the hydrosphere below the blanket of sedimentary particles and detritus of abyssal clays into the rocky crust. The extent of life in oceanic crust is currently unknown and represents another frontier in understanding the geographic and environmental limits to life on Earth. Improved drilling and sampling techniques will be required to examine whether life persists between a rock and hard place below the sea floor. ❐

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PALAEOCLIMATE

Maritime cooling

The Earth's climate has gradually cooled over the past five million years. This cooling initially resulted in a glaciated Northern Hemisphere with moderate glacial–interglacial cycles, and ultimately in the extreme, 100,000-year-long climatic oscillations that have characterized the past million years. A number of tectonic and oceanographic factors and feedbacks seem to have colluded to drive the Earth into its most recent Ice Age 2.7 million years ago. The closure of the seaway that linked the tropical Atlantic and Pacific oceans, is generally thought to have had the greatest impact.

The Central American Seaway finally closed some time between 2.5 and 3 million years ago. Simulations of the ocean circulation suggest that closure is expected to strengthen the Atlantic meridional overturning circulation. This would bring warmer and saltier water surface water to the North Atlantic, where it would sink to fill the deep Atlantic. Proxy reconstructions remain equivocal about the purported strengthening, but biogeochemical models indicate that an increase in the volume of North Atlantic Deep Water would also have promoted the transfer of carbon from the atmosphere to the ocean through a strengthened biological pump and thus contributed to the decline in atmospheric CO_2 concentrations. In addition, the delivery of warmer water to the North Atlantic should have increased the precipitation available to feed growing ice sheets and glaciers. But it has never been clear whether these and other changes that occurred at this time, such as increased stratification in the Southern Ocean, were enough to push the system into an Ice Age.

Peter Molnar and Timothy Cronin suggest that concurrent tectonic activity in the western Pacific may have aided in the climatic cooling (*Paleoceanography* http://doi.org/2s5; 2015). They point out that the Maritime Continent — that is, the islands and peninsulas scattered between the main continental areas of Southeast Asia and Australia — has grown by over one million square kilometres during the past five million years. In addition to constricting the tropical exchange between the Pacific and Indian oceans, the increasing land exposure could have cooled the climate in two other ways.


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First, the growth of the land surface occurred through tectonic uplift and a good deal of volcanism, which delivered fresh, easily weathered igneous rock into a warm, rainy climate. The weathering of this rock probably drew atmospheric CO_2 concentrations down by an estimated 20 ppmv, compared with an overall CO_2 decline of about 120 ppmv over this interval. Second, the emergence of the land surface is expected to create a small but important shift in atmospheric circulation in the tropical Pacific, which in turn would strengthen the growing temperature gradient between the eastern and western tropical Pacific. The establishment of this east–west temperature difference has previously been implicated in the transition from a warmer climate.

Overall, the climate changes wrought by the expansion of the Maritime Continent on a global scale are probably small, relative to the climate upheaval that was occurring in the North Atlantic and Southern oceans. But they are not negligible, and fully considering the more subtle impacts of tectonic changes can only help to elucidate the mechanisms controlling the transition into our current Ice Age.

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