Ancient raindrops reveal the origins of California's Sierra Nevada range

One of the longest ongoing controversies in Earth science concerns the age of California's Sierra Nevada, the tallest mountain range in the continental United States and site of Yosemite National Park, Lake Tahoe and other scenic wonders.

"The debate falls into two camps," said C. Page Chamberlain, professor of geological and environmental sciences at Stanford University. "One is that the mountains rose from sea level in the last 3 to 5 million years, which is very recent on a geologic time scale. The other group suggests a much more ancient origin going back 60 million years or so."

Now, in a study published in the July 7 edition of the journal *Science*, Chamberlain and Stanford colleagues Andreas Mulch and Stephan A. Graham present strong evidence that the Sierra Nevada range has stood tall--7,200 feet (2,200 meters) or higher--for at least 40 million years.

"An elevation profile drawn across the northern Sierra Nevada 40 to 50 million years ago would not look much different than today's profile," said Graham, the Welton Joseph and Maud L'Anphere Crook Professor of Applied Earth Science at Stanford.

"Those mountains probably have persisted since the Mesozoic Era--more than 65 million years ago--until today," Chamberlain added. Back then, according to many scientists, California was split by an ancient subduction zone--a region of constant geologic upheaval, where a plunging oceanic tectonic plate continuously pushed the continental North American plate higher and higher to create the Sierra Nevada range.

This version of events is in sharp conflict with the "recent uplift" scenario, which argues that the Sierra rose from sea level to 7,200 feet about 3 million to 5 million years ago after an enormous block of the Earth's crust broke off and fell into the mantle. According to this hypothesis, the crust was then replaced by hot, buoyant mantle material that eventually raised the mountains. Although the Science study found no evidence to support this scenario, data revealed that a modest uplift of 1,100 to 2,000 feet (350 to 600 meters) did occur as recently as 3 million years ago.

The Stanford team obtained their results by conducting a chemical analysis of ancient raindrops unearthed in the Sierra during the California Gold Rush. In addition to providing important insights for geoscientists, the authors say their findings could lead to more accurate assessments of global climate change.

"If you want to make a climate model and project out into the future, you need to test your model by running it back in time and seeing how it matches similar climate histories in the past," Chamberlain said.

"Determining when the mountains rose is an important question, because the effect of a relatively tall range on precipitation and climate is very significant," said Mulch, a postdoctoral scholar in Stanford's Department of Geological and Environmental Sciences and lead author of the study. "Making the mountains twice as high would therefore make the impact twice as large."

Heavy raindrops

To determine when the Sierra rose to its current height, the scientists used an increasingly popular research tool that combines geology and chemistry to create a record of prehistoric rainfall patterns dating back millions of years. This technique relies on the fact that in nature, hydrogen and other atoms occur in different sizes called isotopes. Deuterium, for example, is a slightly heavier form of hydrogen, and drops of rainwater that contain deuterium isotopes often fall at lower elevations.

"If you have a cloud coming in and dropping out water, as it climbs the mountain its preference is to first drop the heavy water that's rich in deuterium," Chamberlain said. "As you go up in elevation, the raindrops become lighter and lighter. Therefore, the rainwater becomes gradually depleted of deuterium the higher up the mountain range it falls."

Over time, some raindrops are incorporated into molecules of clay and other minerals that form on the ground. These clays provide scientists with a geologic record of ancient precipitation, which can then be compared with samples of modern precipitation collected at the same altitude. If the comparison reveals similar isotopic ratios, then the elevation of the mountain must have been similar in ancient and modern times.

"Determining the height of a now-eroded mountain range has remained frustrating and elusive," said Graham. "Relating the isotopic composition of ancient rainfall to minerals formed in ancient soils provides a powerful way to infer those paleoelevations and is creating a burgeoning set of data from the Himalayas and Tibet, the Andes and now the Sierra Nevada."

Gold Rush diggings

In the study, the Stanford team compared modern rainfall with prehistoric samples dating back to the Eocene epoch 40 million to 50 million years ago. Soil and rocks from the Eocene often are buried deep underground. But in the mid-1800s, gold prospectors began using hydraulic mining to expose gold-bearing gravels along two major Sierra rivers, the Yuba and the American. Using powerful water canons, the miners "cut away half a mountain in a few minutes …[and] changed entire landscapes," wrote historian Joseph H. Jackson.

Hydraulic mining caused severe environmental damage and exposed tons of ancient rocks and minerals that can still be seen today. "If you go up along the Yuba and American rivers east of Sacramento, you'll see the gold diggings," Chamberlain said. "They were mining river gravels that were deposited 45 to 48 million years ago. When these deposits formed, they underwent intense chemical weathering that turned them into clay minerals."

Embedded in the crystalline structure of these soft clays is a continuous record of Eocene precipitation along the western flank of the Sierra Nevada--a record that would have remained locked underground if not for the destructive pursuit of gold 150 years ago.

"If you can follow the river up to what you think was its crest, then you can use the hydrogen-deuterium isotopes in the clay minerals to reconstruct the topography of the mountain, which is what we did," Chamberlain said.

During the study, the Stanford team collected dozens of clay samples from 15 sites along the two rivers--old Sierra mining camps with colorful names like Orleans Flat and You Bet Diggings.

"The highest sampling elevation was about 5,500 feet [1,700 meters] going down to about 980 feet [300 meters] to where the ocean shoreline was roughly 40 million years ago," Mulch said. "I then analyzed the clay minerals in the lab to get an idea of what the isotopic composition of the water was at that time."

When Mulch compared ancient raindrops in the clays with modern precipitation samples, he discovered a remarkable similarity: In both cases, deuterium levels gradually decreased from the lowest-elevation collection site to the highest--a strong indication the topography of the Sierra had changed little since the

Eocene epoch. "With these data, we've been able to extend the record back and say, 'We think these mountains were high 40 to 50 million years ago and did not rise from sea level in the last 3 to 5 million years,'" Chamberlain said.

However, isotope analysis also revealed that the mountains have not remained entirely static. "There is no question that 3 or so million years ago there was some kind of uplift, but no higher than 2,000 feet [600 meters]," Mulch said.

"The cool part is that it's the gold mines and these gold-bearing gravels that are telling us this," Chamberlain added.

Besides isotopic data, Mulch points to other geological evidence that the Sierra range is really tens of millions of years old.

"I'm not emotionally attached to one side of the debate or the other, because obviously I could live with mountains being young or old," he said. "But if you look at these rivers and what they deposited in the riverbeds, the boulders that they transported can be as large as a basketball or even larger. There's no way for me to understand how you could do this if the gradient was that of a meandering river in a flat landscape. This is what mountain rivers do: They transport big boulders. That's what we see in the Himalayas and the Andes, and that's what we're not seeing in the Mississippi or Missouri rivers. They just transport very fine material and not house-sized boulders."

Climate change

The Stanford team has begun extending the technique beyond California. "We're trying to unravel a picture of how all of western North America looked through time in terms of its topography," Chamberlain said. "The Sierra is one piece of the puzzle. What seems to be emerging is that the Great Basin, which includes much of Nevada and Utah, was a large plateau that basically collapsed. So the crest of the Sierra was once the edge of a plateau, similar to the Himalayas and the Tibetan highlands. Can we prove that? We think we're getting close."

Solving these geologic puzzles also has significant implications for modeling global climate change, past and future, he said.

"There are basically six large mountain ranges climatologists need to know the history of--western North America, the Himalayas, Antarctica, Greenland, the spine down Africa and the Andes," Chamberlain noted. "To get an idea of what's going to happen if carbon dioxide levels double in the future, you'd have to go back 20 or 30 million years in time. If you knew what the topography of these six mountain ranges was then, you could include that in your computer models and see how they respond when you double the carbon dioxide."

Source: By Mark Shwartz, Stanford University