論文の内容の要旨

Paleoenvironmental reconstruction using geochemical and rock magnetic analyses for carbonates obtained from the Kingdom of Tonga, South Pacific

（地球化学・岩石磁気学的測定による南太平洋トンガ王国の古環境復元）

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South Pacific islands are extremely vulnerable to environmental changes such as sea-level rise, storm surges, earthquakes, and volcanic eruptions. The changes increase the probability of forced migration in the future. Meanwhile, archaeological studies suggest that a comparable situation occurred in this region during the Middle and Late Holocene. Thus, there is an urgent need to understand the mechanisms, variability, and impacts of environmental changes. However, the limited availability of environmental observations of this region before the mid-twentieth century means that paleoenvironmental reconstructions from natural archives, such as bivalves and speleothems, offer valuable tools for reconstructing the past variability of environmental changes. However, few quantitative paleoenvironmental studies using geochemical or geophysical methods have been reported.

Here, I reconstructed the paleoenvironment in the Kingdom of Tonga (Tonga) using geochemical and rock-magnetic analyses for bivalves and speleothems with developing novel proxies. Tonga is one of the South Pacific island countries and was a source area for the peopling of East Polynesia around 1,000 years ago; thus, it is suitable for studying paleoenvironmental reconstruction in the South Pacific and its related human migration.

First, I examined live-caught and archaeological shells, *Gafrarium tumidum,* to establish a novel proxy for the ratio of the freshwater inlet to the lagoon water. As a result, I defined the lagoon-specific local marine reservoir ages (ΔR_{lagoon}) of prehistoric bivalves as an influx of old ^{14}C from terrestrial limestone. Then, I reconstructed Tongatapu Island's sea-level history using radiocarbon measurements and glacio-hydro-isostatic adjustment (GIA) modeling. Our analyses reconstructing the lagoon's evolution suggest that the average size of *G. tumidum* decreased synchronously with corresponding changes in the paleoenvironment. These changes also correspond to the increasing trend of ΔR_{lagoon} from 105±49 to 156±85 years between ~2.6 and 1.2 ka. The decline in the shellfish assemblage within Fanga'uta Lagoon reported in previous studies was also synchronous with these changes, which were caused by a decrease in the exchange of water in and out of the lagoon. GIA modeling predicts mid-Holocene sea-level highstand (HHS) was less than 1 m above the present sea level in Tongatapu, suggesting that the previously reported observations of an HHS require additional contributions, perhaps from crustal uplift. Furthermore, recent Global Navigation Satellite System (GNSS) observations of vertical uplift rates at Tongatapu have a higher magnitude than the long-term uplift rate obtained from Holocene sea-level data.

Second, I applied a scanning SQUID microscopy (SSM) to conduct paleomagnetic measurements on a stalagmite collected from Anahulu Cave in Tonga. A stronger magnetic field was observed above the grayish surface layer compared to that of the white inner layer associated with the laminated structures of a speleothem at the submillimeter scale with the SSM. The magnetization of the speleothem sample calculated by an inversion of isothermal remanent magnetization (IRM) also suggests that the magnetic mineral content in the surface layer is higher than that in the inner layer. This feature was further investigated by low-temperature magnetometry and suggested that it contains magnetite, maghemite, and goethite. The first-order reversal curve (FORC) measurements and the decomposition of IRM curves show that this speleothem contains a mixture of magnetic minerals with different coercivities and domain states. The contribution from maghemite and goethite to the total magnetization of the grayish surface layer is much higher than for the white inner layer. The speleothem magnetically and visually retaining two distinct layers indicates that the depositional environment was shifted when the surface layer was deposited and was likely changed due to an oxidative environment such as volcanic eruption or/and human activities.

Future investigation is required to reveal the detail of linking environmental changes (e.g., climate change and sea-level change) to human activities in the South Pacific, but I have helped initiate this by demonstrating the potential to reconstruct the paleoenvironment in the Kingdom of Tonga using geochemical analyses for *G. tumidum* and rock magnetic analyses for the speleothem.