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How microbes influenced the Earth's atmosphere three billion years ago

For a long time, climate researchers could not explain the high concentration of greenhouse gases in the Earth's atmosphere around three billion years ago. Now an international research team with the participation of Hendrik Vogel from the Institute of Geological Sciences and Oeschger Centre for Climate Change Research at the University of Bern has solved the mystery. Sediment analyses revealed the surprising result that under the conditions at that time, microbes mainly produced the highly effective greenhouse gas methane for their metabolism.

Three billion years ago, the Earth looked very different than today: the oceans were nearly free of oxygen and the sediments on the ocean floor were rich in iron minerals. The early Sun was much dimmer than today and yet the oceans contained liquid water requiring that Earth was not frozen. This is the 'faint young sun paradox' originally recognized by astronomers Carl Sagan and George Mullen decades ago. There must, therefore, have been high concentrations of greenhouse gases in the atmosphere, but the nature and source of these gases remains a mystery, to this day. Now, measurements of the sediments from Indonesian Lake Towuti provide new clues. At its bottom, conditions in Lake Towuti are similar to those in the oceans three billion years ago. Under the lead of Jens Kallmeyer of the German Research Centre for Geosciences (GFZ) in Potsdam, Sean Crowe from the University of British Columbia in Canada, and Cynthia Henny from the Indonesian Institute of Sciences (LIPI) a research team from fourteen institutions and a total of five countries was able to show that, contrary to conventional models, microbes in Lake Towuti's sediments produce abundant methane—a potent greenhouse gas. On the early Earth, this methane would have accumulated in the atmosphere providing the greenhouse effect needed to warm Earth's surface under the dim early Sun. The study was published today in the journal Nature Communications.

In the middle of the island of Sulawesi lies Lake Towuti, Indonesia's second largest lake with an area of 560 square kilometres and depths of up to 200 metres. The lake has a very special chemistry that is rare on Earth today. In its deepest parts, below 130 metres water depth, it is free of (dissolved) oxygen and rich in dissolved iron. In addition, iron minerals, especially iron oxides account for more than one third of its bottom sediment.

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The puzzle of greenhouse gases three billion years ago

The conditions in Lake Towuti and its sediments are thus very similar to those in the oceans around three billion years ago, which also had sediments comprised of abundant iron minerals. The most iron-rich of these sediments, Banded Iron Formations (BIFs), represent important iron ore deposits. Free oxygen, as we and many microorganisms breathe today, was scarce, both in the oceans and the atmosphere.

Since the sun was weaker than it is today, temperatures on the early Earth could have been much lower. The fact that the oceans were liquid, however, indicates that there must have been high concentrations of greenhouse gases, like carbon dioxide and methane, in the atmosphere to warm Earth's surface under the dim sun. The nature and source of these greenhouse gases remains an unresolved mystery.

Time travel through measurements in Lake Towuti

Doctoral candidates Andre Friese (GFZ), and Kohen Bauer (UBC), now help resolve this mystery by measuring sediments in Lake Towuti. These measurements allow them to travel back in time, so to speak, to study the conditions and processes that prevailed in primeval times. This includes the metabolism of organic material, i.e. its transformation into inorganic substances, which plays an important role in the global carbon cycle and climate regulation.

A specialized drilling platform provided the researchers a vehicle for their journey through time: As part of a drilling project of the International Continental Scientific Drilling Programme ICDP, spearheaded by James Russell (Brown University), Satria Bijaksana (Institut Teknologi Bandung), Hendrik Vogel (University of Bern, Institute of Geological Sciences & Oeschger Centre for Climate Change Research), and Martin Melles (University of Cologne), they have extracted more than a kilometre of sediment through drilling in Lake Towuti. The researchers were on site for two months in 2015, during which time they collected, preserved, and partially analysed the recovered sediment cores. Sediment samples were then shipped out to laboratories of the participating research groups for a wide array of state-of-the-art analyses. These included both mineralogical and microbiological analyses to study microbial iron and methane metabolisms and this information was used in numerical models that helped interpret the results.

Surprising microbial processes

In this way, the researchers were able to analyse and quantify the microbially controlled processes in the sediment of Lake Towuti – with surprising results. Since iron oxides are available in abundance in the sediment, it had been assumed that the microbes would mainly use these minerals – since oxygen was absent - for their metabolism. In the process, this microbial metabolism essentially produces carbon dioxide from sediment organic matter. In fact, Friese and Bauer and their colleagues found that the iron oxides were not metabolized and instead of producing carbon dioxide, the microorganisms mainly produced methane. Why they spurn the iron oxides is not yet completely understood.

“Microorganisms readily metabolize iron oxide minerals in laboratory studies and these studies form the basis of our knowledge for such metabolism on the early Earth” says primary author Kohen Bauer. “Our real-world findings from Lake Towuti now force us to reconsider microbial metabolism in sediments and, by extension, the processes that helped regulate Earth's early climate.”

Projection into prehistory

Since methane is a considerably more potent greenhouse gas than carbon dioxide, this - projected to three billion years ago - is likely to have had an appreciable impact on the composition of the Earth's atmosphere. Whereas the methane in today's Lake Towuti rises from the sediment and is rapidly converted into carbon dioxide through reaction with the oxygen dissolved in Lake Towuti's surface waters, this oxygen dependent reaction pathway did not exist in prehistoric times. Given that three billion years ago there was little free oxygen in the oceans and atmosphere, the methane produced in the oceans would escape to the atmosphere unhindered where it would contribute to a strong greenhouse effect.

"Our results from Lake Towuti challenge current knowledge of microbial processes in iron-rich environments. Some of our findings suggest processes quite different to what we had expected. Understanding these processes in the modern can therefore help to propose mechanisms that determined atmospheric composition three billion years ago," says Hendrik Vogel. "Lake Towuti is a fascinating biogeochemical model system that allows us to get insight into processes that may have persisted in the early Earth oceans. The geologist therefore expects further exciting findings from Lake Towuti in the coming years.

Source: German Research Centre for Geosciences (GFZ)

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Oeschger Centre for Climate Change Research

The Oeschger Centre for Climate Change Research (OCCR) is one of the strategic centers of the University of Bern. It brings together researchers from 14 institutes and four faculties. The OCCR conducts interdisciplinary research right on the frontline of climate change research. The Oeschger Centre was founded in 2007 and bears the name of Hans Oeschger (1927-1998), a pioneer of modern climate research, who worked in Bern.

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Captions

Fig. 1:

BU_en: Drilling barge on Lake Towuti Indonesia
Drilling barge on Lake Towuti, Indonesia's second largest lake. Below a water depth of 130 m, conditions are equivalent to those in the oceans three billion years ago.

Fig. 2:

BU_en: Drilling barge on the shore of Lake Towuti
Drilling barge of the International Continental Scientific Drilling Programme ICDP on the shore of Indonesia's Lake Towuti. It is being assembled on site, from its transport containers.

Fig. 3:

BU_en: Lake Towuti in Indonesia
Lake Towuti is the second largest lake in Indonesia. Below a water depth of 130 m, conditions are equivalent to those in the oceans three billion years ago.