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# サンゴ骨格に記録される炭素同位体比の vital effect の実態解明に向けたサンゴポリプモデルの開発
# A coral polyp model with a carbon stable isotope module for clarifying vital effect in coral skeletal records

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Carbon stable isotope ratio ($d^{13}C$) recorded in coral skeletons exhibits annual variations and is considered to be controlled by the $d^{13}C$ of the dissolved inorganic carbon (DIC) in the ambient seawater and by metabolic activities such as photosynthesis and feeding (Weber et al. 1976; Erez 1978; Fairbanks and Dodge 1979; McConnaughey 1989; Felis et al. 1998; Reynaud-Vaganay et al. 2001). However, because of the complexity of the internal processes, the mechanism of the internal isotope effect (called the ”vital effect”) has been less understood, and the extraction of useful paleoenvironmental proxy from $d^{13}C$ data has been less successful compared with $d^{18}O$ as a temperature and salinity proxy.

Recently, we developed a coral polyp-scale numerical simulation model (Nakamura et al. under review), which is constructed with three components (ambient seawater, coelenteron and calcifying fluid), and incorporates photosynthesis, respiration and calcification processes with transcellular ion transport by Ca-ATPase activity, and passive transmembrane $CO_2$ transport and diffusion. The model calculates dissolved inorganic carbon (DIC) and total alkalinity (TA) in the ambient seawater, coelenteron and calcifying fluid, dissolved oxygen (DO) in the seawater and coelenteron and stored organic carbon ($CH_2O$). To reconstruct drastic variation between light and dark respiration, respiration rate dependency on DO in coelenteron is incorporated. Calcification rate depends on aragonite saturation state in calcifying fluid. The aragonite saturation state increases due to Ca-ATPase driven by the energy generated by the respiration. Our simulation result well reconstructed the ”light-enhanced calcification”, the basic responses of internal $CO_2$ system and DO, and calcification rate responses to the ambient aragonite saturation state. This model describes an internal DIC pass and mass balance inside the polyp. Therefore, considering the isotopic fractionation of each path, the $^{13}C$ mass balance module may be easily incorporated into the polyp model. The aims of this study are to develop a carbon stable isotope module for the coral polyp model to shed light on the ”vital effect”, and to verify its applicability as paleoenvironmental proxy.

There are two primary factors to explain the ”vital effect” of carbon stable isotope; (1) kinetic isotope effect through the $CO_2$ hydration and hydroxylation in the calcifying fluid (e.g. McConnaughey et al. 1997), and (2) influx of lighter $CO_2$ into the calcifying fluid by respiration (e.g. Goreau 1977). To evaluate the efficiency of the kinetic isotope effect, the model was examined for two hypothetical cases: (1) all $CO_2$ system is equilibrium and (2) $CO_2$ hydration and hydroxylation is nonequilibrium; and to evaluate the efficiency of $CO_2$ passage by respiration to calcifying fluid, some different rates of the $CO_2$ flux were tested.

The results of the simulations showed that the kinetic isotope effect was not enough to decrease coral skeletal $d^{13}C$. On the other hand, the $CO_2$ flux by the respiration decreased the skeletal $d^{13}C$ and the simulated $d^{13}C$ reached to a measured level. Therefore, it is considered that the $CO_2$ flux by the respiration is the most important process for the ”vital effect” of coral skeletal $d^{13}C$. Our model reconstructed clear seasonal variations of skeletal $d^{13}C$. In this result, $d^{13}C$ in the summer is lighter than that in the winter. Some coral records show similar trends with our simulation, but some ones indicate opposite trends. In this simulation, because the $d^{13}C$ of DIC in the ambient seawater and temperature are assumed to be constant, the simulated seasonal change is caused only by the seasonal light intensity change. However $d^{13}C$ of DIC in the ambient seawater and temperature must have seasonal change, and the skeletal $d^{13}C$ must be affected by these factors directly or indirectly. Therefore, to reconstruct the coral skeletal $d^{13}C$, these factors also need to be considered.

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