【Grant-in-Aid for Transformative Research Areas（B）】

Carbonate in situ biology aimed at resolving the carbonate paradox

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Project Information	Project Number : 25B401　　Project Period (FY) : 2025-2027 Keywords : biomineralization, calcium carbonate, carbonates, proton

Purpose and Background of the Research

●Outline of the Research

Corals, mollusk shells, crustacean exoskeletons, sea urchin tests, pearls, and star sand have hard minerals formed through biological processes, known as biomineralization. These structures are mainly composed of carbonate minerals, such as calcium carbonate that are the origins of almost all limestones. Although limestone constitutes a major reservoir of carbon on Earth, the formation process of carbonates in the sea has traditionally been considered as a release reaction of carbon dioxide rather than fixing carbon, due to the production of protons during carbonate precipitation (carbonate paradox). This theory was established under the assumption that calcification proceeds through purely inorganic reactions, before the active biological molecules in the biomineralization was understood. Recent advances in biomineralization research have revealed that organisms increase local pH and utilize specific organic molecules to efficiently react the carbonate and calcium ions. Based on these findings, it is suggested that calcification might proceed without releasing carbon dioxide via proton generation. By integrating expertise across material chemistry, life science, ecology, and environmental science, we aim to re-examine the role of carbonates in the global carbon cycle and to establish a new field of 'carbonate biology' that resolves the carbonate paradox.

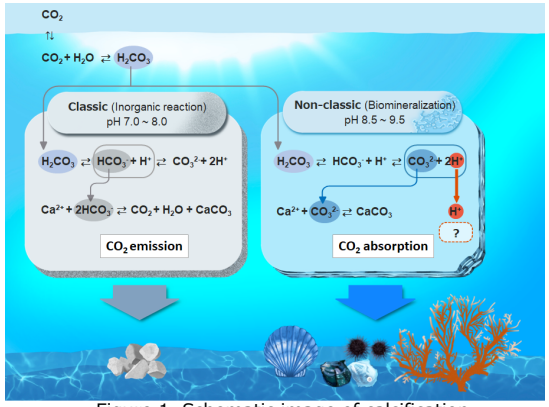

Figure 1. Schematic image of calcification

●Project organization

General Coordination Group Michio Suzuki (The University of Tokyo)

The group organizes the lecture, symposium, museum exhibitions, and SNS to raise public awareness about the role of carbonates in the carbon cycle. Experts in STEAM education are also involved to promote the integration of disciplines and expand outreach through art and design thinking. Final goal of this project is a paradigm shift in society.

A01 Materials Science Group: Taiga Okumura (Waseda University)

The group will decompose the influence of organic molecules and environmental factors on crystal nucleation and growth into individual elementary processes.

A02 Life Sciences Group: Michio Suzuki (The University of Tokyo)

The group will elucidate the molecular mechanisms of organic matrices on calcification.

A03 Ecology Group: Takashi Toyofuku (JAMSTEC)

The group will determine which organisms' calcification processes release protons using sophisticated culture techniques.

A04 Environmental Science Group: Kozue Nishida (Tokyo University of Science)

The group aims to refine the understanding of biologically induced fractionation effects (vital effects) using stable isotope ratios (B, C, O, Sr) and elemental concentrations (such as B and U).

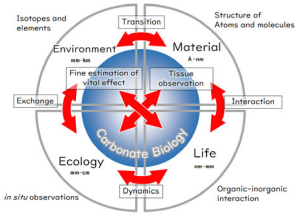

Figure 2. Linkage of each group

Expected Research Achievements

●Role of Carbonates in the Carbon Cycle

The Materials Science Group advances analysis from the atomic to nanometer scale; the Life Sciences Group focuses on biomolecules from the nanometer to millimeter scale; the Ecology Group observes cells and tissues from the millimeter to centimeter scale; and the Environmental Science Group conducts observations and measurements on the macroscale. Through the collaboration among these groups, we aim to clarify the behaviors of calcium, carbonate, protons, and organic molecules during carbonate formation. Although these four research groups approach carbonate formation in organisms at different spatial and temporal scales, we believe that through their collaboration and the integration of their results, we can find an answer to the "carbonate paradox," advancing human scientific knowledge.

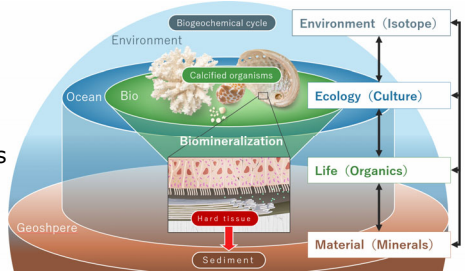

Figure 3. Summary of study phase

●Social Paradigm Shift

We aim to raise awareness across not only academic fields but also society and a broad range of stakeholders regarding the question of whether biologically mediated carbonate formation contributes to carbon fixation. By resolving the "carbonate paradox," we seek to drive a social paradigm shift.

● Ripple Effects

If these efforts lead to the recognition that carbonate formation contributes to carbon fixation, it is expected that the ecological services of coral carbonate production will be re-evaluated increasing the importance of environmental conservation and nature positive. Furthermore, the aquaculture industry involving calcifying organisms including shellfish may be reassessed from a carbon-neutral perspective depending on whether they are recognized as sink or source of CO_2. Additionally, pursuing a deeper understanding of biologically mediated carbonate formation mechanisms could contribute to the development of technologies that enable human society to efficiently capture CO_2 as carbonates.

Homepage Address, etc.	Homepage of the project : https://carb-bio.w3.kanazawa-u.ac.jp/index.html SNS of the project : https://x.com/caco3_biology