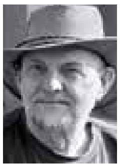
Eukaryotes of



Prof. Józef Kaźmierczak has retired from the Laboratory of Environmental Paleobiology of the PAS Institute of Paleobiology. He focuses on early evolution of living systems, the coevolution of life and the planet Earth, and astrobiology.

jkaz@twarda.pan.pl

Dr. Barbara Kremer works at the Laboratory of Environmental Paleobiology. Her research focuses on the role of microorganisms in the evolution of the biosphere and rock-forming processes.

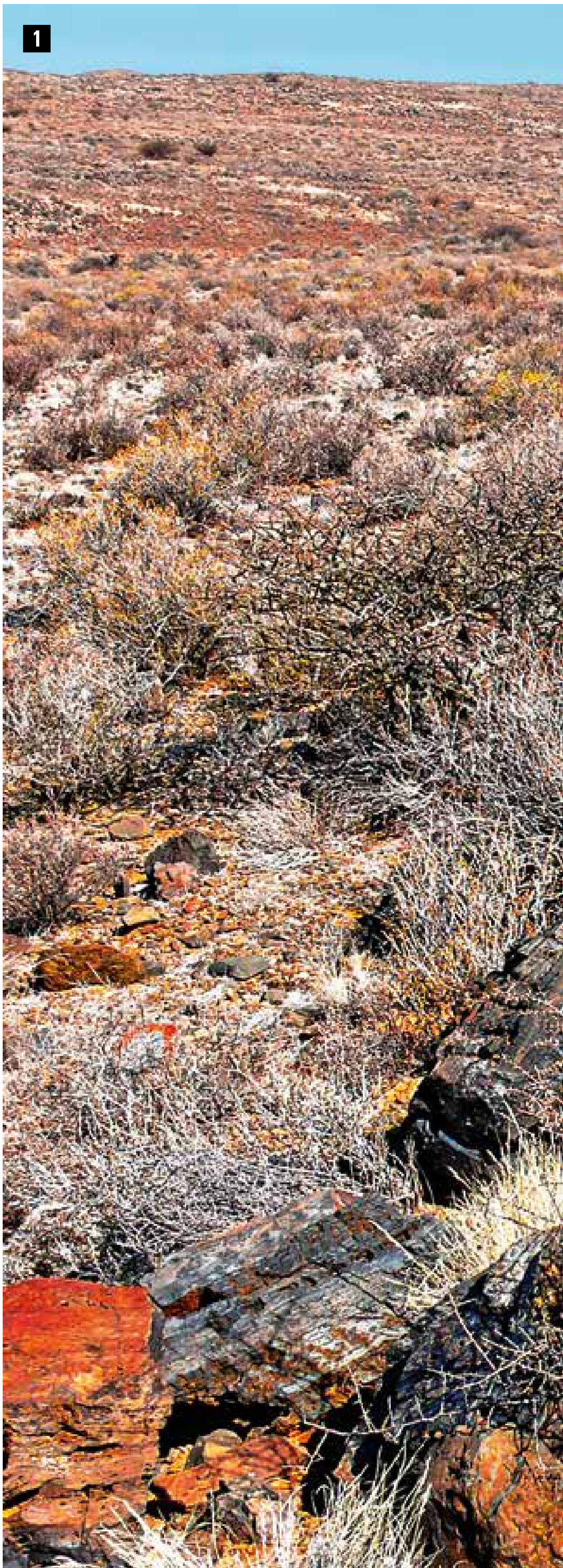
kremer@twarda.pan.pl

When and where did life first appear on Earth? Humankind has been pondering this question for centuries. The discovery of ancient microalgae is providing a partial answer.

Prof. Józef Kaźmierczak
Dr. Barbara Kremer

Institute of Paleobiology, Polish Academy of Sciences, Warsaw

In recent years, the research efforts of many scientific institutions have turned to explaining the origins of life and early stages of evolution, both in the theoretical and experimental sense. Part of this surging interest in biogenesis and early development of living systems stems from NASA's international Astrobiology Roadmap program – particularly as regards establishing guidelines for searching for life on Mars, whether long extinct or current. If we make the logical assumption that the formation of Earth and Mars followed a similar path, at least in the early stages, we can expect to make significant progress by searching for traces of life preserved in our planet's oldest rock formations. For experts preparing and su-

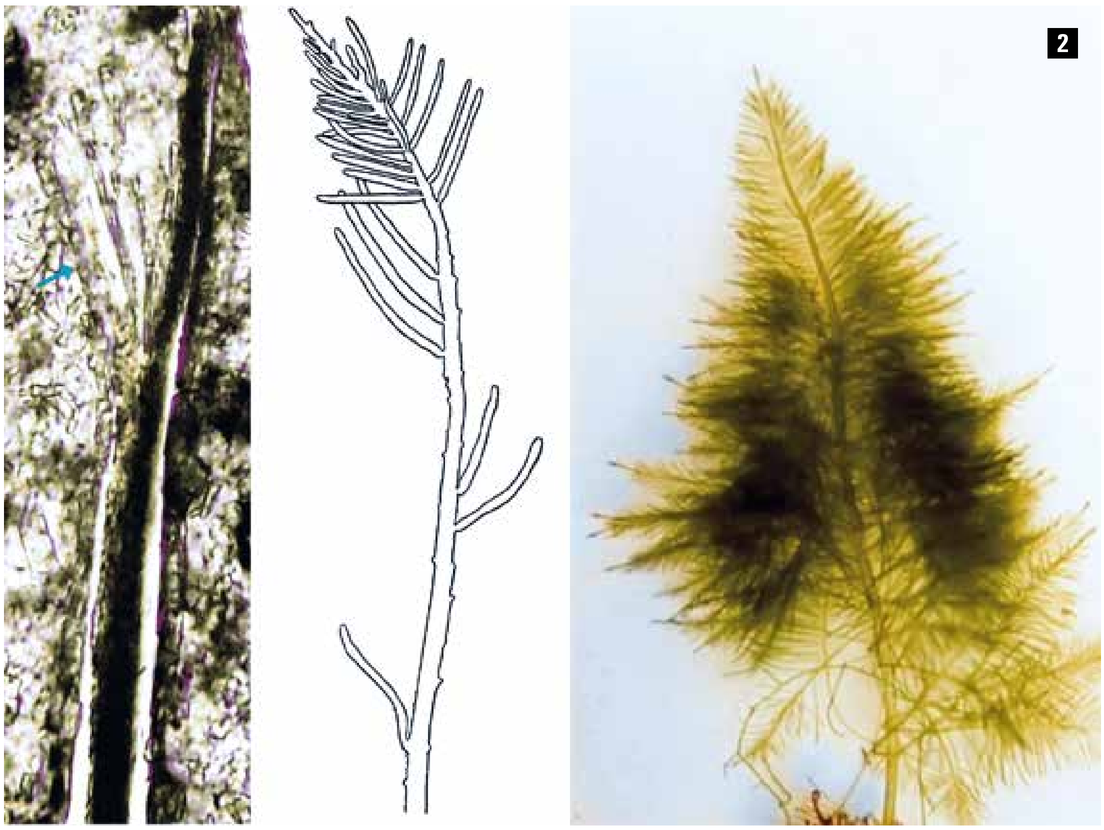


AUTHORS' ARCHIVES

THE EARLIEST EUKARYOTIC FORMS OF LIFE

THE ARCHEAN

Fig. 1
Stromatolites from South Africa, dating back between 2.7–2.8 billion years; they contain the remains of the earliest eukaryotic life forms



AUTHORS' ARCHIVES (3)

Fig. 2
Branched top part of the thallus of siphonous microalgae from the Neoarchean of South Africa (left) and analogous microalgae living today (right).

Fig. 3
Eukaryotic life forms dating back almost 2.8 billion years (Neoarchean, South Africa): fragments of mineralized thalli of siphonous microalgae.

Fig. 4
Chemically macerated fragments of siphonous microalgae thalli with likely reproductive structures, originating from Archean lake stromatolites of South Africa (right).

pervising Mars missions, they provide important clues for selecting landing sites and operational routes for landers and rovers.

Individually and in colonies

Archean geological formations date back to the first two billion years of Earth's existence. This makes them highly interesting to paleobiologists, even though they are poorly preserved and difficult to systematize, and they rarely contain biological objects. Rock formations dating back to the earliest period of the evolution of life are preserved today. They can be found on the planet's surface in just a few locations, including Greenland, Australia and South Africa. Paleobiological study of the Archean has turned up very few fossilized biomorphic objects interpreted as residues of microbes, generally compared to present day cyanobacteria – phototrophic microorganisms lacking a nucleus (prokaryotes).

When life first formed on Earth around 3.7 billion years ago, it existed as individual cells which went on to form colonies and microbial mats. Although individual cells are rarely preserved in rock, microbial mats (in particular formed by cyanobacteria) could be mineralized to form stromatolites which survive until the present day, providing us with evidence of when life first appeared on Earth. However, the question whether eukaryotes (life forms whose cells contain nuclei) existed during the Archean remains unanswered.

Ongoing research

Eukaryotes are certainly one of the greatest evolutionary inventions in the history of life on Earth. Although we don't know exactly when they first appeared, scientists are attempting to learn this using molecular methods known as molecular clocks. They indicate that eukaryotes first developed no earlier than around two billion years ago.

However, the situation looks somewhat different from the perspective of the paleontological record. The earliest known reliable eukaryotic remains originate from sediment dating back between 1.8–1.6 billion years. Recognizing eukaryotes in Archean fossils is very difficult and controversial, since the only criterion at our disposal is morphology. Even though the majority of unicellular eukaryotes are larger than bacteria, some are about the same size as large prokaryotic cells. The cell walls of the majority of unicellular algae have no distinguishing structures. Additionally Archean fossils have undergone diagenesis – they have been exposed to extremely high temperatures and pressures for vast periods of time, which has a detrimental effect on delicate organic matter. Fortunately this is not discouraging scientists from searching for the earliest traces of life.

GLOSSARY

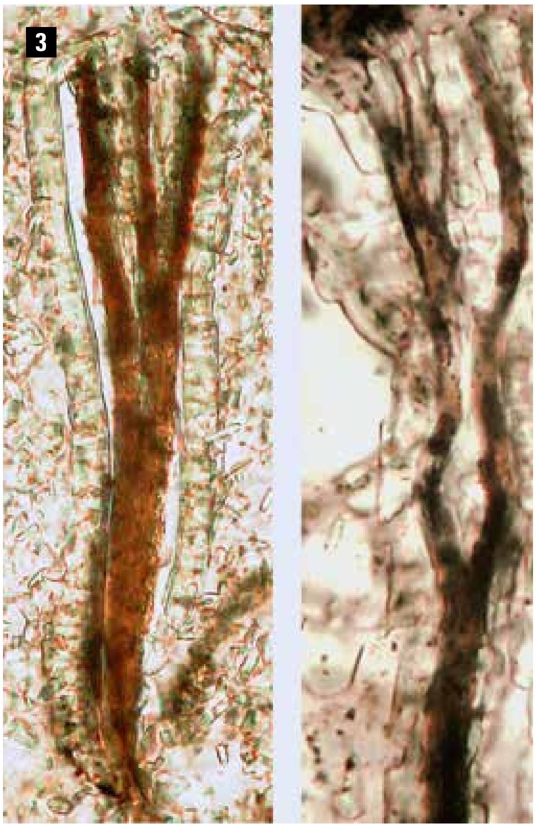
Cyanobacteria)
– phototrophic microorganisms whose cells do not have nuclei (prokaryotes)

Stromatolites
– layered sedimentary structures formed by microbial mats, usually cyanobacteria

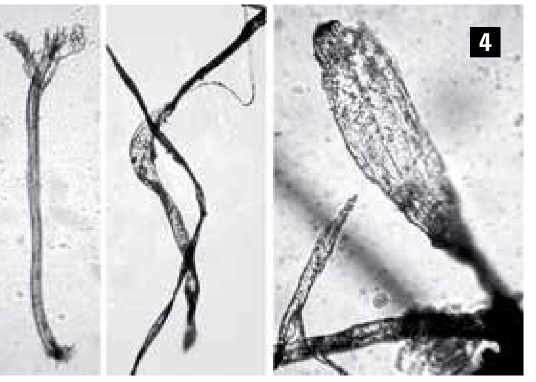
Prokaryotic cells
– cells which don't contain nuclei; found only as unicellular organisms

Eukaryotic cells – cells which contain nuclei; basic functional structural units of all multicellular organisms; also found as unicellular organisms (e.g. protozoa and certain algae)

3



4



The discovery of the remains of the earliest eukaryotes in fossils originating from inland lakes undermines the existing view that life originally formed in the sea, and only later expanded to other environments.

Documenting discoveries

Our project, financed as part of the scientific collaboration between Poland and South Africa and a grant from the National Science Centre (NCN), uses detailed mineralogical, geochemical and nanoscopic analysis to identify the first morphologically preserved eukaryotic microfossils from the Archean. They were discovered through our collaboration with Prof. Władysław Altermann (Pretoria University) in lake stromatolites of the Neoarchean in South Africa (Sodium Group, Ventersdorp Supergroup) dating back around 2.7 million years. They are sparsely branched non-segmented mineral tubes with a diameter between 30 and 70 micrometers and length of a few hundred micrometers; their interiors frequently preserve traces of a carbonaceous substance, likely a residue of degraded cytoplasm. The objects are mineralized with silica and aluminosilicates, with very little organic matter. Bubble-like structures occasionally protrude from the tube walls, reminiscent of the gametangia of certain algae. In anatomical terms, the microfossils are comparable with present day and fossil siphonous chlorophyte microalgae from the Ulvales or Vaucheriales order. This significant morphological similarity between Archean microalgae from South Africa and present-day siphonous algae confirms the view held by evolutionary biologists who see them as precursors of the development of our planet's vegetation.

Inland-lake beginnings?

The discovery of such early eukaryotes is a scientific sensation on a global scale. It pushes the previously documented time of the first appearance of eukaryotes in the fossil record back over a billion years, and means that it is necessary to make a major correction in the calibration of existing phylogenetic biomolecular scales (molecular clocks) and redefine current models of the functioning and evolution of Earth's early biosphere. Our discovery is also significant in devising programs searching for life on other planets. Highly mineralized thalli of microalgae are also evidence of a very early development of biomineralization processes on primal Earth. Since all algae are aerobic organisms – producing oxygen and requiring it for metabolic processes – their presence in the late Archean means we need to revise our current view that the atmosphere at the time contained extremely low levels of oxygen. Additionally, the lake environment of our microalgae indicates the existence of inland bodies of water supporting mineralization in hydrochemical terms. The discovery of the remains of the earliest eukaryotes in fossils originating from inland lakes undermines the existing view that life originally formed in the sea and only expanded to other environments later.

Józef Kaźmierczak, Barbara Kremer

Further reading:

Kaźmierczak J., Kremer B., Altermann W., Franchi I. (2016). Tubular microfossils from 2.8- 2.7 Ga-old lacustrine deposits of South Africa: A sign for early origin of eukaryotes? *Precambrian Res. 286*, 180–194.

Knoll A.H., Javaux E.J., Hewitt D., Cohen P. (2006). Eukaryotic organisms in Proterozoic oceans. *Phil. Trans. R. Soc. B 361*, 1023–1038.

Knoll A.H., Bergmann K.D., Strauss JV. (2016). Life: the first two billion years. *Phil. Trans. R. Soc. B 371: 20150493*.