GEOLOGY

Growth, Death, and Climate Featured in Salt Lake City

SALT LAKE CITY—More than 5600 geologists and paleontologists gathered here from 20 to 23 October for the annual meeting of the Geological Society of America (GSA). Change over geologic time figured in several highlights from the meeting: evolutionary change 250 million years ago in the world's greatest mass extinction, climate change in the warm intervals between glacial epochs, and size change among mammals of the past 80 million years.

Ancient Climate Shivers Strike Close to Home

You might not expect to find similar climate histories at a Club Med in the Bahamas and at chilly Lake Baikal in Siberia. But both sites have yielded unsettling hints that global climate may be unstable—prone to sudden cold snaps—during warm interludes between ice ages, like the one we now enjoy.

Four years ago, researchers studying deep layers of the Greenland ice sheet thought they had found evidence for brief cold spells during the warm interglacial period 120,000 to 130,000 years ago. But the ice record of that time later proved unreliable. Now, two groups reported at the meeting that signs of a brief interglacial chill have turned up again, in an ancient coral reef blasted open for a new marina by a Club Med and in bottom muds from the Siberian lake.

Because some corals thrive only in the brightly lighted waters just below the sea surface, ancient reefs are a good gauge of past sea level, which in turn reflects the amount of water locked up in polar ice. Geologists Brian White and Allen Curran of Smith College in Northampton, Massachusetts, had studied reefs in the Bahamas that grew during the warm period from 120,000 to 130,000 years ago, after the melting of glaciers from the previous ice age had raised sea level by about 100 meters. Any cold spell in the warm interval would have caused sea level to fall, exposing reefs to erosion by waves and weather and producing a distinctive "erosional surface."

But White and Curran saw no clear signs of a chill during that period until they brought paleontologist Mark Wilson of The College of Wooster in Ohio—a specialist in erosional surfaces—to the island of San Salvador in the Bahamas. When they went to the marina construction site, they discovered that the dynamiting had exposed a dramatic example of a reef exposed and eroded by a sea-level fall.

"We missed [the erosional surface] before," says Wilson. "But once you saw that fresh exposure, you could trace it through the whole reef," and even on another island. Sea level apparently dropped about 4 meters as an abrupt global cooling froze water into glaciers. That was about 125,000 years ago, as gauged by radiometric uranium-thorium dating of the coral. Sea level stayed low for perhaps 1000 years and then rose quickly to near its former level as the cold spell eased.

NICHOLAS HOTTON/SMITHSONIAN INSTITUTION

Doomed. The mammal-like reptile *Dicynodon leoniceps* fell victim to extinctions that swept both the land and the sea.

Work that Eugene Karabanov of the University of South Carolina, Columbia, and colleagues in the United States and Russia reported at the meeting reveals a mid-interglacial cooling as well. During the winter of 1996, Karabanov and his colleagues let their drilling barge freeze into Lake Baikal for stability and drilled out sediment cores that reached as far back as 5 million years ago. (See the Report on p. 1114 for more results from the Baikal drilling.) The researchers traced climate by counting remains of lake diatoms—tiny, silica-shelled plants that flourish in warmer conditions. In a section of core laid down during the previous interglacial, the diatoms suddenly became much more scarce, indicating a sudden chilling in south-central Siberia. The diatoms just as quickly recovered, leaving a record of a brief cold spell roughly 121,000 years ago.

Whether the global chill recorded by Bahamian coral and the one in central Asia are the same isn't clear, given the uncertainties of dating. Either way, they have unsettling implications for current climate (*Science*, 17 December 1993, p. 1818). Greenland ice cores and deep-sea sediments have shown that during the last ice age, abrupt climate swings—warmings, in this case—were common. But researchers believe that the buildup and sudden collapse of huge ice sheets triggered those swings. Between glacial periods, that wouldn't occur, so some kind of instability in ocean circulation seems to be the best candidate for shaking up the climate. And unstable ocean circulation could produce some unpleasant surprises as greenhouse gases build up in decades to come.

The Biggest, Baddest Extinction Gets Worse

The extinction that did in the dinosaurs at the end of the Cretaceous period may be the world's most famous extinction, but it wasn't the worst. That honor goes to an event 250 million years ago that exterminated 90% of the genera in the oceans and ushered in the age of the dinosaurs on land. This ecological disaster at the end of the Permian period has long been viewed as "the most profound in the history of the planet," as Samuel Bowring of the Massachusetts Institute of Technology put it at the GSA meeting. Now the catastrophe looks even more devastating, thanks to Bowring and paleontologist colleagues, who presented evidence suggesting that the marine extinctions were concentrated during a geologic moment—just a few hundred thousand years.

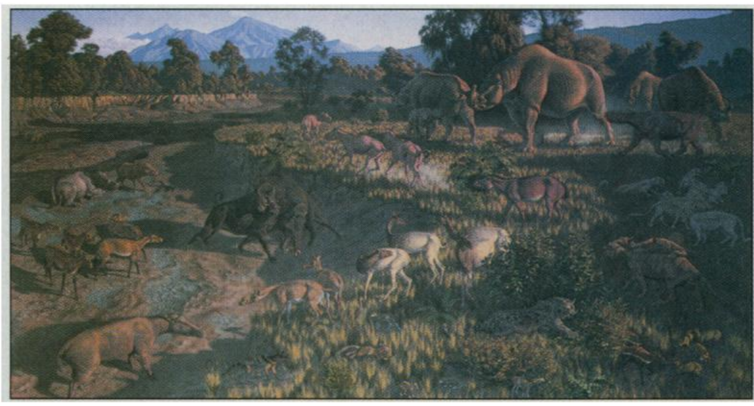
That makes for an "awfully fast" event, says paleontologist Douglas Erwin of the National Museum of Natural History in Washington, D.C., one of Bowring's collaborators. What's more, work by another group shows that the extinctions on land took place at the same time. Better timing of the extinctions may offer clues to their cause, which may have involved a combination of lethal forces, perhaps including a huge volcanic eruption.

Paleontologists had already mapped out the order of extinctions of such organisms as corals and trilobites near the boundary between the Permian and Triassic periods, but determining how fast it all happened was more difficult. Presuming that the distinctive fossils used to mark time in the rock record had evolved at a steady pace during the late Permian, paleontologists had estimated that the dying extended for millions of years. But without absolute dates, that was only a guess. "No dates, no rates," as geochronologist Bowring puts it.

Now, Bowring and Erwin, in cooperation with Jin Yugan of the Nanjing Institute of Geology and Paleontology, have applied an established dating technique—based on the clocklike radioactive decay of uranium to lead—to marine rocks around the Permo-Triassic boundary at Meishan, China. By dating zircon minerals from volcanic ash beds just above and just below the extinction layer, the team has narrowed the interval of intense extinction. "It looks like appreciably less than 500,000 years," says Erwin.

At this point the team can't say whether the extinction really did span that period or actually took place in a geological instant, like the end-Cretaceous event. To decide, paleontologists will need to intensify their sampling of the extinction interval to see whether all the Permian species vanished simultaneously.

If terrestrial plants and animals—which were also hit hard between the Permian and Tertiary—died out earlier or later than the marine species, the extinction interval would have to be lengthened. But because land and sea share no fossils that could be used to mark time in both, researchers couldn't say whether disaster befell both realms at the same time.



SMITHSONIAN INSTITUTION/NMNH

Heavies. By 35 million years ago, the mouse-sized mammals of 65 million years ago had given rise to hefty descendants, like this *Brontotherium* in Nebraska.

At the meeting, paleontologist and geochemist Kenneth MacLeod and his colleagues reported a geochemical marker that ties extinctions on land to those in the sea. Numerous researchers had found that the abundance of the lighter isotope of carbon, ^{12}C, suddenly increased in marine sediments right at the time of the Permo-Triassic extinctions. No one is sure of the cause, but because carbon flows freely between land and sea as atmospheric carbon dioxide, that sudden spike of light carbon should turn up on land as well. Indeed, MacLeod found it preserved in ancient soil minerals and in fossil tusks of mammal-like reptiles called therapsids from southern Africa. And the Permo-Triassic boundary on land, as marked by the extinction of the therapsid *Dicynodon*, also fell at the time of the carbon-isotope spike.

The coincidence of Permo-Triassic extinctions on land and in the sea means "you really need to invoke a global forcing mechanism," says MacLeod. A leading candidate has been the largest volcanic eruption ever, the Siberian Traps. They poured out 2 million cubic kilometers of lava in a million years or so and would have created a global, cooling haze. Bowring's dating at Meishan confirms an earlier suggestion that the bulk of the Siberian Traps eruptions coincided with the extinctions within dating uncertainties of a few hundred thousand years (*Science*, 6 October 1995, p. 27).

Still, says Erwin, the eruption isn't likely to be the sole cause, because its emissions couldn't have contributed enough isotopically light carbon to create the carbon-isotope spike. And another suspect, a lethal shot of carbon dioxide from the deep sea into shallow waters (*Science*, 1 December 1995, p. 1441), seems an unlikely killer of plants and animals on land. But then, asks Erwin, "who says there has to be only one cause?" Perhaps only a convergence of stresses can explain this most disastrous interval in the history of life.

For Mammals, Bigger Is (Usually) Better

Rules are made to be bent, or so the history of life seems to imply. Nineteenth-century paleontologist Edward Drinker Cope studied North American mammals and came up with a simple rule: Average body size in mammals gets bigger over time. Although Cope's rule, as it later came to be known, hasn't always proved true when applied to other animals, such as mollusks (*Science*, 17 January, p. 313), a comprehensive analysis confirms its broad outlines in North America, where Cope worked. But a study by paleobiologist John Alroy of the National Museum of Natural History in Washington, D.C., shows subtleties Cope never suspected: Mammals have indeed grown larger over time, but they have also tended to avoid intermediate sizes. Part of the reason, Alroy suspects, may be found in North America's climatic patterns.

At the GSA meeting, Alroy presented his analysis of an 80-million-year record of North American mammal diversity amassed from the literature (*Science*, 27 June, p. 1968), combined with published estimates of body size based on fossil teeth. Like other researchers before him, Alroy found that mammals in the late Cretaceous period, 80 million to 65 million years ago, were all small, in the range of 5 grams to 1 kilogram—typical of today's small mammals such as rodents. After the dinosaurs were wiped out 65 million years ago, mammal size jumped. By 55 million years ago, the typical large mammal weighed in at 5 kilograms, and by 6 million years ago, it was a hefty 300 kilograms. On average, Alroy found that new species were 10% bigger than their ancestors.

That pattern—exactly what Cope's rule predicts—held until about 45 million years ago. At that point, a gap opened in the distribution of body mass between small and large mammals. Intermediate-size mammals—those weighing 1 kilogram to about 10 kilograms, or about the size of a raccoon—became scarce.

Researchers have explained Cope's rule by theorizing that for mammals, bigger is better in many different environments. The larger the animal, the better it can run from or fend off predators, for example; increasing size also brings greater physiological efficiencies, such as staying warm using a minimum of energy. But Alroy suspects that the lack of intermediate sizes may be due at least in part to a particular external influence: climate.

North American climate began cooling and drying just about the time the size gap began to open up, he notes, transforming the densely wooded landscape into a broken woodland with more open space. In such dry, open environments today, intermediate-size animals are scarce, says Alroy, suggesting that the ancient drying of North America helped open the gap. For example, some intermediate-size mammals tend to move from tree to tree eating fruit—and so perhaps faced extinction when the trees became too far apart for hopping from one to the next.

Other paleontologists are interested by Alroy's data, although like Alroy they are not ready with a full explanation. "The overall pattern is intriguing," says paleontologist Catherine Badgley of the University of Michigan, Ann Arbor. "I and a lot of other people think that [patterns like the gap] are driven by climate conditions." But to nail down the link, someone should "go to other regions that have similar—or different—patterns in climate change and test whether the trend in body size is borne out," says paleontologist David Jablonski of the University of Chicago. Don't hold your breath. For his North American study, Alroy consulted more than 4000 lists of mammal species that detailed where and when they lived. Such a study in another region may be a while in the making.

–Richard A. Kerr