論文の内容の要旨

# The advancement of alkenone paleothermometry: applications to coastal, lake, and subaerially exposed sediments

## （アルケノン古水温計の新展開―沿岸・湖沼堆積物と堆積岩への適用―）

梶田展人

Long Chain alkenones (LCAs) are a class of $C_{37}$–$C_{42}$ unsaturated ketones synthesized by a specific group of haptophyte algae (Isochrysidales). In the open ocean, both in vitro experiments and ocean observational analysis indicated there is a linear relationship between the alkenone unsaturation ratio and sea surface temperature (SST). Therefore, LCAs in marine sediment cores have been widely used as a quantitative paleo-SST proxy since the 1990s. In this doctorate dissertation, after summarizing the development history of alkenone paleothermometry (Chapter I), I first present applicational studies of this method to coastal shallow-sea sediments to understand the relationship between climate change and human civilization flourished in coastal East Asia (Chapter II). Next, I present proxy developments on alkenone paleothermometry for further advances in the field, in particular for enabling applications to on-land geological sections and lake sediments (Chapter III). Finally, I proposed the potential for further development of LCAs as a reliable paleothermometer (Chapter IV).

In Chapter II, I reconstructed paleoclimate changes during the Holocene to investigate the influence of climatic events on the human histories in coastal East Asia. The coastal marine sediment cores are useful to reconstruct the paleoclimate because of the strong correlations of SST with atmospheric temperature (AT) in the shallow coastal area. In the first part, I investigate the estuary region of the Yangtze River (China), the

oldest Neolithic civilization, well-known for paddy rice cultivation that flourished during the mid-Holocene (ca. 5500–2200 BCE). However, although it is known that this Neolithic civilization collapsed at around 4.2 ka BP, the reason behind the collapse remains controversial. Sedimentary cores (MD06-3039 and 3040) collected from the inner shelf of the East China Sea, off the southeast coast of China, provide an excellent insight into estimating the regional paleoenvironment since ca. 5500 BCE. We analyzed the alkenone unsaturation ratios and our data indicated abrupt cold episodes (i.e., 3–4°C drop in SST) occurred frequently in the Yangtze delta region during 2600–1900 BCE. These episodes could have been related to the global climatic transition called the "4.2 ka event", when the dynamic of the East Asian monsoon might have been altered. These cold episodes could be sufficiently severe to damage rice cultivation and constitute a plausible explanation for the demise of the Yangtze Neolithic civilization. In the second part, I investigate the offshore of Tokyo area, central Japan, to enrich our understanding of climate change in East Asia and its impact on Japanese civilizations during the Holocene. Previous studies already reported paleo-SST records measured on midden shells along the coast of Tokyo Bay. However, continuous, high time-resolution and quantitative paleotemperature records were still lacking. A piston core was retrieved from Tokyo Bay from which 22 mollusk shells were extracted. An age model for the core, determined via accelerator mass spectroscopy (AMS) $^{14}C$ dating of the shells and a scoria layer from the Hoei eruption (1707 CE), showed that the sediment core recovered the period from ca. 2400 BCE to the present. We analyzed the alkenone unsaturation ratios to reconstruct the variations in the SST. The SST during the Meghalayan was generally warmer than the present exhibiting a declining trend, which roughly matches with the orbital-forcing changes in summer insolation and with the millennial-scale

southward shift of the subarctic front in the northeastern Pacific Ocean. The largest cold period, which occurred ca. 2300 BCE and had a minimum temperature of 19.5 °C, interrupted the warm conditions. This cold period may correspond to the 4.2 ka event. Our results also revealed that several cold periods occurred, which may have been caused by decreases in solar activity or large volcanic eruptions. Particularly, large decadal to centennial-scale cold periods were observed ca. 440 BCE and 100CE during the Yayoi era, which might be related to the occurrence of the large civil war and the decrease in the Jomon population, respectively. The coldest period after the establishment of a governmental centralized system was recorded ca. 1050 SE, which may have been caused by the combination of a strong El-Niño mode and reduced solar activity. These climate change events may eventually lead to major shifts in Japanese social systems.

In Chapter III of the doctorate dissertation, I reported my works about the developments of LCAs as a paleotemperature proxy. I applied alkenone paleothermometer to previously unstudied geological materials, i.e., a terrestrial outcrop and lacustrine sediment. I detected that LCAs and the other biomarkers are preserved in the rock outcrop of the Kazusa Group exposed in central Japan, the most continuous sedimentary succession in the world, covering almost the entire Pleistocene. The alkenone unsaturation ratios and *n*-alkane-based proxies appeared to reflect the glacial-interglacial changes in the SST and terrestrial climate, respectively. LCAs-based paleo-SSTs during 1.1–1.0 Ma were significantly higher than present-day SSTs in the same area, as supported by foraminiferal Mg/Ca-based SSTs, and thus possibly reflects a direct intrusion of the warm Kuroshio Current. Applying these biomarkers, which might

be circumstantially preserved owing to their immunity to high temperature and consolidation stress during burial and uplift, we expect that the Kazusa Group should reveal detailed oceanic and atmospheric changes of the Kuroshio region.

I also discovered LCAs in sediment from the brackish Lake Takahoko, in northern Japan. Identifying the lacustrine haptophyte species that produce LCAs is essential for LCAs-based paleotemperature reconstruction because the haptophytes inhibiting lakes are largely diversified and have different temperature calibrations. The identity of LCA-producing species in Lake Takahoko was investigated using 18S ribosomal DNA and organic geochemical analysis. Two distinct genetic groups, termed as Tak-A and Tak-B, were identified within the Group II haptophyte phylotype. Tak-A was closely related to Hap-A, which was obtained from Lake George, USA; and Tak-B was identified as *Isochrysis galbana*. Hap-A and *Isochrysis galbana* have similar temperature calibrations because they are closely related species. Therefore, Tak-A and Tak-B were expected to share similar calibrations and the changes of their relative abundances in the lake should not significantly disturb the paleotemperature reconstructions. The alkenone temperature recorded in the surface sediment corresponds to the lake temperature observed in early to late summer. This is likely related to the haptophyte bloom season in Lake Takahoko. Considering the haptophyte bloom season, Lake Takahoko may be a viable location for reconstructing an LCAs-based paleotemperature record.