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HKU Palaeobiologists Unlock 500,000 Years of Fossil Records Revealing Climate Change Impacts on the Southern Ocean Ecosystems and Risks of Marine Carbon Removal

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Image 1: This photograph beautifully captures the majestic scenery of the Southern Ocean, a vital component of the global climate system and a hotspot for deep-sea biodiversity. Whales gracefully swimming through the frame serves as a powerful symbol of the rich and vibrant life that thrives in these waters. Photo credit: Minoru Ikehara.

Climate change impacts not only life on land but also the largely unexplored deep-sea ecosystem, home to unique and largely unexplored fauna. Deep-sea animals, which have adapted to stable and extreme environments, are particularly vulnerable to changes in temperature and food availability. This raises a crucial question: What environmental factors are most important for deep-sea ecosystems, and how might they be disrupted?

The deep sea remains one of the least understood ecosystems on Earth. Ongoing human-induced climatic change, as well as geoengineering technologies that are intended to mitigate its effect, could drastically alter these habitats in the coming decades. However, understanding these potential impacts is challenging because biological monitoring typically focuses on short-term changes, which fail to capture the long-term environmental drivers that shape deep-sea ecosystems. To address this challenge, researchers are turning to the deep-sea fossil record, which offers a unique window into how deep-sea ecosystems and their fauna have responded to environmental changes over hundreds of thousands of years.

A study co-led by Professor Moriaki YASUHARA and Ms Raine CHONG from the School of Biological Sciences, the Swire Institute of Marine Science, and the Institute for Climate and Carbon Neutrality at The University of Hong Kong (HKU), as well as Dr May HUANG from Department of Geosciences of Princeton University, has shed light on how the deep-sea ecosystem in the Southern Ocean has evolved over the past 500,000 years. The study, published in the journal *Current Biology*, reveals that temperature changes and food input have played distinct roles in shaping deep-sea ecosystems.

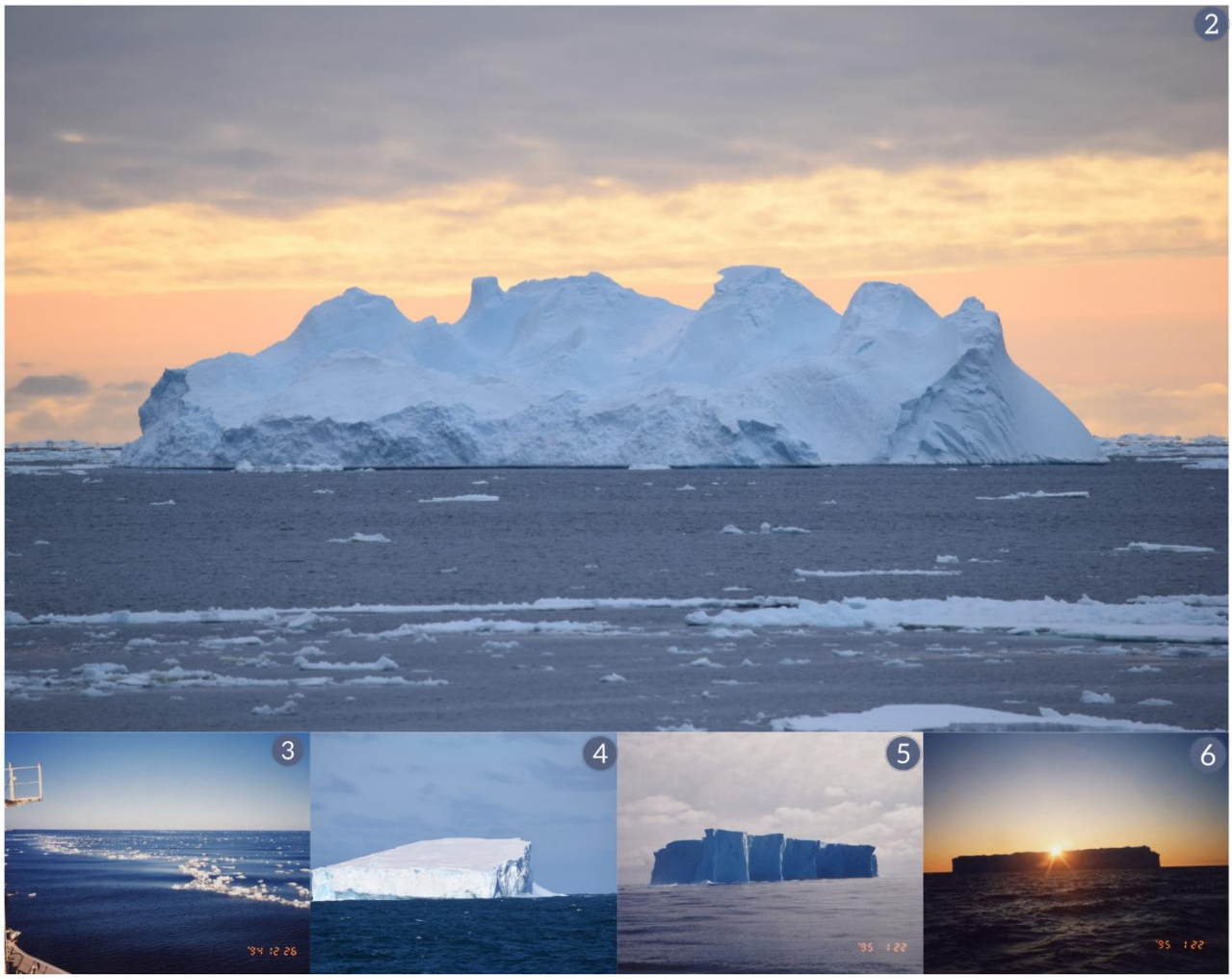

Image 2 – 6: Photos of the Southern Ocean. Some of these photos (Images 3, 5, 6) were taken during a cruise in the 1990s, during which scientists collected the sediment core that forms the basis of this study. Photo credit: Minoru Ikehara.

Deep-sea temperature is stable, with only minor changes occurring even over long-time scales. Despite this stability, deep-sea organisms are highly adapted to such stable environments, making them particularly sensitive to even slight temperature fluctuations. Unlike surface water, the deep sea lacks primary production due to the absence of sunlight, which prevents phytoplankton growth and photosynthesis. Instead, deep-sea organisms rely on food that descends from the ocean surface, known as particulate organic material or marine snow. This includes dead plankton, a primary food source of organisms living on the deep ocean floor.

A new study conducted by the research team, utilising empirical data from deep-sea fossils extracted from sediment cores spanning 500,000 years, clearly demonstrated that temperature and food input have significantly modified deep-sea communities over long time scales, each affecting different species.

Professor Yasuhara stated, ‘It’s important not only to advance fundamental science by understanding how ecosystems on our planet operate but also to address the growing challenges posed by human-induced climatic change.’

As global concern over ongoing human-induced climatic warming and its future escalation intensifies, scientists and engineers are working hard to develop mitigation technologies to combat climatic change. These geoengineering technologies, collectively referred to as ocean-based climate intervention (OBCI), include approaches such as marine carbon dioxide removal (mCDR), which aim to reduce future warming by putting and storing carbon or carbon dioxide in deep-sea sediment, where they remain stable due to the low-temperature and high-pressure environments.

One prominent example of mCDR is iron fertilisation, a process in which iron is added to the ocean surface to enhance primary production, resulting in increased sinking of organic carbon to the deep-sea floor. While mCDR and OBCI are technologically advanced and nearly ready for implementation, they have yet to be deployed on large scales. One major concern is how these technologies will affect deep-sea ecosystems.

Yasuhara continues, 'Deep sea covers over 40% of our planet's surface, and its ecosystem is known to be highly vulnerable. The deep sea also harbours countless species that are still undiscovered. I would say the vast majority of species remain unknown to us. Our study, using a fossil record from a deep-sea sediment core for the past 500,000 years, shows that both temperature and food input, driven by changes in natural iron fertilisation through dust input and the resulting surface production enhancement, have altered deep-sea ecosystems in different ways substantially. This means we must be cautious when making decisions about this important and delicate ecosystem. Careful ecosystem impact assessments are needed to evaluate, on a case-by-case basis, whether human-induced warming or mCDR involving surface productivity changes is more harmful. Only then can we make a cautious and sensible decision about whether to proceed with mCDR.'

Professor Yasuhara also remarked that the Southern Ocean can be seen as a 'canary in a coal mine' because it's a key sensitive region in the global ocean circulation and climatic system. 'Our study highlights the sensitivity of its deep-sea ecosystem. Increased deep-sea biological monitoring efforts in this region are needed, as it could provide early warning signals of climatic changes. Our study also showed that the present-day style of the deep-sea ecosystem in the Southern Ocean was established 430,000 years ago. I hope such a long-standing ecosystem won't be completely altered in the near future, especially since we don't know how much this human-induced warming will escalate and fundamentally change our global climatic system in future.'

About the Journal Paper: Moriaki Yasuhara, Huai-Hsuan May Huang, Raine Wing Ki Chong, Yuanyuan Hong, Hokuto Iwatani, Jingwen Zhang, Katsunori Kimoto, Minoru Ikehara (2024/2025). *Climatic forcing of the Southern Ocean deep-sea ecosystem. Current Biology*.

The Journal Paper can be accessed here: https://doi.org/10.1016/j.cub.2024.11.026

Image 7: This image, taken in 1996, shows the sediment core sampling process in the Southern Ocean. The samples collected during this process were used in the research. Photo credit: Minoru Ikehara.

Image 8: Beneath the vast blue sky, the icebergs of the Southern Ocean stand silently, witnessing one of Earth's most untouched and fragile beauties. Photo credit: Minoru Ikehara.

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