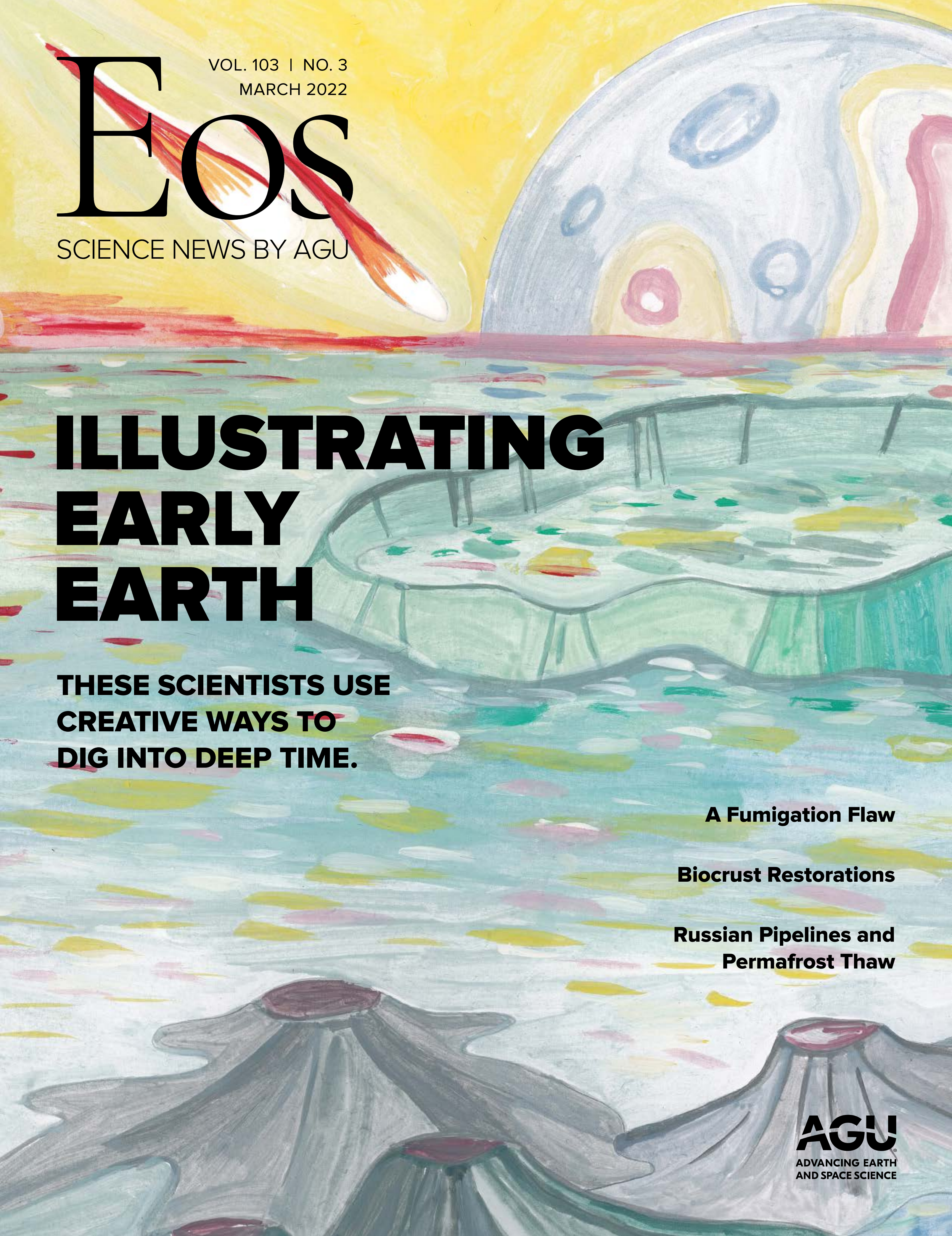
VOL. 103 | NO. 3
MARCH 2022

Eos

SCIENCE NEWS BY AGU



ILLUSTRATING EARLY EARTH

THESE SCIENTISTS USE CREATIVE WAYS TO DIG INTO DEEP TIME.

A Fumigation Flaw

Biocrust Restorations

Russian Pipelines and Permafrost Thaw

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ADVANCING EARTH AND SPACE SCIENCE

How Much Did the Moon Heat Young Earth?

A young Moon looms over Earth in this artist's rendering. Credit: Dan Durda

The Moon used to orbit Earth 10–15 times closer than it does today. Orbiting even closer than geosynchronous satellites, our only natural satellite exerted a strong gravitational pull on our planet, deformed it, and heated its interior.

A recent study published in *Paläontologische Zeitschrift* suggested that considerable tidal heating was generated for about a hundred million years after the formation of the Moon (bit.ly/tidal-heating). The heat could have directly increased the surface temperature of early Earth by several degrees. Indirectly, the process may have further heated the surface by triggering global volcanic activity and thus enriched the atmosphere with greenhouse gases.

Never-Ending Dance of a Planet and Its Moon

About 4.5 billion years ago, a Mars-sized body likely collided with Earth. The collision propelled molten debris into orbit around Earth, and over time the wreckage coalesced into the Moon. Although scientists have largely accepted the giant impact theory of lunar origin, debates about the timing of the impact and the mechanisms that led to the formation of the Moon are ongoing. What is clear is that the Moon formed much closer to Earth than it is now, and it has been drifting away ever since.

Paradoxically, the Moon and Earth are growing apart due to gravity. The Moon's gravity exerts a stronger pull on the part of Earth that faces it (as opposed to the antipodes), stretching the planet into a slightly oblong, bulged shape. These tidal forces are the primary cause of tides on Earth. That would be the end of the story were it not for the fact that Earth rotates on its axis faster than the Moon orbits the planet. As a result of this discrepancy, the planet puts on the brakes while the Moon speeds up in its orbit, slowly drifting away.

Tidal forces contribute to heating in Earth's interior. "The tides generate friction, and friction leads to heat," explained René Heller, a scientist at the Max Planck Institute for Solar System Research and a lecturer at the University of Göttingen in Germany.

Tidal heating is not a significant phenomenon on Earth now, but conditions were different billions of years ago. Previous works found that tidal heating was relevant for a few million years after the formation of the Moon (bit.ly/tidal-heating-history). Heller and colleagues have suggested that the period of significant heating lasted about a hundred million years.

"The energy that would have been dissipated in the Earth, according to the authors, is of the order of magnitude of the heat content of the Earth," said Tilman Spohn, a professor and executive director of the International Space Science Institute in Switzerland. Spohn was not involved in the study. "If you release it at once, you would double [Earth's] internal temperature." (Both Spohn and the researchers noted that such a release would not be sudden.)

Warming Up Early Earth

The new research contributes to one of the most famous problems in astrophysics. Tidal heating could have raised the temperature of early Earth by a few degrees and therefore played a minor but not irrelevant role in solving the so-called faint young Sun paradox. (Read more on p. 28.) Evidence has suggested that Earth harbored liquid water as far back as 4.4 billion years ago. That observation is difficult to reconcile with our understanding of the evolution of the Sun, whose energy output at the time was about 30% lower than it is today. For decades, scientists have been trying to model various atmospheric conditions that would have kept early Earth from becoming a snowball. "There are theories that try to solve the faint young Sun paradox which ignore tidal heating entirely and just focus on the Earth's atmosphere," said Heller. "The truth will need to combine all these effects."

Furthermore, tidal heating likely triggered global volcanism. We need only to look at Jupiter's moon Io to see the effect playing out in real time. Thanks to enormous tidal stresses that melt the moon's interior, Io is the most volcanically active body in the solar system. Similar volcanic activity on early Earth would have released greenhouse gases into the atmosphere.

All studies addressing the faint young Sun paradox have to contend with sparse geological records of early Earth, however. "The mineral zircon is almost the only record we have for early Earth," warned Junjie Dong, a graduate student at Harvard University who was not involved with the recent study. "The evidence for liquid water on the surface is based on isotopic records in zircons, and there are still people who dispute that interpretation."

Regardless, the researchers said the concept of tidal heating of early Earth should not be brushed aside. "I would take [the study] as a reminder or suggestion that maybe we should reconsider the early evolution of the Earth-Moon system," said Spohn. The next step would be to construct a more detailed model by considering the evolution of the Moon's orbit, tidal heating of the Moon itself, and a thorough treatment of Earth's internal structure.

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