Study: Mountains reached current elevation earlier than thought

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The Ruby Mountains, in northeast Nevada, are within the Basin and Range region where Andreas Mulch and his colleagues analyzed samples of volcanic glass. Credit: Andreas Mulch

Geologists studying deposits of volcanic glass in the western United States have found that the central Sierra Nevada largely attained its present elevation 12 million years ago, roughly 8 or 9 million years earlier than commonly thought.

The finding has implications not only for understanding the geologic history of the mountain range but for modeling ancient global climates.

"All the global climate models that are currently being used strongly rely on knowing the topography of the Earth," said Andreas Mulch, who was a postdoctoral scholar at Stanford when he conducted the research. He is the lead author of a paper published this week in the online *Early Edition of the Proceedings of the National Academy of Sciences*.

A variety of studies over the last five years have shown that the presence of the Sierra Nevada and Rocky Mountains in the western United States has direct implications for climate patterns extending into Europe, Mulch said.

"If we did not have these mountains, we would completely change the climate on the North American continent, and even change mean annual temperatures in central Europe," he said. "That's why we need to have some idea of how mountains were distributed over planet Earth in order to run past climate models reliably." Mulch is now a professor of tectonics and climate at the University of Hannover in Germany.

Mulch and his colleagues, including Page Chamberlain, a Stanford professor of environmental earth system science, reached their conclusion about the timing of the uplift of the Sierra Nevada by analyzing hydrogen isotopes in water incorporated into volcanic glass.

They analyzed volcanic glass at sites from the Coast Ranges bordering the Pacific Ocean, across the Central Valley and the Sierra Nevada and into the Basin and Range region of Nevada and Utah.

The ratio of hydrogen isotopes in the glass reflects changes that occurred to the water vapor content of air over the Pacific Ocean as it blew onto the continent and crossed the Sierra Nevada. As the air gains elevation, it cools, moisture concentrates and condenses, and it rains. Water containing heavier isotopes of hydrogen tends to fall first, resulting in a systematic decrease in the ratio of heavy water molecules to lighter ones in the remaining water vapor.

Because so much of the airborne moisture falls as rain on the windward side of the mountains, land on the leeward side gets far less rain—an effect called a "rain shadow"—which often produces a desert.

The higher the mountain, the more pronounced the rain shadow effect is and the greater the decrease in the number of heavy hydrogen isotopes in the water that makes it across the mountains and falls on the leeward side of the range. By determining the ratio of heavier to lighter hydrogen isotopes preserved in volcanic glass and comparing it with today's topography and rainwater, researchers can estimate the elevation of the mountains at the time the ancient water crossed them.

Volcanic glass is an excellent material for preserving ancient rainfall. The glass forms during explosive eruptions, when tiny particles of molten rock are ejected into the air. "These glasses were little melt particles, and they cooled so rapidly when they were blown into the atmosphere that they just froze, basically," Mulch said. "They couldn't crystallize and form minerals."

Because glass has an amorphous structure, as opposed to the ordered crystalline structure of minerals, there are structural vacancies in the glass into which water can diffuse. Once the glass has been deposited on the surface of the Earth, rainwater, runoff and near-surface groundwater are all available to interact with it. Mulch said the diffusion process continues until the glass is effectively saturated with water.

Other researchers have shown that once such volcanic glass is fully hydrated, the water in it does not undergo any significant isotopic exchange with its environment. Thus, the trapped water becomes a reliable record of the isotopic composition of the water in the environment at the time the glass was deposited.

"It takes probably a hundred to a thousand years or so for these glasses to fully hydrate," Mulch said. But 1,000 years is the blink of an eye in geologic time and, for purposes of estimating the timing of events that occur on scales of millions or tens of millions of years, that degree of resolution is quite sufficient.

Likewise, you need deposits of volcanic ash that were laid down relatively quickly over a broad area. But that's the norm for explosive eruptions. Though some ash may circulate in the upper atmosphere for a few years after a major eruption, significant quantities are generally deposited over vast areas within days.

The samples they studied ranged from slightly more than 12 million years old to as young as 600,000 years old, a time span when volcanism was rampant in the western United States owing to the ongoing subduction of the Pacific plate under the continental crust of the North American plate.

"As we use these ashes that are present on either side of the mountain range, we can directly compare what the water looked like before and after it had to cross this barrier to atmospheric flow," Mulch said. "If you just stay behind the mountain range, you see the effect of the rain shadow, but you have to make inferences about where the water vapor is coming from, what happened to the clouds before they traveled across the mountain range.

"For the first time, we were able to document that we can track the [development of the] rain shadow on both sides of the mountain range over very long time scales."

Until now, researchers have been guided largely by "very good geophysical evidence" indicating that the range reached its present elevation approximately 3 or 4 million years ago, owing to major changes in the subsurface structure of the mountains, Mulch said.

"There was a very dense root of the Sierra Nevada, rock material that became so dense that it actually detached and sank down into the Earth's mantle, just because of density differences," Mulch said. "If you remove a very heavy weight at the base of something, the surface will rebound."

The rebound of the range after losing such a massive amount of material should have been substantial. But, Mulch said, "We do not observe any change in the surface elevation of the Sierra Nevada at that time, and that's what we were trying to test in this model."

However, Mulch said he does not think his results refute the geophysical evidence. It could be that the Sierra Nevada did not evolve uniformly along its 400-mile length, he said. The geophysical data indicating the loss of the crustal root is from the southern Sierra Nevada; Mulch's study focused more on the northern and central part of the range. In the southern Sierra Nevada, the weather patterns are different, and the rain shadow effect that Mulch's approach hinges on is less pronounced.

"That's why it's important to have information that's coming from deeper parts of the Earth's crust and from the surface and try to correlate these two," Mulch said. To really understand periods in the Earth's past where climate conditions were markedly different from today, he said, "you need to have integrated studies."

Source: Stanford University

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