

Observations Based on the Variation in Alkaline Earth Elements' (Ca, Mg, Ba and Sr) Distribution in the *Porites* Skeleton of the Central West Coast of Saudi Arabia

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Abstract. The concentration of alkaline earth elements (Ca, Mg, Ba and Sr) were measured in a *Porites lutea* colony in an attempt to establish the vertical variation in their distribution and to determine relationship between the strontium and calcium ratio with the Sea Surface Temperature (SST). The results indicate that a good relationship exists between the Sr/Ca ratio and sea surface temperature independent of the ambient climate.

Keywords: Saudi Arabia, Sea surface temperature (SST), Alkaline earth elements, *Porites*, Sr/Ca ratio.

Introduction

Porites lutea, commonly known as massive corals, is included in the large group of stony coral; order Scleractinia, family Poritidae and genus *Porites*. These are wide spread along the Saudi Arabia coast of the Red Sea and are abundantly found on lagoon and back reefs margins. They are cream or bright yellow-green in colour with smooth surface (Veron, 1986). This species has hemispherical colony and very small corallites (1-1.5mm in diameter) with five tall pali. It forms large colonies even reaching more than 3m high and 4m in diameter.

Porites species as *Scleractinian* precipitate aragonite (CaCO₃) and grows at a rate of 5.68 to 8.3 mm per year along the Red Sea coast of Saudi Arabia (Al-Sofyani, 1987). A number of cations and anions are

associated with the crystals (Livingston and Thompson, 1971; St. John, 1974). During their slow growth, many a time annual density bands are produced.

The chemistry of skeleton of *Porites* corals is very sensitive to climate changes and has proven to be a very powerful tool in reconstructing various features of the coupled oceanic-atmospheric system including sea surface temperature - SST (Beck *et al.*, 1992; Barnes and Lough, 1993; Corrège, 2006; de Villiers *et al.*, 1994 and 1995; McCulloch and Esat, 2000; Marshal and McCulloch, 2002; Yu, 2005) sea surface salinity (SSS), and the oxygen isotopic composition of seawater (Dunbar and Wellington, 1981; Cole and Fairbanks, 1990; Cole *et al.*, 1993; Quinn *et al.*, 1993; Dunbar *et al.*, 1994; Linsley *et al.*, 1994; Wellington and Dunbar, 1995; Wellington *et al.*, 1996; Charles *et al.*, 1997; McCulloch *et al.*, 1999; Linsley *et al.*, 2000; LeBec *et al.*, 2000; Hendy *et al.*, 2002). *Porites lutea* has been investigated extensively for reconstructing paleoclimatic conditions (Linsley *et al.*, 1994; de Villiers *et al.*, 1994; Gagan *et al.*, 1994; Allison *et al.*, 1996; McCulloch *et al.*, 1994). The aim of this note is to study the past climate by using the variation in percentage of alkaline earth elements distribution and their relative ratios in particular reference to the west coast of Saudi Arabia. Here more emphasis is given to the Sr/Ca ratio and its relationship with the sea surface temperature as shown by Beck *et al.* (1992). This note is just a model study to establish if any relationship exists between the Sr/Ca ratio and the SST.

Study Area

The study area (Fig. 1) lies on the eastern bank of the Red Sea which lies between arid, desert and semi-desert land with well developed reef systems all along due to its greater depths and efficient water circulation. Very high surface temperatures coupled with high salinities makes this region one of the hottest and saltiest bodies of seawater in the world. The average surface water temperature of the Red Sea during the summer is about 26°C in the north and 30°C in the south, with only about 2°C variation during the winter months. The overall average water temperature is 22°C. Over the Red Sea and its coast extremely low rainfall with an average of 6 cm/year is mostly in the form of showers of short spells that are associated with sporadic thunderstorms and occasionally with dust storms. The warmer water and the desert air

results in excess evaporation as high as 205 cm/yr. Such an intensive evaporation in conjunction with sparse river discharges into the sea, results in high surface salinity (36 and 38 ‰) making Red Sea as one of the most saline water bodies in the world. The watermass so formed, subsequently drives the thermohaline circulation of Red Sea thereby transporting the surface water to subsurface and is discharged to Arabian Sea where it ventilates the land-locked Arabian Sea at around 900 to 1000 m and plays a vital role in geochemical processes. In general tide ranges between 0.6 m in the north, near the mouth of the Gulf of Suez and 0.9 m in the south near the Gulf of Aden but it fluctuates between 0.20 and 0.30 m away from the nodal point. The central Red Sea (Jeddah area) is almost tideless.



Fig. 1. Location map.

Materials and Methods

A *Porites lutea* sample measuring 14x20x11 cm was collected from a depth of 3m at a location (Latitude 21° 42' 36.14"N and Longitude 39° 05' 47.07"E) off Sharm Obhur in 2004 (Fig. 1). The sample was washed with sea water to remove the live tissues and dried. A slice of 1 cm thickness was removed from the center. Later on from this slice a strip of 1 cm wide was cut through the entire 14 cm length of the slice. This strip of 14 cm length, 1 cm of width and 1 cm thickness was further cut into 1 cm pieces. Thus 14 sub-samples were made and numbered starting from top to bottom, so that the sub-sample no. 1 is most recent one and sub-sample no. 14 as the oldest (Fig. 2). This method was adopted due to the absence of growth bands in the sample.

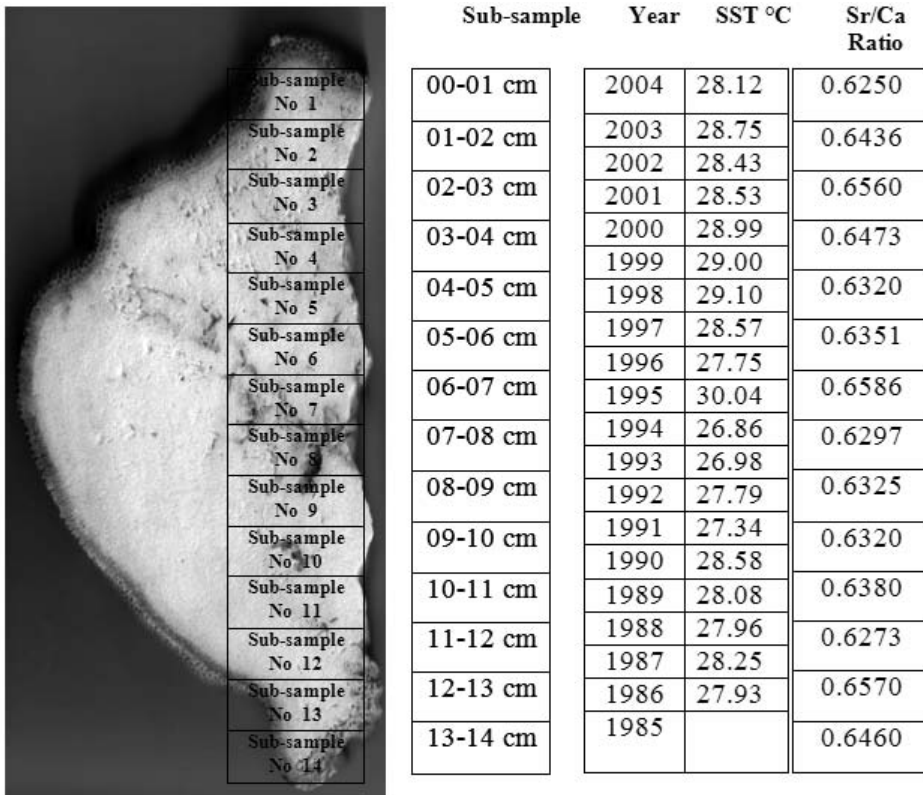


Fig. 2. Slice of the *Porites* sample from which the 1cm interval sub-samples were taken and the corresponding year of formation along with the Sr/Ca.

Finally, these sub-samples were subjected to alkaline earth elements analyses by using Perkin-Elmer Optima 2000DV ICP-AES. The analysis was carried by following the steps given below:

- i) about 30 mg of each of powdered sub-samples was digested in 10 ml of 3N HCl, the complete evolution of CO₂ was ensured,
- ii) the solution was filtered through the Watman No. 42 paper to remove the unleached silicate detritus,
- iii) solution was diluted to 50 ml and
- iv) three point calibration using Sigma-Aldrich mixed standards was used for quantification.

As the SST data at the coral sample location was not available, the data from the region closest to the required location is utilized from the data of NOAA/NASA AVHRR Ocean Pathfinder version 4.1 monthly data, derived from the 5 channel Advanced Very High Resolution Radiometers (AVHRR) on board the NOAA-7, 9, 11, 14, 16, and 17 polar orbiting satellites (Vazquez *et al.*, 1998), the data is extracted for the area between 21 to 22° N and 38.5 to 39.9°E which have a spatial resolution of 4 km. Out of the monthly available SST for the present study the highest temperature of the year is taken for the comparison with the Sr/Ca ratio (Fig. 3).

Results and Discussion

The earlier studies (Al-Sofyani, 1987) have shown that the growth rate of *Porites* species ranges from 5.68 to 8.30 mm per year along the Red Sea coast of Saudi Arabia. Considering this study as the base for the growth rate of *Porites* in this region, in present context the average of these two extremes was taken. The average of 6.99 (~ 7) mm per year was arrived. Later, the same value is used to calculate the total age of the sample which comes out to be around 20 years. As the sample was collected in December 2004 it is assumed that the top layer of ~7 mm is representing the record of the year 2004. Similarly the total of 14 cm thickness goes back to the year 1985.

Alkaline earth elements in marine sediments have received considerable attention in view of their assimilation up by marine

organisms such as foraminifera, corals and mollusks. Mg, Sr, and Ba are associated with carbonates by forming magnesite (MgCO_3), strontianite (SrCO_3), and witherite (BaCO_3) in the marine environments (Kim *et al.*, 1999). The high precision measurement of the Sr/Ca ratio in corals has the potential for measuring the sea surface temperatures with very high accuracy (Marshall and McCulloch, 2002; Ren *et al.*, 2003; Shen *et al.*, 2005).

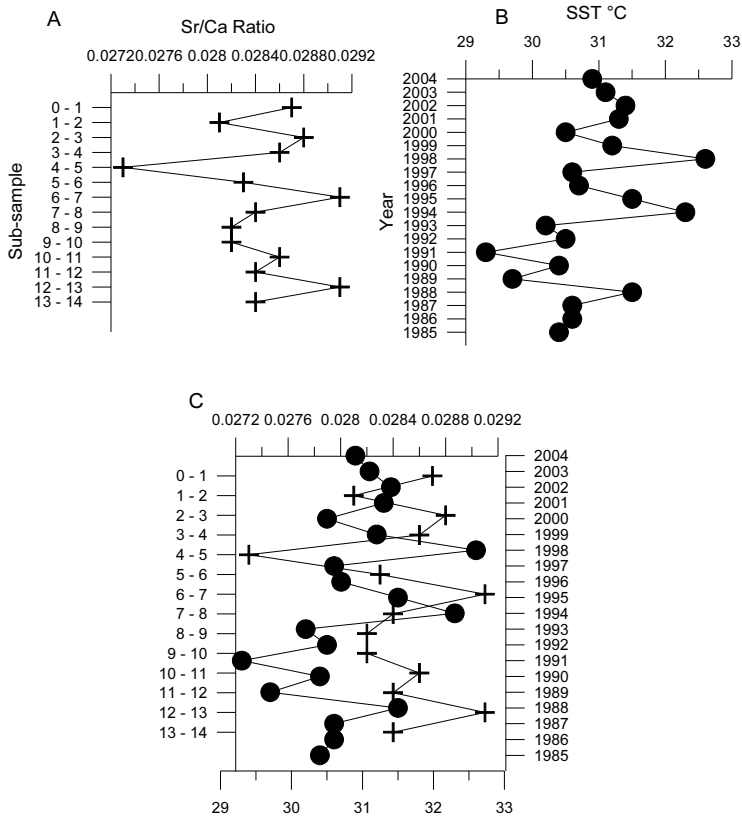


Fig. 3. Downward relationship between: (A) Sr/Ca ratio and Time (B) SST and Time (C) Overlapping of A and B to show the interrelationship between the parameters.

These 14 sub-samples were subjected to elemental analysis of 11 elements out of which only 4 elements (Ca, Mg, Ba and Sr) have shown detective values which are tabulated in Table 1.

Table 1. Distribution percentage of Ca, Mg, Ba, Sr, and Sr/Ca ratio in different sub-samples of coral.

Sub-Sample No.	Section (cm)	Ca (%)	Mg (%)	Ba (%)	Sr (%)	Sr/Ca Ratio
1.	0-1	21.7900	0.1640	0.0223	0.6250	0.0287
2.	1-2	22.8500	0.1428	0.0009	0.6436	0.0281
3.	2-3	22.7900	0.1227	ND	0.6560	0.0288
4.	3-4	22.5900	0.1367	0.00003	0.6473	0.0286
5.	4-5	23.1400	0.1301	ND	0.6320	0.0273
6.	5-6	22.4000	0.1344	ND	0.6351	0.0283
7.	6-7	22.6500	0.1248	ND	0.6586	0.0291
8.	7-8	22.1400	0.1115	ND	0.6297	0.0284
9.	8-9	22.4600	0.1219	ND	0.6325	0.0282
10.	9-10	22.3800	0.1242	ND	0.6320	0.0282
11.	10-11	22.3300	0.1321	ND	0.6380	0.0286
12.	11-12	22.0800	0.1212	ND	0.6273	0.0284
13.	12-13	22.6100	0.1203	ND	0.6579	0.0291
14.	13-14	22.7700	0.1057	ND	0.6460	0.0284

ND == Not Detected

Distribution of Elements

Calcium. The calcium is the most dominating in all the sub-samples varying from 21.7900 to 23.1400%, except these values, most of the variation is in a narrow band of distribution. This limited variation may be inferred that there is not much variation in the conditions for the availability of calcium especially below the level of 5 cm.

Magnesium. The distribution pattern of magnesium is very much restricted in a narrow range, which varies between 0.1056 & 0.1640 % and most of the values are close to the lower end of the values.

Barium. Barium is least in the abundance and shows its presence in the upper two or three sub-samples.

Strontium. The distribution of strontium though limited in range of 0.6250 & 6586 % is quite significant and will be helpful in deciphering the paleoclimate.

The distribution patterns of all the elements are restricted in a limited range. This confirms the fact that there is little change during the two decades for which records, are preserved in the sample under study. The

calcium is dominant in all the sub-samples whereas, magnesium and strontium though present in all the sub-samples, but in a very restricted quantity. Moreover, barium is restricted only in the upper three sub-samples. This restricted barium presence in the upper 4 cm part of the sample, and the absence below that level could be inferred that fresh water inflow was scarce and very much restricted in time under consideration.

Following Shen *et al.*, 2005 the plot (Fig. 3A) of Sr/Ca ratio against the time (in year), shows that 4 values are below the mean value (0.0284); with two prominent lows. The first (0.0281) one is at 01-02 cm and the other (0.0273) occurs at 04-05 cm level. Further, it is also observed that most of the Sr/Ca ratios fall below the average value (0.02844).

Similarly, the SST values against the time (Fig. 3B) show that there are four highs in comparison to the mean value of SST (30.86°C) seen at 01-02, 04-05, 07-08 and 11-12 cm levels and the rest are below the average. These higher values correspond to the years 2002 (31.4°C), 1998 (32.6°C), 1994 (32.3°C) and 1988 (31.5°C) respectively (Fig. 3). Among these, the SST at the level close to 04-05 cm sub-sample is highest followed by the value at the level close to 07-08 cm sub-sample, besides the relatively low SST values are observed at 01-02 and 11-12 cm sub-sample.

The superimposition (Fig. 3C) of the values of highest SST of the years on the Sr/Ca ratio values brings out a correlation between these two parameters *i.e.* the low values of Sr/Ca ratio at 01-02 and 04-05 cm very well correspond to the warmer conditions, indicated by high values of the SST in the years 2002 and 1998 in the region. The other two higher values of SST did not show any prominent relationship with the Sr/Ca ratio values. The level of 04-05 cm which represents 31.6°C for the year 1998 is well known year of maximum warming observed over the Stanley Reef of Australia and designated as the El-Nino event during the period of 1997-98 (Marshall and McCulloch, 2002). A point can be noted here that Marshall and McCulloch (2002) have reported 30°C SST during 1997-98 from their area of study whereas, in the preset area, the data show relatively higher sea surface temperature.

This modest study from an isolated Red Sea region can be concluded by mentioning that the area also shows a good relationship between Sr/Ca and SST. Moreover, these observations are not the reflection of

local changes but that of other factors also. Furthermore, a note of caution can be added here that this conclusion is based on the limited observations but their corroboration with other region encouraged the authors to bring out this work and suggest that to make these observations, more useful especially to examine the response of coral reefs of Saudi Arabia to climate change the spatial and temporal extent of study needs to be encouraged.

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مشاهدات مبنية على اختلاف توزيع العناصر القلوية الأرضية
(الكالسيوم، والمغنيسيوم، والإسترونشيوم، والباريوم) في هيكل
بوراييتس لوتيا (*Porites lutea*) في وسط الساحل الغربي
للمملكة العربية السعودية

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المستخلص. قيست تراكيز العناصر القلوية الأرضية (الكالسيوم،
والمغنيسيوم، والاسترونشيوم، والباريوم) في مستعمرة بوراييتس
لوتيا، في محاولة لتقييم التغير الرأسى في توزيع هذه العناصر،
ومضاهاة نسبة الاسترونشيوم والكالسيوم مع حرارة سطح البحر.
وتشير النتائج إلى وجود علاقة جيدة بين نسبة الاسترونشيوم/
الكالسيوم مع حرارة سطح البحر مستقلة عن مناخ البيئة.