

## Opposed trend of skeletal carbon isotopic ratios found in two different coral species collected from the same site: Genus-dependent responses

M. Shimamura<sup>1</sup>, K. Hyeong<sup>1</sup>, T. Watanabe<sup>2</sup>, T. Irino<sup>3</sup>, C. M. Yoo<sup>1</sup>, W. S. Kim<sup>1</sup>

1) Korea Ocean Research and Development Institute, Ansan P. O. Box 29, Seoul 425-600, Korea

2) Hokkaido University, Graduate School of Science, N10W8, Kita-ku, Sapporo 060-0810, Japan

3) Hokkaido University, Faculty of Environmental Earth Science, N10W5, Kita-ku, Sapporo 060-0810, Japan

**Abstract.** For better understanding of carbon isotope systematic of coral skeleton, two different coral species growing next to each other, *Porites sp.* and *Platygyra ryukyuensis*, were collected at a site from Ishigaki Island, Japan, and analyzed for oxygen and carbon isotope ratios. Oxygen isotope ratios of both corals show seasonal variations well matching each other and that of observed sea surface temperatures. However, carbon isotope ratios were opposed in trends between two coral species. Carbon isotope ratios of *Porites* show a seasonal fluctuation matching that of solar radiation, while those of *Platygyra* are opposite in trend to that of solar radiation with weaker amplitude. Given that both coral colonies had been exposed to same environmental conditions during the growth period, these opposite trends should be attributed to different species-dependent vital response to the same environmental condition. A vector analysis indicates that seasonal variation of carbon isotope ratios are dominantly controlled by metabolic isotopic effect in both corals and also that the opposite trends in seasonal fluctuations of two coral species result from the opposite direction of metabolic isotope effect acting on two coral species. *Porites* shows a negative slope in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plot, in which seasonal shifts of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  from colder to warmer season are explained with increased temperature and increased photosynthesis/respiration (P/R) ratios, indicating increased food-dependency on symbiotic algae (autotrophy) during warmer season. In contrast, *Platygyra* shows a positive slope in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plot, in which seasonal shift of  $\delta^{13}\text{C}$  to summer is caused by decreased P/R ratios, indicative of reduced dependency on autotrophy during warmer season. This physiological characteristic of *Platygyra* might provide a tolerance to colder and weaker solar radiation environmental condition, which allows its wide distribution in middle latitude region.

**Key words:** coral skeleton, carbon isotope compositions, species dependency, *Porites*, *Favia*.

### Introduction

Geochemical composition of reef-building coral skeleton has been a popular tool for high-resolution paleoclimatic reconstructions because coral skeleton shows systematic seasonal changes in isotopic and elemental compositions according to seasonal environmental changes. In particular, the stable oxygen isotopic values ( $\delta^{18}\text{O}_{\text{c}}$ ) and Sr/Ca ratios of coral skeleton have proven to be reliable proxies for sea surface temperature (SST) and salinity (SSS) (Gagan et al. 2000). Boron isotopic composition, Cd/Ca, U/Ca ratios have been used as pH, upwelling, and temperature indicators, respectively (Pelejero et al. 2005; Reuer et al. 2003; Min et al. 1995).

Various controlling factors have been proposed for carbon isotopic value of coral skeleton ( $\delta^{13}\text{C}_{\text{c}}$ ), including the  $\delta^{13}\text{C}$  of dissolved inorganic carbon (DIC) in seawater (Nozaki et al. 1978; Swart et al. 1996), light intensity for photosynthesis of the zooxanthellate (Weber and Woodhead 1970; Swart

1983; Wellington and Dunbar 1995; Reynaud-Vaganay et al. 2001; Grottoli 2002; Asami et al. 2004; Shimamura et al. 2008), utilization and  $\delta^{13}\text{C}$  of  $\text{CO}_2$  originating from respiration (Swart et al. 2005), kinetic isotope effects (KIE) related to the coral calcification rate (McConnaughey 1989a,b; Omata et al. 2005; Suzuki et al. 2005), changes in the coral autotrophy/ heterotrophy diet (Carriquiry et al. 1994; Felis et al. 1998; Grottoli 2002), and coral spawning (Gagan et al. 1994, 1996). However, vital effects and physical controlling mechanisms of  $\delta^{13}\text{C}_{\text{c}}$  are not fully understood yet. Because of it, the carbon isotopic value of coral skeleton ( $\delta^{13}\text{C}_{\text{c}}$ ) has limited applicability in paleo-environmental reconstructions, other than chronology of long-lived coral records (e.g., Cole et al. 1993). Given that  $\delta^{13}\text{C}_{\text{c}}$  is measured simultaneously with  $\delta^{18}\text{O}_{\text{c}}$ , shows seasonal variation as clearly as  $\delta^{18}\text{O}_{\text{c}}$  does, and reflects both environmental and biological signals, it has great

potential as a powerful tool for paleo-environmental reconstructions.

For better understanding of controlling factor of  $\delta^{13}\text{C}$ , two different coral species growing next to each other, *Porites* sp. and *Platygyra ryukyuensis*, were collected at a site from Ishigaki Island, Japan, and analyzed for  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ . The results were compared with observed environmental variables. *Platygyra* is one of hermatypic reef building massive corals that show a wide geographical distribution from tropics to higher latitude regions up to 35°N in the northwest Pacific (Yamano et al. 2004). Its geographical distribution extending to middle latitude region could allow us the development of a coral environmental proxy that can be used for middle latitude region. *Porites* was sampled together for the comparison with the results of *Platygyra* because it has provided reliable reconstructions of environments in tropical to subtropical regions of low latitude.

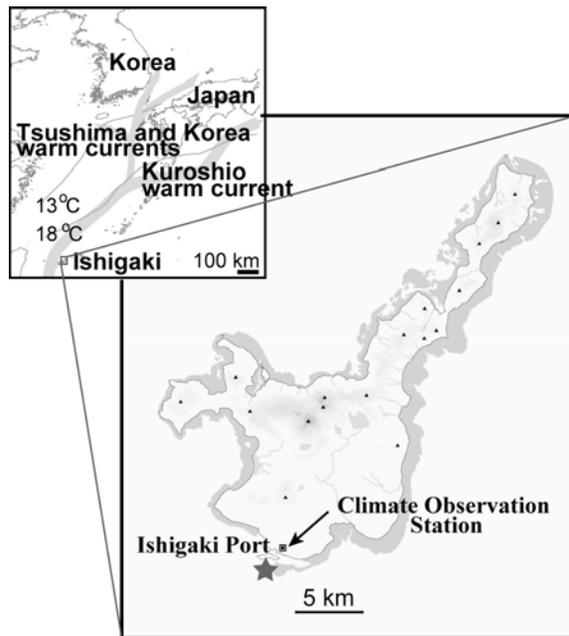


Figure 1: Location map showing the coral sampling sites (star mark) and climate observation station operated by Meteorological Agency of Japan.

### Study site and method

Ishigaki Island is located in the southern part of Ryukyu Island Chain, Japan (Fig. 1). Two coral colonies, *Platygyra ryukyuensis* and *Porites* spp., each ~20cm in height, were collected in September, 2005 at 2 m water depth below mean sea level near the Ishigaki Port in the southern part of Ishigaki Island (Fig. 1). The coral collection site (24°25'N, 124°09'E) is about 30 m away from the seawall of the port, facing open ocean. The coral colonies had grown next to each other and thus had been exposed to the

same environmental conditions (i.e. SST, SSS, light intensity,  $\delta^{13}\text{C}$  of DIC, and etc.). SST and light intensity were observed at a climate observation station of Japan Meteorological Agency, located in the Ishigaki Port (Fig. 1). The highest light intensity were observed in June–July, whereas the highest SST is recorded in July–August during the study period

The collected coral samples were cut into 5 mm-thick slabs oriented parallel to the maximum growth axis. These slabs were cleaned with de-ionized water and X-rayed using an M-60 (SOFTEX Co). The X-radiographs of the coral slabs showed clear image of corallites, the skeleton of an individual polyp, and annual growth bands (Fig. 2). A continuous corallite along the major growth axis was selected from each slab for micro-sampling (Fig. 2).

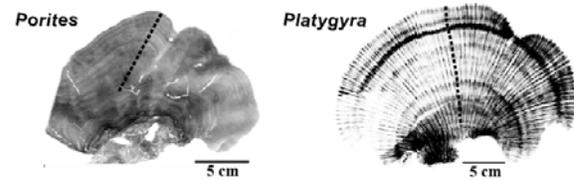


Figure 2: Positive prints of soft X-ray radiographs of coral slabs with micro-sampling transects (dashed lines).

Micro-sampling was carried out using a ledge micro-sampling technique (Gagan et al. 1994). For each sample, a 1-mm-thick and 3-mm-wide ledge was prepared along the selected corallite. The ledges were then ultrasonically cleaned with distilled water and dried in an oven at 40°C. Micro-sampling was undertaken on an accurate-distance ( $\pm 10\mu\text{m}$ ) movable table at a 200 $\mu\text{m}$  interval using a 0.8-mm-diameter end-mill drill bit mounted on a micro-milling machine. Such a sampling interval provides the time resolution of ~6 days for *Platygyra* and ~10 days for *Porites*, but the  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  measurement were undertaken at a time resolution of 25 and 20 days at peak areas, respectively. For *Porites*, sampling was carried out for one corallite that includes theca wall, columellae, and septa because of narrow width of corallite (av. 1mm). *Platygyra* was sampled only along the theca wall because of a wide corallite width (3 ~ 4.4mm) and absence of robust columellae and septa structures.

Powdered coral samples were reacted with 100% phosphoric acid at 70.0°C in an automated individual-carbonate reaction device (Kiel Device) coupled with a Finnigan MAT 251 mass spectrometer. The resulting  $\text{CO}_2$  gas was calibrated using NBS-19 standard. The oxygen isotopic ratio for the sample was reported relative to the Vienna Pee Dee Belemnite (V-PDB) in conventional delta notation. The precision for the analysis were 0.07‰ for both

$\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  based on replicate measurement of NBS-19 standard (n=25).

## Results

Both corals show a clear seasonal variation in  $\delta^{18}\text{O}$  that agree with that of SST (Fig. 3). However,  $\delta^{13}\text{C}$  shows different fluctuation pattern between *Platygyra* and *Porites* in magnitude and seasonality.  $\delta^{13}\text{C}$  of *Porites* varies from 0 to -5‰ for the time period of 1995 to 2005 with a clear seasonality, higher values in summer and lower values in winter. This seasonal fluctuation pattern is in phase with that of solar radiation (Fig. 3). In contrast, *Platygyra* shows  $\delta^{13}\text{C}$  values varying from 0 to -4‰ values with weaker seasonality that is opposed to that of *Porites*, higher in winter and lower in summer (Fig. 3). Since both corals had been exposed to the same environmental conditions during their growth period, these opposed trends should be attributed to the species-dependent vital factors, such as kinetic isotope effect due to different calcification rates between two species or different species-dependent physiological responses of two species to the same environmental condition. Seasonal extension rate and calcification rate, estimated based on  $\delta^{18}\text{O}$  variation and x-ray photo analysis, do not show correlation with  $\delta^{13}\text{C}$ , which means these variations cannot be explained by KIE.

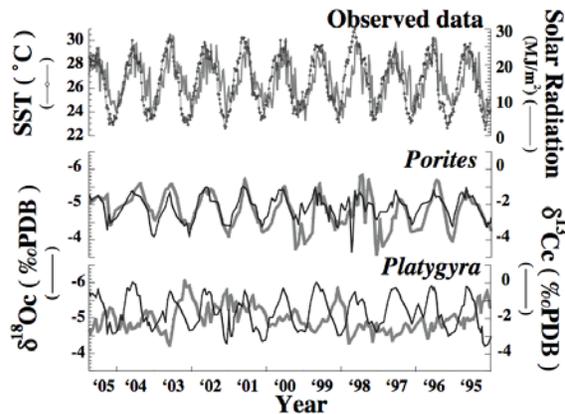


Figure 3: Temporal variation of the observed sea surface temperature and solar radiation, and the measured oxygen and carbon isotope ratios of *Porites* and *Platygyra* during the growth period

## Discussion

In order to understand controlling factors responsible for the opposed seasonal variation in the carbon isotope ratios of two coral species, we carried out a vector analysis similar as in McConnaughey (1989) and Omata *et al.* (2005). In this approach, variation of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  is explained with sum of three vectors with magnitude and direction: 1)

temperature dependency of  $\delta^{18}\text{O}$ ; 2) metabolic isotope effects (MIE) controlled by photosynthesis of symbiotic algae and respiration; and 3) KIE related to calcification rate of skeleton (Fig. 4).

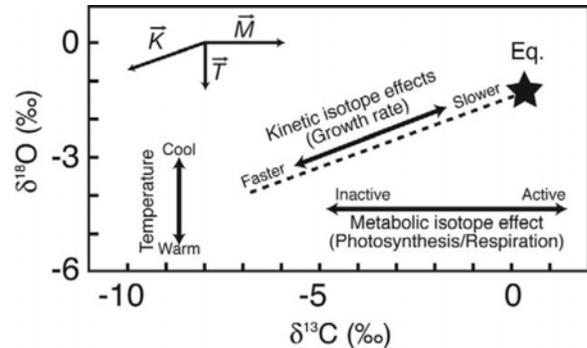


Figure 4: Schematic diagram showing the effects of temperature, kinetic isotope effect and metabolic isotope effect on  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$ , adapted from Omata *et al.* (2005). Eq.: isotopic composition of biogenic carbonate precipitated under isotopic equilibrium; K, M, and T: vectors representing the magnitude and direction of kinetic isotope effect, metabolic isotope effect, and temperature, respectively.

We plotted the determined  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  values in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plane on a yearly base (Fig. 5 as an example). In these plots, *Porites* always shows negative slope for all the years from 1995 to 2005 (Fig. 5), in which seasonal shift of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  from winter to summer can be explained by the sum of negative vector of temperature and positive vector of MIE with a little change in KIE. Negative vector of temperature indicates increase in temperature and positive vector of MIE represents increase in the ratio of photosynthesis to respiration (P/R) toward warmer season. Active photosynthesis of symbiotic algae during warmer season is responsible for the positive vector of MIE.

For the result of *Platygyra*, the slope against whole values showed positive slope in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plot for all the analyzed year (Fig. 5). For each vector components, little variation in magnitude of KIE between seasons as in *Porites*, MIE causes negative  $\delta^{13}\text{C}$  shifts because of the negative vector, and it is opposite to that in *Porites*. It means high P/R ratios during winter and non-active photosynthesis by symbiotic algae during warm season or much higher dependency of zooplankton. Also in general, MIE variation is much greater than KIE.

In contrast, *Platygyra*, shows positive slope in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plot (Fig. 5), in which seasonal shift of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  from winter to summer is now explained by the sum of negative vector of temperature, same as in *Porites*, and negative vector of MIE, opposite to that of *Porites* (Fig. 5). As in *Porites*, KIE has negligible effect on seasonal variation of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  (Fig. 5). Negative vector

of MIE indicates increased importance of respiration relative to photosynthesis during warmer season in *Platygyra*. It can not be conclusive, but might suggest that *Platygyra* is less dependent on autotrophy (food source from symbiotic algae) during warmer season. This physiological characteristic of *Platygyra* might provide a tolerance to colder and weaker solar radiation, which allows wide distribution of *Platygyra* in middle latitude region.

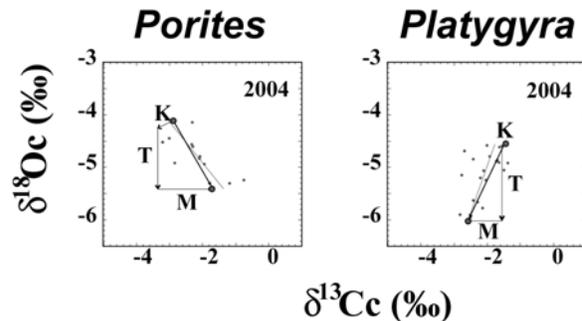


Figure 5: Vector approaches to explain seasonal changes of carbon and oxygen isotopic ratios of the studied corals. K, M, and T show the direction and magnitude of the kinetic, metabolic, and temperature effects, respectively.

## Conclusions

Oxygen isotopic ratios of *Porites sp.* and *Platygyra ryukyuensis* that had grown next to each other show seasonal variations well matching each other and that of observed sea surface temperatures. However, carbon isotope ratios were opposed in trend between *Porites* and *Platygyra*. Carbon isotope ratios of *Porites* showed a seasonal fluctuation matching that of solar radiation, while those of *Platygyra* were opposite in trend to those of solar radiation and *Porites*. Given that both coral colonies had been exposed same environmental conditions, these opposed trends are likely attributed to species-dependent vital factors rather than environments.

Vector analysis indicates that seasonal variation of  $\delta^{13}\text{C}_c$  is dominantly controlled by MIE over KIE in both corals. *Porites* shows a negative slope in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plot, in which seasonal shifts of  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  from colder to warmer season are explained by increased temperature and photosynthesis/respiration (P/R) ratios, indicating more dependency on food from symbiotic algae during warmer season. In contrast, *Platygyra* shows a negative slope in a  $\delta^{18}\text{O}$ - $\delta^{13}\text{C}$  plot and decreased P/R ratios during warmer season, indicative of reduced dependency on autotrophy during warmer season.

## Acknowledgement

We express our sincere thanks to CREES 2005 members for sampling, T. Kuwashima and H. Nomura (Hokkaido University) for coral colony cutting, and Dr. T. Nakamori (Tohoku University) for coral species identification. This research was supported by

Hokkaido University Clark Memorial Foundation (Heisei-17th Doctor Course Student Research Support Grant), KORDI (POSEIDON-PP08410), and Korea-Japan Scientific Cooperation Program funded by KOSEF (PN61200) and JSPS..

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