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.

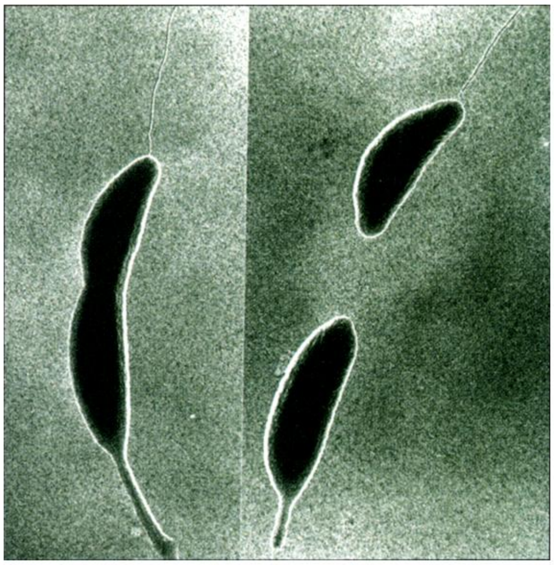
Ackermann, a Ph.D. student in evolutionary biology, studies how reproductive activity, age of maturity, and life-span respond to altered environmental conditions. Working with his adviser, Steve Stearns, he first looked at the effect of high and low mortality rates on the timing of those traits in fruit 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).

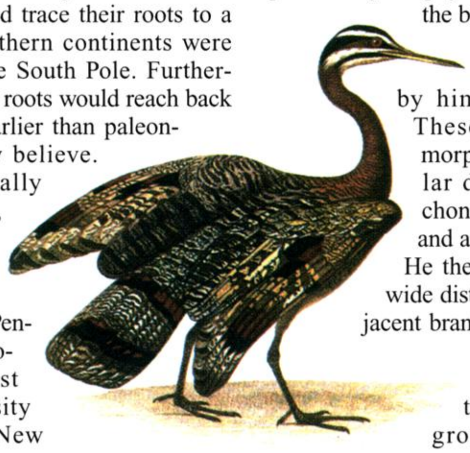
CREDIT: J. MADDOCK/UNIVERSITY OF MICHIGAN faster maturation times, so they reproduce as much as possible before they die. And Ackermann believes that's exactly what's happened in the three lines of *C. crescentus* he is evaluating in this experiment. By the 500th generation, the populations' doubling time had decreased by an average of 34%. A close look revealed that the stalked microbes start to bud off new cells sooner, and the organism was spending less time in the swarmer cell stage.

Eventually, Ackermann wants to track down the genes underlying these changes. And with the genome sequence of this organism already in hand (*Science*, 3 March, p. 1572) and the powerful molecular biology techniques available for bacteria, "I think he's going to come up with tremendous insights into senescence," Tatar notes.

Southern Origins for Modern Birds

As the bitter debate about the connection between birds and dinosaurs continues to roil the paleontology community, feathers are about to fly over another aspect of avian evolution: when and where modern birds first took wing. At the evolution meeting, Joel Cracraft of the American Museum of Natural History in New York City introduced his latest genetic evidence—again, challenging conventional wisdom—that modern birds arose in the Southern Hemisphere.

If he's right, then many birds common throughout the world trace their roots to a time when the southern continents were amassed around the South Pole. Furthermore, some of those roots would reach back millions of years earlier than paleontologists generally believe. "Joel now has really good sequence data, and that is really shifting everything back [in time]," says David Penny, a theoretical evolutionary biologist at Massey University in Palmerston, New Zealand.



Not-so-distant relatives. Although separated by many thousands of kilometers, the South American sunbittern *(above)* and New Caledonia's kagu *(top right)* are close kin.

CREDITS: (TOP TO BOTTOM) PROC. ZOOL. SOC. LONDON, 1862, PLATE 30; CUVIER, *LE REGNE ANIMAL DISTRIBUE D'APRES SON ORGANISATION* (PARIS, 1836–49)

Until recently, most biologists thought that birds diversified into their many modern forms in the past 60 million years. Scant fossils exist from earlier eras, suggesting to paleontologists that few modern birds existed prior to the mass extinction that occurred at the Cretaceous-Tertiary (K-T) boundary 65 million years ago. And because most post–K-T fossils are found in the Northern Hemisphere, these researchers assumed that modern birds arose in the giant continent called Laurasia, which included what is today North America, Europe, Asia, Greenland, and Iceland.

Cracraft is something of an iconclast. In the 1970s, he first suggested that at least one group of flightless birds had a southern heritage, an idea that only gradually gained acceptance. Now, after more than 2 decades of gathering data, he asserts that heritage "is even more pervasive than we thought." He thinks most bird lineages got their start on the great southern continent called Gondwanaland, which encompassed what is now Antarctica, South America, Australia, Africa, and India.

Support for Cracraft's hypothesis comes from several fronts. For one, over the past 5 years, research combining fossil records with genetic and mitochondrial DNA data has indicated that some bird lineages date back to before the K-T boundary. In 1996, for example, Penny and Alan Cooper of Oxford University concluded that 22 of the 42 types of birds they studied had such early origins. Those 22 represent about half the orders of modern birds.

Another line of evidence comes from the branching pattern of the avian family tree, particularly the phylogenetic relationships at the base of this tree. Cracraft has analyzed phylogenies developed both by himself and by others. These trees are based on morphological and molecular data, including mitochondrial DNA and protein and amino acid comparisons. He then looked at the worldwide distribution of birds on adjacent branches of these trees. His conclusion: To explain the current distribution of close relatives, groups of birds that are now half a world apart had to have come from what used to be a single southern continent.

This analysis indicates that Anseriformes, which include ducks and geese, and Galliformes, which encompass chickens and their relatives, are close kin from way back. The most primitive anseriforms are screamers in South America, and the most primitive duck/goose is the Australian magpie goose. Such a distribution requires that at one time, South America and Australia were linked. Similarly, the most primitive galliforms have an Australasian distribution, whereas related turkeylike birds called cracids occur in tropical America, again implying Gondwanaland origins.

Cracraft has also relied on the fossil record to bolster his case, citing finds from Madagascar (*Science*, 15 May 1998, p. 1048) suggesting that a number of other organisms in that country have relatives in both India and South America. This distribution suggests that these land masses were linked longer than many geophysicists suspect. As India broke away from Antarctica, Cracraft speculates, the Kerguelen Plateau formed a land bridge between them that lasted until 80 million years ago. Such a bridge could explain how the flightless elephant bird wound up in Madagascar, even though it's not that closely related to flightless birds elsewhere in Africa.

There were other ancient land connections as well. Between 80 million and 40 million years ago, the Norfolk Ridge stretched between what is now New Zealand and New Caledonia. Its existence may explain why the closest relatives of an extinct flightless bird from New Caledonia called the kagu are in New Zealand. And another close cousin of the kagu, the sunbittern, is in tropical America, perhaps because South America stayed connected to western Antarctica until about 35 million years ago.

"As we get more of those [avian] relationships worked out, more [examples] will reveal themselves," Cracraft predicts. Even though the data are not in yet, he posits a Gondwanaland ancestry for hummingbirds and swifts, pigeons, penguins, and owls. Cracraft stresses that these conclusions don't go against the widely held assumption that much of bird diversity arose after the K-T extinction event. But some arose earlier, he believes.

Although Penny finds Cracraft's hypothesis about Gondwanaland plausible, he expects it to be controversial, especially among paleontologists. Nor is Cracraft sure what reception these ideas will get. He'll find out this week, when he presents his Gondwanaland hypothesis at an international ornithology meeting. He expects quite a few bird biologists there won't hesitate to let him know what they think.

–ELIZABETH PENNISI