Life got bigger in two, million-fold leaps, scientists say

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(PhysOrg.com) -- Extremes are exciting. Does anyone really think dinosaurs would capture our imagination the way they do if they hadn't been so huge? You don't see natural history museums vying for fossil skeletons of prehistoric rodents. It's the Tyrannosaurus rex fossils they salivate and squabble over. And would the Hollywood glitterati cart around those little teacup pups if they weren't so dang tiny and cute? Not likely.

Earth's creatures come in all sizes, yet they (and we) all sprang from the same single-celled organisms that first populated the planet. So how on Earth did life go from bacteria to the blue whale?

"It happened primarily in two great leaps, and each time, the maximum size of life jumped up by a factor of about a million," said Jonathan Payne, assistant professor of geological and environmental science at Stanford.

Payne, along with a dozen other paleontologists and ecologists at 10 different research institutions, pooled their existing databases, combed the scientific literature and consulted with taxonomic experts in a quest to determine the maximum size of life over all of geological time.

That might sound like a rather large undertaking, but, fortunately, the quest was made easier because even the professionals have a fascination with the size of the fossilized.

"The nice thing about maximum size is that people tend to remark on very large fossils, so they are much easier to track down in the geologic literature than anything else," Payne said.

In addition to quantifying the enormity of the two leaps in maximum size, the researchers also pinned down when those leaps took place. Both leaps coincided with periods when there was a major increase in the amount of oxygen in the atmosphere.

Payne said that many researchers already recognized, in a qualitative way, that the change in maximum size had occurred this way. "But our study really reflects the first time that anybody has tried to quantify exactly how stepwise it was and how big those size jumps were," he said.

A paper detailing the research by Payne and his colleagues is scheduled to be published in the Dec. 22, 2008, online early edition of the *Proceedings of the National Academy of Sciences* and is available online through EurekAlert.

The two other principal investigators of the research group, funded through the National Evolutionary Synthesis Center, are Michal Kowalewski of Virginia Tech and Jennifer Stempien of the University of Colorado-Boulder.

So how did it all happen? The first fossilized bacterial cells date to approximately 3.4 billion years ago, although life likely originated several hundred million years before. Between 2.7 and 2.4 billion years ago, cyanobacteria, formerly known as blue-green algae, originated and were of particular evolutionary and geological importance because they excrete oxygen as a waste product during photosynthesis. So far as science can tell, they were the first and only organisms to evolve oxygen-producing photosynthesis.

"All of the oxygen in the atmosphere ultimately exists because of the evolution of cyanobacteria," Payne said. "Plants that produce oxygen today during photosynthesis, their ability to do that is ultimately derived from cyanobacteria."

Single-celled bacteria remained the largest life form on Earth, cranking out the oxygen, until about 1.6 billion years ago. At that point, a new life form shows up in the fossil record.

"The first jump in maximum size happens when the first eukaryotic organisms show up as fossils," Payne said. "And those fossils are approximately a million times bigger than anything that had come before on Earth."

Although the first fossil eukaryotes were likely also single-celled organisms, the eukaryotes distinguish themselves by means of their internal structure and functioning. Instead of having the cellular processes of life take place by means of diffusion in the cell, eukaryotes have organized innards, with a nucleus and other cellular structures that are dedicated to specific functions in the respiratory process.

"The fossil record indicates pretty clearly that you need a eukaryotic cell to make that first size jump," Payne said. "It isn't just that the bacteria don't get there as fast, it is that bacteria still haven't gotten there 1.6 billion years later.

"Clearly, organismal organization matters," Payne said. "Not just at the time the size increase happens, but it continues to be a limitation on size.

For approximately the next billion years, life on Earth stayed about the same size, with only modest increases. Then about 600 million years ago, at the same time as another major boost in the amount of oxygen in the atmosphere, life leaped in size again.

This time, it was a million-fold size leap of multi-cellularity. Payne said there are clearly multi-cellular eukaryotes in the fossil record for several million years before this size leap, but the real explosion of size increase didn't happen until the oxygen level bumped up.

So why do the size leaps seem to hinge on the amount of oxygen in the air?

"There are a few things that could be going on," Payne said. "The first thing is that eukaryotic cells require oxygen for metabolism. So if they want to take organic matter and burn it up to have energy in their cell, they need oxygen. That sets the first and probably most important limitation."

Payne said this limitation also applies to multi-cellular eukaryotes, which likewise depend on extracting oxygen from the surrounding environment and using that in their cells to obtain energy. "There is also evidence that oxygen may mediate some other biochemical processes," he said.

As for just what triggered both the boosts in atmospheric oxygen, Payne said that isn't quite as clear. It may be that the first jump in oxygen came because cyanobacteria simply proliferated to the point that they were cranking out more oxygen than could be consumed through chemical reactions with material at Earth's surface, the only way that oxygen wouldn't have been released back into the atmosphere in the era before oxygen breathing creatures existed.

The possible causes of the second jump in oxygen are less clear, Payne said, but regardless of the puzzles that remain to be sorted out, the timing and magnitude of the jumps up in maximum size are clear. And Payne said the size jumps applied to a vast number of species.

"Whatever is controlling this second size increase appears to operate across many different groups. It is not something limiting one group alone," he said. "There also appears to be an increase even in the maximum size of groups of organisms like multi-cellular algae, so the size increase doesn't appear to be limited just to animals."

One other question remains to be answered: Can we look forward to another great leap in size? Will we see housecats larger than our houses?

"We've speculated on that a little bit, just sort of thinking about what if you went up another step," Payne said.

"The next level of organization, going along this kind of theme, presumably would be something like insect societies, where you have individual multicellular eukaryotes that specialize in terms of what kind of function they carry out in a larger organization of these individuals. Something like an ant colony or a human society would be in some ways the next organizational level.

"But, if you look at human society as an example, we use so much of the gross primary productivity on Earth, it doesn't appear there would be room for a lot of species at that next level of organization and maximum size. At that point you're actually getting towards the physical size limits just imposed by the size of our planet."

Provided by Stanford University

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