

Element-based Biology: Transition and flexibility of elemental utilization by life

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Purpose and Background of the Research

● Outline of the Research

Life on Earth relies on elements available in the environment, whose composition varies across space and time. In response, organisms have evolved mechanisms to acquire necessary elements and, in some cases, to switch the elements they use, thereby maintaining their functions. At the same time, biological activity has reshaped Earth's elemental environment, as exemplified by oxygenic photosynthesis and the subsequent oxidation of the surface. Thus, Earth's elemental environment and life have co-evolved, with organisms selecting specific elements from those available to build their functions (Figure 1). However, why particular elements were selected and how diversity in elemental use emerged remain unclear.

Because this diversity has developed alongside changes in Earth's elemental environment, it cannot be explained by life science alone; understanding the local elemental conditions in which organisms evolved is essential. While such environmental changes have been studied mainly in geoscience, reconstructing element distributions in actual habitats is necessary to understand biological selection and flexibility.

To address this, we integrate life science and geoscience to establish a new concept—that organisms alter both the types of elements they use and how they use them in response to their environment—and thereby pioneer a new field, Element-based Biology (Figure 1).

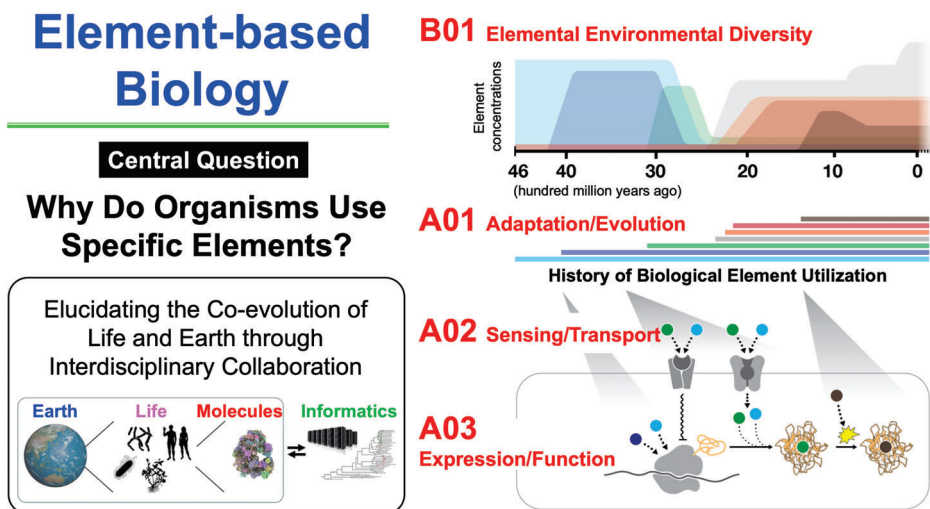


Figure 1. Conceptual framework and research structure of “Element-based Biology”

● Organization of the Research Area

To address why organisms select and use particular elements, this research area integrates life science and geoscience. We focus on three aspects: adaptation and evolution, sensing and uptake, and the regulation of biological functions by elements, organized as A01 (Adaptation/Evolution), A02 (Sensing/Transport), and A03 (Expression/Function) (Figure 2). In each unit, we define the relevant organisms and their spatiotemporal contexts, and reconstruct the corresponding elemental environments through B01 (Elemental Environmental Diversity). This integration enables us to determine how organisms have responded to changes in elemental environments (Figure 2).

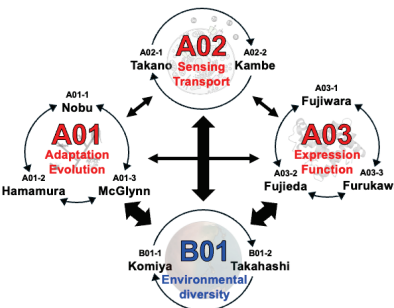


Figure 2. Planned research groups

Expected Research Achievements

This research area addresses the central question of why organisms select and use specific elements (Figure 3), and defines the objectives of each planned research group.

● A01: Adaptation and Evolution

We identify key evolutionary transitions in elemental use through microbial phylogeny and reconstruct their environmental context with B01 to evaluate how elemental environments have shaped evolution.

● A02: Sensing and Transport

We clarify how organisms sense and transport elements and, in collaboration with B01, determine the environmental conditions under which these mechanisms emerged and were maintained.

● A03: Expression and Function

We examine how gene expression, protein structure, and enzymatic activity depend on elemental environments, and test their changes and adaptability through element substitution informed by B01.

● B01: Elemental Environmental Diversity

We reconstruct spatiotemporal variations in elemental environments using geological samples and examine their relationships with biological evolution, including the influence of biological activity.

Coordinating projects will use geological records to identify microbial elemental use over time and clarify how life has selected elements. Based on geochemical predictions, we will identify potentially usable elements and determine the cellular /molecular requirements for their use. Together, this framework will establish the concept that organisms flexibly modify their use of elements in response to environmental changes, and advancing Element based Biology.

What Changes Occurred in Earth's Elemental Environment?

In What Elemental Environment Did Life Originate?

How Did Organisms Switch the Elements They Use?



When Did Specific Elements Come into Use?

Element Utilization in Life: Evolution, Mechanisms, and Life-Earth Co-evolution

Figure 3. Objectives of this research area

Website(s)

<https://element-based-biology.jp/>