Puzzling Over the Origin of Species In the Depths of the Oldest Lakes

The creatures in Baikal and other ancient lakes could help researchers unravel fundamental mysteries about why some life forms speciate and others do not

After 3 days of sorting through numbingly cold mud from the bottom of Lake Baikal in southern Siberia, Oleg Timoshkin was growing restless. Timoshkin, a biologist at the Limnological Institute in nearby Irkutsk, and his fellow scientists on this most venerable of lakes on a warm July afternoon had yet to find anything interesting.

Then at about 3 o'clock, the scientists aboard the *Vereschagin*, a vessel named after one of the first Russian biologists to study the lake, hit the jackpot. The next slug of mud winched to the surface was teeming with densely packed white mollusks, pink amphipod crustaceans, and writhing flatworms. Timoshkin, a flatworm expert, rushed some of the brownish goo to the ship's lab and placed it under a dissecting microscope. A few painstaking hours later, he tweezed from the muck a tiny, translucent worm with a yellowish-green stomach—a kind of specimen that he had never seen before in more than 2 decades of work. Timoshkin later confirmed that the mystery beast was a new deep-water subspecies, *Geocentrophora wagini abyssalis*, one of roughly 140 types of Baikal flatworms that exist nowhere else in the world.

Welcome to a freshwater horn of plenty, where scientists have racked up an average of 20 new species a year over the past decade while probing the oldest and deepest lake on Earth. The diversity of life forms in Baikal and other ancient lakes makes them "unique crucibles of evolution," says Lisa Park, a paleolimnologist at the University of Akron, Ohio. The Speciation in Ancient Lakes group, which includes several dozen specialists from around the world, met last autumn in Irkutsk to mull over the forces that shape these biological hotspots. Researchers unveiled fresh findings on the genetics of ancient lake species that are helping to unravel why some creatures are prone to speciation and others are not.

Hard to fathom. The breathtaking abundance of amphipods deepens the intrigue over the forces driving speciation in Lake Baikal. A continent away, interbreeding among Lake Victoria's cichlids (*right*) is blurring species distinctions.

CREDITS: (LEFT) OLEG TIMOSHKIN; (RIGHT) OLE SEEHAUSEN/UNIVERSITY OF HULL

Forced to speciate

Baikal is one of a dozen present-day lakes that have persisted for at least 1 million years; most lakes clock out at about 18,000 years. And Baikal's biological diversity—more than 2500 identified faunal species, primarily invertebrates that are nearly all unique to this body of water—is unsurpassed, says Risto Väinölä of the Finnish Museum of Natural History in Helsinki. "We are seeing diversity that you would expect over a continental scale, taking place within a single lake," he says. Illustrating that point at the meeting, Väinölä described new molecular data on amphipods, colorful, voracious scavengers that in Baikal can grow to a world-record length of 9 centimeters. Some of the lake's 350 amphipod species that look alike and live in the same sections of lakebed are in fact genetically divergent, Väinölä has found. The finding, he says, implies that there may be three times as many amphipod species in Baikal as are currently enumerated.

That only deepens the intrigue over the complex set of forces behind Baikal's startling diversity. One obvious factor is the lake's longevity: An estimated 20 million to 25 million years have passed since its primordial waters first began to pool in the rift formed when the central part of the Eurasian landmass began to separate from the smaller southern plates. In contrast, "most lakes are by nature suicidal," mere water holes that accumulate sediments, turn into swamps, and become land, says evolutionary biologist Koen Martens of the Royal Belgian Institute of Natural Sciences in Brussels. Baikal has accrued a thick sediment layer that offers a window on ancient climates (see sidebar), but it is its depth—1637 meters at the deepest point—that is the lake's fountain of youth. That Baikal straddles a rift also helps prolong its life: Its lakebed is sinking by about 20 millimeters a year, roughly equivalent to its sediment buildup. The next two oldest and deepest lakes, Africa's Tanganyika at 9 million to 12 million years old and Malawi at roughly 3 million years old, are situated in rifts as well.

The peculiar geology of rifts—in particular, Baikal's patchwork of substrates—appears to influence speciation. For example, in the amphipod genus *Plesiogammarus*, six closely related species have staked out different turfs. *P. zeinkowiczii*, with its big eyes and long antennae, lives atop coarse, freshly laid sediment, whereas *P. brevis*, with its slitlike eyes and short antennae, burrows several centimeters into a siltier layer. Its cousins in between, not surprisingly, have eyes and antennae that are medium sized. As an animal adapts to a substrate type, it may lose the ability to breed with cousins on other substrates, even in close proximity, says evolutionary biologist Ellinor Michel of the Institute for Biodiversity and Ecosystem Dynamics in Amsterdam. Thus, Baikal may offer a clutch of rare examples of sympatric speciation, in which species can arise from an ecological specialization, rather than a physical barrier to gene flow.

Driven to speciate

Also attracted to Baikal's biological bonanza are researchers probing the genetic underpinnings of speciation. In collaboration with Evgeny Sverdlov of the Institute of Molecular Genetics in Moscow, a team led by molecular biologist Dmitry Sherbakov of the Limnological Institute is using a novel approach to hunt for rapidly evolving DNA regions in Baikal species with relatively small genomes, including the omul fish and the amphipods. The researchers combine the DNA of two closely related species and isolate stretches that do not stick together. These leftover regions are the ones that have diverged. "By finding the genes that evolved fastest, we can identify those responsible for adaptation to environmental variables such as depth and cold," explains Sherbakov, who described their findings at the meeting. For instance, some species of amphipods have an armor coat that appears to have evolved in parallel many times. The genes that encode armor may be among those that have evolved the fastest, he says.

Other ancient lakes may also contribute to this effort to tease out the genetic triggers of speciation. There are more than 1400 species of cichlid fish in three African lakes—Malawi, Tanganyika, and Victoria—representing the biggest radiation of any animal genus within a geographic region. Cichlids give scientists an "evolutionary playing field" on which to test hypotheses, says Axel Meyer of the University of Konstanz, Germany. Meyer, an evolutionary biologist, is homing in on quickly evolving DNA regions in the cichlids from Lake Tanganyika. He's looking for genes that encode differences in traits such as head shape and body color. Perceiving color is critical to cichlids: Females choose mates according to the color pattern of the males, which varies by species. So far, Meyer has found that a gene known to cause color loss in some mammals varies among cichlid species.

Color vision drives cichlid speciation, and a loss of ability to discern color patterns appears to be accelerating the demise of species in Africa's Lake Victoria, says Ole Seehausen, an evolutionary ecologist at the University of Hull, U.K. Today, there are roughly half of the 600 to 800 species that were present just 50 years ago. Many have fallen prey to Nile perch, which was introduced into the lake in the early 1950s. But for decades, Victoria's waters have grown steadily murkier, in part due to algal blooms linked to the loss of cichlids.

Because the cichlids have evolved so recently, species are still capable of interbreeding and producing viable offspring. In clearer waters in Victoria, species stick to their ecological niches and generally steer clear of one another, mating according to color pattern, Seehausen explains. But the murky waters have now made female cichlids blind to love. As a result, mating between species is now rampant, further reducing the lake's already crippled cichlid diversity (*Science*, 19 September 1997, p. 1808). Victoria and other ancient lakes "are poised to suffer a great loss" of biological diversity, says George Coulter, an African lakes specialist now retired in New Zealand. Conservation work, he says, must go hand in hand with research.

Further insights into the mechanisms of speciation could be gleaned from more comparative work across the ancient lakes, scientists say. For example, Park of the University of Akron and Elizabeth Gierlowski-Kordesch of Ohio University in Athens are collecting data on animal life from 35 present-day and now-dry fossil lakes with life spans exceeding 100,000 years. Their efforts so far suggest that the total number of species in ancient lakes may have been underestimated by as much as 50%, Park says. They hope to unveil their database before the next ancient lakes jamboree, set for 2006 in Berlin.

There should be plenty more findings to reveal then as well. Like its other long-lived brethren, Baikal and the secrets it may reveal about how species arise have scientists coming back, year after year, to its enchanted waters.

–Erica Goldman

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A relative cinch. Unlike ocean setups, which require a sophisticated platform to keep steady in pitching waves, Baikal's roughly 7 months of ice cover each year provided a stable drilling platform.

A Window on Ancient Siberia

For decades, scientists have been mining the ocean floor for clues to past climates found in gases and fossils locked in the sediments. But it wasn't until 1989 that Douglas Williams, a geologist at the University of South Carolina (USC), Columbia, was able to mount an effort to extract such a record from a continent's interior. With Mikhail Kuzmin of the Institute of Geochemistry in Irkutsk, Russia, Williams set out to reconstruct Siberia's past from the muck at the bottom of Lake Baikal.

Perhaps the most provocative insights have come from studying the minuscule remains of diatoms whose silicon skeletons have accumulated in the sediment over the eons. Severe cooling can drive these single-celled algae to local extinction, whereas warming nurtures reappearance and diversification. These biological proxies for climate change have revealed that during some periods when ocean cores showed milder cooling over the past 8 million years, Baikal was in the throes of glaciation.

Past climate changes can also be inferred from the ratio of carbon isotopes in the sediments. Methane hydrates, found for the first time in fresh water in Baikal in 1997, are frozen, cagelike arrangements of methane and water. They contain a preponderance of carbon-12, which leaves a distinct signature in the composition of plankton and sediments. When the climate warms, methane is unlocked and released into the lake and eventually the atmo sphere. "It is somewhat like opening a Coke can," says USC geologist Alexander Prokopenko. Thus a deficit of methane hydrates in the cores indicates regional warming.

Although the Baikal Drilling Project ended 4 years ago, its findings on everything from ancient temperature regimes to the rise and fall of diatom species are still cascading into the literature. The project has also provided the impetus for drilling at other ancient lakes: The International Continental Scientific Drilling Program, a nine-nation consortium, will sponsor an expedition next year to Lake Malawi to retrieve the first ancient sediments from the continental tropics that, researchers hope, will contain a fossil timeline of evolution in this African ancient lake.

–E.G.