In some wet tropical mountains, carbon dioxide is captured and flushed out of the atmosphere.

CLIMATE

Tropical uplift may set Earth's thermostat

Indonesia's mountains could be cause of current glacial age

By **Paul Voosen**

Hate the cold? Blame Indonesia. It may sound odd, given the contributions to global warming from the country's 270 million people, rampant deforestation, and frequent carbon dioxide (CO_2)-belching volcanic eruptions. But over much longer times, Indonesia is sucking CO_2 out of the atmosphere.

Many mountains in Indonesia and neighboring Papua New Guinea consist of ancient volcanic rocks from the ocean floor that were caught in a colossal tectonic collision between a chain of island volcanoes and a continent, and thrust high. Lashed by tropical rains, these rocks hungrily react with CO_2 and sequester it in minerals. That is why, with only 2% of the world's land area, Indonesia accounts for 10% of its long-term CO_2 absorption. Its mountains could explain why ice sheets have persisted, waxing and waning, for several million years (although they are now threatened by global warming).

Now, researchers have extended that theory, finding that such tropical mountain-building collisions coincide with nearly all of the half-dozen or so significant glacial periods in the past 500 million years. "These types of environments, through time, are what sets the global climate," said Francis Macdonald, a geologist at the University of California, Santa Barbara, when he presented the work last month at a meeting of the American Geophysical Union in Washington, D.C. If Earth's climate has a master switch, he suggests, the rise of mountains like Indonesia's could be it.

Most geologists agree that long-term changes in the planet's temperature are governed by shifts in CO_2, and that plate tectonics somehow drives those shifts as it remakes the planet's surface. But for several decades, researchers have debated exactly what turns the CO_2 knob. Many have focused on the volcanoes that rise where plates dive beneath one another. By spewing carbon from Earth's interior, they could turn up the thermostat. Others have emphasized rock weathering, which depends on mountain building driven by plate tectonics. When the mountains contain seafloor rocks rich in calcium and magnesium, they react with CO_2 dissolved in rainwater to form limestone, which is eventually buried on the ocean floor. Both processes matter; "the issue is which one is changing the most," says Cin-Ty Lee, a volcanologist at Rice University in Houston, Texas.

Having the right rocks to drive the CO_2-chewing reaction is not sufficient. Climate matters, too. For example, the Siberian Traps, a region that saw devastating volcanic eruptions 252 million years ago, are rich in such rocks but absorb little, says Dennis Kent, a geologist at Rutgers University in New Brunswick, New Jersey. "It's too damn cold," he says. Saudi Arabia has the heat and the rocks but lacks another ingredient. "It's hotter than Hades but it doesn't rain." Indonesia's location in the rainy tropics is just right. "That is probably what's keeping us centered in an ice age," Kent adds.

Over the past few years, Macdonald and his collaborators have searched for other times when tectonics and climate could have conspired to open an Indonesia-size CO_2 drain. They found that glacial conditions 90 million and 50 million years ago lined up neatly with the collisions of a chain of island volcanoes in the now-vanished Neo-Tethys Ocean with the African and Asian continents. A similar collision some 460 million years ago formed the Appalachians, but it was thought to have taken place in the subtropics, where a drier climate does not favor weathering. By reanalyzing ancient magnetic fields in rocks formed in the collision, Macdonald's team found the mountains actually rose deep in the tropics. And their uplift matched a 2-million-year-long glaciation. "They're developing a pretty compelling story that this was a climate driver in Earth's past," says Lee Kump, a paleoclimatologist at Pennsylvania State University in University Park.

But those cases could be exceptions. So the team compiled a database of every tectonic "suture"—the linear features left by tectonic collisions—known to contain ophiolites, those bits of volcanic sea floor, over the past half-billion years. Based on magnetism in each suture's rocks and a model of continental drift, they mapped their ancient latitudes to see which formed in the topics, and when. "We were surprised that this is not as complicated as we thought," Macdonald said.

The team compared the results to records of past glaciations and found a strong correlation. They also looked for declines in volcanism, which might have cooled the climate. But their influence was much weaker, Macdonald said.

Kimberly Lau, a geochemist at the University of Wyoming in Laramie, calls the work "exciting in idea and novel in execution." Lee, however, would like to see direct evidence from ancient sediments that the collisions drove up rock weathering. "They have to go to the sink and study those," he says. And a recent study challenges the mountain thermostat idea with evidence for the importance of volcanoes. The study used ages from thousands of zircons, durable crystals that can indicate volcanic activity, to show that upticks in volcanic emissions were the dominant force driving the planet's warm periods. It's likely both teams have at least one hand on the truth, adds Lee, who contributed to the zircon paper.

The beauty of his team's model, Macdonald said at the end of his talk, is that it explains not just why glacial times start, but also why they stop. A hothouse Earth appears to be the planet's default state, prevailing for three-fourths of the past 500 million years. An Indonesia-style collision may push the global climate into a glacial period, but only for a while. Mountains erode and continents drift. And the planet warms again. ■

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