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Even the oldest eukaryote fossils show dazzling diversity and complexity

The sun has just set on a quiet mudflat in Australia's Northern Territory; it'll set again in another 19 hours. A young moon looms large over the desolate landscape. No animals scurry in the waning light. No leaves rustle in the breeze. No lichens encrust the exposed rock. The only hint of life is some scum in a few puddles and ponds. And among it lives a diverse microbial community of our ancient ancestors.

In a new account of exquisitely preserved microfossils, researchers at UC Santa Barbara and McGill University revealed that eukaryotic organisms had already evolved into a diverse array of forms even 1.64 billion years ago. The paper, published in the journal [Papers in Paleontology](#), recounts an assemblage of eukaryotic fossils from an era early in the group's evolutionary history. The authors describe four new taxa, as well as evidence of several advanced characteristics already present in these early eukaryotes.

"These are among the oldest eukaryotes that have ever been discovered," explained lead author [Leigh Anne Riedman](#), an assistant researcher in UCSB's Department of Earth Science. "Yet, even in these first records we're seeing a lot of diversity."

Eukarya forms one of the major domains of life, encompassing the plant, animal and fungi clades, as well as all other groups whose cells have a membrane-bound nucleus, like protists and seaweeds. Many scientists had thought early eukaryotes were all fairly similar during the late Paleoproterozoic, and that diversification took place around 800 million years ago. But Riedman and her co-authors found fossils of a delightfully diverse, and complex, cast of characters in rock nearly twice as old.

Scientists knew from previous studies that eukaryotes had evolved by this time, but their diversity in this era was poorly understood. So Riedman headed to the Outback in late 2019. Within one week, she had collected about 430 samples from eight cores drilled by a prospecting company; they now reside in the library of the Northern Territory Geological Survey. The two cores used for this study spanned roughly 500 meters of stratigraphy, or 133 million years, with around 15 million years of significant deposition.

Riedman returned to the United States with shale and mudstone: remnants of an ancient coastal ecosystem that alternated between shallow, subtidal mudflats and coastal lagoons. A dip in hydrofluoric acid dissolved the matrix rock, concentrating the precious microfossils which she then analyzed under the microscope.

“We were hoping to find species with interesting and different characteristics to their cell walls,” Riedman said. She hoped that these features could shed light on what was happening within the cells during this time period. Reaching any conclusions about the cellular interior would require a great deal of sleuthing, though, since the fossils preserve only the exterior of the cells.

The researchers were surprised by the diversity and complexity preserved in these fossils. They recorded 26 taxa, including 10 previously undescribed species. The team found indirect evidence of cytoskeletons, as well as platy structures that suggest the presence of internal vesicles in which the plates were formed — perhaps ancestral to Golgi bodies, present in modern eukaryotic cells. Other microbes had cell walls made of bound fibers, similarly suggestive of the presence of a complex cytoskeleton.

The authors also found cells with a tiny trapdoor, evidence of a degree of sophistication. Some microbes can form a cyst to wait out unfavorable environmental conditions. In order to emerge, they need to be able to etch an

opening in their protective shell. Making this door is a specialized process. “If you’re going to produce an enzyme that dissolves your cell wall, you need to be really careful about how you use that enzyme,” Riedman said. “So in one of the earliest records of eukaryotes, we’re seeing some pretty impressive levels of complexity.”

Many people in the field had thought this ability emerged later, and the evidence for it in this assemblage further emphasizes how diverse and advanced eukaryotes were even at this early juncture. “The assumption has always been that this is around the time that eukaryotes appeared. And now we think that people just haven’t explored older rocks,” said co-author [Susannah Porter](#), an Earth science professor at UC Santa Barbara.

This paper is part of a larger project investigating early eukaryote evolution. Riedman and Porter want to know in what environments early eukaryotes were diversifying, why they were there, when they migrated to other places, and what adaptations they needed in order to fill those new niches.

A big part of this effort involves understanding when different characteristics of eukaryotes first arose. For instance, the authors are quite interested to learn whether these organisms were adapted to oxygenated or anoxic environments. The former would suggest that they had an aerobic metabolism, and possibly mitochondria. Every modern eukaryote that’s been found descends from ancestors that possessed mitochondria. This suggests that eukaryotes acquired the organelle very early on, and that it provided a significant advantage.

Riedman and Porter are currently working on a fresh account of eukaryote diversity through time. They’ve also collected even older samples from Western Australia and Minnesota. Meanwhile, their geochemist collaborators at McGill are spearheading a study on oxygen levels and preferred eukaryote habitats, aspects that could shed light on their evolution.

“These results are a directive to go look for older material, older eukaryotes, because this is clearly not the beginning of eukaryotes on Earth,” Riedman said.

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