The Italian central Apennines are a source of CO_2, study finds

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The Apennines in Central Italy: The CO_2 balance for a relatively young mountain range was measured here. The photo shows a nature reserve located in the Lazio region. Groundwater flows through the Mesozoic limestone massifs and emerges at springs like this one. These springs feed into adjacent rivers that wind their way through the complex, tectonically active landscape. Credit: Photo: Erica Erlanger, GFZ

Tectonically active mountains play an important role in the natural CO_2 regulation of the atmosphere. Competing processes take place here: At Earth's surface, erosion drives weathering processes that absorb or release CO_2, depending on the type of rock. At depth, the heating and melting of carbonate rock leads to the outgassing of CO_2 at the surface.

In the central Italian Apennine Mountains, researchers led by Erica Erlanger and Niels Hovius from the GFZ German Research Centre for Geosciences and Aaron Bufe from the Ludwig-Maximilians-Universität München have now investigated and balanced all of these processes in one region for the first time—using, among others, analyses of the CO_2 content in mountain rivers and springs. They found that weathering in this region leads to an overall CO_2 uptake.

However, these near-surface processes only determine the CO_2 balance in areas with a thick and cold crust. On the western side of the Central Apennines, the crust is thinner and the heat flow is higher. There, CO_2 outgassing from depths is up to 50 times greater than CO_2 uptake through weathering.

All in all, the analyzed landscape is a CO_2 emitter. The structure and dynamics of Earth's crust, therefore, control the release of CO_2 here more strongly than chemical weathering. The study was published today in the journal *Nature Geoscience*.

The role of mountains in Earth's CO_2 budget

In addition to man-made CO_2 emissions, many natural processes—both biological and geological—also play a role in balancing the global CO_2 budget. Mountain landscapes strongly modulate the carbon cycle, and it is important to adequately consider the competition of CO_2 emission and CO_2 uptake occurring here in climate models.

On the one hand, rocks on the Earth's surface are weathered by chemical dissolution processes: erosion continuously exposes rock, which—depending on the type of rock—weathers at different rates and either absorbs or releases CO_2. Silicate minerals, for example, bind CO_2 and form limestone. In turn, the weathering of carbonate and sulfide-containing minerals releases CO_2.

A research team led by Aaron Bufe and Niels Hovius has investigated the competition of CO_2 release and drawdown from weathering in a further study published in the journal *Science* at the beginning of March. phys.org/news/2024-03-geologis … -ranges-largest.html">They analyzed the influence of the erosion rate on the CO_2 balance using various mountain regions around the world as an example.

However, mountain building does not only influence erosion and weathering rates on Earth's surface. Where tectonic plates slide over each other, heating of carbonate rocks in the crust and mantle can lead to chemical reactions associated with CO_2 emissions.

"Previous studies have often focused on a single process and have treated weathering on the surface and processes at depth separately. We wanted to change that," says Niels Hovius.

Investigations in the Apennines: CO_2 outgassing or storage—which process dominates?

The competition between near-surface and deep-seated processes is now the focus of a new study by Erica Erlanger, post-doctoral scientist at the GFZ and the Université de Lorraine (France), Aaron Bufe, Professor of Sedimentology at the LMU Munich and former post-doctoral scientist at the GFZ, and Niels Hovius, Head of the Geomorphology Section at the GFZ and Professor at the University of Potsdam, together with colleagues from France, Italy, the U.S. and Switzerland.

The central Apennines in Italy prove to be a particularly suitable region for this study, as Erica Erlanger, first author of the study, explains: "This area is part of an active mountain range with closely spaced zones of thick, cold crust and thin, warm crust, allowing us to investigate the influence of subsurface activity. The climatic conditions as well as the topography and the rock types on the surface are similar throughout the area, so there should not be any large differences in weathering activity."

Sampling and analysis of CO_2 content

In the western central Apennines, the crustal thickness is around 20 kilometers and the heat flux is up to over 100 milliwatts per square meter, while the crust in the east is more than 40 kilometers thick, with a heat flux of around 30 milliwatts per square meter.

The researchers took a total of 104 water samples in the western Tevere and eastern Aterno-Pescara River systems, 49 of them in summer 2020 and 55 in winter 2021, covering the warmest and driest seasons and the wettest and coldest seasons to estimate the minimum (summer) and maximum (winter) CO_2 fluxes.

Water samples are suitable because rivers and springs transport carbon, which originates both from depths and from weathering reactions near the surface. The chemical analysis of the samples included determining the relative abundance of various carbon isotopes. These can provide information as to whether the carbon originates from a plant or from the atmosphere or was released from a subducted rock.

"On this basis, we were able to calculate the quantities of CO_2 released by weathering or from carbonates at depths, and the quantities of CO_2 bound by weathered silicates," explains Erlanger.

In order to estimate an overall balance for the CO_2 budget of the

Apennines, the researchers also took into account estimates for inorganic CO_2 emissions from gas vents known from the western side of the Apennines, as well as from organic CO_2 exchange.

Central Apennines as a net CO_2 source, but with a split CO_2 balance

The research team found that the weathering processes in the entire study area predominantly capture CO_2 and do not release it. Remarkably, however, where the crust is thin and the heat flow is high, CO_2 release from depths outpaces weathering-related CO_2 fluxes by a factor of 10 to 50. Overall, the region is, therefore, a CO_2 source.

"Importantly, fluctuations in CO_2 release from deep rock are much greater than fluctuations in chemical weathering fluxes. This means that the regional geodynamics in the central Apennines influences the carbon cycle most strongly by modulating the release of CO_2 from depth, and not by impacting weathering reactions," summarizes Erica Erlanger.

"Based on the geological evolution of the area, we estimate that CO_2 outgassing from the crust and mantle has probably occurred over the last 2 million years."

"Our investigations will contribute to a better understanding of the actual CO_2 balance for the atmosphere and, thus, to better long-term climate models," says Aaron Bufe. "They also help to clarify how our planet has maintained the narrow range of conditions that are conducive to life by balancing CO_2 outgassing and CO_2 storage processes over geological times."

Niels Hovius says, "If we want to investigate the role of mountains for Earth's carbon cycle in a more general sense, even seemingly simple geological questions will require a more holistic approach. Of particular interest are geologically young mountain belts at plate boundaries, where carbonate rocks are likely to predominate both near the surface and at depth.

"Today's Mediterranean region and other comparatively young mountain ranges, such as the Indonesian archipelago, exhibit geological conditions and rock types similar to the central Apennines. So, the next big question we face is whether outgassing in active tectonic areas could be a global phenomenon in space and time."

More information: Erica Erlanger et al, Deep CO2 release and the carbon budget of the central Apennines modulated by geodynamics, *Nature Geoscience* (2024). DOI: 10.1038/s41561-024-01396-3

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