More 'reactive' land surfaces cooled the Earth down

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Zermatt in the Western Alps. Credit: F. von Blanckenburg

There have been long periods of cooling in Earth's history. Temperatures had already fallen for more than 10 million years before the last ice age began about 2.5 million years ago. At that time, the northern hemisphere was covered with massive ice masses and glaciers. A geoscientific paradigm, widespread for over 20 years, explains this cooling with the formation of the large mountain ranges such as the Andes, the Himalayas and the Alps. As a result, more rock weathering has taken place, the paradigm suggests. This in turn removed more carbon dioxide (CO_2) from the atmosphere, so that the greenhouse effect decreased and the atmosphere cooled. This and other processes eventually led to the ice Age.

In a new study, Jeremy Caves-Rugenstein from ETH Zurich, Dan Ibarra from Stanford University and Friedhelm von Blanckenburg from the GFZ German Research Centre for Geosciences in Potsdam were able to show that this paradigm cannot be upheld. According to the paper, weathering was constant over the period under consideration. Instead, increased reactivity of the land surface has led to a decrease in CO_2 in the atmosphere, thus cooling the Earth. The researchers published the results in the journal *Nature*.

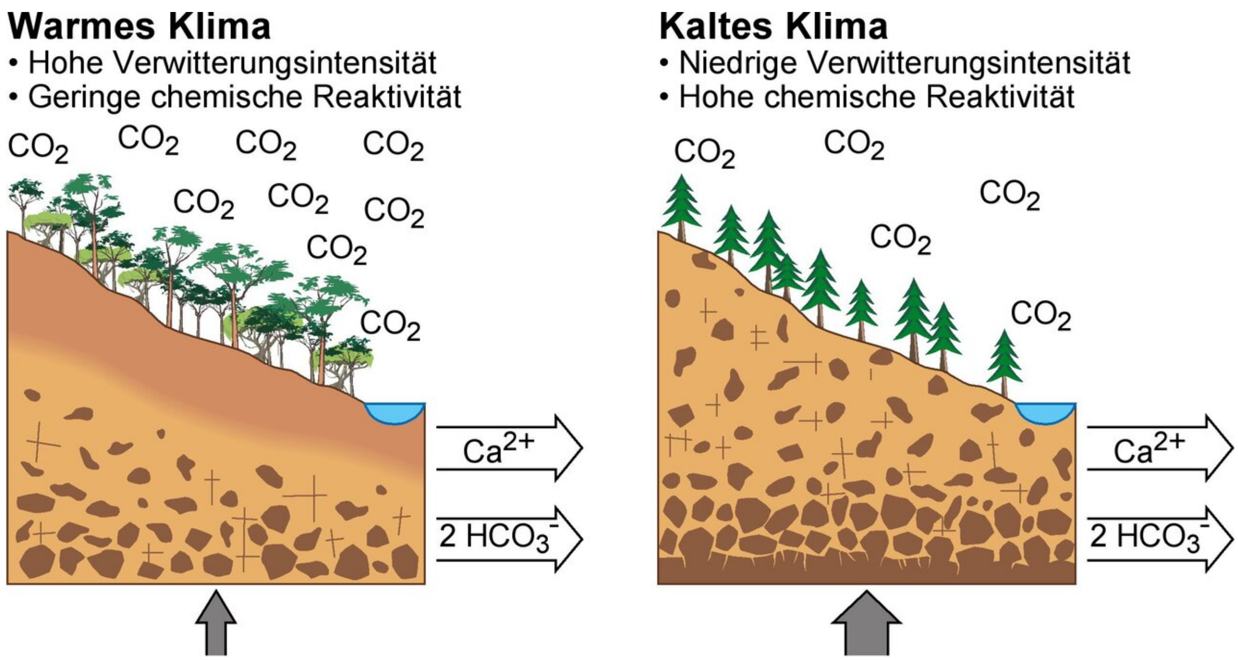
A second look after isotope analysis

The process of rock weathering, and especially the chemical weathering of rocks with carbonic acid, has controlled the Earth's climate for billions of years. Carbonic acid is produced from CO_2 when it dissolves in rainwater. Weathering thus removes CO_2 from the Earth's atmosphere, precisely to the extent that volcanic gases supplied the atmosphere with it. The paradigm that has been widespread so far states that with the formation of the large mountains ranges in the last 15 million years, erosion processes have increased—and with them also the CO_2-binding rock weathering. Indeed, geochemical measurements in ocean sediments show that the proportion of CO_2 in the atmosphere has strongly decreased during this phase.

Soil formation in the Chilean coastal mountains. The soil is already heavily weathered, but granite blocks remain and can react chemically: The 'reactivity' of this soil is high. Credit: F. von Blanckenburg, GFZ

"The hypothesis, however, has a big catch," explains Friedhelm von Blanckenburg of GFZ. "If the atmosphere had actually lost as much CO_2 as the weathering created by erosion would have caused, it would hardly have had any CO_2 left after less than a million years. All water would have had frozen to ice and life would have had a hard time to survive. But that was not the case."

That these doubts are justified, was already shown by von Blanckenburg and his colleague Jane Willenbring in a 2010 study, which appeared in *Nature* likewise. "We used measurements of the rare isotope beryllium-10 produced by cosmic radiation in the Earth's atmosphere and its ratio to the stable isotope beryllium-9 in ocean sediment to show that the weathering of the land surface had not increased at all," says Friedhelm von Blanckenburg.



The 'reactivity' of the land surface. If there are more non-weathered mineral grains such as feldspar or mica in the soil, it can react as extensively chemically with little CO2 as an already heavily weathered soil with a lot of CO2. Credit: CC-BY 4.0: F. von Blanckenburg, GFZ

The land's surface has become more reactive

In the study published now, Caves-Rugenstein, Ibarra and von Blanckenburg additionally used the data of stable isotopes of the element lithium in ocean sediments as an indicator for the weathering processes. They wanted to find out how, despite constant rock weathering, the amount of CO_2 in the atmosphere could have decreased. They entered their data into a computer model of the global carbon cycle.

Indeed, the results of the model showed that the potential of the land surface to weather has increased, but not the speed at which it weathered. The researchers call this potential of weathering the reactivity of the land surface. "Reactivity describes how easily chemical compounds or elements take part in a reaction," explains Friedhelm von Blanckenburg. If there are more non-weathered and therefore more reactive rocks at the surface, these can in total react as extensively chemically with little CO_2 in the atmosphere as already heavily weathered rocks would do with a lot of CO_2. The decrease in CO_2 in the atmosphere, which is responsible for the cooling, can thus be explained without an increased speed of weathering.

"However, a geological process is needed to rejuvenate the land surface and make it more reactive," says Friedhelm von Blanckenburg."This does not necessarily have to be the formation of large mountains. Similarly, tectonic fractures, a small increase in erosion or the exposure of other types of rock may have caused more material with weathering potential to show at the surface. In any case, our new hypothesis must trigger geological rethinking regarding the cooling before the last ice age."

More information: Neogene cooling driven by land surface reactivity rather than increased weathering fluxes, *Nature* (2019). DOI: 10.1038/s41586-019-1332-y , nature.com/articles/s41586-019-1332-y

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