Written on water: Reconstructing the ancient history of an ocean current

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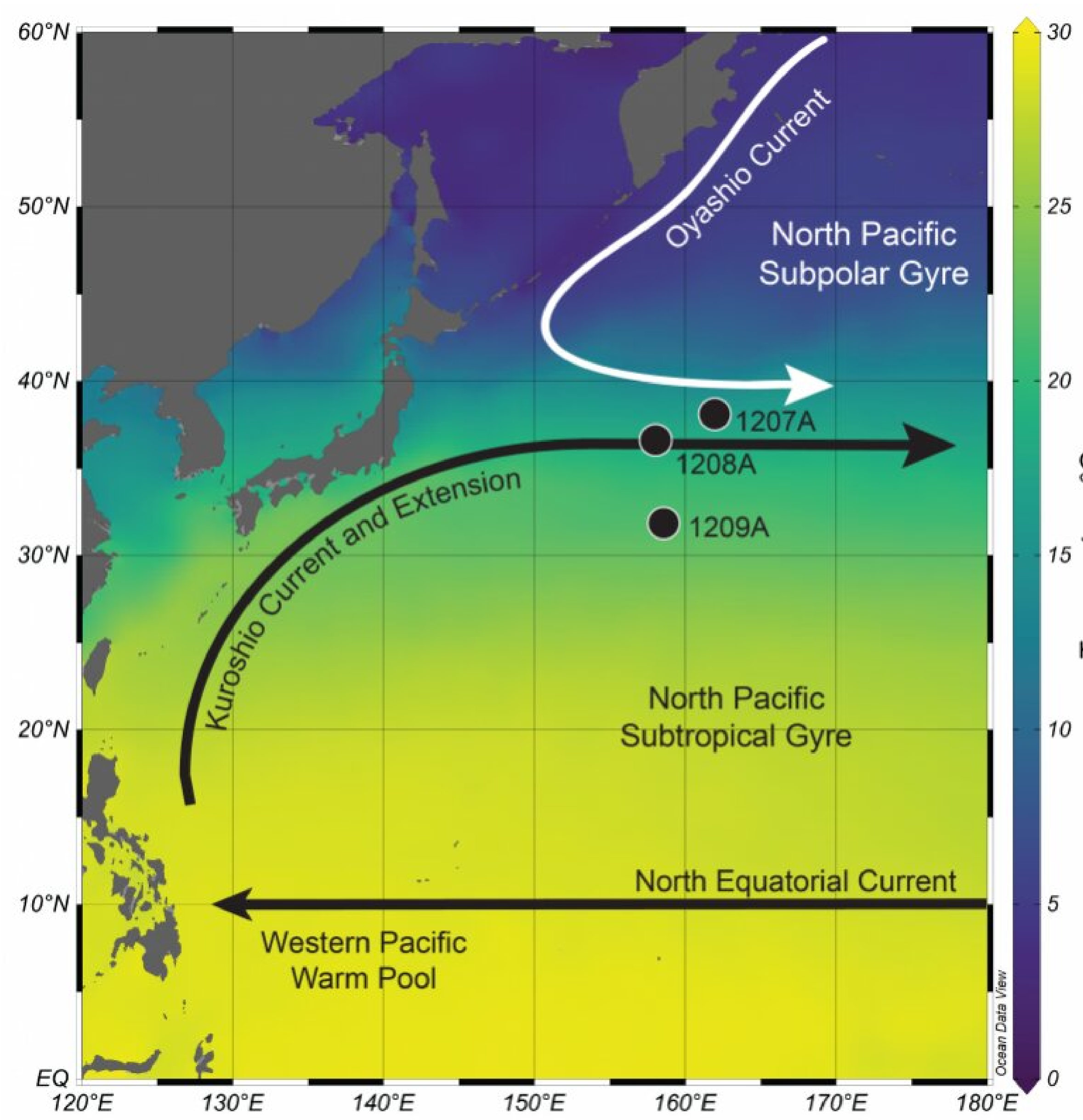


Modern-day sea surface temperature map of the northwest Pacific Ocean. The Kuroshio Current and Extension are represented by the black line and arrow, whereas the Oyashio Current is represented by the white line and arrow. The location of the three sediment cores (numbered 1207, 1208, and 1209) used in the study, drilled upon Shatsky Rise, are denoted by the circles. Credit: Binghamton University

Ocean currents embody motion, snaking their way from the tropics to the poles and back, shifting vast quantities of water from moment to moment. But they are also incredibly old, following their basic course for millions of years.

Tracing a history written in water is the work of paleoceanographers such as Adriane Lam, Presidential Diversity Postdoctoral Fellow in Binghamton University's Department of Geological Sciences and Environmental Studies. Lam is the lead author of "Pliocene to earliest Pleistocene (5–2.5 Ma) Reconstruction of the Kuroshio Current Extension Reveals a Dynamic Current," recently published in the journal *Paleoceanography and Paleoclimatology*. Co-authors include Assistant Professor of Geological Sciences and Environmental Studies Molly Patterson, as well as Kenneth MacLeod of the University of Missouri, Solveig Schilling of the University of Texas at Austin, R. Mark Leckie of the University of Massachusetts Amherst, Andrew Fraass of England's University of Bristol, and Nicholas Venti of the University of Delaware.

The major western boundary current in the northern Pacific Ocean, the Kuroshio Current and Extension, is analogous to the Gulf Stream, which flows along North America's east coast. Driven by the wind, boundary currents are the workhorses of the ocean, moving heat, salt and gasses from the equatorial seas to the middle latitudes, Lam explained.

"In other words, these currents help distribute heat from the tropics to higher latitudes. In fact, corals occur at their highest latitude of anywhere in the world within the Kuroshio Current because the waters are so warm," she said.

That warmth stems from the surface waters that collect in the western Pacific Ocean along the equator, called the Western Pacific Warm Pool. The Kuroshio Current takes these waters north, past the Japanese coast, and then eastward at the 36°N latitude, where it joins the open Pacific Ocean. At this point, it becomes the Kuroshio Current Extension.

The current and extension vent vast amounts of heat and moisture evaporating from the warm water into the lower atmosphere in the Northern Hemisphere. Because of this, they help shape precipitation patterns over Japan and North America's West Coast, as well as the paths of typhoons, which feed off warm waters. In addition to affecting the weather, the Kuroshio also likely affects the climate, although its impact on thousand- and million-year time scales is still unclear.

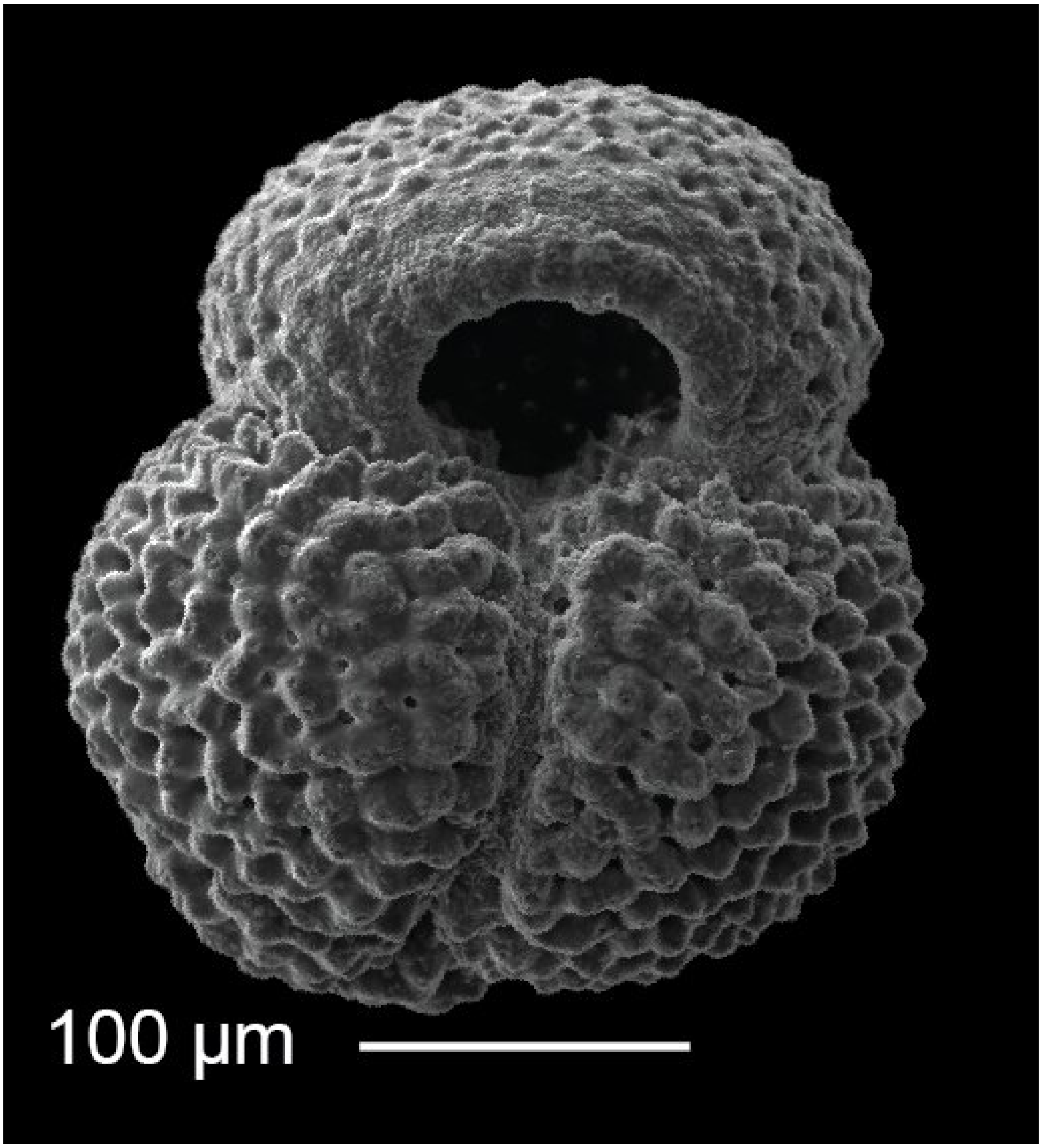
The Kuroshio also plays a major role in ecosystems and the fishing industry. In the northwest Pacific, it meets the Oyashio Current, which brings the cool waters of the polar region southward. Where the two currents meet, a strong temperature gradient forms due to the mixing of warm and cool waters. It also creates a region of upwelling, where nutrient-rich waters from the deep ocean are brought to the surface as the currents flow eastward.

It's not just the waters that mingle: the warm- and cool-water organisms that live in the respective currents also flow together in a transition area between ecosystems, known as an ecotone. Its inhabitants include several species of fish and plankton, which ultimately power Japan's prolific fishing industry and form a major part of that nation's economy.

Because of their impact on biodiversity, weather and the climate, understanding how boundary currents such as the Kuroshio will respond to climate change and increasing CO_2 levels in the atmosphere is critical. Today, these currents are warming two to three times faster than other areas of the ocean, Lam said.

Ocean model studies and observational data also show that the Kuroshio Current Extension is shifting northward and increasing its transport capacity, but researchers don't yet know how these changes will affect the organisms that live there, or local and regional weather and climate patterns.

The recently published research is the first of its kind to reconstruct the Kuroshio as it was 2.5 to 5 million years ago, a time that spanned both periods of global warming and cooling, as well as the closure of a major seaway in what is now Central America. Looking at the current's distant past may answer some of the questions about its future.



A scanning electron microscope image of Globigerinoides ruber, a planktic foraminifera species that was used in the geochemical study to reconstruct the behavior of the Kuroshio Current Extension. Credit: Binghamton University

Past and future oceans

During the Pliocene, which spans 2.5 to 5.3 million years ago, atmospheric CO_2 levels were near those we face today: about 350 to 450 parts per million. Today's atmosphere has about 415 parts per million of CO_2.

"The fun part of this time period is that the continents were arranged similar to today, which makes the Pliocene a great time period to use as an analogue as to how the Earth system will respond to increased CO_2 concentrations and warming," Lam said.

There were some differences in regard to landmasses, she noted: Until about 2.5 million years ago, a waterway existed between North and South America that allowed surface waters from the Pacific and Atlantic oceans to mingle. When the Central American Seaway closed, it may have brought the Kuroshio Current Extension into its current configuration.

The Pliocene included a period from 3 to 3.3 million years ago known as the mid-Piacenzian Warm Period (mPWP), which saw increased carbon dioxide levels and global warming. Once that period ended, cooling resumed, accompanied by the growth of glaciers and sea ice in the Northern Hemisphere's high latitudes.

In the recently published study, the researchers reconstructed the Kuroshio throughout the mPWP, using chemical signatures from the fossilized shells of marine plankton that once lived in the Kuroshio region's surface waters.

"Our data indicate that during the first phase of mPWP warming in the Pliocene, the current warmed up and potentially shifted its latitudinal position northward. It then cooled back down and perhaps shifted its position back south during a brief period of global cooling," she said.

Reconstructing the current

Scientists use different techniques to reconstruct the history of an ocean current, depending on the time scale in question. For shorter timescales, they rely on observational data to see how a current's path changes seasonally, from year to year or decade to decade. But when it comes to climate change, that dataset can fall short.

"This is why it is useful and necessary to reconstruct the behavior of western boundary currents through deep time, using the sedimentary record from millions of years ago," Lam explained. "Through the lens of the sedimentary record, the shorter-term variations in the current are 'smoothed' or averaged out, so we are essentially only able to recover signals that indicate the longer-term, larger changes of the currents."

In the study, the researchers used the chemical signals obtained from fossil plankton that lived in the surface ocean, as well as three deep-sea sediment cores from Shatsky Rise, a location on the northwest Pacific seafloor. Planktic foraminifera have lived in the open oceans for the last 170 million years; their durable shells, called "tests," are made of calcium carbonate and accumulate on the ocean floor when they die.

In a previous study, Lam calculated the diversity of fossil plankton at each site used in the later chemical study. She found that diversity was highest at the northernmost site of Shatsky Rise, from 12 million years ago until today. This finding indicates the ecotone created by the current has been around for a very long time—and likely the Kuroshio has, too.

Researchers don't know how warm the current became during the mPWP, or how much the chemical signal is affected by salinity as well as temperature changes. To get a better picture, Lam and colleagues from other SUNY schools are currently working on a grant that would use different chemical methods to answer these questions.

"The ocean is hugely affected by climate change, and we must think about ways in which we can protect it and marine organisms. This is especially true for the Kuroshio Current Extension, as this region is home to some of the highest biodiversity in our world ocean," Lam said.

More information: Adriane R. Lam et al, Pliocene to earliest Pleistocene (5–2.5 Ma) Reconstruction of the Kuroshio Current Extension Reveals a Dynamic Current, *Paleoceanography and Paleoclimatology* (2021). DOI: 10.1029/2021PA004318

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