodged from the reef for the isotopic analyses on March 15, 2001. The sample was 14.23 cm long along the vertical growth axis with a radius of 10.23 cm after collection. On November 10, 1999, a Tidbit temperature logger (Stow Away, USA) was also set at the study site to record *in situ* seawater temperature every 1 h during the study. The temperature logger was collected on March 15, 2001 and the recorded SSTs were compiled at the laboratory using a personal computer. During the study period, surface seawater from Sites 1 and 2 was collected monthly and temperature was measured by a standard mercury thermometer (Table 1).

Sample preparation and analytical methods

A slab (~5 mm thick) was cut longitudinally from the coral sample along its growth axis using a diamond rock saw. It was ultra-sonically cleaned with Milli-Q water, dried up in an oven and X–radiography was performed to observe the density bandings. For the isotopic analysis, a vertical bar (~$96 \times 4 \times 3$ mm^3) was cut along the major growth axis by a fine diamond saw and it was cleaned ultrasonically and dried up. Approximately, 1 mm of aragonite was gradually shaved from the top of the bar as a sub-sample using a dental drill. A sub-sample depth was measured by an absolute digimatic solar caliper (CD-S20C, Mitutoyo, Japan) after shaving. From each sub-sample, ~0.15 mg of aragonite was taken and reacted with 100% phosphoric acid at 70°C for isotopic analysis. The reaction was performed in an automated individual-carbonate reaction device (Kiel device) and isotopic values were measured using a mass spectrometer (Finnigan MAT 251, Germany). Isotopic values are presented in conventional δ notation relative to the isotopic ratio of CO_2 gas derived from the Pee Dee Belemnite (PDB) standard through NBS-20. Oxygen isotopic values in the coral skeleton were expressed in per mil (‰) as follows:

$$\delta^{18}O_c = \{(^{18}O/^{16}O)_{sample} / (^{18}O/^{16}O)_{standard} - 1\} \times 1000 \quad (1)$$

Skeletal $\delta^{13}C$ values are measured simultaneously in terms of $^{13}C/^{12}C$ ratios. For 6 replicate measurements, the precision of internal standard was 0.021 and 0.012% for $\delta^{18}O$ and $\delta^{13}C$, respectively.

In addition, $\delta^{18}O$ values of 15 seawater samples were measured using the same mass spectrometer. To measure $\delta^{18}O$ values in water samples, a 2.0 ml of the sample was taken into a syringe and equilibrated with 4.0 ml of CO_2 of known $\delta^{18}O$ by shaking it at 25 ± 0.1°C for 12 h (Yoshida and Mizutani, 1986). The equilibrated CO_2 gas was then pushed through the vacuum line of the spectrometer for CO_2 extraction and the CO_2 value was measured. Seawater $\delta^{18}O$ values are also expressed in per ml (‰) relative to the Vienna-standard mean ocean water (V-SMOW) standard as follows:

Table 1. $\delta^{18}O$, temperature and salinity of seawater samples collected from Khang Khao Island, Thailand.

SAMPLE NO.	Date	Time	SST (°C)	Salinity (psu)		$\delta^{18}O$ (‰, SMOW) (±1σ)	
				Site 1	Site 2	Measured	Average
981117	17 Nov 1998	14:15	28.4	31.973	-	-	
990303	3 Mar 1999	14:20	29.0	32.515	-	-	
990826	26 Aug 1999	11:30	30.2	28.431	-	-	
991110	10 Nov 1999	12:50	29.2	31.401	-	-	
000122	22 Jan 2000	10:50	27.1	32.042	32.052	-0.300 (±0.030)	
000222	22 Feb 2000	15:25	27.5	32.352	32.389	-0.248 (±0.029) -0.248 (±0.042)	-0.248 (±0.035)
000408	8 Apr 2000	-	-	32.389	32.301	-0.208 (±0.036) -0.257 (±0.017)	-0.232 (±0.026)
000505	5 May 2000	11:15	30.5	31.645	31.841	-0.350 (±0.025)	
000520	20 May 2000	10:40	31.0	31.126	30.687	-0.485 (±0.006) -0.443 (±0.039)	-0.464 (±0.022)
000610	10 Jun 2000	11:13	30.5	30.412	30.661	-0.533 (±0.024) -0.541 (±0.036)	-0.537 (±0.030)
000617	17 Jun 2000	10:30	30.0	27.355	27.727	-0.984 (±0.019) -0.893 (±0.031)	-0.938 (±0.025)
00072001-2	20 Jul 2000	12:15	29.2	27.541	27.723	-0.919 (±0.030) -0.777 (±0.028)	-0.848 (±0.029)
000727	27 Jul 2000	10:30	29.4	21.129	18.691	-1.670 (±0.032) -1.549 (±0.019)	-1.609 (±0.025)
000829	29 Aug 2000	11:00	29.4	26.362	26.464	-0.985 (±0.030) -0.962 (±0.016)	-0.973 (±0.023)
001005	5 Oct 2000	13:45	30.5	28.965	26.979	-0.724 (±0.048) -0.725 (±0.032)	-0.724 (±0.040)
001019	19 Oct 2000	14:59	30.1	30.383	30.288	-0.666 (±0.015) -0.583 (±0.019)	-0.625 (±0.017)
00110801-2 (1)	8 Nov 2000	12:00	28.6	31.260	31.006	-0.389 (±0.027) -0.340 (±0.024)	-0.365 (±0.025)
01031501-1	15 Mar 2001	12:35	29.0	31.879	31.961	-0.326 (±0.020) -0.344 (±0.026)	-0.335 (±0.023)
01072001-2	20 Jul 2001	11:50	29.9	28.794	27.886	-0.700 (±0.040)	
02092501-2	25 Sep 2002	11:50	29.9	25.442	25.450	-	

- : Not measured; sample number shows sampling date (e.g. 981117 stands for 17 November 1998).

$$\delta^{18}O_w = \{(^{18}O/^{16}O)_{sample} / (^{18}O/^{16}O)_{SMOW} - 1\} \times 1000 \quad (2)$$

The salinity of seawater samples were measured by a salinometer (601 MK III, YEO-KAL, Australia) after calibrating with an IAPSO standard seawater (salinity = 34.996 psu, K_{15} = 0.99990).

RESULTS AND DISCUSSION

Temperature records and salinity of seawater

SST and salinity variations in the upper Gulf of Thailand are shown in Figure 2 and 3b, respectively. Mean weekly and monthly temperature data were calculated by hourly recorded measurements in Site 1 (Figure 2). The monthly mean SST at Site 1 ranged from a minimum temperature of 26.0℃ in January 2000 to a maximum temperature of 30.6℃ in May 2000, by which period they fluctuated grossly for 4.6℃ based on the daily average from November 1999 to March 2000. To know the temperature trend for previous years, we also collected the temperatures data from http://www.cdc.noaa.gov/index.html during the period of January 1998 to October 1999. The collected data shows the minima in January during the dry season and the maxima in July during the wet season. In addition, while collecting the surface seawater samples, measured SST by the thermometer gave a range from 27.1 to 31.0℃ (Table 1).

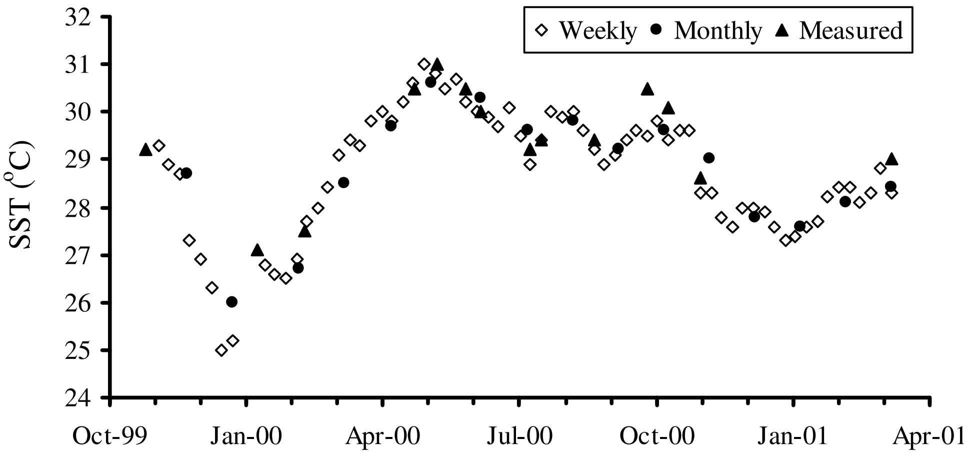

Figure 2. Weekly, monthly and measured mean of SSTs at Site 1, Khang Khao Island, Thailand from 10 November 1999 to 15 March 2001.

We observed the sea surface salinity every month during the study (Table 1). The salinity ranged between 21.129 to 32.389 psu at Site 1 compared to 18.691 to 32.389 psu at Site 2. Range in the salinity variation in Site 2 (~13 psu) is slightly higher than that in Site 1 (~11 psu). Using data in Table 1, we depicted changes in salinity at Site 1 and 2, which clearly showed a similar trend for both sites (Figure 3b). The salinity decreased at both sites from late May to October and increased from November to April during the study. The salinity decreased drastically on July 27, 2000 by 21.129 psu at Site 1 and 18.691 psu at Site 2. The decrease of salinity during May to October refers to the period of hot and wet season, while the increase during November to April refers to the period of cool and dry season in Thailand. Unfortunately, since we do not have salinity data at both sites for the previous years, we cannot elaborate whether or not the seasonal salinity trend is consistent annually or not. As comparison, previous study (Allison et al., 1996) found that no seasonal salinity trends were apparent consistently in the area of Phuket Island, Thailand.

Figure 3a shows the monthly mean rainfall data from January 1998 to March 2001 (~3 years dataset) recorded at Chon Buri weather station (the nearest weather station from Khang Khao Island) and Bangkok weather station. These stations recorded that the lowest rainfall occurred during November to February. The lowest rainfall data between November and February would be followed by the increase of the seawater salinity as shown in Figure 3b. In contrast, these rainfall data could not elucidate the drastic decrease in salinity on July 27, 2000. Strongly, seasonal rainfall is not always reflected by seawater salinity variations (Allison et al., 1996). It is possible that the salinity trend expected from the rainfall may be swamped by the influx of another water body of higher or lower salinity. In addition, the report from Thailand Meteorological Department asserts that there was a very heavy rainfall with severe floods in Thailand after July 5 to August 2000 when the maximum rainfall was recorded at 343.8 mm for 24 h in Trat Province of eastern Thailand on August 31, 2000. We suspect that such a heavy rainfall and flood including river run-off could have caused such drastic decrease in the salinity on July 27, 2000 at both sites of Khang Khao Island.

Seawater oxygen isotopes

Seawater oxygen isotope ($\delta^{18}Ow$) is related to changes in the salinity as a response to changes in evaporation, precipitation and mixing of waters from different sources (Al-Rousan et al., 2002). The effect of the salinity on $\delta^{18}Ow$ differs from one ocean to others. For instance, a change of 1 psu in the salinity just leads to a change of 0.029‰ in $\delta^{18}Ow$ at the Red Sea (Craig, 1966; Andrié and Merlivat, 1989). At the northern end of the Gulf of Aqaba, the salinity of the surface seawater has minor variations over the year and is considered to have little effect only on the variation of the seawater $\delta^{18}O$ (Heiss et al., 1999; Al-Rousan et al., 2002, 2003). A similar phenomenon is also seen in Southwest Lagoon, near Amédée Lighthouse, New Caledonia. Since a small difference of 0.2 psu in the surface seawater salinity corresponds to only 0.06‰ change in the seawater $\delta^{18}O$, its influence on the $\delta^{18}Oc$-SST calculation is negligible (Watanabe et al., 2003). Conversely, there was a high correlation between the salinity and the surface seawater $\delta^{18}O$ at our sampling area (Site 1) during the study as shown in Figure 4. This is represented by the equation below:

$$\delta^{18}Ow = 0.1208\ SSS - 4.1904\ (r = 0.993) \quad (3)$$

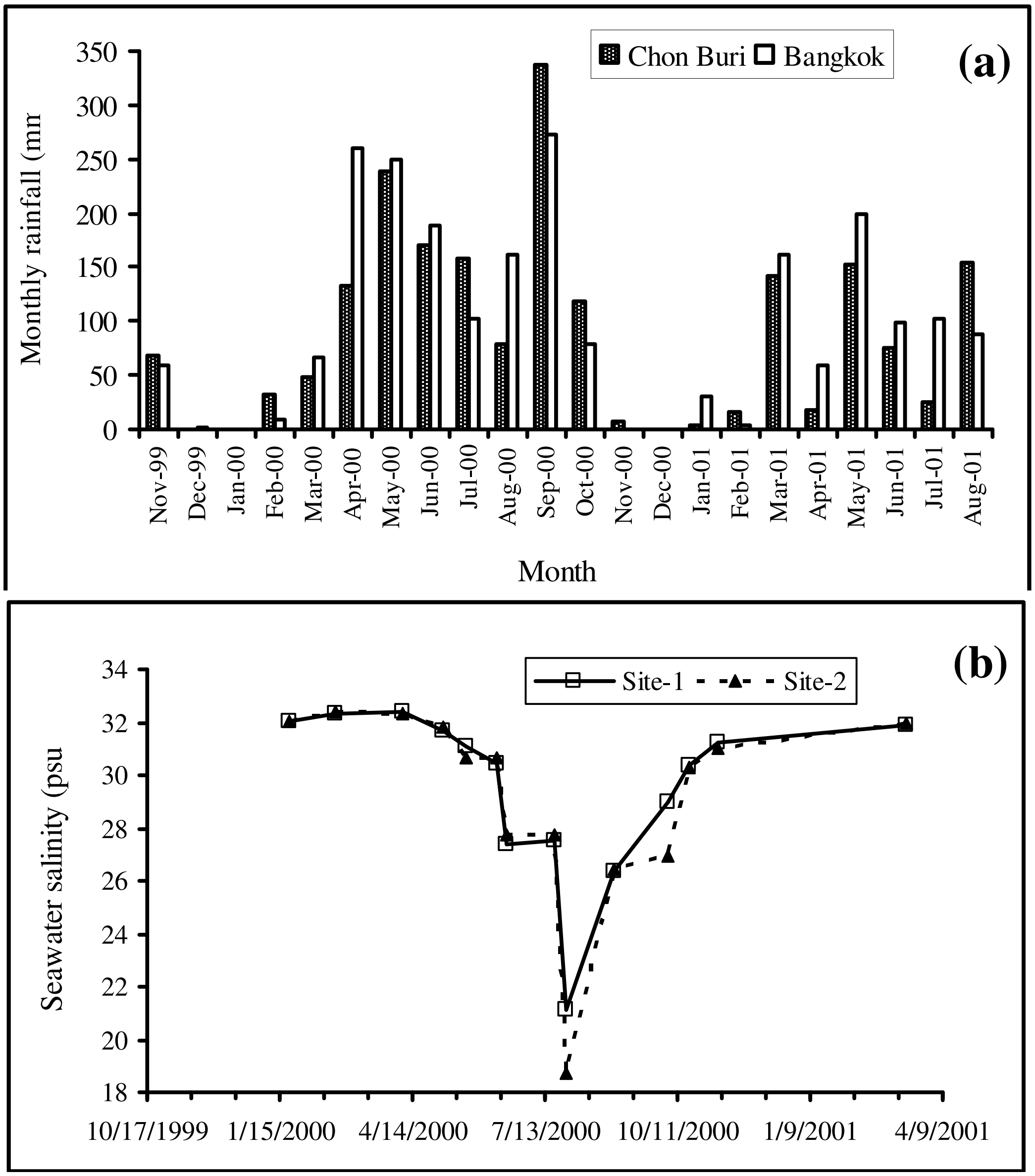

Figure 3. Seasonal variations record of Khang Khao Island, Thailand from November 10, 1999 toMarch 15, 2001: (a) Monthly rainfall records at Chon Buri and Bangkok weather station from November 1999 to August 2001 (data collected by Thailand Meteorological Department), (b) Seawater salinity at Site 1 and Site 2.

Seawater $\delta^{18}O$ in this site ranged from –1.609 to –0.232‰ (–0.611‰ on average) (Table 1). In the tropical ocean, seawater $\delta^{18}O$ is strongly related to the salinity. Higher salinities resulting from enhanced evaporation and lower salinities due to fresh water dilution are normally accompanied by $\delta^{18}O$-enrichment and $\delta^{18}O$-depletion of the reef water (Aharon and Chappell, 1983; Fairbanks et al., 1997). Hence we argue that, besides SST, the salinity will also take part in influencing oxygen isotope variation in the *Porites* coral collected from Khang Khao Island, Thailand.

Isotopic records in coral skeleton

The aragonite sub-samples were obtained from the surface to ~3 cm below the ARS line of the slab for isotopic measurements. Figure 5a shows the profile of the skeletal isotopic records from the coral slab of *P. lutea* to a depth of 47 mm covering the period from ~1998

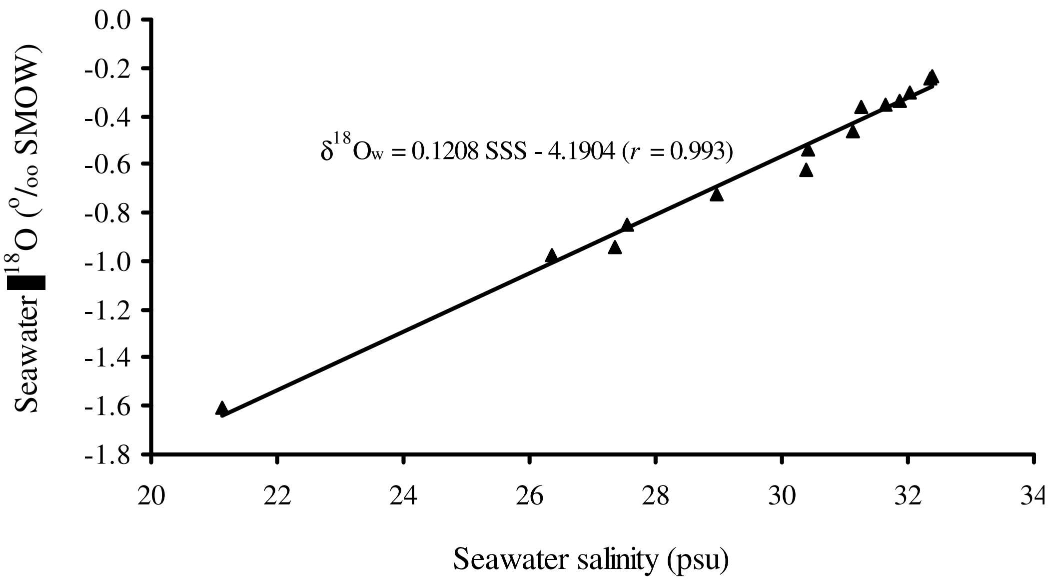

Figure 4. Relationship between δ^{18}O (‰ SMOW) and salinity of seawater at Site 1 of Khang Khao Island, Thailand based on monthly sampling from January 2000 to March 2001.

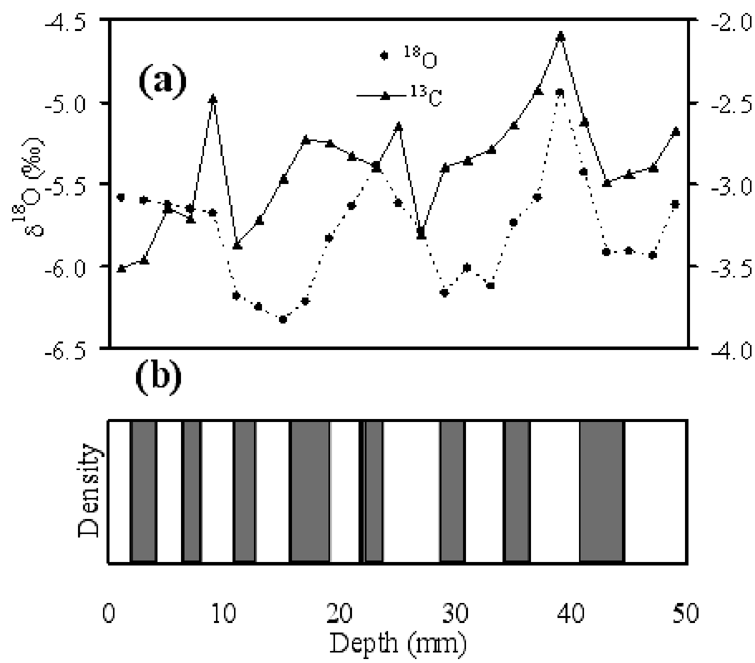

Figure 5. Skeletal (a) δ^{18}O and δ^{13}C values of coral skeleton and (b) growth increment and density band of the coral sample where ash, white and black line indicate high density band, low density band and ARS line, respectively.

to early 2001 (Table 2). The skeletal δ^{18}O values ranged from –6.40 to –4.95‰ during these last ~3 years (Table 2). Figure 5a shows a clear cyclic annual pattern of δ^{18}Oc records especially for the year 1999 – 2000. The maxima occur at the depth of 35.2, 20.9 and 2.7 mm from the surface for interval year between 1999 to 2000, whereas the minima lies within the depth of around 27.3 – 31.3 mm and 9.2 – 14.3 mm for the year of 1999 and 2000,

Table 2. Isotopic values in a slab of a *P. lutea* collected on 15 March, 2001 from Khang Khao Island, Thailand.

Sub-sample no.	Sampling range (mm)	Depth (mm)	$\delta^{18}O$ (‰, PDB) (±1σ)	$\delta^{13}C$ (‰, PDB) (±1σ)
1	0 - 0.63	0.31	-5.54 (±0.013)	-3.52 (±0.005)
5	2.52 - 2.82	2.7	-5.60 (±0.027)	-3.46 (±0.008)
9	3.74 - 4.04	3.9	-5.67 (±0.039)	-3.14 (±0.011)
13	5.22 - 5.66	5.4	-5.65 (±0.028)	-3.21 (±0.017)
17	6.97 - 7.40	7.2	-5.63 (±0.019)	-2.47 (±0.010)
21	8.72 - 9.58	9.2	-6.18 (±0.045)	-3.36 (±0.014)
23	10.44 - 11.30	10.9	-6.40 (±0.014)	-3.22 (±0.003)
25	12.16 - 13.02	12.6	-6.31 (±0.027)	-2.96 (±0.011)
27	13.88 - 14.74	14.3	-6.31 (±0.042)	-2.73 (±0.013)
29	15.46 - 16.46	16.0	-5.89 (±0.011)	-2.76 (±0.017)
31	17.32 - 18.73	18.0	-5.64 (±0.048)	-2.83 (±0.026)
33*	20.14 - 21.56	20.9	-5.39 (±0.045)	-2.90 (±0.021)
35	22.60 - 23.64	23.1	-5.62 (±0.072)	-2.65 (±0.029)
37	24.68 - 25.72	25.2	-5.79 (±0.035)	-3.31 (±0.015)
39	26.76 - 27.80	27.3	-6.16 (±0.036)	-2.90 (±0.012)
41	28.85 - 29.83	29.3	-6.02 (±0.025)	-2.85 (±0.016)
43	30.81 - 31.79	31.3	-6.13 (±0.045)	-2.79 (±0.016)
45	32.75 - 33.75	33.3	-5.74 (±0.019)	-2.64 (±0.017)
46	33.75 - 34.73	34.2	-5.59 (±0.028)	-2.42 (±0.008)
47	34.73 - 35.71	35.2	-4.95 (±0.039)	-2.10 (±0.031)
48	35.71 - 36.69	36.2	-5.43 (±0.036)	-2.62 (±0.017)
49	36.69 - 37.67	37.2	-5.92 (±0.015)	-2.99 (±0.010)
53	40.20 - 41.04	40.6	-5.91 (±0.067)	-2.94 (±0.009)
57	43.39 - 44.17	43.8	-5.94 (±0.033)	-2.90 (±0.013)
61	46.53 - 47.33	46.9	-5.63 (±0.040)	-2.67 (±0.015)

* The position of red colored line stained by alizarin red on 6 January, 2000.

respectively. Our skeletal isotopic records in Figure 5a show that the highest $\delta^{18}Oc$ occurs at the end and at the beginning of each year (December - January), while lower $\delta^{18}Oc$ occurs in the middle of each year (May - July). We also analyzed skeletal $\delta^{13}C$ values which showed the annual cyclic changes (Figure 5a). The skeletal $\delta^{13}C$ values ranged from –3.52 to –2.10‰ during these last ~3 years. The maxima occur at the depth of 37.2, 25.2, 9.2 and 0.3 mm from the surface for the year 1998, 1999, 2000 and 2001, respectively, whereas the minima lie within the depth of 35.2, 23.1 and 7.2 mm from the surface for the year, early 1999, fall 1999 and 2000, respectively.

Recently, Adkins et al. (2003) proposed that the stable isotopes fractionation during calcification, at least in non-zooxanthellae corals, is influenced by the pH of the water surrounding; as pH increases the composition of carbon and oxygen isotopic decreases. In addition, it has been firmly established that the oxygen isotopic composition of the coral skeletons is related to the temperature. However, not all authors have observed the expected skeletal $\delta^{18}O$ variations from the consideration of both temperature and salinity dependence effects. One of the goals of this study is to predict which $\delta^{18}O_c$ value should be recorded in our *Porites* sample during stained experiment through consideration of seawater $\delta^{18}O$ compositions controlled by SSS changes. We have used the equation of Abe et al. (1998) to predict the $\delta^{18}Oc$ values that should be recorded ($\delta^{18}Oc_{predict}$)

$$\delta^{18}Oc = -0.162\ SST - 0.587 + \delta^{18}Ow \qquad (4)$$

In order to calculate $\delta^{18}Oc_{predict}$, we incorporated monthly mean SST (Figure 2) and $\delta^{18}Ow$ values to the Equation (4). Figure 3b was used to estimate correspondence monthly SSS and then $\delta^{18}Ow$ values were corrected by using Equation (3). The corrected $\delta^{18}Ow$ values were subsequently converted from SMOW to PDB basis ($\delta^{18}Ow_{PDB}$).

Table 3 shows the results of the calculation. The skeletal oxygen isotope predicted the range from –6.65 to –5.13‰. The $\delta^{18}Oc_{predict}$ range (1.52‰) is larger than actual $\delta^{18}Oc$ values (1.01‰) recorded during stained experiment (Table 2). Judging by this difference in range,

Table 3. Monthly mean of SST, seawater salinity estimated, $\delta^{18}O_w$ corrected and $\delta^{18}O_c$ predicted values in a *P. lutea* of Khang Khao Island, Thailand.

Date	SST(°C)	SSS $_{(estimated.)}$*	$\delta^{18}O_{w(corrected)}$** (‰ PDB)	$\delta^{18}O_{c(predicted)}$*** (‰ PDB)
15-Mar-01	27.5	31.879	-0.339	-5.38
13-Feb-01	27.9	31.750	-0.355	-5.46
14-Jan-01	27.6	31.625	-0.370	-5.43
15-Dec-00	27.8	31.300	-0.409	-5.50
15-Nov-00	29.0	31.325	-0.406	-5.69
16-Oct-00	29.6	30.150	-0.548	-5.93
16-Sep-00	29.2	27.800	-0.832	-6.15
17-Aug-00	29.8	24.450	-1.237	-6.65
18-Jul-00	29.6	27.675	-0.847	-6.23
18-Jun-00	30.3	27.355	-0.886	-6.38
19-May-00	30.6	31.200	-0.421	-5.97
19-Apr-00	29.7	32.175	-0.303	-5.70
20-Mar-00	28.5	32.425	-0.273	-5.48
19-Feb-00	26.7	32.352	-0.282	-5.19
6-Jan-00	26.0	31.950	-0.330	-5.13

*Estimated from Figure 2b; ** corrected using equation in Figure 4;*** calculated by Abe et al. (1998) equation: $\delta^{18}Oc = -0.162\ SST - 0.587 + \delta^{18}O_w$. Bold marks refer to values within the range of $\delta^{18}O_c$ records in *Porites* of Khang Khao Island, Thailand.

one might claim that paleo-temperature equation by Abe et al. (1998) used is not appropriate. A possible reason for such slight discrepancy in the range between $\delta^{18}Oc_{predict}$ and $\delta^{18}Oc$ could be that our *Porites* sample did not correctly record some SST and SSS events (Shimamura et al., 2005) in Khang Khao Island, Thailand.

Densitometry

X-radiography of the ARS treated coral showed four pairs of skeletal density bandings for one year (Figure 5b), while an alternative high and low density bandings is often used for one year coral growth (Knutson et al., 1972; Al-Rousan et al., 2003). Assuming that the coral was growing on the collection date of March 15, 2001, the depth range from the surface to 2.8 mm represents the year of 2001, from 2.8 to 21 mm represents the year of 2000, from 21 to 35.3 mm represents the year of 1999 and the interval range from 35.3 to 47 mm refers to the year of ~1998. Annual layer comprises high density (dark) and low density (light) band couplet. However, the position of density bands is not similar for each year and a seesaw pattern can be observed whereby the $\delta^{18}O_c$ values are not always enriched within the low density bands area. We found some intermediate density bands (Figure 5b) which indicate that other possible environmental factors influenced it.

The slow extension rate during January to March 2000 indicated winter monsoon (cool and dry season) in Khang Khao Island, Thailand. Moreover, the lowest extension rate around November 2000 to March 2001 is possibly induced by the lowest photosynthetic activity of the symbiotic zooxanthellae. This is due to low light level caused by the increase in seawater turbidity for stormy weather. The coral skeleton formed during periods of low zooxanthellae activity should isotopically contain less amount of ^{13}C. The highest extension rate occurred during summer monsoon (hot-rainy season) from the middle of June to the mid of July 2000 when annual seawater temperature is warm. We sign the sudden drastic decrease in the salinity in our location in July 2000 (Figure 2b) by 21.129 psu that possibly disrupts the coral growth. However, it is important to note from the $\delta^{13}Cc$ profile during the study when coral recorded highest carbon isotope ratio (–2.47‰) which did not reflect the highest extension rate due to the highest photosynthetic activity around July to September 2000 (Figure 5). There are two speculations that could elucidate such phenomena. First, a huge amount of extensive freshwater load (253 × 10^8 m^3 $year^{-1}$) (Menasveta et al., 1986) through river run-off may cause the dramatic decrease in the surface seawater salinity (Menasveta and Hongskul, 1988) during the rainy season, also possibly transport ^{13}C-abundance materials to the seawater. Although it is very unlikely that the highest $\delta^{13}Cc$ during this month is not a response of the highest activity of symbiotic zooxanthellae in photosynthetic, it is a response of ^{13}C-abundance materials of coral water surrounding. Of course, much more work remains to be done to prove this statement. Second, during the special event (sudden decrease of the salinity), coral do not correctly record the skeletal isotope ratios. Considering all the factors listed above, it is assumed that reduced sunlight (Wellington and Glynn, 1983) through increased sedimentation (Brown et al., 1986) has played a vital role in the asynchronous deposition of dense bands in the corals of Khang Khao Island, Thailand.

In order to calculate the skeletal extension rate of the studied coral, the periods of the coral growth were assumed using isotopic data combined with the density bandings. The average extension rate of the *Porites* coral was obtained from X-radiography by using ARS line, inferred at ~17.91 mm year^{-1} which is similar to some extent to reports given by Scoffin et al. (1992) but different from Brown et al. (1986) and Allison et al. (1996) for the coral of Phuket, Thailand.

Conclusion

The high correlation (r = 0.993) between seawater $\delta^{18}O$ and monthly recorded SSS in Khang Khao Island, Thailand suggests that the seawater salinity in this area influences considerably the records of $\delta^{18}O$ in *Porites* skeleton. The changes in the salinity also influence the extension rate of coral. We observe one event when the salinity suddenly decreased drastically and hampers the coral growth. During this event, coral might not correctly record the skeletal isotopes ratios. The estimated high extension rate of coral occurs during the summer season, whereas low extension rate lies within the winter monsoon. Light penetration within seawater is controlled by the turbidity caused by river run-off and cloud cover influences the photosynthetic activity of symbiotic zooxanthellae in the coral which in turn affects the skeletal extension rate.

The high and low estimated extension rate corresponds to low and high density bands of our *Porites* coral which suggest that the density bands of coral are useful proxy of the skeletal extension rate. Such a coral dating technique is useful in order to reconstruct the timing of the environmental changes and local pollutions in the Gulf of Thailand. Further investigations are required to understand the influence of sedimentation load and light intensity for the skeletal growth rate and density banding pattern on *Porites* coral of the present study area.

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