Caltech Researchers Invent New Technique For Studying The Thermal History Of Rocks

Another use of radioactive isotopes

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The beautiful valleys of the southern Coast Mountains of British Columbia exist for us to enjoy today because of glacial action in the past. Geologists know, for example, that a giant glacier carved a deep groove in the mountain range to form the present-day Klinaklini Valley. But how fast the cutting actually took place, and when, has hitherto been conjecture.

Now, a 2005 graduate of the California Institute of Technology and his supervising professor have successfully employed a new technique for measuring erosion rates by determining how fast rocks cooled off after being churned up by the glacier. Reporting in the December 9 issue of the journal Science, David Shuster (now at Berkeley Geochronology Center) and Ken Farley, chair of the geological and planetary sciences division at Caltech, along with researchers from Occidental College and the University of Michigan, describe their success in determining how quickly the Klinaklini Valley came into being.

The results show that the two kilometers of overlying rock were removed by the glacier at a rate exceeding five millimeters per year, meaning that the glacial valley deepening occurred six times faster than the normal erosion rate before the glacier came along. The study experimentally confirms the hypothesis that glaciers erode material faster than rivers and are responsible for the topographic relief of mountains. According to Shuster, the study also provides an additional tool for the study of how global climate variations may have influenced mountainous topography.

"This study was possible because of a technique Ken and I developed called helium-helium thermochronometry," Shuster said in a phone interview. "It's an unwieldy name, but it gives us a new way to study the rate at which rocks approached Earth's surface in the past."

The new technique rests on three facts: one, that rocks on the surface have often come from beneath the surface; two, that the ground gets steadily warmer as depth increases; and three, that helium leaks out of a warm rock faster than a cold one. Therefore, if one can figure out how fast the helium leaked out of a rock, then it's also possible to determine how fast the rock cooled and, ultimately, how deeply it was buried, as well as when and how fast it got uncovered.

Helium-helium thermochronometry--or more specifically, 4He/3He thermochronometry--is a novel technique because it requires a rare isotope known as helium-3 to be artificially created in the sample. For this particular study, the researchers collected a calcium phosphate called apatite. As a natural consequence of the decay of uranium and thorium, which exist as trace minerals in apatite, the rock already contains helium-4, but no helium-3.

However, the helium-4 is not dispersed evenly throughout the rock. The dispersal would indeed be even if a rock could just sit for millions of years unheated and unperturbed, but such is not likely in the real world. Rather, the helium-4 tends to leak out during times when the rock is heated. As a consequence, the apatite specimens from the

Klinaklini Valley have uneven distributions of helium-4 because the rocks themselves were once beneath the surface. In fact, the ground temperature in the region increases about 25 degrees Celsius for each kilometer of depth.

But while the helium-4 distribution in the apatite samples is a record of how fast the rocks cooled, the researchers cannot determine the rate by looking at helium-4 by itself. For the data necessary to arrive at the rate of cooling, the researchers took the apatite samples to a medical lab in Massachusetts that operates a cyclotron for treating cancer with proton bombardment. By hitting each 100-micron apatite crystal with energetic protons, the researchers managed to create an even dispersal of helium-3 in the samples. The helium-3 comes about as a natural consequence of the proton bombardment.

With both helium-4 and helium-3 now in each apatite sample, the researchers could then compare the ratio of the two isotopes by heating each sample at progressively higher temperatures, making more and more helium leak out, and measuring how much of each isotope was released at each temperature. This allowed them to figure out how the helium-4 was dispersed in each sample and, thus, how fast the rocks had cooled.

"Our technique is for temperatures between about 30 and 70 degrees Celsius," says Farley. "This is the last cooling before a rock comes to the surface, and no other technique accesses this information."

As a result, the team showed that the cooling of the rock happened very quickly about 1.8 million years ago, that the entire valley was carved out in about 300,000 years, and that the total lowering of the area by glacial action was about two kilometers.

"We can say that the glacier was ripping out a huge amount of material and dumping it into the ocean," adds Farley, who is also the Keck Foundation Professor of Geochemistry. "And rather than taking evidence from a single instant, we can for the first time see an integral of hundreds of thousands of years. So this is a new way to get at the rate at which glaciers do their work."

"Why this intense erosion occurred 1.8 million years ago is not well understood, but it seems to coincide with some very interesting changes that took place in Earth's climate system at that time," says Shuster.

According to Shuster, various minerals can be used in the proton-bombardment procedure, although apatite was ideal for the study of the Coast Mountains.

In addition to Shuster and Farley, the other authors are Todd Ehlers, a former postdoctoral researcher at Caltech who is now a member of the University of Michigan faculty, and Margaret Rusmore, a geology professor at Occidental College.

The title of the paper is "Rapid Glacial Erosion at 1.8 Ma Revealed by 4He/3He Thermochronometry."