Earth's Rock Record Could Reveal the Motions of Other Planets

Studying the layers of Earth's crust, scientists have created a "Geological Orrery" to measure planetary motions dating back hundreds of millions of years

A mural titled "The Origin of Life on Earth" at NASA Ames Research Center. The mural depicts the formation of our planet and the conditions that led to the evolution of life. (NASA Ames/David J. Des Marais/Thomas W. Scattergood/Linda L. Jahnke)

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On a planet like Earth, as the rock and the water go through cycles and changes, melting and cooling and eroding and accreting, stripped out in wide valleys and stacked up in towering mountains, the natural phenomena of the past leave traces behind in the crust of the planet. By coring out ancient ice, for example, scientists can study the trapped particles and learn about atmospheric conditions millions of years ago. By studying magnetic minerals embedded in ancient rock, geologists have learned that the magnetic field of the planet reverses poles—about once every 250,000 years on average.

Scientists can learn a great deal about Earth from the geological layers of its crust, but even more information may be hidden within the rock record. According to geologist and paleontologist Paul Olsen of Columbia University, the keys to the history of not only our planet, but also the solar system and the galaxy may be found beneath our feet.

In a study published today in the *Proceedings of the National Academy of Science*, Olsen and colleagues argue that astronomical cycles of the planets can be measured in terrestrial rock layers. Cylindrical cores of rock extracted from the ground, some stretching thousands of feet and spanning millions of years of history, may contain subtle traces of the influence of other planets' gravity, allowing scientists to infer the historical positions of planets hundreds of millions of years ago.

"This is a new world of empirical data that allows for tests of large-scale solar system theory," Olsen says. He calls his model the Geological Orrery, named after 18th century mechanical models of the solar system. The work could not only provide an independent dataset to test existing models of planetary motion, but it has also been used to reveal orbital cycles that had never been measured before. The Geological Orrery could even be used as a new tool to test some of the most fundamental theories in science, such as Einstein's general theory of relativity, the possible existence of additional planets in the ancient solar system, and even the gravitational influences of dark matter in the Milky Way, Olsen says.

Geologist Paul Olsen at Arizona's Petrified Forest National Park, where 200 million-year-old rocks are helping reveal the long-ago motions of other planets. (Kevin Krajick/Earth Institute, Columbia University)

“This paper is an attempt to solve a very difficult and perplexing problem for astronomers and geologists who are interested in the history of the solar system, and how it has affected the Earth’s system—climate, sedimentation, etcetera,” says Spencer Lucas, a geologist and paleontologist at the New Mexico Museum of Natural History and Science who was not involved in the study. “These astronomical cycles have evolved for hundreds of millions of years, and there’s a certain amount of chaos in that evolution, so it has always been a big challenge for geologists and astronomers to try to understand what happened to these cycles.”

The layers of Earth’s crust represent a record of past climates, and those climates were influenced by celestial movements called Milankovitch cycles. Named for Serbian geophysicist and astronomer Milutin Milankovitch, these cycles are the result of Earth’s gravitational interactions with other planets which influence Earth’s trajectory around the sun, including the shape of its elliptical path (eccentricity), as well as the tilt (obliquity) and wobbling (precession) of the planet's axis.

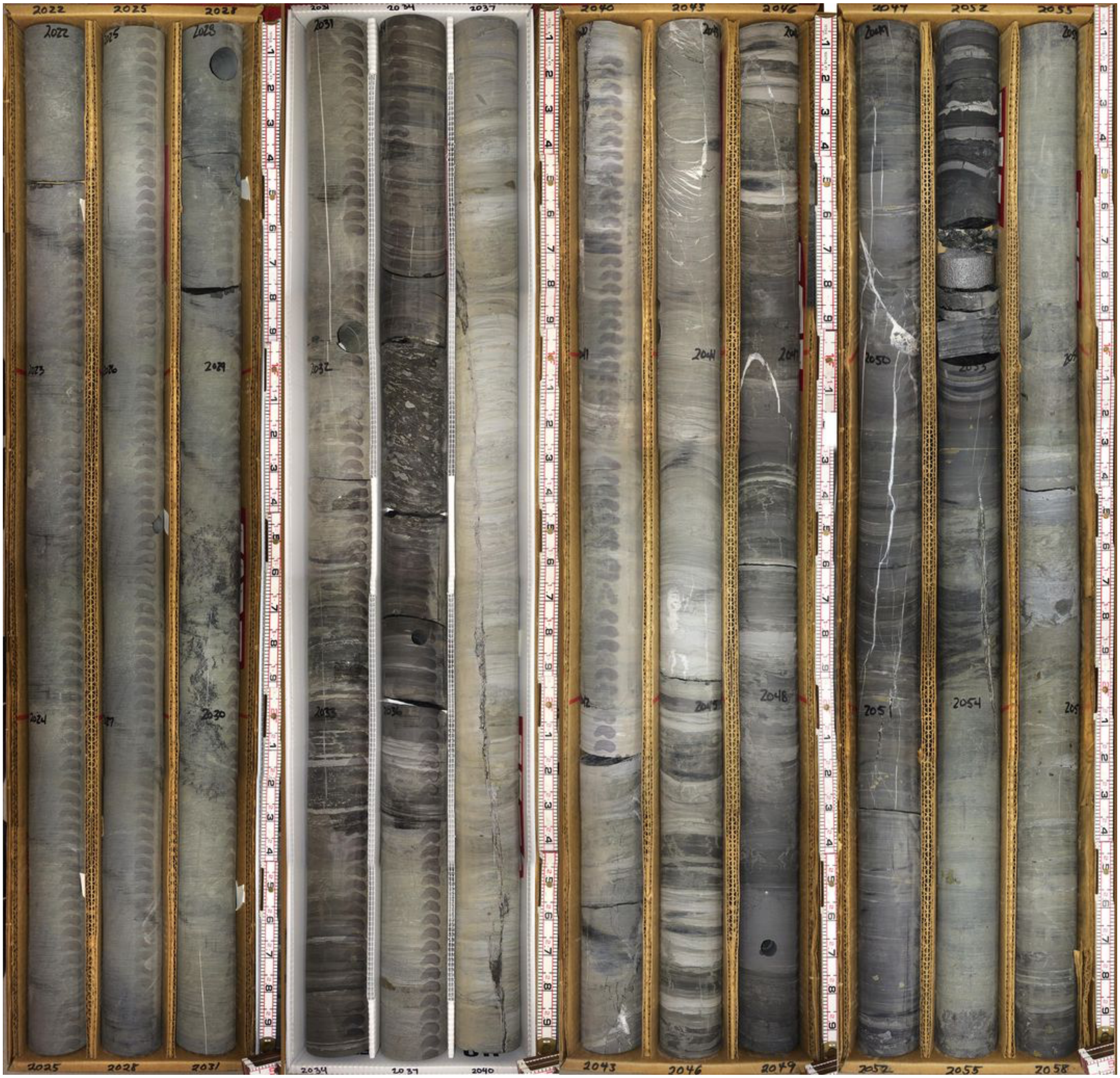
Changes to Earth's orbit affect the planet's climate, and as Olsen first argued in a [1986 paper in *Science*](), a record of past climates could therefore be used to infer the positions and motions of other planets.

But why go through the trouble and expense of digging up earthen cores to ascertain other planets' trajectories? Using the laws of orbital mechanics, scientists can create mathematical models to study the history of our little solar neighborhood in space.

Such models, however, are only reliable to a point, Olsen says. No simple mathematical equations describe the motions of more than two moving bodies in space with a high degree of certainty. With eight planets and the sun, not to mention millions of smaller bodies in the solar system, astronomers cannot develop analytical solutions to describe the exact motions of the planets in the distant past. Instead, researchers compute the former orbits of the planets one small increment at a time. According to the work of Jacques Laskar, director of research at the Paris Observatory and a coauthor of the new paper, errors accumulate at each time interval such that predictions become essentially useless beyond about 60 million years—not very long in the 4.5-billion-year history of the solar system.

Laskar's earlier computational models also provided evidence that the inner planets (Mercury, Venus, Earth and Mars) may behave chaotically. Or in other words, the positions of these four planets could be largely determined by initial conditions, making them almost impossible to predict based solely on the positions and directions seen today.

"These rock records of climate change turn out to be the key to figuring out what the solar system is actually doing," Olsen says.



Rock core of lake sediments extracted from the Newark Basin in central New Jersey spanning about 40,000 years. (Paul Olsen)

Demonstrating the viability of his Geological Orrery has been a lifelong labor of love for Olsen. In his 1986 paper, he analyzed cores from the Mesozoic Newark Supergroup—an assemblage of rocks formed about 200 to 227 million years ago—in central New Jersey. The rock contained a record of the rise and fall of lakes in sync with the magnitude of tropical monsoon rains, which fluctuate according to varying amounts of sunlight at the tropics determined by Earth’s orbit and spin axis.

“What we see in the cores are physical manifestations of the changing water depth,” Olsen says via email. “When the lake was at its deepest, maybe well over 100 meters deep, black finely laminated muds were deposited, and when it was very shallow and even seasonally dry, red muds with abundant desiccation cracks were laid down.”

Olsen used Fourier analysis—a method to represent complex waveforms in simpler sinusoidal components—to show that the cyclical changes to Earth’s climate trapped in the geological record match the Milankovitch cycles of celestial mechanics. But there was one oddity.

“One of the cycles was not tied directly to anything known at the time in orbital cycles,” Olsen says. “It was about two million years long, and I didn't know what it was.”

After receiving a National Science Foundation (NSF) grant in the 1990s to dig up and analyze nearly 22,600 feet of continuous cores from seven sites within the Newark Supergroup, Olsen and his colleagues discovered that the mysterious cycle was a long-period orbital cycle caused by the interactions between Mars and Earth. The finding “provides the first geological evidence of the chaotic behavior of the inner planets,” Olsen and Dennis Kent, a professor of geology at Rutgers University and coauthor on the new research, wrote in a 1999 paper published by the Royal Society.

To further explore these cycles in the rock record, Olsen and his team launched the Colorado Plateau Coring Project in 2013 with another NSF grant. They drilled a core more than 1,640 feet long through the Triassic section of the Chinle Formation in Arizona’s Petrified Forest National Park. The Chinle core contains volcanic ash layers with zircon minerals that can be radiometrically dated.

Installation to extract a core from the Chinle Formation in Petrified Forest National Park, Arizona. (Paul Olsen)

By matching traces of the Earth's magnetic field reversals in the Chinle Formation sample core to those in the Newark core, the researchers were able to infer the exact dates of climatic cycles caused by the gravity of other planets. Their analysis revealed a [405,000-year cycle in celestial mechanics caused by Jupiter and Venus] that has existed for 200 million years, exactly as it is today.

In their most recent paper, Olsen and his team added additional measurements to their models, using a stratigraphic color scale to study the core sample as well as well as geophysical measurements of the core hole (natural radioactivity, rock density and sonic velocity were all measured). The team also scanned the core for X-ray florescence data to carefully analyze all of the astronomical cycles visible in the Newark formation.

Regardless of which measurements were used, the same planetary influences were identified in the rock. "It's really thrilling to see these things work out when they work out. It gives you a sense of reality ... when so many improbable things work out," Olsen says. "It's really quite amazing."

Although the Geological Orrery has potentially far-reaching research implications, Olsen's bold idea has been met with some skepticism. His models attempt to account for an extraordinary number of factors in order to link the rock record to the influence of other planets on Earth's climate (a complex system in and of itself).

Lucas calls the project “a very complex house of cards that isn’t resting on a sound scientific foundation.” He says there are gaps in the Newark formation, so it is not a complete chronology of the 25-million-year period that Olsen’s group studied. (Olsen and Kent, however, used uranium-lead dating in a study last year and found the geological record in the Newark sequence is complete for the relevant timespan.) The Chinle record is incomplete as well, Lucas says, because it was deposited by rivers and the sedimentation rates are “hugely different” between two sections, which makes it difficult to use Chinle to reliably calibrate the dates in the Newark rock.

Even Charles Darwin lamented the incompleteness of the geological record, and geologists widely accept that the record contains gaps, or in scientific parlance, “unconformities.” The fundamental question is how much information can be reliably extracted from an imperfect geological record.

“A lot of geologists start from the point of view that you have to see everything before you can understand anything,” Olsen says. “My modus operandi is to push what's useful in the rock record and paleontological record as far as you can push it to get things out of history that you can't get any other way.”

A painting by Paul Olsen of an imagined view of the Earth from space looking east over New York at night with the main planets used in the Geological Orrery. From bottom to top: Jupiter, Mars (reddish), Venus and the Moon all in conjunction. (Paul Olsen)

Even with gaps in the rock record, some scientists think that Olsen is onto something. “These data that Paul Olsen have been working on for many years now are some of the best data that have ever been collected,” says [Linda Hinnov](), a geologist at George Mason University in Virginia, who was not involved in the study.

Hinnov says that the challenge now is to fill in the gap between about 50 and 200 million years ago. Currently, the geological data and astronomical models have been matched for 0 to about 50 million years ago, as well as between about 200 and 225 million years ago. To extend the Geological Orrery, the gap between these two periods "has to be filled in with data that are at least as good as the data that are presented here," Hinnov says.

Though he is skeptical of some of Olsen's team's specific findings, Lucas agrees that this type of work, connecting the rock record to the celestial bodies in the sky, is going to become critical to solving one of the biggest scientific problems today: understanding what controls Earth's climate. "We don't understand enough about the relationship between these astronomical cycles, past climates, and how the cycles have changed through time," he says. "Anything like this that contributes to our understanding of the Earth's climate system has the potential to help us better understand future climate, which is really what we're talking about predicting."

The Geological Orrery may be incomplete, and like computational models of planetary systems, it may only be accurate to a point. But among the marvels of the cosmos, we are starting to learn how the motions of celestial bodies, millions of miles away and millions of years ago, have shaped the very world we walk on.