The recent ice ages appear to have been triggered by the removal of CO2 from the atmosphere by the chemical weathering of the Himalayas.

There hasn't been anything resembling a glen in Glen Rock, N.J., for as long as anyone can remember. The Rock is another story. Sitting smack in the middle of Doremus Avenue, it is nearly as big as the $350,000 homes that line the streets of this comfortable New York City suburb. Like the craggy coastal islands off New England and the glacial lakes of Alaska, The Rock is a souvenir of the last ice age.

It is one of thousands of massive boulders left behind by retreating ice sheets that at one point covered what is now Canada and reached as far south as northern Pennsylvania, Ohio, Indiana and Illinois. Ice ages return periodically, which is a puzzle in its own right (see "Stardust And Ice Ages," Sept. 1996). The larger mystery is why they happen at all. The fossil record, say geologists, makes it perfectly clear that for most of the 4.5 billion years that the Earth has orbited the sun even the most northern climes have been warm and balmy places. Then, about 40 million years ago something happened to really turn down the thermostat. Pinning down an exact reason has proved difficult. Some scientists have long suspected that the shift in the positions of the continents may have altered ocean currents enough to change the way their waters carry heat from the equatorial to the polar regions. Another possibility was that changing wind patterns had driven the change. Both ideas, while not entirely ruled out, have been shown to have had a smaller effect than originally estimated. Slowly a new theory has begun to emerge. In recent years geologists have gravitated toward a notion that initially seemed downright impossible: Ice ages are caused by the Himalayas, the world's tallest mountains.

**A Delicate Balance**

Although molten rock may course through the planet's depths, it is the distant sun that provides the energy that heats the Earth. Our local star emits electromagnetic radiation across a broad frequency range. Energy at ultraviolet (UV) and visible light frequencies pours into the atmosphere, where it is absorbed by the surfaces that surround us. Then, it is reradiated back into the atmosphere at less energetic infrared frequencies. Unlike the UV and visible light coming in, infrared energy can't easily escape. Its way is blocked by gases that behave much like the panes in a greenhouse window. Any number of gases can contribute to this so-called "greenhouse effect." Historically--in the sense of millions rather than hundreds of years--the most important of the greenhouse gases has been carbon dioxide (CO2). There is no argument that by allowing more infrared-frequency energy to escape into space, falling CO2 levels at the dawn of the ice ages caused temperatures to drop. The mystery was what might have removed the CO2.

Maureen Raymo didn't set out to solve the mystery of the ice ages. She was simply trying to get a better understanding of a process called chemical weathering. "When you start dissolving a rock, ultimately what
you're doing is taking CO2 out of the atmosphere," she says. "CO2 in the atmosphere dissolves in rainwater and makes a very dilute acid that dissolves bits of the rock." Eventually, the elements in the solution recombine to form new minerals. "The CO2 that was in the atmosphere ends up in a carbonate rock," Raymo says. And so, removing CO2 levels turns down the global thermostat.

One day while working as a graduate student, the future MIT geology professor was reviewing mineral content data when she was struck by unusually high readings of minerals in water samples from Southeast Asia. She wondered if it were possible for so much weathering to take place that the atmospheric CO2 balance could be disrupted in a way that caused energy to flow out of the atmosphere, sufficiently lowering temperatures to trigger an ice age. The coincidence of the rise of the Himalayas and the fall of global temperatures at the start of the most recent round of ice ages was unmistakable.

As pieced together by Raymo, the events needed to trigger the ice age would have taken place like this: First, the well-known geologic process known as seafloor spreading forced the landmass we today call India up against the firmly anchored Asian continent. With no place to go but up, the mountain chain we now call the Himalayas began to form (see illustrations at right).

Eventually, the mountains grew sufficiently tall to disrupt weather patterns. Prior to the formation of the mountains, moisture-laden winds moved inland. Now, they encountered an unyielding obstacle that forced them upward into the cold sky. The moisture condensed and the rain began to fall.

Raymo reasoned that the rain falling on the Himalayas would have been slightly acidic because of its contact with the CO2 already present in the atmosphere. As it flowed back into the sea, this acidic rain would have been especially aggressive in dissolving the local rock. And, once back in the ocean, the CO2 that caused the acidic rain to form would have become trapped in carbonate rocks.

"The Himalayas are like a huge sponge pulling CO2 out of the atmosphere," says Raymo. "I think these mountains are in large part responsible for all of the global cooling of the last 40 million years." In theory all the pieces fit. Now all that she had to do was convince her skeptical colleagues.

**Strontium Connection**

Help would come from an unexpected source--research into the composition of calcium carbonate that had developed at the bottom of the sea. Calcium carbonate contains several forms of the element strontium. The "heavy" variety, known as strontium 87, is associated with the chemical weathering of certain types of rocks. Its lighter chemical twin, strontium 86, originates from deep inside the Earth. A core drilled from the ocean floor will show varying amounts of the two forms of strontium, laid down at different points in the planet's distant past. Strontium 86 will dominate during periods when seafloor spreading was in progress. Strontium 87 will dominate if heavy chemical weathering was taking place.

If Raymo's theory was correct, strontium 87 would have been the dominant chemical species when the CO2 levels, hence temperatures, were bottoming out. Unknown to Raymo, some of her colleagues were already making precisely these measurements. "When I saw a strontium isotope curve for the first time, I realized that this was the smoking gun," she says.

The rock in Glen Rock may not actually be a chip off the world's tallest mountain, but without the Himalayas, it wouldn't be in the middle of Doremus Avenue.
A sharp increase in strontium 87 due to accelerated chemical erosion levels coincided with formation of the Himalayas.

Mountains Up, Temperatures Down
Seafloor spreading compressed India against Asia, creating the Himalayas. Their presence increased local rainfall, which accelerated CO2 removal from the air. With less CO2 to prevent the outflow of heat, the planet's temperature dropped, ushering in the first ice age.