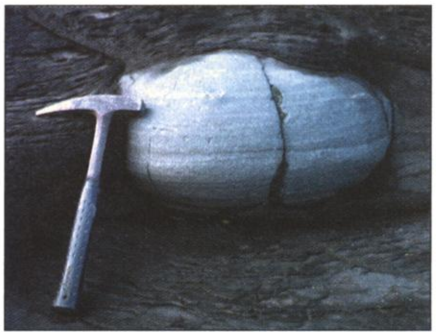
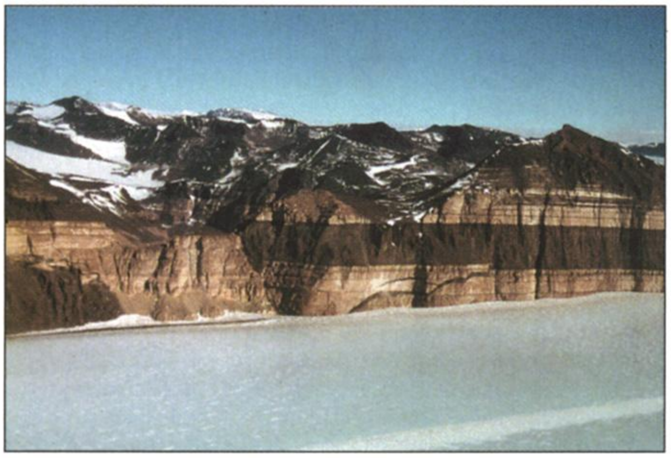
EARTH SCIENCE

Did Volcanoes Drive Ancient Extinctions?

Episodes combining climatic warmth, massive volcanic eruptions, oceanic anoxia, and bursts of methane may lie behind major extinctions

Massive extinctions involving many or most existing species, although not much fun for the organisms involved, are a boon to paleontologists, who use them to mark the passing of geologic time. For most of paleontology's history, however, its practitioners didn't know why life occasionally took a tumble. By the turn of this century, they had just one certain example of extinction cause and effect: An asteroid or comet surely did in many species 65 million years ago when the dinosaurs perished.





Cause and effect? The massive volcanic activity evidenced in this dark magma intrusion in Antarctica may have triggered suffocating anoxia marked by layered, organic-rich rock in Yorkshire, United Kingdom.

Now, with the publication in recent weeks of two papers on an extinction 183 million years ago, researchers can add five suggestive cases to the list. These extinctions coincide with massive outpourings of lava, accompanied by signs that global warming threw the ocean-atmosphere system out of whack. Although no one can yet pin any of these mass extinctions with certainty on the volcanic eruptions, "it's getting a little hard to believe they're all coincidences," says geologist Paul Olsen of Columbia University's Lamont-Doherty Earth Observatory in Palisades, New York. The episodes "may reflect some poorly understood instability of the ocean-atmosphere system." And it's possible, notes Olsen, that humankind with its volcano-like outpourings of greenhouse gases could trigger a similar climatic catastrophe.

The latest example of a possible volcano-climate disaster befell life in the Jurassic period 183 million years ago. The immediate cause of this modest loss of species early in the Toarcian stage was likely the absence of oxygen in bottom waters, says paleoceanographer Hugh Jenkyns of Oxford University. This anoxia left its mark in 2 meters of black, organic-rich sediments laid down with the extinctions early in the Toarcian. It is one of the three big oceanic anoxia events of the past 200 million years.

Just when the Toarcian extinctions and anoxia occurred, and thus what might have triggered them, is now much clearer thanks to a geochronology study published in the August issue of *Geology*. Geochronologist József Pálfy of the Hungarian Natural History Museum in Budapest and paleontologist Paul Smith of the University of British Columbia in Vancouver reported that they have improved the dating of both the extinctions and an accompanying large volcanic outpouring. Uncertainties in the age of the extinctions had ranged as high as 15 million years, but by using the uranium-lead radiometric technique to date layers of volcanic ash from local European eruptions, they pinned down the start of the Toarcian to 183.6 million years, give or take a million years or so.

Putting the early Toarcian extinctions at about 183 million years brought them tantalizingly close to a million-year-long set of volcanic eruptions that spewed a few million cubic kilometers of dark basaltic lava across South Africa and Antarctica when they were joined in the supercontinent of Pangea. Pálfy and Smith gathered the latest argon-argon and uranium-lead dates, recalculated them to account for uncertainties peculiar to each, and found a peak in this so-called Karoo-Ferrar volcanism at 183 million years ± 2 million years.

The rough coincidence of a large volcanic outpouring and a sizable extinction event brings to five the number of examples of apparent volcanic-extinction correlations, including three of the big five mass extinctions. As Olsen pointed out recently (*Science*, 23 April 1999, p. 604), increasingly abundant and reliable radiometric dating techniques have linked in time three of the largest mass extinctions—the Cretaceous-Tertiary 65 million years ago, the Triassic-Jurassic 200 million years ago, and the Permian-Triassic 251 million years ago—with three of the largest flood basalts: the Deccan Traps of India, the Central Atlantic Magmatic Province of northeastern South America, and the Siberian Traps, respectively. And deep-sea extinctions and a turning point in mammal evolution 55 million years ago at the Paleocene-Eocene boundary (*Science*, 19 November 1999, p. 1465) coincide with the massive lavas laid down when Greenland and Europe parted tectonic ways. The coincidences are within a million years or so, as tight as current dating allows.

"The very big flood basalt provinces are remarkably correlated with extinctions," says geochronologist Paul Renne of the Berkeley Geochronology Center in California. "The correlation is suggestive, intriguing," says paleontologist David Jablonski of the University of Chicago. "There are just enough clues to suggest you should go after it."

A second recent paper on Toarcian events 183 million years ago should help in the pursuit. In the 27 July issue of *Nature*, geologist Stephen Hesselbo of Oxford University, Jenkyns, and their colleagues presented evidence that a huge amount of methane gushed into the atmosphere and ocean 183 million years ago over a period of less than 5000 years. They found that the carbon isotopic signature of bits of fossil wood preserved in early Toarcian rock in England and Sweden changed so much and so rapidly that only methane could be responsible; the methane had presumably been trapped below the sea floor as icy methane hydrates. Earlier research had

CREDITS: DAVID ELLIOT/OSU; HUGH JENKYNS/OXFORD UNIVERSITY identified similar methane bursts 55 million years ago at the Paleocene-Eocene boundary, 90 million years ago at the Cenomanian-Turonian oceanic extinctions and anoxic event, and 120 million years ago during a massive submarine basalt eruption (*Science*, 28 January, p. 576).

Researchers are still "stumbling around," as Olsen puts it, trying to make sense of the coincidences of extinctions, eruptions, and methane outbursts, but most would agree with paleontologist Peter Harries of the University of Southern Florida in Tampa that "there's certainly something strange going on." Exactly what, no one is willing to say, but a plausible scenario being discussed begins with the generally warm climate of most of the past 250 million years. The eruption of millions of cubic kilometers of gas-laden magma over a million years or less boosts the greenhouse, warming the world further. That warming destabilizes sub–sea-floor methane hydrates, releasing methane, a powerful greenhouse gas that oxidizes to another greenhouse gas, carbon dioxide. The planet gets warmer still. Then the scenario gets really fuzzy. The heat itself might drive species to extinction on land and sea, or the altered climate might induce changes in ocean circulation and biological productivity that bring on the suffocating oceanic anoxia, an outcome that could conceivably be in our own greenhouse future.

Sorting out cause and effect in curious coincidences as old as 250 million years is going to be a challenge, researchers note, particularly given the less-than-perfect pattern of coincidences. The Paleocene-Eocene event has no anoxia, the 120-million-year event has methane, anoxia, and a flood basalt eruption but no extinctions, and the Triassic-Jurassic event has as yet no sign of methane. A large impact looks simple by comparison.

–RICHARD A. KERR

MEETING **EVOLUTION 2000**

Evolutionary Trends From Bacteria to Birds

BLOOMINGTON, INDIANA—Talks at Evolution 2000, held here in late June, covered the gamut of evolutionary biology, from life history changes in bacteria to the origins of modern bird diversity.

Stalked Microbe Shows That Even Bacteria Get Old

They may not get gray hair, wrinkles, or stiff joints, but some bacteria apparently age. Until now biologists have considered bacteria immortal: When a single cell divides, it becomes two seemingly identical daughters, making parent and offspring indistinguishable and, in a sense, rendering each cell perpetually young. But by working with a stalked microbe called *Caulobacter crescentus*, evolutionary biologists have now shown that these simple organisms slow down in at least one very critical life function: reproduction. Moreover, when populations of this microbe are forced to evolve, they change in much the same way as do multicellular organisms subjected to similar evolutionary pressures, reported Martin Ackermann of the University of Basel at the meeting.

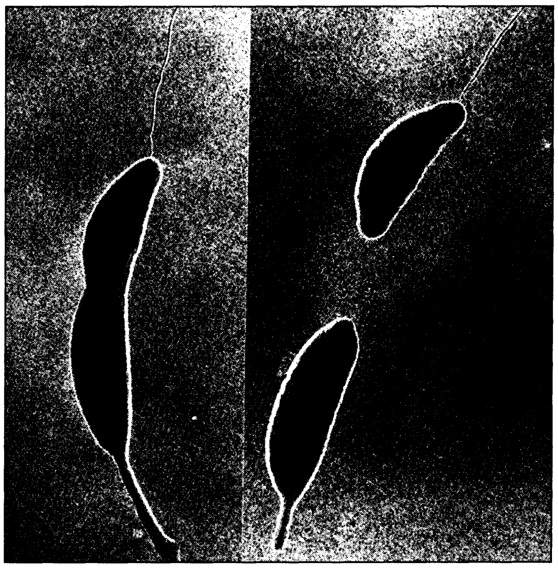
Ackermann, a Ph.D. student in evolutionary biology, studies how reproductive activity, age of maturity, and life-span respond to altered environmental conditions. Working with his adviser, Steve Stearns, he first looked at the effect of high and low mortality rates on the timing of those traits in fruit flies. Then 2 years ago, Basel microbiologist Urs Jenal introduced Ackermann to *C. crescentus*. Most bacteria reproduce by dividing symmetrically, making it impossible to know which is the "older" or parent cell. In contrast, *C. crescentus* puts down roots, then that sessile "parent" buds off new, mobile cells. Moreover, the simple microbe is a far more appealing candidate than the complex fruit fly for studying the genetics of life history traits, says Ackermann.

It took a while to figure out how to study individual *C. crescentus* microbes, however. Eventually, Ackermann came up with a special microscopy chamber, a modified microscope slide containing a small channel. Ackermann inoculates the channel with lots of *C. crescentus*, 20 to 100 of which grow a stalk and take up residence in the channel. Then he keeps a constant flow of media through the channel to remove newly budded progeny. In this way, he and his colleagues can monitor aging in the stationary cells. "The system is awesome," comments Bruce Levin, an evolutionary biologist at Emory University in Atlanta. "It gives us a first chance of looking at senescence in bacterial populations"—work that may later be applicable to understanding aging in stem cells.

The bacteria take about 3 hours to build their stalks and bud off their first swarmer cells. Thereafter, budding takes about 2 hours and is repeated over and over, Ackermann reported. He did four experiments with this chamber, following each cell through more than 100 reproductive cycles. In each, he found that reproduction slowed as the cells got older. "The old cells have a large variability in cell cycle length," says Ackermann, with some taking 50% longer and some failing to reproduce at all.

His colleagues are quite impressed. "He's demonstrated senescence in the simplest, most stripped-down form," comments Marc Tatar, an evolutionary biologist at Brown University in Providence, Rhode Island. Even though it lacks mitochondria or meiosis in its life cycle—two putative contributors to aging—*C. crescentus* still loses its functionality over time. Says David Reznick, an evolutionary biologist at the University of California, Riverside: "Aging may be a more fundamental feature of how organisms work than people thought."

Ackermann has also begun experimental evolution studies on *C. crescentus*. In one, he subjected populations to high mortality rates for more than 2500 generations, effectively cutting short the lives of many individual microbes. In theory, organisms with shortened life expectancies should evolve



Golden hours. As this stalked microbe (left) ages, it takes longer to bud off progeny (right).

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