THE SECRET LIVES OF PASSIVE MARGINS INCLUDE MORE THAN SEA-LEVEL CHANGE

The eastern seaboard of North America is a textbook example of a passive continental margin, and for decades scientists have exploited its potential to record changes in global sea level. Stratigraphic evidence from the Atlantic coastline, for example, suggests that 3.5 million years ago during the mid-Pliocene — the last time carbon dioxide reached 400 parts per million — sea levels were 30 to 60 meters higher than today. These levels imply the total disintegration of the Greenland and West Antarctic ice sheets, along with significant melting in East Antarctica. Now, a new study that investigates the role of the active upper mantle has challenged these estimates.

Using passive margins to reconstruct sea levels relies on the assumption that these coastlines lie far from the tumultuous tectonically active regions of the planet and so provide a constant reference frame against which to measure the height of ancient seas. The elevations of past shorelines are preserved in the geologic record through features like wave-cut terraces, fossil coral reefs and shallow marine deposits.

However, because of active flow in the upper mantle, "everywhere on the surface of the Earth is riding on a magic carpet," says David Rowley, a geologist at the University of Chicago and the lead author of the recent study, which appeared in Science. This means that scientists are "forever having to tease out what the magic carpet is doing relative to what sea level is doing." The team used seismic tomography data to disentangle these effects by modeling how mantle flow — especially in the uppermost 350 kilometers of the asthenosphere (the ductile layer immediately below the rigid crust) — has caused uplift along the Atlantic coastal plain over the last 3.5 million years.

Their results suggest a convoluted pattern of deformation that explains much of the modern coastal topography, accounting for at least some of the elevation change previously attributed to higher sea levels. The researchers find an optimal match between their model and the observed geologic data with a sea-level contribution closer to 25 meters — lower than previous estimates but still compatible with some contribution from East Antarctica (melting there is required for sea-level changes greater than 14 meters).

Previous attempts to reconstruct sea level along the Atlantic coast corrected for other forces that cause uplift along passive margins, such as isostatic rebound associated with the loss of material through erosion and melting of the North American Ice Sheet after the last glacial period ended 14,000 years ago. Modeling of the lower mantle had previously indicated that there has been net subsidence of the Atlantic coast because a slab of ancient oceanic crust that lies beneath North America is slowly sinking back into the mantle.

But no one had investigated the role of the upper mantle. "As the slab sinks, it's creating a space problem" beneath the crust, Rowley says. "And the question is: What's coming in to fill that space?" Their model suggests that newly upwelled mantle flows in from the Mid-Atlantic Ridge, with a secondary contribution from the Bermuda Rise. Because it is young, and thus hot and buoyant, this flux of fresh mantle material causes uplift and complicates interpretations of past sea levels.

Rowley arrived at this problem, however, from a completely different angle. For nearly a decade, he and colleagues worked to develop a model that simulates how mantle dynamics influence Earth's crust, an effect known as dynamic topography. Rowley's interest in the eastern seaboard arose through serendipity, he says: He happened upon a news article in Science describing a prominent wave-cut feature of Pliocene age called the Orangeburg Scarp that runs from Florida to North Carolina. This feature, he knew from modern shorelines, had to have started out perfectly horizontal. Any deviation from this original orientation would reveal the influence of other geologic processes. Rowley says he jumped at the chance to validate the model against such a well-constrained benchmark.

The Orangeburg Scarp runs from Florida to North Carolina. This feature represents a historical shoreline and would have originally been perfectly horizontal. Thus, deformation of the scarp reveals the influence of other geologic processes, including uplift along the eastern seaboard of North America.

Kathleen Cantner, AGI

"Relative to the total radius of Earth, [the amount of uplift we predict] is trivial," Rowley says. "But when you are looking at a very subtle feature like a shoreline that is very sensitive, you can see that amplitude quite perfectly." Their model reproduced the observed deformation of the Orangeburg Scarp, and also identified a roughly circular area centered around Norfolk Arch in Virginia that has risen nearly 60 meters in the last 3.5 million years. Farther north, the coast of New Jersey appears to have subsided over this interval. The spatial variability in dynamic topography alone illustrates that local forces are in play, Rowley says, demonstrating why extracting a global sea-level signal from any one site is problematic.

"[Dynamic topography] makes the determination of the height of sea level from looking at [geologic features] complicated unless one has models of what these perturbations might be and how they might contaminate the [sea-level] record," Rowley says. Such corrections might be possible in a perfect world, but at present, he says, the models cannot remove the effects of dynamic topography with great precision. "I don't think we're going to come to some simple consensus that sea level was X number of meters [higher during the Pliocene] to within plus or minus even 10 meters." As it stands, he says, ancient shorelines have much more to tell about mantle dynamics than they do about past sea levels.

So the question is not how much of East Antarctica melted during the Pliocene (a question Rowley says they can't answer), but more fundamentally: Can passive margins be used for accurate reconstructions of sea level at all?

Nicolas Flament, a mantle dynamics expert at the University of Sydney in Australia who was not involved in the study, says that the new work "confirms that long-term global sea-level change cannot be determined at a single passive margin. In other words, it confirms that continental margins are not passive." Others wouldn't go quite that far. Kenneth Miller, a geologist at Rutgers University who produced a widely cited sea-level record based on stratigraphic evidence from New Jersey, says that although Rowley's results challenge the assumptions behind his method of reconstruction, they do not invalidate his conclusions because the new results fall within his error estimates.

Flament says he is optimistic that stratigraphy and mantle flow modeling together can produce valid reconstructions of sea level when considered along multiple margins simultaneously. "The detailed comparison between the topography predicted by the mantle flow model and the geological data is very important for us to understand what drives coastline shifts," Flament says. "Here we have a regional example and one of the next challenges is to take this to a global scale."

Julia Rosen

ORIGINS OF HUMAN CULTURE LINKED TO RAPID CLIMATE CHANGES

During the Middle Stone Age, between 80,000 and 40,000 years ago, anatomically modern humans emerged in what is now South Africa. A new study, published in Nature Communications, links a series of technological innovations that appear in the archaeological record during this time period marked by a series of rapid climate changes.

To reconstruct a record of Middle Stone Age climate variability, set against the backdrop of the last glacial period, the team, led by Martin Ziegler of Cardiff University in Wales, drilled a marine sediment core off the Eastern Cape coast of South Africa, near the mouth of the Kei River.

Sediment records of river discharge rates revealed that the region experienced pulses of elevated rainfall and increased humidity in the Middle Stone Age, coinciding with well-documented cold events in the Northern Hemisphere and desertification in sub-Saharan Africa thought to be linked to large-scale changes in the circulation of the Atlantic Ocean.

When the timing of these wet pulses was compared to archaeological datasets, Ziegler and his colleagues found a statistically significant correlation between the timing of increased rainfall and the appearance of several major Middle Stone Age industries, including engraved stone and bone tools and shell jewelry. The authors propose that increased rainfall led to favorable environmental conditions and larger human populations capable of accelerated innovation.

"The correspondence between climatic ameliorations and cultural innovations supports the view that population growth fueled cultural changes through increased human interactions," said study co-author Chris Stringer, an anthropologist at London's Natural History Museum, in a statement.

Mary Caperton Morton

These two-sided points recovered from Blombos Cave in South Africa were manufactured about 75,000 years ago by anatomically modern humans.