



Press Release

How oxygen enriched the Earth's atmosphere 2.5 billion years ago

University of Tübingen researchers investigate how O₂-producing cyanobacteria survived toxic iron compounds to flourish and multiply

Christfried Dornis
Director

Janna Eberhardt
Research reporter

Phone +49 7071 29-77853
janna.eberhardt[at]uni-tuebingen.de

presse[at]uni-tuebingen.de
www.uni-tuebingen.de/aktuell

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Cyanobacteria as they still exist today were the first organisms to carry out photosynthesis and release oxygen. Produced in primeval oceans around 2.5 billion years ago, this oxygen accumulated in the Earth's atmosphere on an immense scale. A research team led by University of Tübingen geomicrobiologist Professor Andreas Kappler has used laboratory experiments to investigate how this process was even possible, given that the iron dissolved in ocean water strongly inhibited the growth of cyanobacteria. The researchers discovered that silicate, which is also present in ocean water, played a key role, as did the daily cycle of light and darkness. The study has been published in the journal *Nature Communications*.

Oxygen was a troublesome waste product for cyanobacteria. As it accumulated, evolution responded, until today, oxygen is indispensable for most known life forms. "The early oceans contained a lot of dissolved iron, which reacts with oxygen to form highly reactive oxygen radicals. These reactive oxygen species, as they are called, are toxic to bacteria," explains Andreas Kappler. Until now, it was therefore assumed that oxygen radicals strongly inhibited the release of oxygen by cyanobacteria and that free oxygen only entered the atmosphere several million years after the emergence of cyanobacteria. "However, this assumption also raised the question of how cyanobacteria could survive under such conditions," says the study's first author, Kappler group doctoral student Carolin Dreher.

The role of silicate

To better understand the living conditions of cyanobacteria in primeval oceans, the research team studied the growth of *Synechococcus* cyanobacteria in the laboratory at different concentrations of dissolved iron and silica. Silica is dissolved silicon, which was also present in large

quantities in the waters of the primordial oceans. “We know this from the world's largest iron deposits today, the banded iron formations found on several continents. There, both elements, iron and silicon, were deposited alternately in layers,” Kappler says.

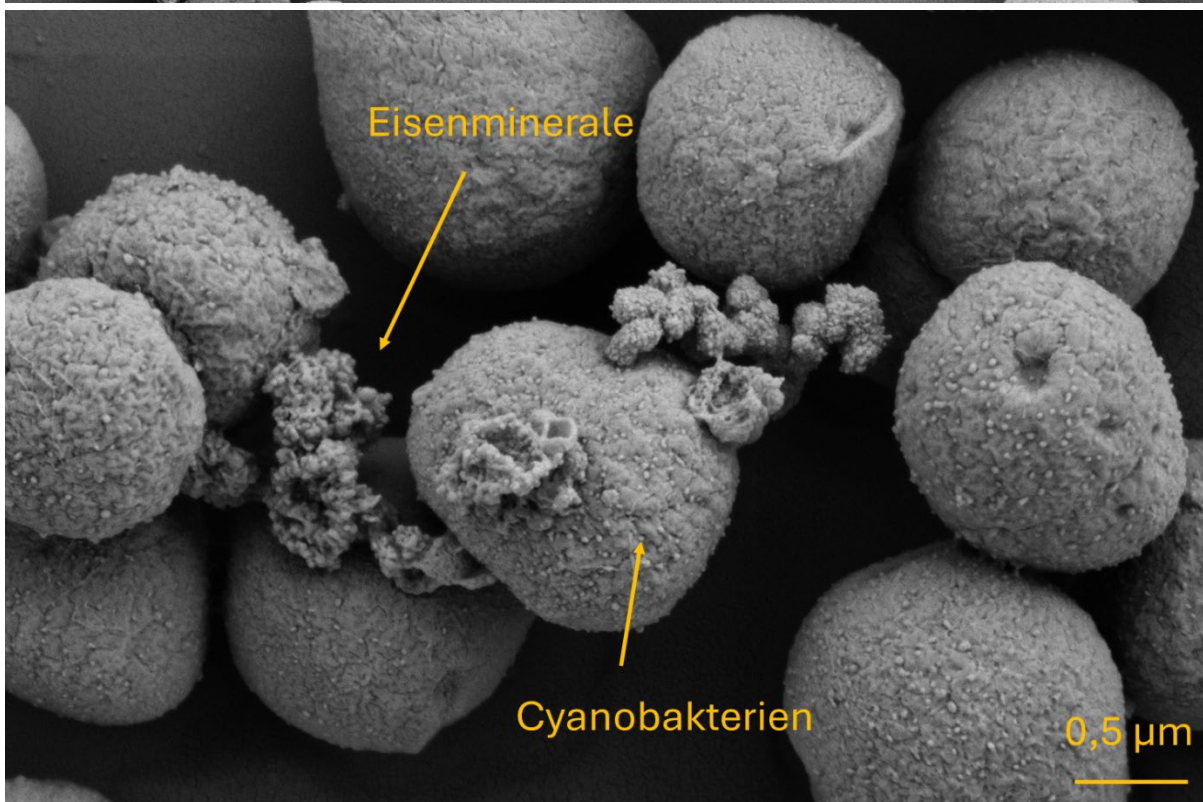
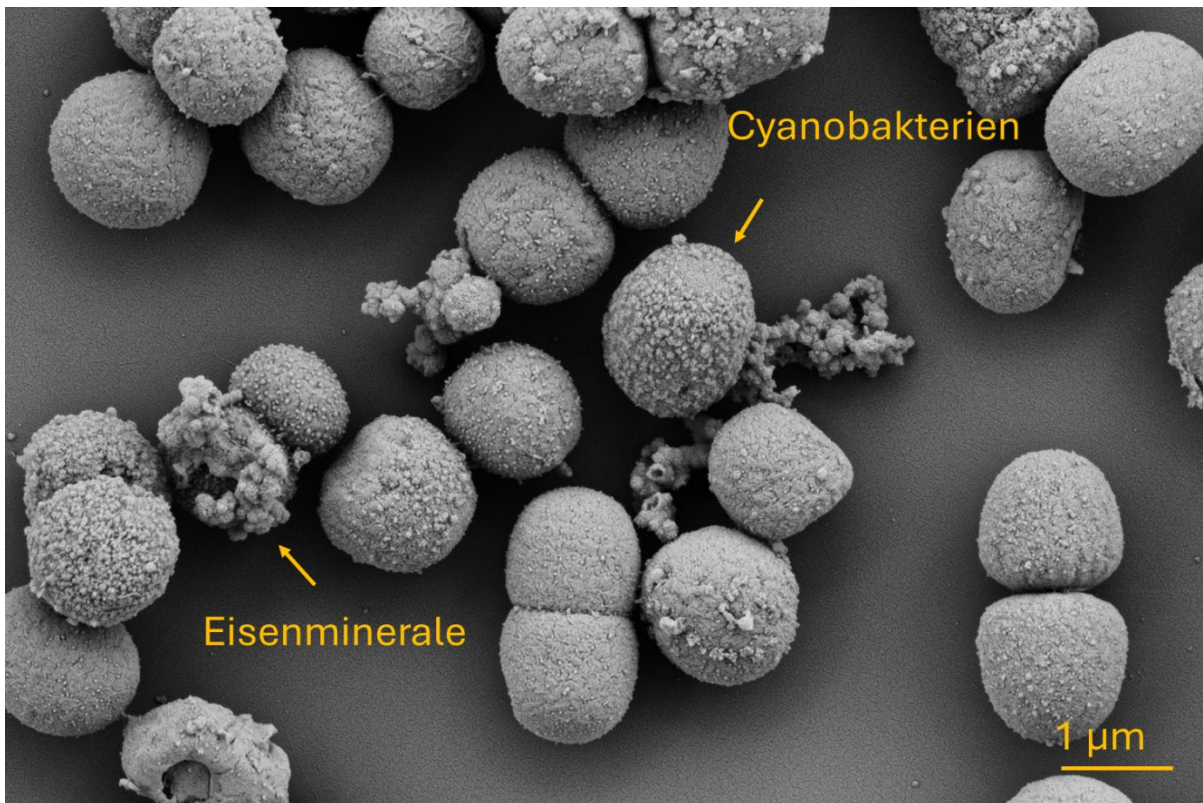
In the experiment, high iron concentrations increased the formation of reactive oxygen compounds and inhibited the growth of microorganisms. “However, when amounts of silicate realistic for the oceans at that time were also present in the experiments, the formation of these toxic compounds decreased significantly,” according to Carolin Dreher. Under these conditions, the cyanobacteria were able to grow and continue to produce oxygen. “High silicate concentrations apparently acted as a chemical protective mechanism that reduced the formation of harmful oxygen compounds, thus enabling the growth of cyanobacteria despite high iron concentrations,” she explains.

The effects of the diurnal switch between light and dark

Furthermore, the researchers found that the alternating phases of day and night also played an important role in oxygen enrichment. “Previous research had used continuous lighting. We found that the formation of harmful oxygen compounds was further reduced in our experiments under a daily light cycle,” reports Dreher. The researchers' computational models based on the experimental data showed that under such conditions, oxygen-rich zones could have formed in the near-surface areas of the oceans at that time.

“Our findings suggest that the chemical conditions in the iron-rich oceans of the early Earth were less of an obstacle to the spread of cyanobacteria than previously thought,” says Kappler. “This could have played a decisive role in enabling these microorganisms to produce enough oxygen over the long term to bring about a lasting change in the composition of the Earth's atmosphere.”

“This study provides fascinating new insights into the long-term development of the Earth's atmosphere, showing that many factors must be considered,” says Professor Karla Pollmann, President of the University of Tübingen.



Scanning electron microscope images of the spherical cyanobacteria *Synechococcus* sp. PCC7002 and the precipitated iron minerals. Images: Carolin Dreher, Jeremiah Shuster



Laboratory bottles after 31 days of testing: Both bottles contain the same amount of iron. On the left, the bottle containing silicate shows a dense growth of green cyanobacteria, covering the orange iron minerals. On the right, the bottle not containing silicate shows an orange precipitation of iron minerals and less dense growth of green cyanobacteria. Photo: Carolin Dreher



Banded iron ores near Tom Price, Western Australia: View of a mine on the southern edge of the formation. Photo: Mark Barley



Banded iron deposits at Gamohaam Hill near Kuruman, Northern Cape Province, South Africa. The lower image shows a close-up of the upper rock formation.
Photos: Andreas Kappler



Sample of banded iron ore from the Hamersley Group, Western Australia.
Photo: Jan-Peter Duda

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Contact:

Professor Dr. Andreas Kappler
University of Tübingen
Geo- and Environmental Science – Geomicrobiology
Phone +49 7071 29-74992
[andreas.kappler\[at\]uni-tuebingen.de](mailto:andreas.kappler@uni-tuebingen.de)