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Combined Effects of Photosynthesis and Calcification on the Partial Pressure of Carbon Dioxide in Seawater

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The effects of marine photosynthesis and calcification on the partial pressure of carbon dioxide in seawater (P_{CO_2}) are examined in the light of recent studies and using original model calculations. The ratio of organic carbon to inorganic carbon production (R_{OI}) determines whether an ecosystem is a net sink or source for atmospheric CO_2. The P_{CO_2} maintains its initial value when the photosynthetic rate is approximately 0.6 times the calcification rate under normal sea surface condition. In case of higher R_{OI}, the P_{CO_2} decreases and seawater can absorb atmospheric CO_2. The ratio of organic carbon to inorganic carbon production can be used as a potential indicator of sink-source behavior in aquatic photo-calcifying systems.

Keywords:
· Carbon dioxide,
· photosynthesis,
· calcification,
· metabolism,
· chemical equilibrium,
· gas exchange,
· seawater,
· partial pressure.

1. Introduction

The role of the oceans in the global carbon cycle is a subject of contention in respect of their role in the maintenance of the atmospheric CO_2 level. The net CO_2 flux between air and sea can be estimated using wind speed, seawater temperature and the difference in the partial pressure of CO_2 between seawater and atmosphere (Bolin, 1960; Broecker and Peng, 1974). Changes in the partial pressure of CO_2 in seawater (P_{CO_2}) are caused by thermodynamic variations (temperature and salinity), biological activity, and CO_2 exchange with air. The effects of biological activity on P_{CO_2} have received less attention than the thermodynamic effects (e.g. Weiss *et al.*, 1982; Takahashi *et al.*, 1993).

Marine photosynthesis and calcification shift the chemical equilibrium of CO_2 in seawater in opposite directions: photosynthesis decreases P_{CO_2} while calcium carbonate production raises P_{CO_2}. Calcification tends to drive CO_2 from the ocean to the atmosphere, although it consumes carbonate and/or bicarbonate ions. This paradox has become well understood due to many enlightening papers (Kano, 1990; Ware *et al.*, 1992; Frankignoulle *et al.*, 1994; Suzuki, 1994; Frankignoulle *et al.*, 1995). Some models have been proposed in which a calcifying system such as a coral reef acts as a source of atmospheric CO_2 (Berger, 1982a, b; Opdyke and Walker, 1992).

The "0.6 rule" was proposed by Ware *et al.* (1992) using a simple chemical equilibrium model (i.e. 0.62 moles of CO_2 are liberated for each mole of $CaCO_3$ precipitated in buffered seawater). Frankignoulle *et al.* (1994) reported that the theoretically predicted Ψ (released CO_2/precipitated carbonate ratio) is 0.6 when the initial P_{CO_2} is 350 μatm, which confirmed the previous estimates obtained by Ware *et al.* (1992).

Some measurements on calcification and P_{CO_2} were made and a discrepancy between observation and model prediction became evident: observed $\Psi = 0.1$ at an organism level for scleractinian coral with zooxanthelle (Frankignoulle and Gattuso, 1993); $\Psi = 0.06$ at a community level (Gattuso *et al.*, 1993). These large differences are attributed mainly to a tight coupling between photosynthesis and calcification (Frankignoulle *et al.*, 1994). Kayanne *et al.* (1995) reported that a fringing reef in the Ryukyus has a decreasing effect on P_{CO_2}, in spite of its rapid calcification. This may also be attributed to a tight coupling between organic and inorganic carbon metabolism. Kano (1990) proposed the coupled model of photosynthesis and calcification and his model is useful for understanding a tight coupling between organic and inorganic carbon processes.

Further consideration of the coupled conditions of organic and inorganic carbon process is essential in order to ascertain the role of the marine calcifying system. In the present study, the combined effects of marine photosynthesis and calcification on P_{CO_2} are examined quantitatively, according to recent studies and original model calculations.

2. Model Description

In order to examine the combined effects of photosynthesis and calcification on the P_{CO_2} in seawater, a model was established using an algorithm originally from Kano (1990) and a modification of Suzuki *et al.* (1995). To sim-