

EARTH MOTHER



The Tree of Light: Decoding 137 and the Quantum Kabbalah

How Genesis, Hebrew Gematria, and Physics Reveal the Hidden Architecture of Reality MAY 12, 2025

A bridge between sacred text and fundamental physics

A calculation of the Fine Structure Constant $1/137$

MAY 10, 2025

An interesting finding between the fine structure constant and the Hebrew standard gematria of the first verse of Genesis 1.1, 2701.

בראשית ברא אלהים את השמים ואת הארץ

In the beginning, Elohim created the heavens and the earth.

If we take the inverse ratio of 2701, we have:

$1/2701 = 0.000370233246945575712699000370233246945575712699000...$

Can you notice a repetition of digits in this sequence?

Yes, it is the sequence 000370233246945575712699, exactly counting 24 digits. Now, if we ignore the first three zeros, we get this sequence:

370233246945575712699

Divide this by 2701, and we have an interesting relationship with the first three decimals of the inverse ratio of the fine structure constant, which is 137.

$$3702332469455757126992701=1.370726 \times 10^{17}$$

If we want to round it exactly to 137, it is:

$$3702332469455757126992701=137.072657...$$

The inverse of the fine-structure constant is approximately 137.035999177 (the current best measurement is 137.035999177(21), meaning the value is known to within 21 parts per trillion). This number is a fundamental constant in physics, used to describe the strength of the electromagnetic force.

Let's investigate to find a closer approach to this value while keeping the information from the first verse of Genesis. It is possible to do so, as the number of the Hebrew letters in this verse is 28. Just subtract its inverse ratio from the value 137.072657..., and we get a very close value of the current best measurement of 137.035999177:

$$3702332469455757126992701=137.072657...-128=137.036942...\approx 137.037$$

To me, this calculation is a breakthrough, and could well be the exact value of the fine structure constant, as it also encodes the approximate value 37 in its decimal. It hints us back to that original numerical construct, $2701 = 37 \times 73$.

The 37th word of Genesis in Hebrew is האור (ha'or), which means "the light."

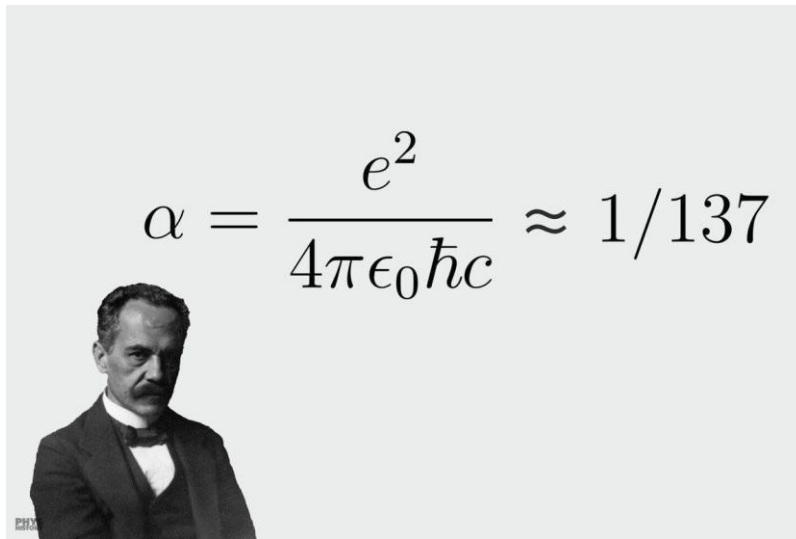
It appears in Genesis 1:4, which in Hebrew reads:

וַיִּרְא אֱלֹהִים אֶת הָאוֹר כִּי טוֹב וַיַּבְדֵּל אֱלֹהִים בֵּין הָאוֹר וּבֵין הַחֹשֶׁךְ

And Elohim saw the light, that it was good: and God divided the light from the darkness.

137 has long fascinated physicists and mystics. Even Feynman famously said:

“It has been a mystery ever since it was discovered... a magic number that comes to us with no understanding by man.”



The light (ha'or) appearing as the 37th word aligns symbolically with this. The beginning of physical reality (light) is a precisely placed threshold, much like the fine structure

constant α (1/137) defines the limit of electromagnetic precision. It governs the division (structure) of light, and Genesis describes the first act of division being that of light from darkness.

So, it would make sense that 137.037 is a more profound value that offers a symbolic bridge between sacred text and fundamental physics.

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And Elohim saw **the light**, that [it was] good: and Elohim divided the light from the darkness.

What about the 137th Hebrew word of Genesis?

The 137th word (HaAretz, הָאָרֶץ, “the earth”) falls in Genesis 1:12, which reads:

וַתוֹצֵא הָאָרֶץ דָּשָׁא עֵשֶׂב מִזְרִיעַ זֶרַע, לְמִינֵהוּ, וְעֵץ עֹשֶׂה-פְּרִי אֲשֶׁר זָרַעוּ-בּוֹ, לְמִינֵהוּ; וַיֵּרָא אֱלֹהִים, כִּי-טוֹב

And **the earth** brought forth grass, [and] herb yielding seed after his kind, and the tree yielding fruit, whose seed [was] in itself, after his kind: and Elohim saw that [it was] good.

The fine structure constant is defined as the inverse ratio of 137.037, and it links two important relevant words in Genesis:

- 037 → הָאֹר (ha'or, “the light”) — the 37th Hebrew word.
- 137 → הָאָרֶץ (HaAretz, “the earth”), the 137th Hebrew word.

The number 233, the standard gematria of עֵץ הַחַיִּים (Etz HaChayim, “Tree of Life”), appears within the 24-digit repeating decimal of $1/2701$ (370233246945575712699), and 2701 is the triangular number of 73, itself linked to חכמה (Chokmah, “Wisdom”). 137.037 encodes a symbolic fusion of הָאָרֶץ (Ha'aretz, “the earth”) and הָאֹר (Ha'or, “the light”), with the structure of עֵץ (Etz, “Tree”) acting as the conduit between the two, the Tree of Light. This evokes the image of Earth not just as matter, but as a Vessel of Light. So, 137.037 is literally “The earth the light” (הָאָרֶץ הָאֹר). The fusion (הָאָרֶץ הָאֹר) evokes powerful symbolism “earth as a vessel of light,” or “The light of the earth,” which we couldn't highlight in the current best measurement, 137.035999177(21), yet beautifully crystallised in the

rounded form 137.037. These numerical echoes trace a path between Torah, quantum physics, and the encoded structure of creation.

In Kabbalah, the Tree of Life (עץ החיים) is a diagram of divine emanations through which the Infinite reveals itself. The fine-structure constant ($\approx 1/137$) governs how light interacts with matter, essentially how energy gives rise to form, or how light branches into reality, just like a tree.

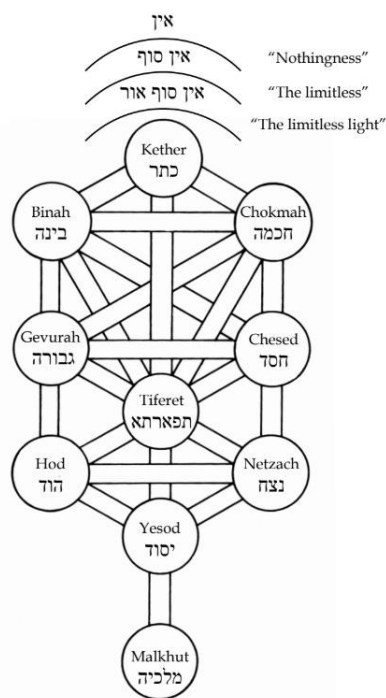
The Hebrew root of the Kabbalah is Kuf-Beit-Lamed, קבל, which is translated as “Capacitor, Condenser.” Every sub-particle of matter, human being, planet, galaxy, and anything would act as a capacitor or condenser, storing energy from the infiniteness and limitless source of light (Ein Sof Aur).

The creative energy flow is conducted through a Divine Map, the Tree of Life, known as the Kabbalah. It has ten Sephiroth, each representing a jewel of wisdom, and three other mysterious and unknown Sephiroth above Kether כתר, which means “crown,” at the top, on the head of the Tree of Life. These three are described as follows:

- The first one is called אין Ain in Hebrew, meaning “nothingness”. Undifferentiated consciousness in its purest original state, “I-less” or “ego-less.”
- The second one, below Ain, is called Ain Soph, סוף אין, “the limitless.” Differentiated Consciousness with “I,” Self-Realisation, the Monad (Point) before Emanation.
- The third aspect of the Absolute is called Ain Soph Aur, סוף אין אור, “the limitless light.” Emanating Consciousness. The fabric of consciousness as it exists during the perpetual and eternal unfolding of physical manifestation,

the first emanation of the unknown, called Χρίστος
 ‘Christos’ “Christ.”

On the usual diagram of the Kabbalah, there are ten Sephiroth, but we don’t see the three others above Kether, as they are unknown. However, they are just as important as the others, considering that the Kabbalah is completed through the Seal of Unity (13 Sephiroth in total).



From the book “The Quantum Blueprint,” Chapter
 “Introduction to Kabbalah.”

Read this previous article for
 further content on the Kabbalah

The Tree of Life metaphorically
 parallels the mechanics of
 quantum observation. In
 quantum physics, a particle
 exists in multiple states, or a
 superposition, until it is
 observed; at that point, the

wavefunction collapses into one measurable outcome. This mirrors the Kabbalistic idea of divine light flowing through the structured Tree of Life, where infinite potential is channelled into finite reality. The fine-structure constant, 137.037, defines how light interacts with matter, marking the moment energy becomes a measurable form. It is, in essence, the universal ratio that marks the transition from possibility to perception, from chaos to order, akin to branches taking shape on a cosmic tree.



The Tree of Life metaphorically parallels the mechanics of quantum observation. Generated with AI.

Now, in Hebrew morphology, most root words (שורשים / shoshim) are 3-letter trilaterals, each carrying a core meaning that is expanded by vowels, prefixes, and suffixes. There is also a rich intersection of number theory, gematria, and Hebrew linguistics. Indeed, let's explore the possibility of numeric triplets as encoded roots, just like Hebrew trilateral roots.

Looking at the repeating decimal as triplets (sets of 3 digits):

370 – 233 – 246 – 945 – 575 – 712 – 699

- The first number, 370, can be interpreted as the light האור (ha'or) 37 multiplied by 10 (the ten divine emanations or attributes through which the Divine interacts with the universe). There are other possible layers. The ordinal gematria value of חכמה (Chokmah) in Hebrew is also 37. The number 370 can also be linked to שלם (Shalam), Complete.
- The second number, 233, is עץ החיים (Etz HaChayim), the Tree of Life.
- The third number, 246, matches appropriately with להאיר (Leha'ir), "to illuminate" from Genesis 1:15.
- The fourth number, 945, can refer to התפללת (Hitpalalta), "You prayed."
- The fifth number, 545, can refer to נצתה (Natzta), "You have kindled (as in sparking a light or illumination)."
- The sixth number, 712, is well discussed in my book *The Quantum Blueprint*, particularly in a Kabbalistic context. The Hebrew word Musarot (מוסרות), the plural form of Moserah (מוסרה), which comes from the root Asar ("to bind" or "to tie," אסר), can mean "correction" or "bonds." The standard gematria of Musarot (מוסרות) is 712. The number 712 has two interesting meanings in this context. The groom corrects the emotions of the lower levels, hence "correction," and connects the two females, thereby "bonding" the mother with the daughter. There is a more profound truth about the essence and function of the two feminine aspects within the Tree of Life, and their union leads to the value of PI (π), the Key to bridging heaven and earth. This refers to our inner alchemical work. The number 712 can also refer to Tashiv (תשיב), "You will return" or "you will restore," thus speaking of returning to the Source.
- The last number, 699, close to 700, corresponds to ת (Tav, the final letter) in sofit gematria. It could be a sign of

completion, a seal, a cosmic return. In the chapter *The Sign of the Covenant* of the book "The Quantum Blueprint." The number 700 is thoroughly studied. The aggregate of the three primary colours (Red, 284; Yellow, 228; Blue, 188) is 700, which is also the sum of the gematria values of *Bereisheit* ("In the beginning," בראשית), *Elohim* (אלהים), *Hashmim* the heavens (השמים) and *Hartz* ("the earth," הארץ), using the Biblical Gematria Cipher from Genesis 1.1. These Hebrew words are in the first, third, fifth, and seventh positions in the first verse (odd numbers).

700 is also the sum of the gematria values of *Haalma* ("The virgin," העלמה), *Hara* ("Child," הרה), *Ben* ("Son," בן), and *Immanuel* (עמנואל) from Isaiah 7:14, using the Reversal Cipher.

So, combining all the Hebrew words that are potentially encoded in the decimal repetition 370233246945575712699:

370 – 233 – 246 – 945 – 575 – 712 – 699

It possibly translates to the Hebrew phrase:

שלם עץ החיים ליהאיר התפללת נצתה תשיב אצרות

1. Complete the Tree of Life so it may shine; your prayer has been kindled, and you will restore the treasures.
2. A perfect Tree of Life shall shine; your prayer is kindled like a flame, and thus you will reveal the hidden treasures.
3. Behold, the Tree of Life is made whole that it may give light; thy prayer hath been kindled, and thou shalt restore the treasures.

Earth set to change forever: a sixth ocean “on the verge of forming”

The Great Rift Valley in Africa is undergoing a process that could split the continent in two.

A geological phenomenon is occurring in the **heart of East Africa** that could **forever alter the Earth’s map**.

A **new ocean is in the process of forming**, a consequence of tectonic movements that are **splitting the African continent**. This event, which **could happen in the next five to ten million years**, will mark the creation of a sixth ocean, an unprecedented geological event in our planet’s recent history.

The formation of a sixth ocean, and the tectonic shifts that lie ahead, are proof that **Earth is a dynamic, ever-evolving planet**. Although these events occurred over millions of years, they remind us that the planet is ‘alive’, and that **in the distant future, Earth will be a very different place than we know it today**.

A Lost World Beneath the Pacific Ocean? Mysterious Structures Discovered Deep Within Earth’s Mantle

JANUARY 10, 2025

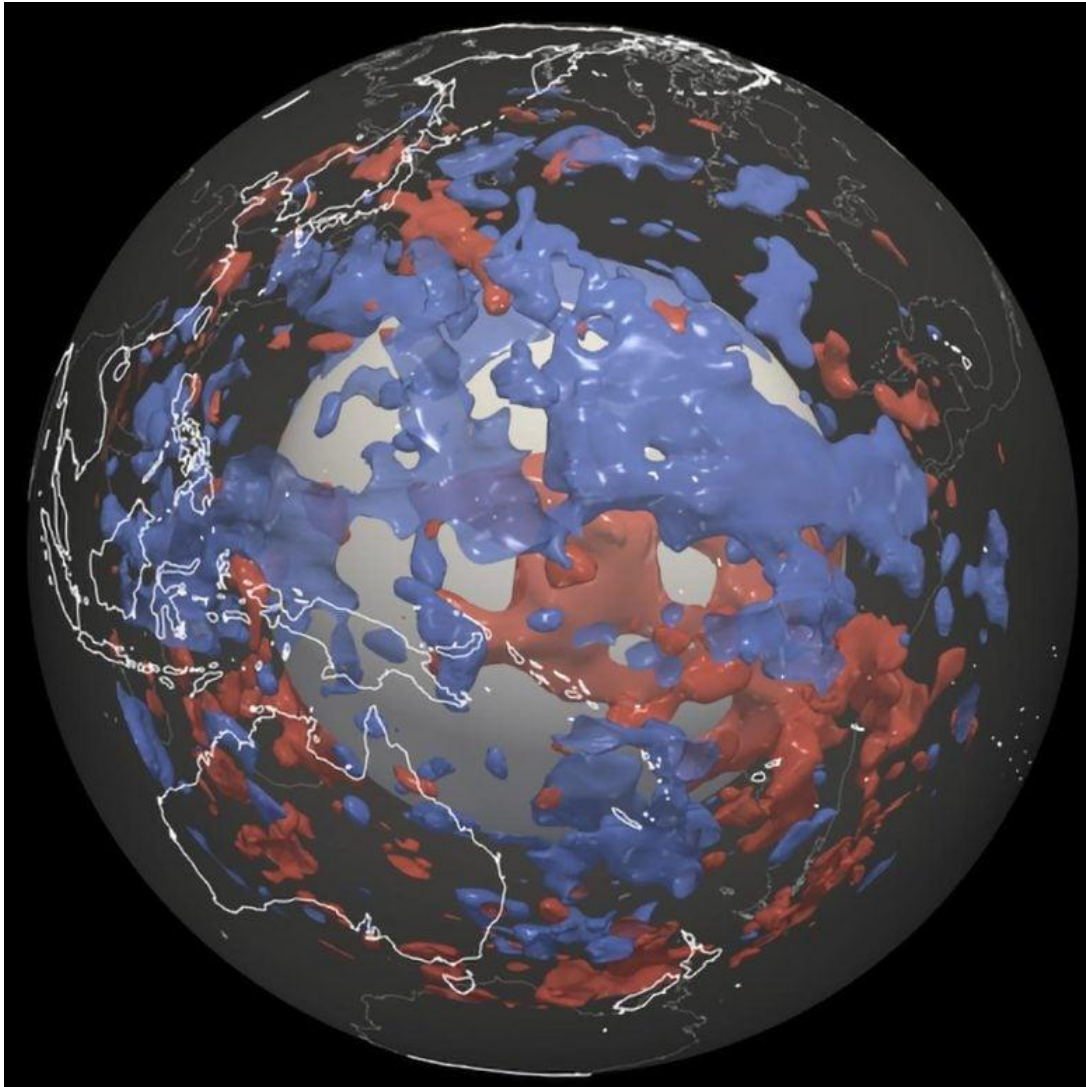


Geophysicists have discovered unexpected structures deep within the Earth's mantle, resembling subducted tectonic plates in areas where no subduction should have occurred, using a new high-resolution seismic model. This finding suggests the mantle may contain ancient or iron-rich materials, challenging existing theories and highlighting the need for further research into Earth's internal dynamics.

Unexpected mantle structures hint at ancient or unknown materials, challenging current tectonic theories and prompting deeper research.

No one can see inside the Earth or drill deep enough to collect rock samples from the mantle—the layer between Earth's core and its outermost rigid layer, the lithosphere. Measuring temperature and pressure at those depths is also impossible. To overcome these challenges, geophysicists rely on indirect methods to study what lies deep beneath our feet.

One key method involves analyzing seismograms, which are recordings of earthquake waves. By measuring how fast these waves travel through the Earth, scientists can infer details about its internal structure. This process is similar to how doctors use ultrasound to create images of organs, muscles, or veins inside the body without surgery.



Using a new model, researchers uncover zones in the Earth's lower mantle where seismic waves travel slower (red) or faster (blue). The large blue zone in the western Pacific (right above the center of the image) was previously unknown. Credit: Sebastian Noe / ETH Zurich

Seismic waves provide information

Here's how it works: when an earthquake occurs, seismic waves radiate outward from the epicenter in all directions. As they travel through the Earth, these waves can be refracted

(bent), diffracted (spread around obstacles), or reflected (bounced back). The speed of these waves depends not only on the type of wave but also on the density and elasticity of the materials they pass through. Seismographic stations around the world record these waves, allowing geophysicists to analyze the data. From these recordings, scientists can infer the Earth's internal structure, its composition, and the dynamic processes occurring deep within the planet.

Using seismic recordings, Earth scientists determined the position of submerged tectonic plates throughout the Earth's mantle. They always found them where they expected them to be: in an area known as subduction zones, where two plates meet and one subducts beneath the other into the Earth's interior. This has helped scientists investigate the plate tectonic cycle, i.e., the emergence and destruction of plates at Earth's surface, through our planet's history.

Plate remnants where there shouldn't be any

Now, however, a team of geophysicists from [ETH Zurich](#) and the [California Institute of Technology](#) has made a surprising discovery: using a new high-resolution model, they have discovered further areas in the Earth's interior that look like the remains of submerged plates. Yet, these are not located where they were expected; instead, they are under large oceans or in the interior of continents – far away from plate boundaries. There is also no geological evidence of past subduction there. This study was recently published in the journal *Scientific Reports*.

What is new about their modeling approach is that the ETH researchers are not just using one type of earthquake wave to study the structure of the Earth's interior, but all of them. Experts call the procedure full-waveform inversion. This makes the model very computationally intensive, which is why the researchers used the Piz Daint supercomputer at the CSCS in Lugano. Is there a lost world beneath the Pacific Ocean?

“Apparently, such zones in the Earth's mantle are much more widespread than previously thought,” says Thomas Schouten, first author and doctoral student at the Geological Institute of ETH Zurich.

One of the newly discovered zones is under the western Pacific. However, according to current plate tectonic theories and knowledge, there should be no material from subducted plates there, because it is impossible that there were subduction zones nearby in the recent geological history. The researchers do not know for certain what material is involved instead, and what that would mean for Earth's internal dynamics. “That's our dilemma. With the new high-resolution model, we can see such anomalies everywhere in the Earth's mantle. But we don't know exactly what they are or what material is creating the patterns we have uncovered.”

It's like a doctor who has been examining blood circulation with ultrasound for decades and finds arteries exactly where he expects them, says ETH professor Andreas Fichtner.

“Then if you give him a new, better examination tool, he suddenly sees an artery in the buttock that doesn’t really belong there. That’s exactly how we feel about the new findings,” explains the wave physicist. He developed the model in his group and wrote the code.

Extracting more information from waves

So far, the researchers can only speculate. “We think that the anomalies in the lower mantle have a variety of origins,” says Schouten. He believes it is possible that they are not just cold plate material that has subducted in the last 200 million years, as previously assumed. “It could be either ancient, silica-rich material that has been there since the formation of the mantle about 4 billion years ago and has survived despite the convective movements in the mantle, or zones where iron-rich rocks accumulate as a consequence of these mantle movements over billions of years” he notes.

For the doctoral student, this means above all that more research with even better models is needed to see further details of Earth’s interior. “The waves we use for the model essentially only represent one property, namely the speed at which they travel through the Earth’s interior,” says the Earth scientist. However, this does not do justice to the Earth’s complex interior. “We have to calculate the different material parameters that could generate the observed speeds of the different wave types. Essentially, we have to dive deeper into the material properties behind the wave speed,” says Schouten.

Reference: “Full-waveform inversion reveals diverse origins of lower mantle positive wave speed anomalies” by Thomas L. A. Schouten, Lars Gebraad, Sebastian Noe, Anna J. P. Gülcher, Solvi Thrastarson, Dirk-Philip van Herwaarden and Andreas Fichtner, 4 November 2024, *Scientific Reports*.

DOI: [10.1038/s41598-024-77399-2](https://doi.org/10.1038/s41598-024-77399-2)

[ETH Zurich](#)[Geophysics](#)[Seismology](#)[Tectonic Plates](#)

Fertilizing the Ocean with Iron

Should we add iron to the sea to help reduce greenhouse gases in the air?

“Give me half a tanker of iron, and I’ll give you an ice age” may rank as the catchiest line ever uttered by a biogeochemist. The man responsible was the late John Martin, former director of the Moss Landing Marine Laboratory, who discovered that sprinkling iron dust in the right ocean waters could trigger plankton blooms the size of a small city. In turn, the billions of cells produced might absorb enough heat-trapping carbon dioxide to cool the Earth’s warming atmosphere.

Never mind that Martin was only half serious when he made the remark (in his “best Dr. Strangelove accent,” he later recalled) at an informal seminar at Woods Hole Oceanographic Institution (WHOI) in 1988. With global warming already a looming problem, others were inclined to take him seriously.

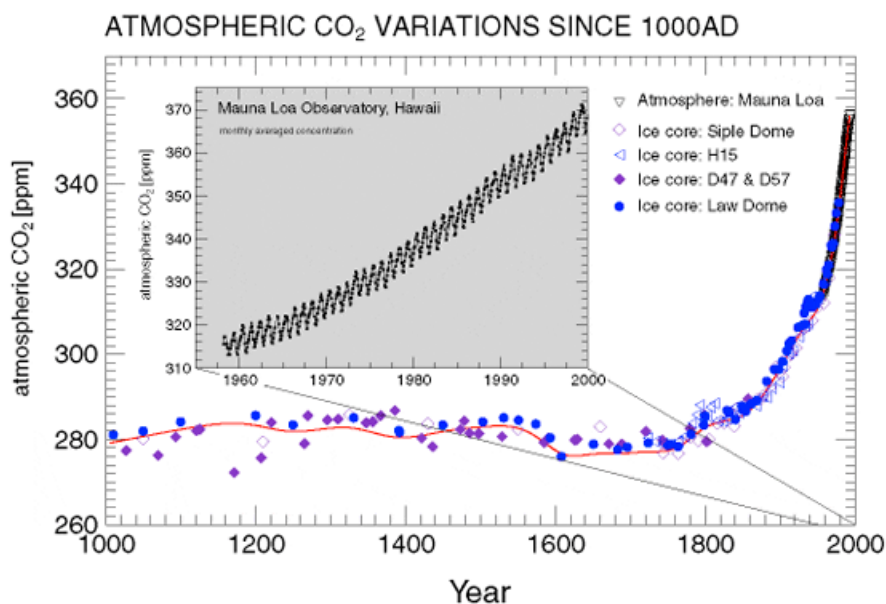
At the time, ice-core records suggested that during past glacial periods, natural iron fertilization had repeatedly drawn as much as 60 billion tons of carbon out of the atmosphere. Laboratory experiments suggested that every ton of iron added to the ocean could remove 30,000 to 110,000 tons of carbon from the air. Early climate models hinted that intentional iron fertilization across the entire Southern Ocean could erase 1 to 2 billion tons of carbon emissions each year—10 to 25 percent of the world’s annual total.

Since 1993, 12 small-scale ocean experiments have shown that iron additions do indeed draw carbon into the ocean—though perhaps less efficiently or permanently than first thought. Scientists at the time agreed that disturbing the bottom rung of the marine food chain carried risks.

Underlying proposals to add iron to the ocean as a means to mitigate climate change is the brutal fact that atmospheric carbon dioxide levels have increased precipitously since the 1850s and continue to rise. CO₂ levels for the past 1,000 years were derived from ice cores. The inset shows direct atmospheric CO₂ observations from Mauna Loa, Hawaii, beginning in 1958. (Adapted from Sarmiento & Gruber. Inset: from C.D. Keeling and the National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory)

Twenty years on, Martin's line is still viewed alternately as a boast or a quip; an opportunity too good to pass up or a misguided remedy doomed to backfire. Yet over the same period, unrelenting increases in carbon emissions and mounting evidence of climate change have taken the debate beyond academic circles and into the free market.

Today, policymakers, investors, economists, environmentalists, and lawyers are taking notice of the idea. A handful of companies are planning a new round of larger experiments. The absence of clear regulations for either conducting experiments at sea or trading the results in "carbon offset" markets complicates the picture. But economists conclude that the planet's growing urgency to solve its emissions problem will reward anyone who can make iron fertilization work.



In past experiments “we were trying to answer the question, ‘how does the world work?’—not ‘how do we make the world work for us?’ ”

Kenneth Coale, the present-day director of Moss Landing Marine Lab, said recently. “They’re totally separate. We have not done the experiment to address the issues that we’re talking about today.”

“We’re in a learning process that involves a balance of science, commercial, and a whole variety of social activities and interests,” Anthony Michaels, director of the Wrigley Institute for Environmental Studies at the University of Southern California, said. “We’ve got to set up a measured process for moving forward.”

The two scientists were speaking at a fall 2007 conference that brought together some 80 participants representing the scientific, commercial, regulatory, and economic sides of the debate. The conference was convened by WHOI marine geochemists Ken Buesseler and Scott Doney, and Hauke Kite-Powell of the WHOI Marine Policy Center. In talks and wide-ranging discussions, participants raised serious doubts about the practicality, efficacy, and safety of large-scale iron fertilization. Yet many also seemed to accept that more science—in the form of carefully designed and conducted experiments—was the best way to put those doubts to rest.

NOT AS SIMPLE AS IT SOUNDS

Martin made his pronouncement jokingly because he knew that he was glossing over several hindrances to using iron fertilization to sequester carbon in the ocean. Opponents to the idea are quick to point out the three major ones: It may be less efficient than it at first seems; it raises a host of new, worrying consequences; and its effectiveness is difficult for anyone to measure.

In certain regions, including the equatorial and north Pacific and the entire Southern Ocean, a simple iron addition does cause phytoplankton to grow rapidly. But tiny zooplankton, known as “grazers,” eat much of the bloom almost as soon as it starts. This begins a chain of recycling that ensues from the sea surface to the seafloor as grazers, krill, fish, whales, and decomposers feed upon each other. Much of the immense carbon prize won by the iron

addition quickly leaks back into the atmosphere as carbon dioxide gas.

What is critical for the effectiveness of iron fertilization schemes is the amount of organic carbon that actually sinks from the surface and is sequestered in the depths. Only a small percentage of carbon—in the form of dead cells and fecal pellets—falls to the seafloor and stays there, unused, for millennia. A higher percentage (between 20 and 50 percent) will at least reach middle-depth waters, where the carbon will remain in underwater currents for decades. Proponents consider this result good enough to buy society time to come up with other, more permanent solutions to greenhouse gas increases.

Beyond the inefficiency of carbon sequestration, iron fertilization would likely cause other changes “downstream” of the ocean patches where iron was added. The huge green phytoplankton blooms would take up not just iron but other nutrients, too—nitrate, phosphate, and silica—essentially depleting nearby waters of the building blocks needed for plankton growth.



“You might make some of the ocean greener by iron enrichment, but you’re going to make a lot of the ocean bluer,” said Robert Anderson, senior scholar at Lamont-Doherty Earth Observatory.

Other participants at the WHOI conference—John Cullen, a biological oceanographer at Dalhousie University in Canada, Andrew Watson, a biogeochemist at the University of East Anglia, U.K., and Jorge Sarmiento, a modeler at Princeton's Geophysical Fluid Dynamics Laboratory—pointed out several other ecological concerns. Large-scale iron fertilization, in altering the base of the food chain, might lead to undesirable changes in fish stocks and whale populations. Increased decomposition of sinking organic matter could deprive deep waters of oxygen or produce other greenhouse gases more potent than carbon dioxide, such as nitrous oxide and methane. The plankton-choked surface waters could block sunlight needed by deeper corals, or warm the surface layer and change circulation patterns.

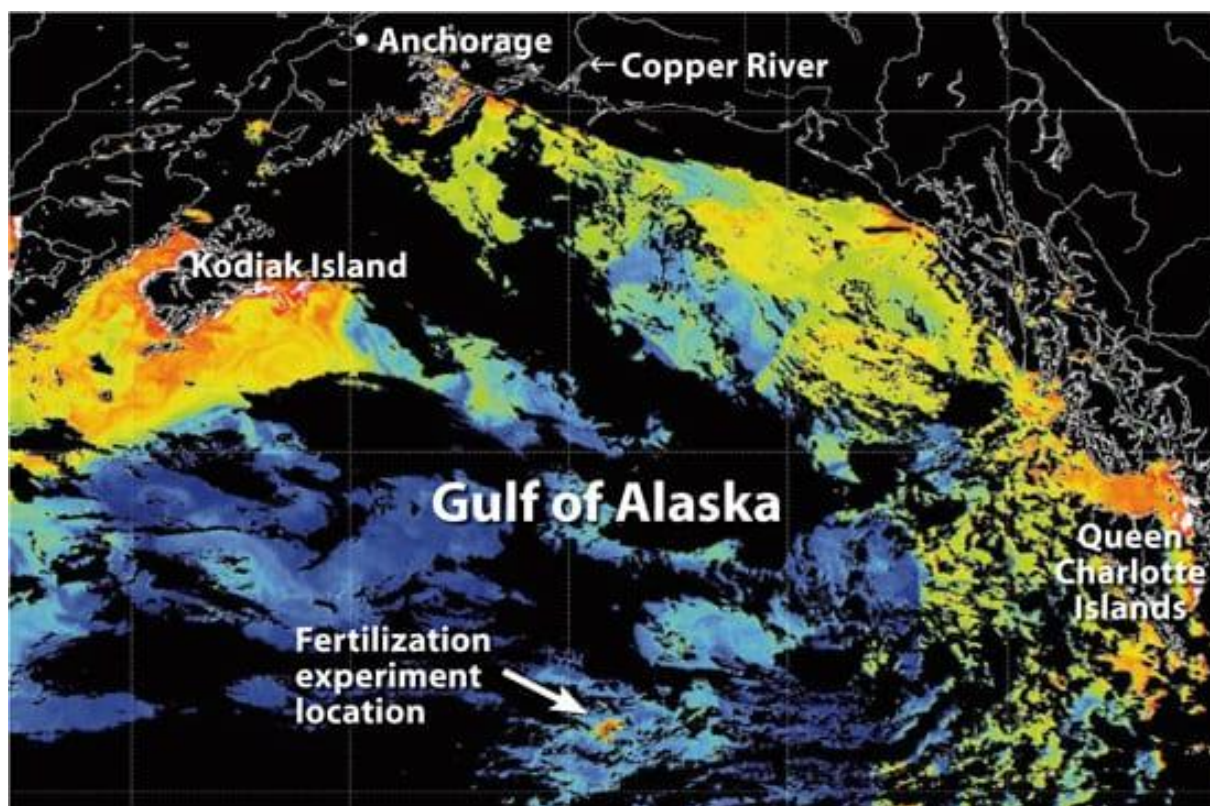
On the other hand, more plankton might produce more of a chemical called dimethylsulfide, which can drift into the atmosphere and encourage cloud formation, thus cooling the atmosphere and helping to counteract greenhouse warming. And others argue that increased plankton supplies might enhance fish stocks.

Then there is the practical problem of verification. Iron fertilization companies would earn profits by measuring how much carbon they sequester and then selling the equivalent to companies (or people) that either wish to or are required to offset their emissions. Any plan to sell sequestered carbon requires a reliable accounting, and this promises to be difficult in the ocean.

So far, only three of 12 iron addition experiments have been able to show conclusively that any sequestration happened at all, according to Philip Boyd of the New Zealand National Institute of Water and Atmospheric Research. Perhaps more worrying to an investor, those sequestration numbers were low—about 1,000 tons of carbon per ton of iron added, as opposed to the 30,000 to 110,000 suggested by laboratory experiments.

CAREFULLY DESIGNED RESEARCH

Despite the suspected drawbacks to full-scale iron fertilization, private companies—and many scientists—support the idea of another round of experiments. Learning more about the ocean is in everyone's interest, they argue, and the larger experiments now being proposed are still far too small to wreak environmental havoc.



Iron fertilization experiments can set off blooms that are visible from space. In the bottom center of the satellite image above, note the red patch (indicating high levels of chlorophyll) from the Subarctic Ecosystem Response to Iron Enrichment Study in 2002. (Image provided by Jim Gower, Bill Crawford, and Frank Whitney, Institute of Ocean Sciences, Sidney BC.)

While the past experiments showed widely variable results, proponents read this as an opportunity for refinement through engineering. For millennia, humans have been repeating processes that at first were marginally useful and tuning them to our purposes. Continued research could address a number of key questions (see box below), and those answers could point the way to higher yields and efficiency.

Proponents of iron addition do acknowledge the possibility of environmental ill-effects. Still, no such effects have been detected

during the past 12 experiments, probably because the experiments were small—around a ton of iron added over a few hundred square kilometers of ocean. By incrementally scaling up, they believe they can detect and avoid environmental problems.

As for the verification problem, both carbon markets and international ocean law are moving to accommodate so-called “carbon sink” projects, such as iron fertilization, which capture and sequester carbon from the air, according to Till Neeff of EcoSecurities, a leading trader of carbon credits, based in London. By the time the science is worked out, he said, the economics may be worked out as well.

Anchoring all of the arguments for continued research is the brutal fact of global carbon emissions. The most practical hope for dealing with emissions at the moment lies in a piecemeal strategy of “stabilization wedges.” Under this proposal, the world develops a portfolio of emissions reductions and carbon-capture projects, each of which offsets one piece of the global emissions pie. Combined, these wedges must begin to slow the growth of, and eventually lead to a net reduction in, our current global emissions of 7 to 8 billion tons of carbon per year. But with minimal progress so far on any wedges, and with China and India committing to major emissions increases as they develop, iron fertilization beckons as one tool in a toolbox of partial solutions.

“No option is without its impacts,” said WHOI biogeochemist Ken Buesseler, “whether we use wind turbines, grow biofuels or use energy-saving fluorescent bulbs, which contain mercury.”

BUT IS IT LEGAL?

At present, iron fertilization falls into a gray area in both international law and formal carbon-trading markets, but this is changing.



Scientists aboard the Australian research vessel *Aurora Australis* studied the natural cycling of iron in the Southern Ocean in 2001. Ken Buesseler, a marine chemist at Woods Hole Oceanographic Institution, was aboard that expedition, and in 2002 he served as chief scientist of the Southern Ocean Iron Experiment (SOFEX). The three-ship operation added iron to stimulate a phytoplankton bloom in the Southern Ocean and investigated the results. (Photo by Ken Buesseler, Woods Hole Oceanographic Institution)

Iron fertilization would happen on the open ocean, which is not owned by any country, according to David Freestone, senior adviser in the Legal Office of the World Bank, who briefed the symposium participants. While international treaties such as the London Convention, which governs ocean dumping and pollution, might address iron addition, treaty nations have not yet decided whether it might constitute pollution because its possible side effects remain unknown. Further, no overarching international agency exists to enforce the treaty, so responsibility falls to individual nations, he said. Ship crews intending to flout an international treaty could do so by electing to fly the flag of a country that has not signed it—a route that has already been publicly considered by one company.

Carbon trading markets are young but growing, Neeff said. Strictly regulated markets, set in motion by the Kyoto Protocol treaty, last year traded 430 million tons of carbon offsets (worth billions of dollars) among companies required to reduce total emissions. (One ton of carbon equals 3.67 tons of carbon dioxide.) Regulatory markets don't allow for iron fertilization at present, but this may change as more carbon sink projects gain approval.

Then there are voluntary markets, Neeff said, where concerned individuals or companies buy carbon offsets to assuage their conscience or green their image. Traders would be free to sell offsets from iron fertilization in these markets. Voluntary markets are growing rapidly, Neeff said, but so far they are much smaller than regulatory markets, equivalent to 7 million tons of carbon, worth about \$400 million, per year.

Voluntary markets represent one more worry for opponents of iron fertilization. Iron fertilization companies might make superficial estimates of the amount of carbon they sequester and enter a hefty balance in their trading ledgers. Any large profits made from under-regulated credits would encourage other outfits to go into business. The collective impacts to the world's international waters could be both disastrous and impossible to trace to any single liable party, Cullen said.

But those are future scenarios. By the time iron fertilization moves from experiment to industry, laws may well be in place to regulate it, said Kite-Powell. Over the same period, increasing demand for carbon offsets is likely to ensure that iron fertilization is profitable, he said, referring to a recent economic analysis indicating a potential value of \$100 billion over the next century.

NEXT STEPS: SCIENTISTS AND INDUSTRY

Iron fertilization is being pulled in two directions, as comments during a panel discussion at the conference made clear.

Iron fertilization is not a silver bullet, said Margaret Leinen, the chief science officer at the firm Climos and former assistant director of

geosciences at the National Science Foundation. But given the enormity of the greenhouse gas problem and the lack of progress so far, “let’s look at it in our portfolio for mitigation,” she said. “Uncertainty about the impacts shouldn’t preclude careful research.”

Lisa Speer of the Natural Resources Defense Council took a different view: “There is a limited amount of money, of time, that we have to deal with this problem,” she said. “The worst possible thing we could do for climate change technologies would be to invest in something that doesn’t work and that has big impacts that we don’t anticipate.”

Between these viewpoints a middle ground emerged: “There are plenty of ways to do it wrong, but done right, [iron fertilization] does actually sequester carbon for hundreds of years in the place that it would ultimately end up anyway,” Watson said. That may be a tremendous advantage compared with more familiar but less secure approaches like planting trees, he said. Skeptics should not dismiss the idea out of hand before scientists have had the chance to work out the details.

One way to quell doubts lies with carefully conducting larger experiments. But iron fertilization is unlikely to receive much more federal funding. It falls to entrepreneurs concerned about the climate problem to fund the work, and they need scientists’ participation to make sure the right questions are asked and answered.

In a parallel with the way universities routinely conduct trials of the safety and efficacy of potential pharmaceuticals, Michaels pointed out that oceanographers may need to learn how to be involved with tests of iron fertilization. “We have to evolve a set of skills within our community to have those kinds of roles,” he said. “Who else should be figuring that out but us?”

Though many scientists are keen on the idea of future research, fewer are willing to team up with a private company to do it, for fear of a real or perceived effect on the impartiality of their research. Still, researchers may need to convince themselves that just because the idea is potentially profitable doesn’t mean it’s wrong—or simply accept that further research is going to happen.

“Commercial efforts are moving forward with or without scientific input,” Buesseler said. “We need to be able to evaluate their impacts and changes to the ocean carbon cycle, based upon the best possible oceanographic methods.”

For their part, private companies hope to collaborate with researchers. Of the handful already in business, one—Climos—recently proposed a code of ethics supporting involvement by scientists and full environmental audits of experiment plans. Russ George, president of rival company Planktos, who also attended the conference, agreed in principle to the code. On Nov. 5, Planktos announced that it had dispatched a ship equipped for an iron fertilization experiment but made no statements about how it might comply with the code.

What’s emerging for the next few years is the prospect of a round of experiments involving around 100 tons of iron, which is 100 times larger than previously tried. Financed by private companies, they could either be conducted by private interests with limited sampling gear or by teams of scientists through grants. New, autonomous technology promises to extend the duration of monitoring and improve measurements of how carbon sinks through the ocean.

Yields from previous experiments cannot be used to project whether larger-scale fertilizations would send millions, thousands, or even fewer tons of carbon into the ocean’s middle depths, Buesseler said. Still, commercial groups sponsoring new experiments hope to sell those carbon dioxide equivalents as voluntary offsets. While scientific research would focus on learning more about how the ocean works, the companies involved would be looking for ways to increase efficiency, make larger blooms in the future, and monitor any negative effects. As government-sponsored research on iron fertilization moves ahead in different countries, funding for larger experiments could develop into private and public partnerships.

Experiments on such a scale drive home one final point: that the near future of iron fertilization is modest on all counts—size of experiments, likely profits, environmental side-effects, and amount of carbon sequestration. However profitable iron fertilization becomes, the dent it puts in atmospheric carbon levels in coming years will remain a small

one. As these ocean scientists work to assemble their stabilization wedge to mitigate carbon dioxide emissions, they remind the rest of the world that many more wedges must be found.

The Ocean Iron Fertilization Symposium: Some 80 natural and social scientists from several countries—along with environmental advocates, business representatives, policymakers, legal experts, economists, and journalists—gathered at Woods Hole Oceanographic Institution (WHOI) on Sept. 26-27, 2007, to discuss the pros and cons of ocean iron fertilization as a means to mediate global warming. This series of Oceanus articles summarize the wide range of issues raised at the conference, convened by WHOI scientists Ken Buesseler, Scott Doney, and Hauke Kite-Powell. They reviewed and edited these articles, with input from many conference participants. All the articles in this series are published in a print edition of Oceanus (Vol. 46, No. 1). Videos and PDF versions of presentations at the conference are available at <http://www.whoi.edu/conference/OceanIronFertilization>. The symposium was sponsored by the Elisabeth and Henry Morss Jr. Colloquia Fund, the Cooperative Institute for Climate Research at WHOI, the WHOI Marine Policy Center, the WHOI Ocean and Climate Change Institute, the WHOI Ocean Life Institute, and Woods Hole Sea Grant.

UNRESOLVED QUESTIONS

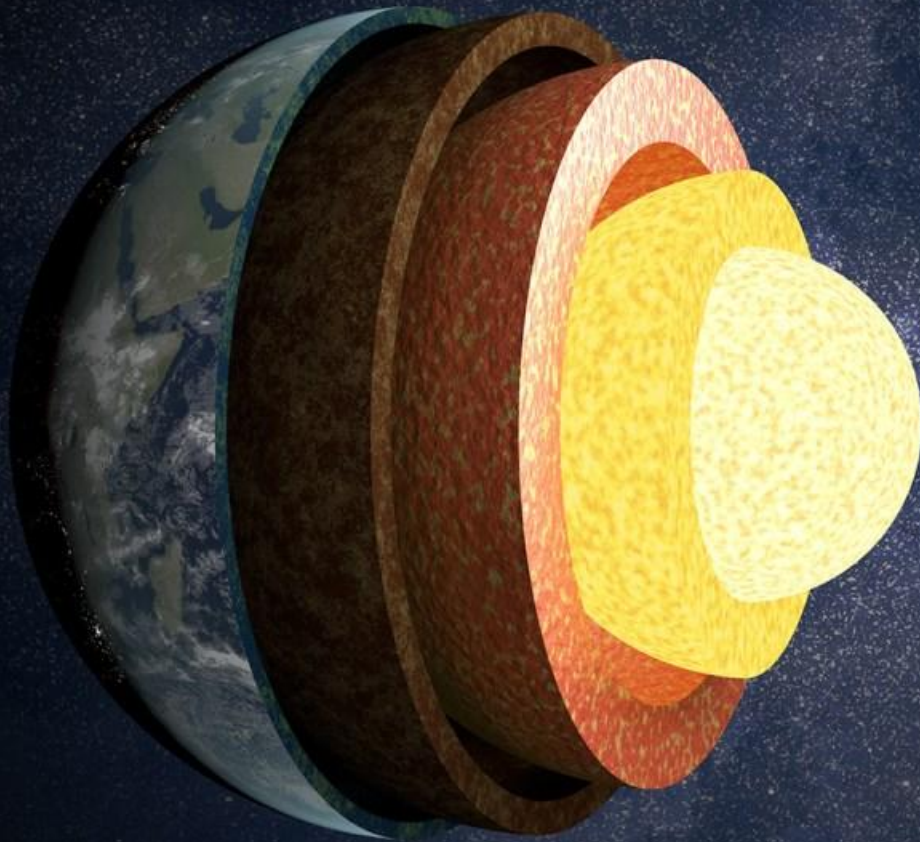
Twelve small experiments have shown that blooms of phytoplankton consistently result from intentional addition of iron to the ocean. But the efficacy and ecological impacts of iron fertilization remain uncertain, particularly with larger-scale experiments. If and when a new round of experiments is begun, these questions will be first on the list:

- How long will carbon be sequestered in the ocean?
- How deep is deep enough to accomplish this?
- How can sequestration efficiency be increased?
- How does the ocean food web change during and after a bloom?
- Which phytoplankton and grazers raise sequestration efficiency?
- Which parts of the ocean are best for iron fertilization?
- What size and what shaped patch should be fertilized?

- How often and how continually should iron be added?
- What kinds of currents and surface conditions give the best results?
- How can the amount and fate of carbon from a bloom be verified?
- How could effects downstream of experiments be detected?
- How could the production of other greenhouse gases be monitored?

Earth's inner core may be changing shape

The entire surface of the inner core, or small patches of it, may be swelling and contracting



The surface of Earth's solid inner core, which rotates within the liquid outer core, may be changing.

DECEMBER 12, 2024

WASHINGTON, D.C. — Earth's inner core, a solid metal ball gyrating within the molten outer core, may be both slowing down and changing shape.

Recent analyses of earthquake waves have suggested that around 15 years ago, the inner core's rotation may have slowed so much that it appeared to pause or reverse direction relative to the surface. But a new analysis suggests something more must be changing at Earth's center.

The most probable explanation is that the inner core is not only rotating differently — [its surface is probably also morphing](#), geophysicist John Vidale of the University of Southern California in Los Angeles reported December 9 at a meeting of the American Geophysical Union. The finding could help resolve a long-standing debate over what is changing at the inner core.

No instrument can physically probe Earth's core. So, researchers study it using seismic waves from earthquakes. Scientists typically use quakes that occur in the South Sandwich Islands near Antarctica, which repose on the opposite side of the planet from instrument arrays in Alaska. The earthquake waves travel through the planet like sonar waves through water, with some passing through the inner core on their way to Alaska. Instruments there then record the waves as squiggly signatures called waveforms, which contain information about what the waves encountered on their journey through Earth.

For robust detections of changes in the inner core, researchers compare similar-sized quakes that occurred in the same place but at different times. Such twin temblors, known as doublets, should generate the same waveforms if their journeys through Earth were identical. But researchers have observed that some doublets in the South Sandwich Islands generate different waveforms in Alaska, indicating that something in the inner core had changed between the times the two quakes in those doublets occurred.

In 2023, geophysicists reported that the waveform differences stemmed from the inner core's rotation slowing down so much that it appeared to have [stopped moving — or even reversed](#) — relative to the surface sometime around 2009 (*SN*: 1/23/23). Then, earlier this year, Vidale's team seemingly confirmed the reversal. They were able to match some waveforms [before and after the turnaround](#), identifying times when the inner core had reassumed a previous orientation toward the surface (*SN*: 6/25/24).

For the new study, Vidale and colleagues analyzed about 200 pairs of earthquakes that occurred from 1991 to 2024. They examined matching waveform pairs from before and after the reversal, recorded at two separate receiver arrays located near Fairbanks, Alaska, and Yellowknife, Canada.

Intriguingly, 10 doublets showed subtle differences in waveforms at Yellowknife that were not present in the Fairbanks waveforms. The team knew that the waves reaching these arrays, which are roughly 1,600 kilometers apart, take slightly different paths through Earth: Waves reaching Fairbanks penetrate deep into the inner core while those reaching Yellowknife graze its exterior.

"The simplest explanation is deformation to the shallow inner core," Vidale says.

It's possible that the entire geoid-shaped inner core is deforming, like a football being reshaped so its ends point in two new directions. Alternatively, he says, patches of the inner core's surface may be swelling or contracting. That would be like small bumps and

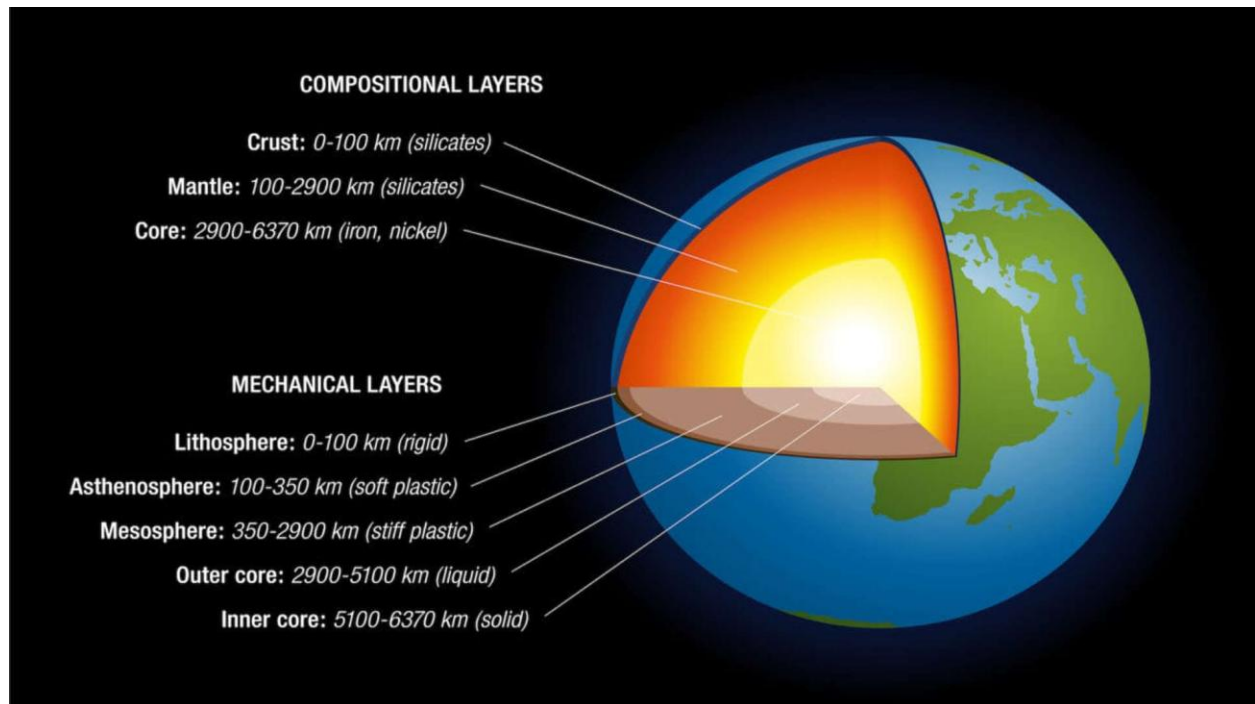
dents forming on the metaphorical football. It's also possible that both processes are occurring. Such changes could be driven by the gravitational pull of the mantle — Earth's largest internal layer — or by material flowing in the outer core, Vidale says.

This is not the first time researchers have reported that the inner core's surface changes over time. In 2006, geophysicist Lianxing Wen of Stony Brook University in New York reported that [patches of the region's surface](#) may rise or subside by hundreds of meters per decade, possibly due to material exiting the inner core as it cools. But unlike Vidale, Wen and colleagues like geophysicist Xin Zhang of the University of Science and Technology of China in Hefei maintain that [the inner core does not rotate differently than Earth](#). "Surface changes can fully explain all the results," Zhang says.

Geophysicist Xiaodong Song of Peking University in Beijing, who was one of the first to report that the [inner core rotates differently](#) from the rest of the planet, generally agrees with Vidale's findings. While the waveform differences are probably caused mostly by rotational changes, other processes such as surface changes may also be occurring, he says. "It's not either or."

As for how all of this affects life on Earth, "we don't know that this is going to affect anything on the surface," Vidale says. "But we can't say for sure until we figure out what's happening."

Huge Underground Ocean Discovered Just Bellow Earth's Surface



The underground ocean is not in liquid form but rather trapped within a blue mineral called ringwoodite. This rock, found in the Earth's mantle, holds water molecules within its crystal structure, storing it away in a compact form. Interestingly, this discovery challenges old ideas about where Earth's water comes from.

How This Discovery Changes Our Understanding

Previously, scientists believed Earth's water mostly came from comets. However, this new finding suggests that much of Earth's water may have seeped from deep within the planet. Scientists think this could explain why surface oceans have remained the same size for millions of years, even while the rest of the earth has changed.

Seismology: The Key to Uncovering the Ocean

The discovery was made using advanced seismological techniques. Specifically, by studying how seismic waves travel through the Earth, scientists were able to detect the presence of water deep underground. This method

has proven effective in revealing hidden features below the Earth's surface and seems like an incredible way to use the effects of a natural disaster for good.

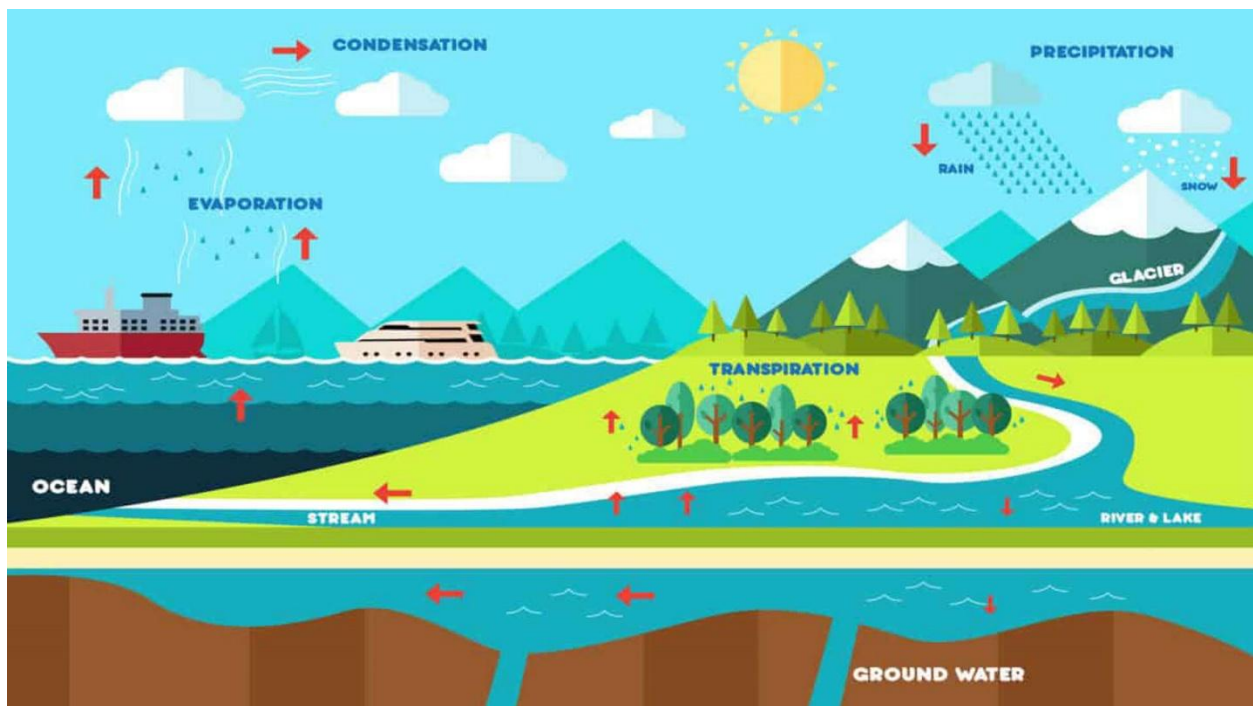
The Role of Seismic Waves in Research

Seismic waves, created by earthquakes, can travel deep into the Earth and give scientists clues about the planet's interior. When these waves slow down, it indicates the presence of water within the rocks slowing the waves.

Consequently, this slowdown was the key to confirming the massive underground ocean.

The Importance of Ringwoodite

Ringwoodite plays a central role in this discovery because it can trap water in its structure. So this means it has the ability to store vast amounts of water without turning into liquid. Additionally, this makes it a crucial element in understanding how water can exist so deep within the Earth.

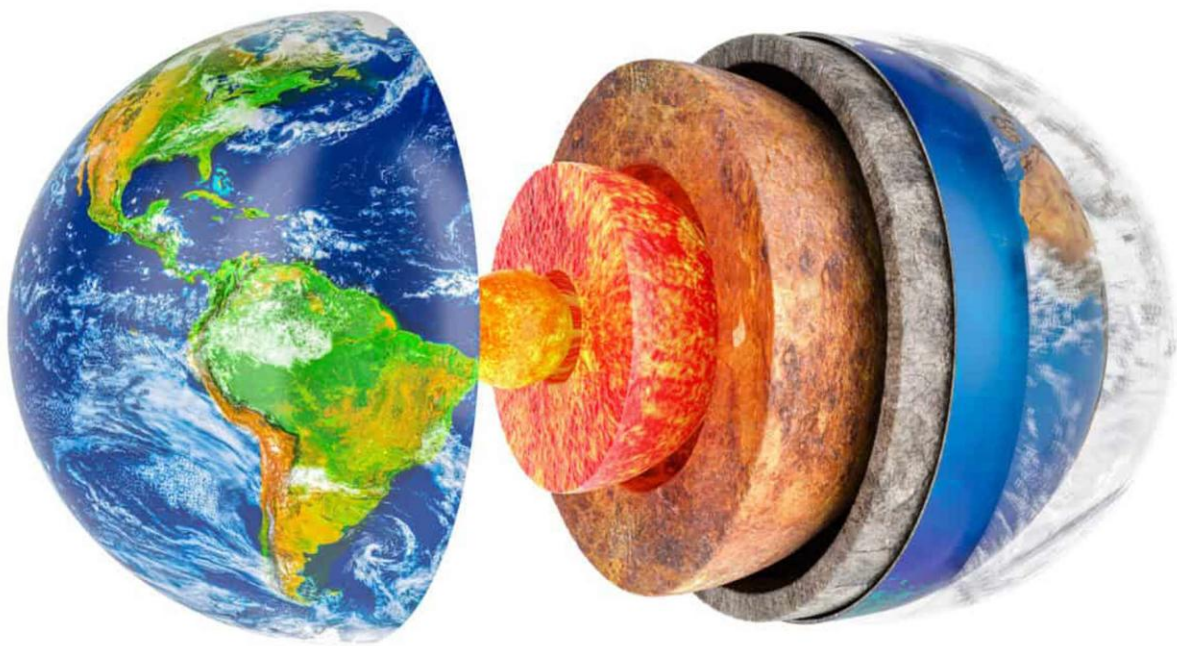


Implications for Earth's Water Cycle

This underground reservoir could be an essential part of Earth's water cycle. For example, it might help regulate the amount of water on the surface, keeping oceans stable over time. Without this hidden ocean, much of the Earth's surface could be covered by water. If you live around sea level, this means your home would most likely be underwater!

A Shift in Theories About Water Origins

As mentioned earlier, this discovery challenges the traditional belief that Earth's water came primarily from comet impacts. Instead, it suggests that water may have been present inside the Earth all along. This new perspective could lead to a rethinking of planetary formation and may help us understand the origin of our planet.



Potential for More Discoveries

The scientists behind this discovery believe there could be even more hidden oceans deep within the Earth. With the use of advanced technology, future research may reveal other unknown features of our planet's interior. Excitingly, this could further expand our understanding of Earth's evolution and how this planet became our home.

Impact on Earth's Stability

The existence of this hidden ocean has implications for Earth's long-term stability. Specifically, it may help explain how the planet has maintained such a stable environment for life. This underground water could act as a buffer, preventing extreme changes on the surface and keeping our home comfort.

Researchers plan to gather more seismic data from around the world to see if similar reservoirs exist in other regions. Then, this data will help scientists better understand Earth's water cycle and how it interacts with the planet's interior. This seems like a good opportunity for international collaboration between scientists, as the findings could have global implications.

Conclusion: A New Era in Earth Science

The discovery of a massive underground ocean 435 miles beneath the Earth's surface has opened up new possibilities in Earth science. It reshapes our understanding of the origins of water and the stability of our planet. As scientists continue to study this find, more revelations are sure to come, changing how we view Earth's complex systems.



Want to build healthier cities? Make room for bird and tree diversity



The stresses of the city, [where more than 70% of Canadians now live](#), can [increase the risk of poor mental health](#) even further.

When most people think about caring for their mental health, they may think about getting more exercise, getting more sleep and making sure they're eating healthy. Increasingly, research is showing that spending time in nature surrounded by plants and wildlife can also contribute to [preventing and treating mental illness](#).

Our research focuses on the importance of birds and trees in urban neighborhoods in promoting mental well-being. [In our study](#), we combined more than a decade of health and ecological data across 36 Canadian cities and found a positive association between greater bird and tree diversity and self-rated mental health.

The well-being benefits of healthy ecosystems will probably not come as a great surprise to urban dwellers who relish days out in the park or hiking in a nearby nature reserve. Still, the findings of our study speak to the potential of a nature-based urbanism that promotes the health of its citizens.

Birds, trees and human connection

Across cultures and societies, people have [strong connections with birds](#). The beauty of their bright song and color have inspired art, music and poetry. Their contemporary cultural relevance has even earned them an affectionate, absurdist internet nickname: "[birbs](#)."

There's something magical about catching a glimpse of a bird and hearing birdsong. For many urbanites, birds are our daily connection to wildlife and a gateway to nature. In fact, even if we don't realize it, humans and birds are intertwined. Birds provide us with many [essential services](#)—controlling insects, dispersing seeds and pollinating our crops.

People have similarly intimate connections with trees. The terms tree of life, family trees, even tree-hugger all demonstrate the central cultural importance trees have in many communities around the world. In cities, trees are a staple of efforts to bring [beauty and tranquility](#).

When the Australian city of Melbourne gave urban trees email addresses for people to report problems, residents responded by writing [thousands of love letters to their favorite trees](#). Forest bathing, a [practice of being calm and quiet among trees, is a growing wellness trend](#).

Birds and trees as promoters of urban wellness

Contact with nature and greenspace have a suite of mental health benefits.

Natural spaces [reduce stress](#) and offer places for recreation and relaxation for urban dwellers, but natural diversity is key. A growing amount of research shows that the extent of these benefits may be related to the [diversity of different natural features](#).

For example, in the United States, higher bird diversity is associated with [lower hospitalizations for mood and anxiety disorders](#) and longer [life expectancy](#). In a European study, researchers found that [bird diversity was as important for life satisfaction as income](#).

People's connection to a greater diversity of birds and trees could be because we [evolved to recognize that the presence of more species indicates a safer environment](#)—one with more things to eat and more shelter. Biodiverse environments are also less work for the brain to interpret, [allowing restoration of cognitive resources](#).

To explore the relationship between biodiversity and mental health in urban Canada, we brought together unique datasets. First, we collected bird data sourced from community scientists, where people [logged their bird sightings on an app](#). We then compared this data with [tree diversity data from national forest inventories](#).

Finally, we compared both of these data sets to a [long-standing health survey](#) that has interviewed approximately 65,000 Canadians each year for over two decades.

We found that living in a neighborhood with higher than average bird diversity increased reporting of good mental health by about 7%. While living in a neighborhood with higher than average tree diversity increased good mental health by about 5%.

Importance of urban birds and trees

The results of our study, and those of others, show a connection between urban bird and tree diversity, healthy ecosystems and people's mental well-being. This underscores the importance of urban biodiversity conservation as part of healthy living promotion.

Protecting wild areas in parks, planting pollinator gardens and reducing pesticide use could all be key strategies to protect urban wildlife and promote people's well-being. Urban planners should take note.

We're at a critical juncture: just as we are beginning to understand the well-being benefits of birds and trees, we're losing species at a faster rate than ever before. It's estimated that there are [three billion fewer birds](#) in North America compared to the 1970s and invasive pests will [kill 1.4 million street trees over the next 30 years](#). By promoting urban biodiversity, we can ensure a sustainable and healthy future for all species, including ourselves.

Great Green Wall of China Completed Through the 'Sea of Death'

China has finished building a 3,046km green wall through the Taklimakan Desert. The large green belt of red willows, saxaul, and other trees will act as a giant sand-stopping barrier.

The Taklimakan Desert sits in Northwest China's Xinjiang Uygur Autonomous Region. It is the world's second-largest drifting desert. Its winds and frequent sandstorms often blow around huge quantities of sand, burying roads, river channels, and farms.

The effects are so far-reaching that farmers call this desert the Sea of Death. This, plus the ongoing expansion of the Gobi Desert, led to the launch of China's Three-North Shelterbelt Forest Program in 1978.



An aerial photo shows the planting seedlings in the Taklimakan Desert in 2021. Photo: Xinhua

100 billion trees

The project is the largest ecological engineering project on the planet. Spanning six decades (it is scheduled to finish in 2050), it will plant around 100 billion trees to create barriers to blowing sand around all of China. The now-completed Taklimakan Desert project is just one of many regions slated for this treatment.

So far, an army of 600,000 workers has planted 300,000 square kilometers of trees. According to Chinese state news, they hope to increase forest coverage to four million square kilometers by 2050.

Total forest coverage has already increased from 10% in 1949 to 25% in 2023. Desertification currently affects 27% of China. The United Nations recently revealed that 77% of all land on Earth is drier than it was 39 years ago.

Desertification is accelerating worldwide due to climate change and human activity, but China is in danger of becoming one of the most affected areas.



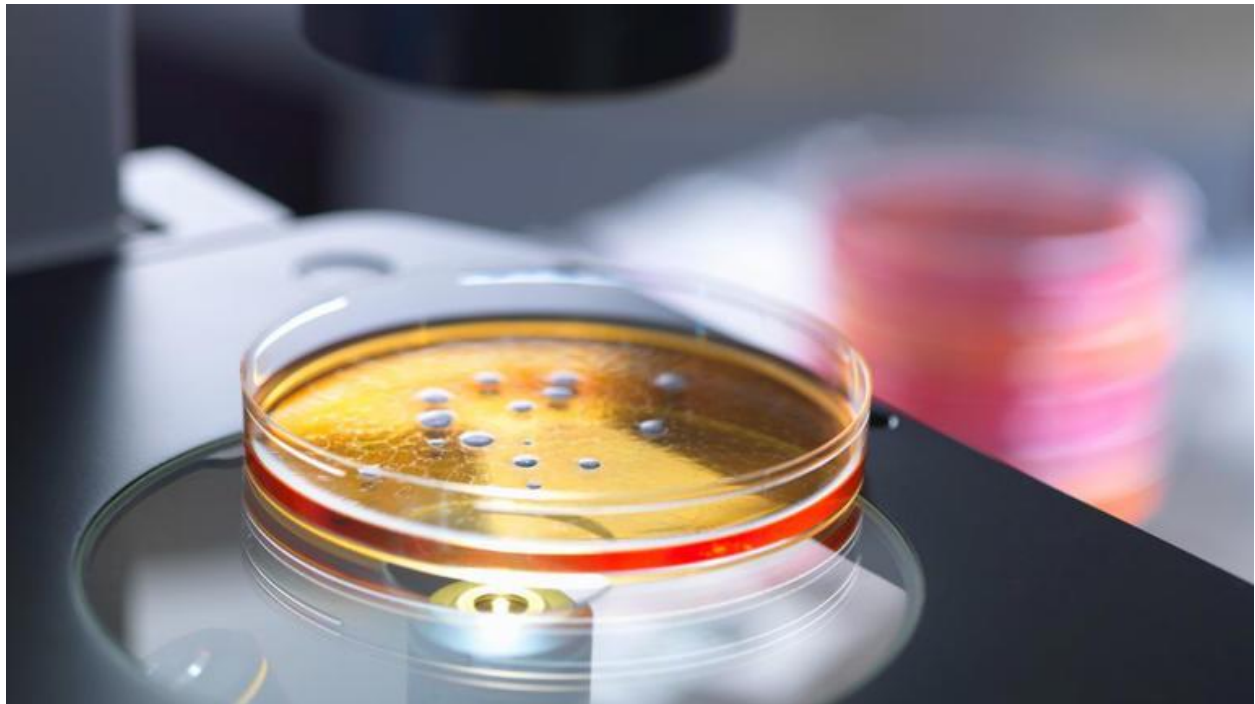
Part of the green belt along the Taklimakan Desert highway. Photo: Xinhua

While some have praised China for minimizing desertification, others are concerned that the green belt's non-native tree species create an unnatural

monoculture. However, finding plants that work in green belts in such a harsh environment is not easy.

China will need to maintain this Great Green Wall by continually planting more trees to keep the blowing sands at bay.

Scientists warn of ‘unprecedented’ risks of research into mirror life



It's not currently possible to create mirror bacteria, synthetic organisms in which the molecular structure found in nature is reversed. © Rafe Swan/Image Source/Getty Images

A group of 38 scientists working in nine countries has sounded an alarm about the potential creation of mirror bacteria — synthetic organisms in which the molecular structure found in nature is reversed and could put humans, animals and plants at risk of exposure to dangerous pathogens.

While the science and technology necessary to create mirror bacteria in a laboratory is a decade or more away, the scientists argued that the possibly lethal risks posed by this new field of research are “unprecedented” and “overlooked.”

“Driven by curiosity and plausible applications, some researchers had begun work toward creating lifeforms composed entirely of mirror-image biological

molecules,” the researchers wrote in a report published December 12 by the journal [Science](#).

“Such mirror organisms would constitute a radical departure from known life, and their creation warrants careful consideration.”

A fundamental feature of all known life is a uniform chirality, or handedness. For example, DNA and RNA are made from “right-handed” nucleotides, and proteins are made from “left-handed” amino acids. Just as a right-handed glove cannot fit a left hand, interactions between molecules often depend on chirality.

While the authors, who included experts in immunology, plant pathology, ecology, evolutionary biology, biosecurity and planetary sciences, had initially been skeptical that mirror bacteria could pose major risks, the experts said they had now become “deeply concerned.”

“It’s a genie you don’t want to let out of the bottle,” said report coauthor Jonathan Jones, a group leader at The Sainsbury Laboratory in Norwich, United Kingdom.

“The risk of something bad happening is low, but the consequences of something bad happening are really awful,” he added.

Unless compelling evidence were to emerge that mirror life would not pose extraordinary dangers, research with the goal of creating mirror bacteria should not be permitted, and funders should make clear that they will not support such work, the scientists recommended.

Risks of mirror bacteria

The authors based the Science paper on a 300-page [technical report](#) by Adamala et al. that detailed the feasibility and risks of mirror bacteria.

The report said that creating mirror life was a longer-term aspiration of multiple laboratories and major funders of research as part of efforts to better understand life and potentially aid in the development of drugs and other therapeutics.

Many synthetic biologists seek to understand how cells could be created from their constituent molecules with the aim of shedding light on how life first arose and understanding what other kinds of life might be possible. The report said that if a cell with natural chirality can be created from lifeless molecules, then, in theory, a mirror-image cell could be created from mirror-image molecules using the same methods.

No imminent threat exists, the report stressed, and there are currently sizable technical hurdles to creating mirror bacteria. Doing so within a decade would require substantial, coordinated efforts similar in scale and budget to the [Human Genome Project](#), which mapped 92% of the human genome over the span of 12 ½ years.

Organisms vulnerable to infection

Immune systems rely on recognizing specific molecular shapes found in invading bacteria. If these shapes were reflected — as they would be in mirror bacteria — recognition would be impaired and immune defenses could fail, potentially leaving organisms vulnerable to infection.

“We cannot rule out a scenario in which a mirror bacterium acts as an invasive species across many ecosystems, causing pervasive lethal infections in a substantial fraction of plant and animal species, including humans,” the scientists argued in the Science report.

“Even a mirror bacterium with a narrower host range and the ability to invade only a limited set of ecosystems could still cause unprecedented and irreversible harm.”

Transmission via animals and humans could enable the spread of such bacteria into different ecosystems. Jones, an expert in plant immune systems, said that mirror bacteria would be extremely difficult to detect in plants.

“Even if it didn’t grow very well initially, mutations would kick in and there’d be selection for something that grew better. That’s the way evolution works,” Jones explained.

Tom Ellis, a professor of synthetic genome engineering at Imperial College's Centre for Synthetic Biology and department of bioengineering, said that mirror life was still very much science fiction rather than science fact.

"Broadly I agree with the concerns, although they are very speculative considering research is currently at a very early stage and a long way from being any threat," said Ellis, who wasn't involved in the research.

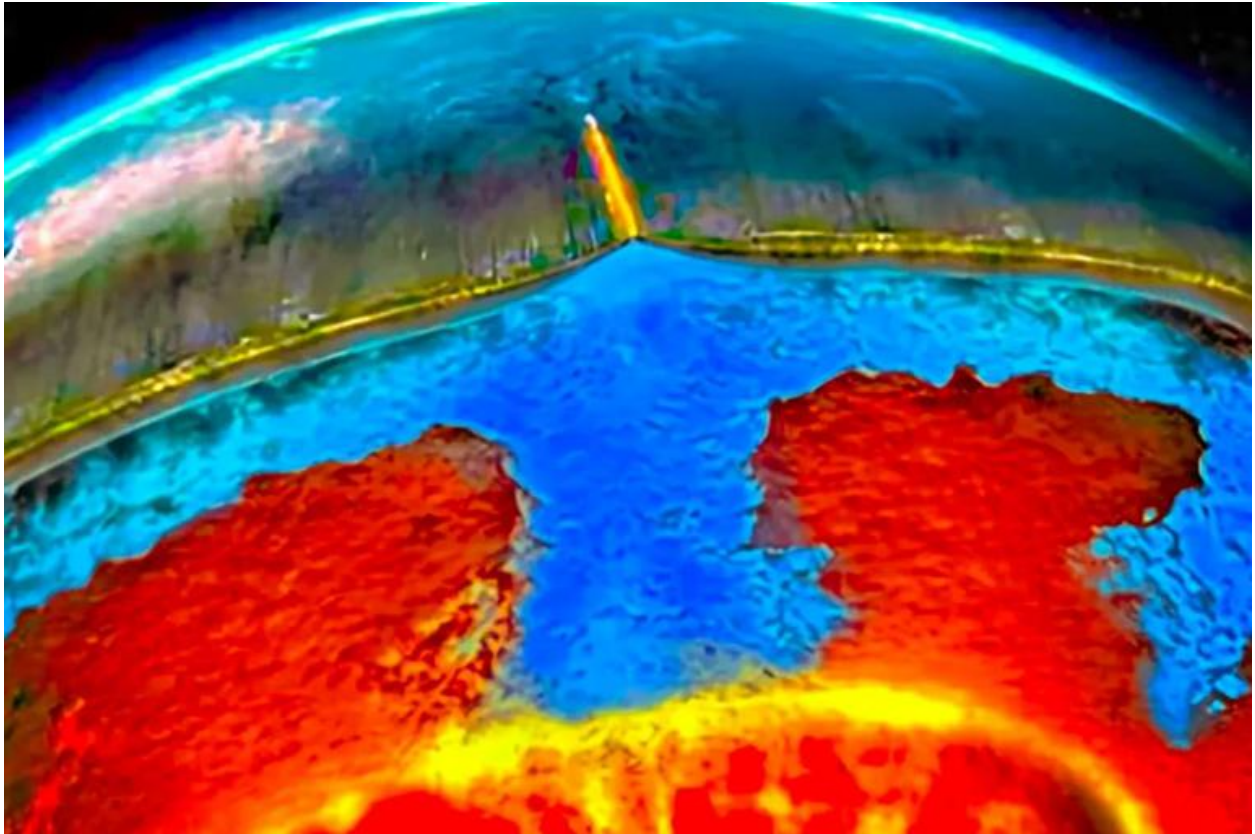
Scientists had been trying to create synthetic life using non-mirror molecules for more than a decade, Ellis said, but they were still a "long way" from having self-sustaining cells that can divide, replicate and evolve.

"This 'synthetic cell' work is challenging enough already when (scientists) use normal molecules, enzymes and chemicals. When they have to do all that but only with mirror molecules, that all need to be made and invented, then it makes it ... 1000x harder," he said via email.

"The scale of difficulty is akin to humans preparing to land on Mars, and people starting to talk about flying to other stars and galaxies," he said. "There's such a leap in difference of the achievement needed, and the basic initial goal isn't even done yet."

Correction: An earlier version of this story misstated the source of the technical report by Adamala et al. that accompanied the Science article published on December 12.

Massive subterranean ocean found : 3 times more water than Earth's surface oceans combined



Massive subterranean ocean found : 3 times more water than Earth's surface oceans combined© Daily Galaxy

At the heart of this revelation lies a remarkable mineral called ringwoodite.

This unique rock type possesses an extraordinary ability to trap water within its crystal structure. Geophysicist Steve Jacobsen, a key member of the research team, explains, "The ringwoodite is like a sponge, soaking up water. There's something very special about the crystal structure of ringwoodite that allows it to attract hydrogen and trap water."

Ringwoodite's water-holding capacity is truly remarkable. Scientists estimate that if this mineral contained just 1% water, it would equate to **a volume three times**

greater than all surface oceans combined. This astonishing fact highlights the potential magnitude of Earth's hidden water reserves and their significance in the global water cycle.

The water stored within ringwoodite exists in a fascinating fourth state, neither solid, liquid, nor gas. Instead, it resides in a mysterious form akin to water inside a sponge, challenging our conventional understanding of water's physical states.

Unveiling the depths: how seismic waves revealed the subterranean ocean

The discovery of this massive underground ocean was made possible through the analysis of seismic data. Researchers studying Earth's tremors and quakes noticed that seismometers were detecting shockwaves originating from deep beneath the surface. Upon closer examination, they realized these waves were interacting with water held within the ringwoodite mineral.

This groundbreaking finding has led scientists to reconsider the global water cycle. Jacobsen suggests, "I think we are finally witnessing evidence for a whole-Earth water cycle. This may very well shed light on the enormous amount of liquid water that graces the surface of our life-sustaining planet."

The implications of this discovery extend beyond Earth sciences, potentially influencing our understanding of :

- Plate tectonics and volcanic activity
- The formation and evolution of continents
- The origins of Earth's oceans
- The potential for life in extreme environments

Other hidden water sources within Earth's crust

While the ringwoodite-bound ocean is undoubtedly the most significant discovery, it's not the only hidden water source within our planet. The Earth's crust harbors numerous other reservoirs that contribute to the global water cycle. These include :

These hidden water sources play crucial roles in various geological processes, including tectonics, magmatism, and the overall water cycle. Their existence and interactions continue to fascinate scientists and drive further research into Earth's complex hydrological systems.

Implications for future research and understanding

The discovery of this massive subterranean ocean opens up new avenues for scientific exploration and raises intriguing questions about our planet's formation and evolution. As we continue to unravel the mysteries of Earth's inner workings, we may find ourselves *rewriting textbooks* and reassessing long-held beliefs about the origins and distribution of water on our planet.

This groundbreaking finding serves as a reminder of the **vast unknowns that still exist within our own world**. It underscores the importance of continued scientific inquiry and the potential for revolutionary discoveries that can reshape our understanding of Earth and its systems.

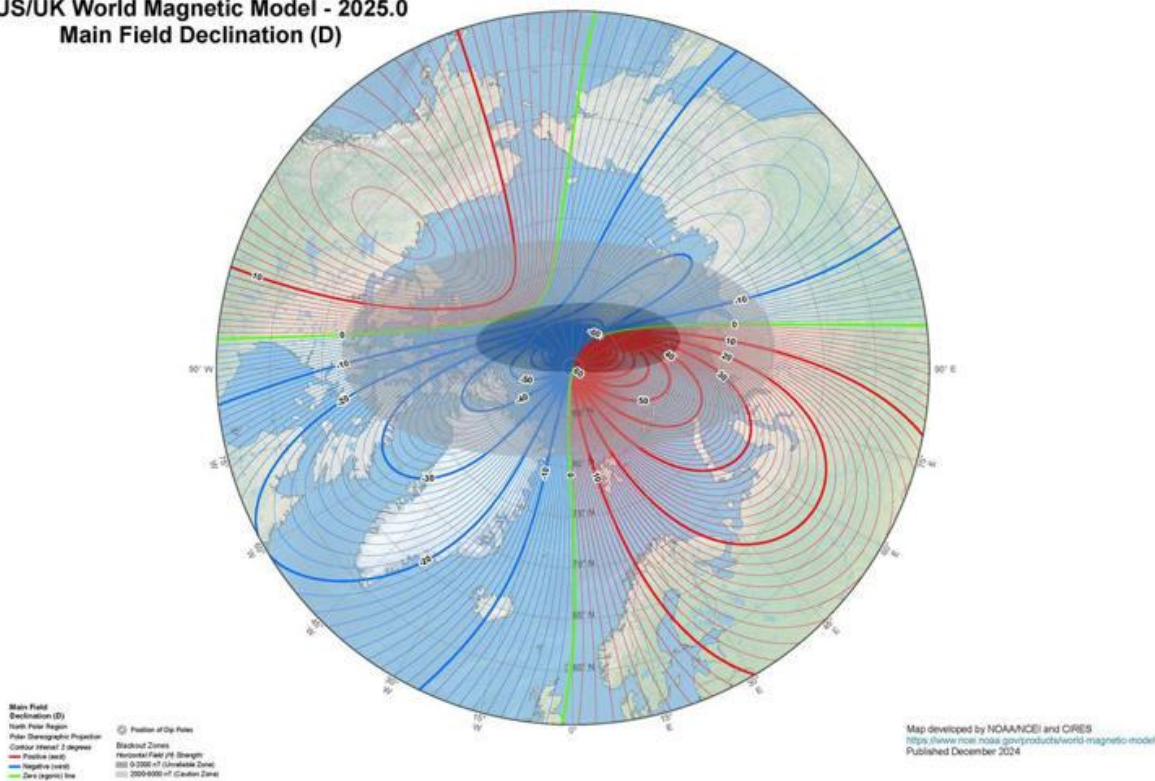
As we look to the future, this discovery may have far-reaching implications for fields beyond geology, including :

- Climate science and the study of long-term water cycle patterns
- The search for extraterrestrial life and potentially habitable environments
- Resource management and the exploration of new water sources
- Our understanding of planetary formation and evolution in the broader context of our solar system

The unveiling of this hidden ocean beneath our feet serves as a powerful reminder of the wonders that still await discovery on our home planet. As we continue to probe the depths of Earth, we may find that the most astonishing revelations lie not in the vast expanse of space, but in the unexplored realms right beneath our very feet.

Earth's Magnetic North Pole Officially Has A New Position

US/UK World Magnetic Model - 2025.0
Main Field Declination (D)



Feast your eyes on the World Magnetic Model 2025, one of the key tools developed to model the change in Earth's magnetic field. - Image credit: NOAA/NCEI.© IFL Science

Hoping to keep tabs on the magnetic north's wandering ways, the World Magnetic Model 2025 has been released this week, revealing the latest official predicted placement of Earth's magnetic fields. This version will remain valid until

late 2029, during which time we can expect to see the magnetic north pole slowly edge further toward Russia.

Earth's magnetic north pole is different from the geographic North Pole. The latter (the so-called "True North") directly points toward the geographic North Pole, a fixed point on the Earth's surface located at 90° North latitude where the Earth's axis of rotation meets the surface.

Meanwhile, the magnetic north pole is an ever-changing point that's dictated by liquid metals sloshing around Earth's outer core. These molten metals are conductive and in constant motion due to the planet's rotation and heat-driven convection. In tune with the principles of electromagnetism, the movement creates electric currents, which generate a magnetic field with two poles.

Since the magnetic poles are constantly moving, albeit very slowly, the NOAA and the British Geological Survey (BGS) have to regularly revise their models.

On December 17, they [released the latest update](#), including the new World Magnetic Model High Resolution (WMMHR2025). WMMHR2025 offers a significant improvement in spatial resolution – approximately 300 kilometers (186 miles) at the equator – compared to the standard model's resolution of 3,300 kilometers (2,050 miles) at the equator.

The update is extremely important for technology that relies on the Earth's magnetic field, namely the Global Positioning System (GPS) and other satellite-based navigation systems used elsewhere in the world.

The new version is of timely importance too as the magnetic north pole's movement [seems to be accelerating](#).

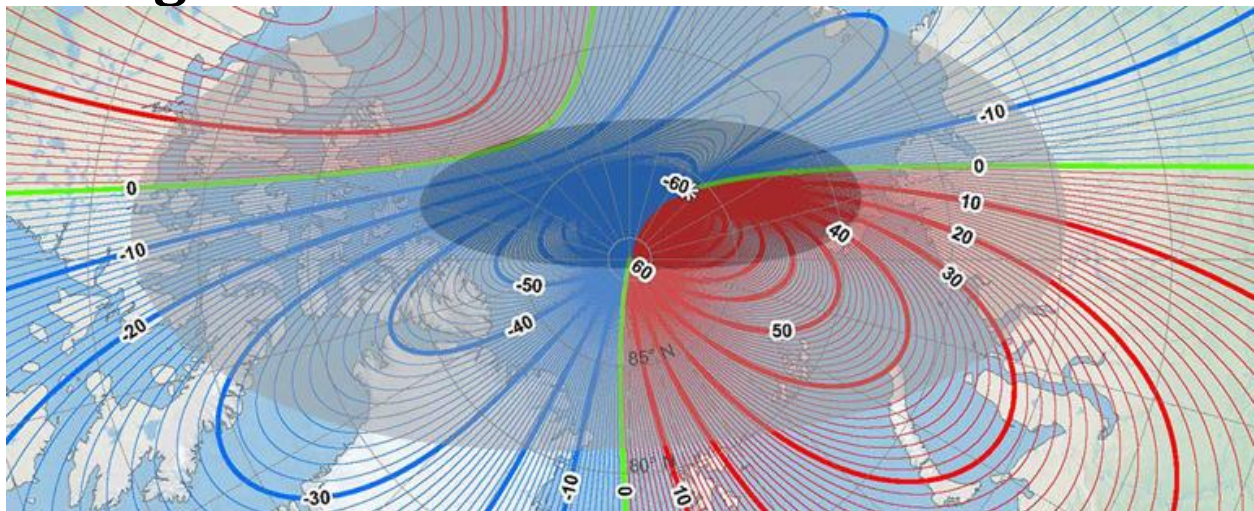
Since the 1830s, the north magnetic pole of Earth has relocated some 2,250 kilometers (1,400 miles) across the upper stretches of the Northern Hemisphere from Canada towards Siberia. Between 1990 and 2005, the rate of pole movement increased from less than 15 kilometers (9.3 miles) per year to around 50 to 60 kilometers (31 to 37 miles) per year.

"The WMM is officially released today, ensuring users can have the most up-to-date information so they can continue to navigate accurately for the next five

years,” Dr William Brown, global geomagnetic field modeler at BGS, said in a [statement](#).

“The current behavior of magnetic north is something that we have never observed before. Magnetic north has been moving slowly around Canada since the 1500s but, in the past 20 years, it accelerated towards Siberia, increasing in speed every year until about five years ago, when it suddenly decelerated from 50 to 35 km per year, which is the biggest deceleration in speed we’ve ever seen,” added Dr. Brown.

The Magnetic North Pole Has Officially Changed Position

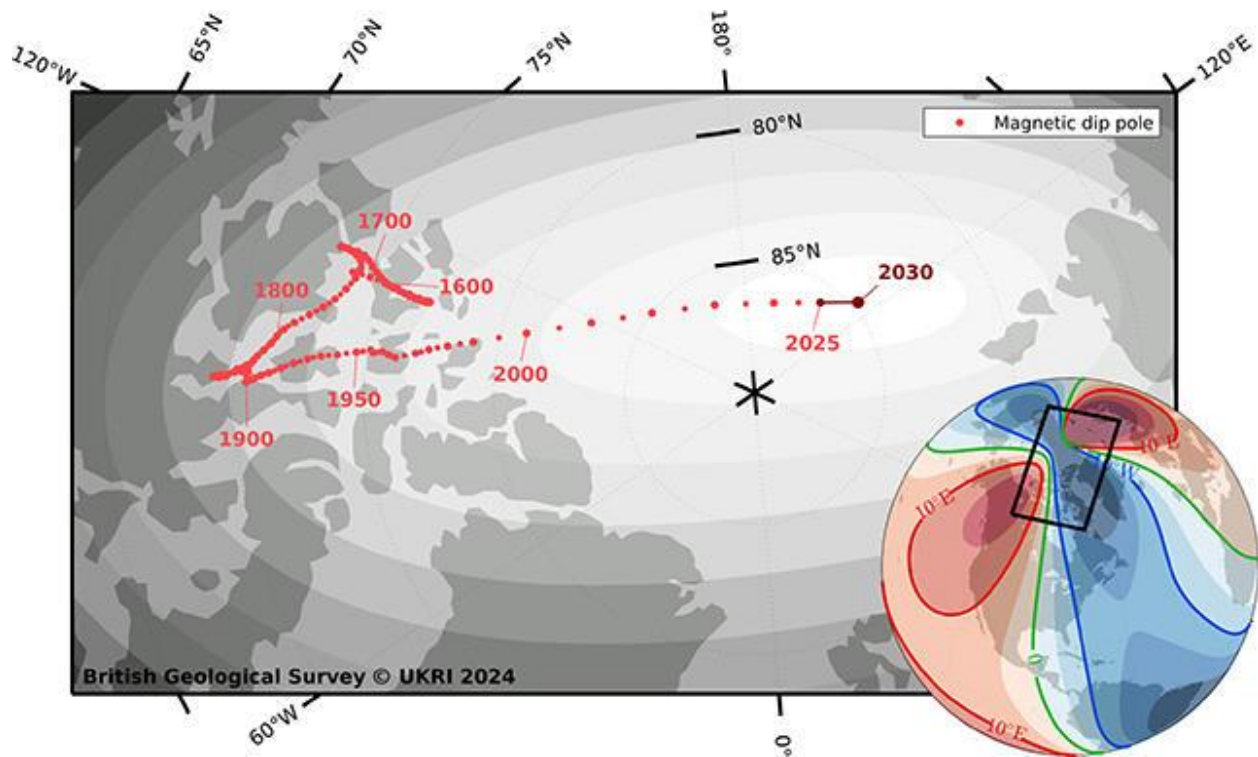


World Magnetic Model

It's time to recalibrate the navigation systems on ships, airplanes, and (given the time of year) Santa's sleigh: the position of the [magnetic North Pole](#) is officially being changed, continuing its shift away from Canada and towards Siberia.

Experts from the US National Oceanic and Atmospheric Administration (NOAA) and the British Geological Survey (BGS) have joined forces – as they do every five years – to produce a new, more accurate [World Magnetic Model](#) (WMM).

While the geographical North Pole stays fixed in place (at the very summit of the Earth's rotational axis), the WMM pinpoints the magnetic North Pole – where Earth's magnetic field points straight down, a perfectly vertical magnetic field.



Magnetic north has shifted a lot over the centuries. (BGS)

And as the iron and nickel [inside our planet shift](#), so does Earth's magnetic field, meaning the North (and South) Poles are also constantly on the move. If you're using a compass or a GPS system, knowing exactly where these points are is crucial.

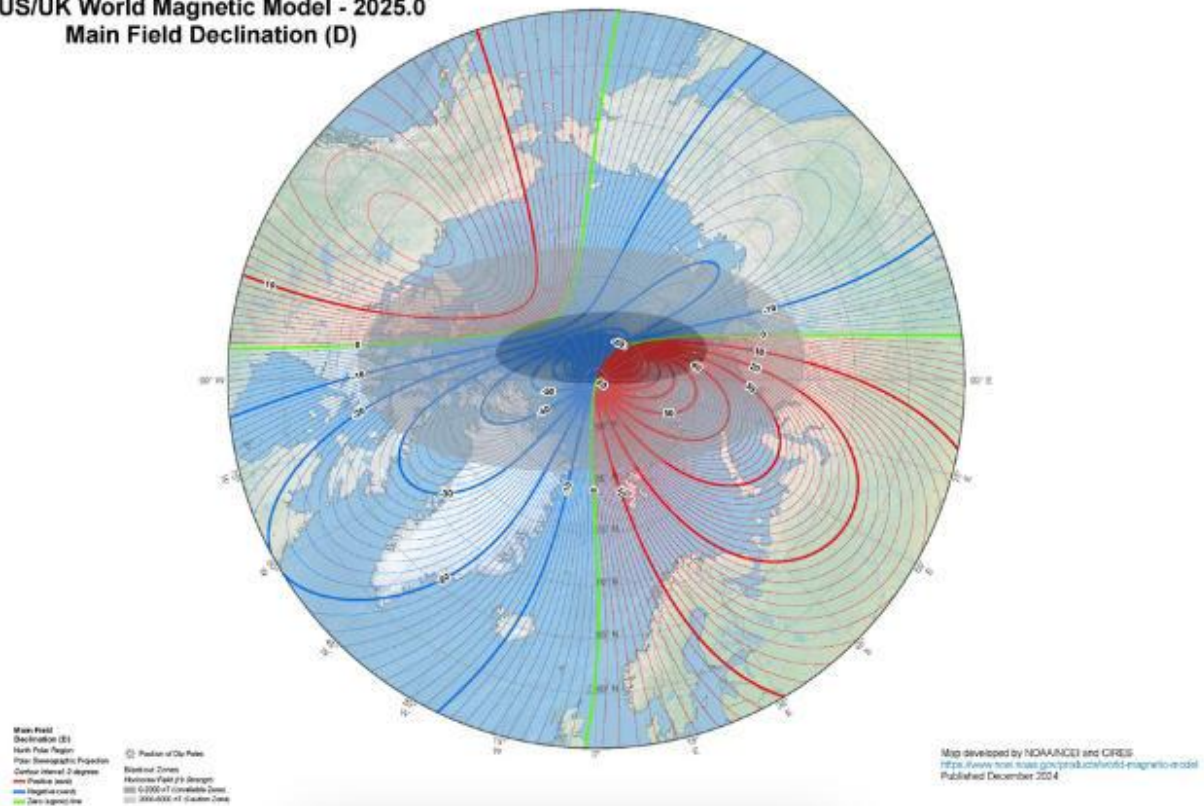
"The current behaviour of magnetic north is something that we have never observed before," [says](#) global geomagnetic field modeller William Brown, from BGS.

"Magnetic north has been moving slowly around Canada since the 1500s but, in the past 20 years, it accelerated towards Siberia, increasing in speed every year until about five years ago, when it suddenly decelerated from 50 to 35 kilometers [31 to 22 miles] per year, which is the biggest deceleration in speed we've ever seen."

[Research suggests](#) that two giant magnetic lobes – one under Canada and one under Siberia – are what's driving the shifting of magnetic north. Sometimes the shifts are dramatic enough that [an emergency update](#) is required, outside of the usual 5-year cycle.

Now we have a more accurate map of magnetic north, one that should be good for another half a decade. For the first time, a **higher resolution** map is also available, which offers more than 10 times more detail: it has a spatial resolution of about 300 km at the equator compared to the standard 3,300 km.

US/UK World Magnetic Model - 2025.0
Main Field Declination (D)



The 2025 World Magnetic Model. (NOAA/NCEI)

According to the BGS team, traveling 8,500 km (5,282 miles) from South Africa to the UK in a straight line would leave you 150 km (93 miles) off course by the end, if you used the old WMM compared to the new WMM for your navigation.

That's how much difference it can make, and mapping and logistics companies, together with governments and official agencies, will now be making updates.

However, we won't have to apply any updates to our own phones or sat navs – it'll all happen automatically.

The magnetic North Pole was first discovered by **Sir James Clark Ross** in northern Canada back in 1831.

Since then, researchers have gradually been able to track it with more precision, using ground measurements taken all across the globe as well as readings from [satellites in space](#).

Is Planet Earth Alive?



SCIENCE — [Earth and Space](#)

Have You Ever Wondered...

- Is planet Earth alive?
- What is the Gaia hypothesis?
- Who developed the Gaia hypothesis?

The conditions on other planets are often too hot, too cold, or simply too [brutal](#) to [sustain](#) life of any kind. Earth, on the other hand, boasts the perfect conditions for an [astounding](#) [variety](#) of life forms.

There are billions of human beings, [countless](#) fish in the sea, and an amazing number of animal species. If you add in the insects, bacteria, [fungi](#), and overwhelming number of different types of plants, it's clear that Earth is full of [abundant](#) life.

In the solar system, Earth may be [synonymous](#) with life, but is the planet itself alive? That's the question that some scientists have been [posing](#) for several decades now.

In one sense, it's an easy question to [dismiss](#). No, planet Earth is not a living [entity](#) like a human being, a badger, a mosquito, or even a tomato plant. That fact, however, hasn't stopped people from treating Earth like a living creature throughout time.

For example, Native Americans and other native peoples around the [globe](#) have long held the belief that Earth is alive. Even the ancient Greeks had a goddess of the Earth that they called Gaia (pronounced "Guy-uh").

The ancient Greek goddess Gaia also lends her name to a hypothesis developed in the 1970s by British chemist James Lovelock and American biologist Lynn Margulis. The Gaia hypothesis, as it's known, is a bit of a [misnomer](#), though.

It's not really a scientific hypothesis that can be tested through experimentation. Instead, the Gaia hypothesis is more like a viewpoint, a perspective, or a way of looking at the world. According to Margulis and Lovelock, Earth, rather than acting like an inanimate, non-living object, instead behaves like a living system.

For example, Lovelock and Margulis noted that Earth appears to display a form of self-regulation, otherwise known as homeostasis. Life-sustaining attributes, such as temperature, atmospheric oxygen content, and [ocean](#) salinity, have all been maintained with remarkably little variability.

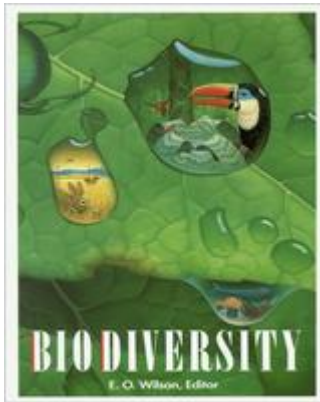
Furthermore, all of those attributes depend in many ways on living things to [sustain](#) them. While the Gaia hypothesis didn't attract much support early on, many scientists in recent years have started to look at complex systems on Earth in a new light thanks to the ideas of Lovelock and Margulis.

In essence, many scientists are now beginning to believe that Earth itself and life on Earth have evolved together over time in such a way that each has affected the other every step of the way. Rather than life on Earth simply reacting to the environment, life on Earth also affects and changes the environment around it.

Viewed in this way, Earth can be seen as a huge, complex system in which the environment and living things interact constantly to form a self-regulating [whole](#). While still not a living organism like a plant, animal, or human being, Earth can nonetheless be seen as a living system that behaves in significant ways like a living organism.

Is The Earth Alive? That Depends On Your Definition Of Life





Chapter 56 The Earth as a Living Organism

JAMES E. LOVELOCK

Launceston, Cornwall, United Kingdom

The idea that the Earth is alive may be as old as humankind. The ancient Greeks gave her the powerful name Gaia and looked on her as a goddess. Before the nineteenth century even scientists were comfortable with the notion of a living Earth. According to the historian D. B. McIntyre (1963), James Hutton, often known as the father of geology, said in a lecture before the Royal Society of Edinburgh in the 1790s that he thought of the Earth as a superorganism and that its proper study would be by physiology. Hutton went on to make the analogy between the circulation of the blood, discovered by Harvey, and the circulation of the nutrient elements of the Earth and of the way that sunlight distills water from the oceans so that it may later fall as rain and so refresh the earth.

This wholesome view of our planet did not persist into the next century. Science was developing rapidly and soon fragmented into a collection of nearly independent professions. It became the province of the expert, and there was little good to be said about interdisciplinary thinking. Such introspection was inescapable. There was so much information to be gathered and sorted. To understand the world was a task as difficult as that of assembling a planet-size jigsaw puzzle. It was all too easy to lose sight of the picture in the searching and sorting of the pieces.

When we saw a few years ago those first pictures of the Earth from space, we had a glimpse of what it was that we were trying to model. That vision of stunning beauty; that dappled white and blue sphere stirred us all, no matter that by now it is just a visual cliché. The sense of reality comes from matching our personal mental image of the world with that we perceive by our senses. That is why the astronaut's

view of the Earth was so disturbing. It showed us just how far from reality we had strayed.

The Earth was also seen from space by the more discerning eye of instruments, and it was this view that confirmed James Hutton's vision of a living planet. When seen in infrared light, the Earth is a strange and wonderful anomaly among the planets of the solar system. Our atmosphere, the air we breathe, was revealed to be outrageously out of equilibrium in a chemical sense. It is like the mixture of gases that enters the intake manifold of an internal combustion engine, i.e., hydrocarbons and oxygen mixed, whereas our dead partners Mars and Venus have atmospheres like gases exhausted by combustion.

The unorthodox composition of the atmosphere radiates so strong a signal in the infrared range that it could be recognized by a spacecraft far outside the solar system. The information it carries is *prima facie* evidence for the presence of life. But more than this, if the Earth's unstable atmosphere was seen to persist and was not just a chance event, then it meant that the planet was alive—at least to the extent that it shared with other living organisms that wonderful property, homeostasis, the capacity to control its chemical composition and keep cool when the environment outside is changing.

When on the basis of this evidence, I reanimated the view that we were standing on a superorganism rather than just a ball of rock (Lovelock, 1972; 1979), it was not well received. Most scientists either ignored it or criticized it on the grounds that it was not needed to explain the facts of the Earth. As the geologist H. D. Holland (1984, p. 539) put it, "We live on an Earth that is the best of all possible worlds only for those who are well adapted to its current state." The biologist Ford Doolittle (1981) said that keeping the Earth at a constant state favorable for life would require foresight and planning and that no such state could evolve by natural selection. In brief, scientists said, the idea was teleological and untestable. Two scientists, however, thought otherwise; one was the eminent biologist Lynn Margulis and the other the geochemist Lars Sillen. Lynn Margulis was my first collaborator (Margulis and Lovelock, 1974). Lars Sillen died before there was an opportunity. It was the novelist William Golding (personal communication, 1970), who suggested using the powerful name Gaia for the hypothesis that supposed the Earth to be alive.

In the past 10 years these criticisms have been answered—partly from new evidence and partly from the insight provided by a simple mathematical model called Daisy world. In this model, the competitive growth of light- and dark-colored plants on an imaginary planet are shown to keep the planetary climate constant and comfortable in the face of a large change in heat output of the planet's

star. This model is powerfully homeostatic and can resist large perturbations not only of solar output but also of plant population. It behaves like a living organism, but no foresight or planning is needed for its operation.

Scientific theories are judged not so much by whether they are right or wrong as by the value of their predictions. Gaia theory has already proved so fruitful in this way that by now it would hardly matter if it were wrong. One example, taken from many such predictions, was the suggestion (Lovelock et al., 1972) that the compound dimethyl sulfide would be synthesized by marine organisms on a large scale to serve as the natural carrier of sulfur from the ocean to the land. It was known at the time that some elements essential for life, like sulfur, were abundant in the oceans but depleted on the land surfaces. According to Gaia theory, a natural carrier was needed and dimethyl sulfide was predicted. We now know that this compound is indeed the natural carrier of sulfur, but at the time the prediction was made, it would have been contrary to conventional wisdom to seek so unusual a compound in the air and the sea. It is unlikely that its presence would have been sought but for the stimulus of Gaia theory.

Gaia theory sees the biota and the rocks, the air, and the oceans as existing as a tightly coupled entity. its evolution is a single process and not several separate processes studied in different buildings of universities.

It has a profound significance for biology. It affects even Darwin's great vision, for it may no longer be sufficient to say that organisms that leave the most progeny will succeed. It will be necessary to add the proviso that they can do so only so long as they do not adversely affect the environment.

Gaia theory also enlarges theoretical ecology. By taking the species and the environment together, something no theoretical ecologist has done, the classic mathematical instability of population biology models is cured.

For the first time, we have from these new, these geophysiological models a theoretical justification for diversity, for the Rousseau richness of a humid tropical forest, for Darwin's tangled bank. These new ecological models demonstrate that as diversity increases so does stability and resilience. We can now rationalize the disgust we feel about excesses of agribusiness. We have at last a reason for our anger over the heedless deletion of species and an answer to those who say it is mere sentimentality.

No longer do we have to justify the existence of the humid tropical forests on the feeble grounds that they might carry plants with drugs that could cure human disease. Gaia theory forces us to see that they offer much more than this. Through their capacity to evapotranspire vast volumes of water vapor, they serve to keep the

planet cool by wearing a sunshade of white reflecting clouds. Their replacement by cropland could precipitate a disaster that is global in scale.

A geophysiological system always begins with the action of an individual organism. If this action happens to be locally beneficial to the environment, then it can spread until eventually a global altruism results. Gaia always operates like this to achieve her altruism. There is no foresight or planning involved. The reverse is also true, and any species that affects the environment unfavorably is doomed, but life goes on.

Does this apply to humans now? Are we doomed to precipitate a change from the present comfortable state of the Earth to one almost certainly unfavorable for us but comfortable to the new biosphere of our successors? Because we are sentient there are alternatives, both good and bad. In some ways the worse fate in store for us is that of becoming conscripted as the physicians and nurses of a geriatric planet with the unending and unseemly task of forever seeking technologies to keep it fit for our kind of life—something that until recently we were freely given as a part of Gaia.

Gaia philosophy is not humanist. But being a grandfather with eight grandchildren I need to be optimistic. I see the world as a living organism of which we are a part; not the owner, nor the tenant, not even a passenger. To exploit such a world on the scale we do is as foolish as it would be to consider our brains supreme and the cells of other organs expendable. Would we mine our livers for nutrients for some short-term benefit?

Because we are city dwellers, we are obsessed with human problems. Even environmentalists seem more concerned about the loss of a year or so of life expectation through cancer than they are about the degradation of the natural world by deforestation or greenhouse gases—something that could cause the death of our grandchildren. We are so alienated from the world of nature that few of us can name the wild flowers and insects of our locality or notice the rapidity of their extinction.

Gaia works from an act of an individual organism that develops into global altruism. It involves action at a personal level. You well may ask, So what can I do? When seeking to act personally in favor of Gaia through moderation, I find it helpful to think of the three deadly Cs: combustion, cattle, and chain saws. There must be many others.

One thing you could do, and it is no more than an example, is to eat less beef. If you do this, and if the clinicians are right, then it could be for the personal benefit

of your health; at the same time, it might reduce the pressures on the forests of the humid tropics.

To be selfish is human and natural. But if we chose to be selfish in the right way, then life can be rich yet still consistent with a world fit for our grandchildren as well as those of our partners in Gaia.



Is the Earth itself a giant living creature?

An old, much-ridiculed hypothesis said yes. It's time to take it seriously.

by [Brian Resnick](#)

Apr 22, 2024,

[Brian Resnick](#) was Vox's science and health editor and is the co-creator of *Unexplainable*, Vox's podcast about unanswered questions in science.

In the 1970s, chemist James Lovelock and microbiologist Lynn Margulis put forth a bold theory: [The Earth is a giant living organism](#).

When a mammal is hot, it sweats to cool itself off. If you nick your skin with a knife, the skin will scab and heal. Lovelock and Margulis argued that our planet has similar processes of self-regulation, which arguably, make it seem like the Earth itself is alive.

The idea wasn't unprecedented in human history. "The fundamental concept of a living world is ancient," says [Ferris Jabr](#), a science journalist and author of the upcoming book [Becoming Earth: How Our Planet Came to Life](#). The book explores all the ways life has shaped our physical world and, in doing so, inevitably revisits the question "Is the Earth alive?"

Lovelock and Margulis called the idea "the Gaia Hypothesis" — named after the ancient Greek goddess of the Earth. It was openly mocked by many in mainstream Western science. "For many decades, the Gaia hypothesis was considered kind of this fringe sort of woo-woo idea," Jabr says. "Because for biologists," Jabr says, life is a specific thing. "It is typically thought of as an organism that is a product of Darwinian evolution by natural selection. And Earth as a planet does not meet those criteria."

It didn't help that the original articulation of Gaia granted Earth a certain degree of sentience. The hypothesis argued "all of the living organisms on Earth are [collaborating](#) to [deliberately](#) create a climate that is suitable for life," as Jabr says. But yet, this idea has persisted, for a few reasons. Scientists have never been able to precisely define [what life is](#). So, it's been hard to dismiss Gaia completely.

The Gaia hypothesis has also evolved over the years. Later iterations deemphasized that life was "collaborating" to transform the Earth, Jabr explains. Which still leaves a lot to be explored: Certainly living things don't need to be thought of as conscious, or have agency, to be considered alive. Consider the clam, which lacks a central nervous system.

Jabr found in the years since Gaia was first introduced, scientists have uncovered more connections between biology, ecology, and geology, which make the boundaries between these disciplines appear even more fuzzy. The Amazon rainforest essentially “[summons](#)” its own rain, as Jabr explains in his book. They learned how life [is involved in the process](#) that generated the continents. Life plays a role in [regulating Earth’s temperature](#). They’ve learned that just about everywhere you look on Earth, you find life influencing the physical properties of our planet.

In reporting his book, Jabr comes to the conclusion that not only is the Earth indeed a living creature, but thinking about it in such a way might help inspire action in dealing with the [climate crisis](#).

Brian Resnick spoke to Jabr for an episode of [Unexplainable](#), Vox’s podcast that explores scientific mysteries, unanswered questions, and all the things we learn by diving into the unknown. You can [listen to the full conversation here](#). This interview has been edited for length and clarity.

Brian Resnick

Do you think the Earth is alive?

Ferris Jabr

I do. I think Earth is alive. We can think of Earth as a genuine living entity, in a meaningful sense, and in a scientific sense. There are four parts to the argument that substantiate that statement.

Brian Resnick

What’s the first?

Ferris Jabr

Life isn’t just [on](#) Earth. It literally [came out](#) of Earth. It is literally part of Earth. It is Earth. All of the matter that we refer to as life is Earth animated — that’s how I come to think about it. If you accept that, then at a bare minimum, you

have to accept as a scientific fact that the surface of the planet is genuinely alive, because it is matter that has become animated.

Brian Resnick

Earth animated? What do you mean by that?

Ferris Jabr

Every single living organism is literally made of Earth. All of its constituent elements and components are parts of the planet. We all come from the planet. We all return to the planet. It's just a big cycle. And so life, the biological matter on the planet, is literally the matter of the planet, animated. It is *living matter*.

Imagine a vast beach and sandcastles and other sculptures spontaneously emerge from the sand. They are still made of sand, right? They're not suddenly divorced from the beach just because they've arisen from the beach. Those castles and sculptures are still literally the beach. And I think it's the same with life and Earth.

Brian Resnick

So, the physical components of Earth are the material of life. And so distinguishing these two — Earth and life — seems silly because they comprise each other?

Ferris Jabr

The more you think about this, the more the boundaries dissolve.

Every layer of the planet that we've been able to access, we find life there. And in the deepest mines that we have dug, we continue to find microbes and sometimes even more complex organisms like nematodes, these tiny, worm-like creatures.

Brian Resnick

So all life contains Earth, and Earth contains life?

Ferris Jabr

There are components of the Earth that are not alive in any way. The center of the planet, it's all molten rock and there might be some solid metal in the core.

But think about a redwood tree: It is mostly dead wood in terms of its volume and mass. It is mostly nonliving tissue. And then a little bit of tissue that is laced with living cells. So, you know, most complex multicellular living entities are a jumble of the animate and inanimate. Earth is not unusual in that way.

Brian Resnick

What is part two of your argument?

Ferris Jabr

All these organisms [on Earth], they give Earth a kind of anatomy and physiology. Life dramatically increases the planet's capacity to absorb, store, and transform energy, to exchange gases, and to perform complex chemical reactions.

Brian Resnick

What's a good example of this?

Ferris Jabr

You can think of all of the photosynthetic life on the planet acting in concert. It's not that they're deliberately collaborating to do something, but they're all doing their own thing at the same time.

[NASA](#) has made these amazing videos and animations and they've literally called them "[Earth breathing](#)," because you can see how the levels of carbon dioxide and oxygen in the atmosphere fluctuate with the seasons. The amount

of vegetation that rings the continents, especially in the Northern Hemisphere, in the mid-latitudes, it changes dramatically with the seasons. It has a sinuous rhythm. It looks like a pulse or like breathing.

Brian Resnick

So, are you saying something like all of the algae or plankton in the ocean are generating this together? ... Is that kind of like how all of the cells in my lungs are working together to exchange gases? Or is that not quite the right way to think about it?

Ferris Jabr

I think we have to be careful with making too direct a comparison. You as an organism are a product of evolution by natural selection. Your structure, your anatomy is something that was written into your genome. That's not how the Earth system formed.

Brian Resnick

I'm realizing a key to this conversation is what you just corrected me on. When we're discussing this notion about the "Earth being alive," we're not suggesting it's not alive in the same way you and I are. But there's these equivalent processes that look very similar to the way my body maintains homeostasis, for example. It's not like the Earth is exchanging gases and doing metabolism-like things in the way I've been evolved to. It's not achieving homeostasis the way you or I do. But yet it is doing something that seems analogous. Is that the kind of thing that you're arguing here, overall?

Ferris Jabr

Absolutely.

When we're looking at the planet, we see life-like qualities, things that resemble the characteristics of the organism, which is the most familiar life form to us. But it is not exactly the same. It is still genuinely alive, in my opinion, but is not exactly an organism.

Life is a phenomenon that occurs at multiple scales. The way I think of it is that it's not identical at all of those scales, but it rhymes and there are analogies between each of those scales.

I like to think of a leaf on a tree in a forest on a planet.

There's no disagreement whatsoever within science that the cells that compose that leaf are alive. The tissues that those cells form are alive. The leaf as a whole is a living tissue. The tree we consider an organism that is also alive. We consider each of those layers to be alive. There's no debate or controversy about that.

Once we go above the scale of the organism, this is where the debate begins. Can we think of the forest, the ecosystem, as alive as well? And then one more level higher. Can we think of the planet as alive?

My argument is, yes, that each of those levels, each of those scales is equally alive but not identical. And there are analogous processes that happen at each. But they're not exactly the same.

Brian Resnick

What is the next plank of your argument?

Ferris Jabr

Life is also an engine of planetary evolution. The planet evolves over time dramatically. It is not exactly the same as standard Darwinian evolution through natural selection, but it is very much a type of evolution.

Organisms and their environments continually co-evolve. Each is profoundly changing the other.

This reciprocal transformation is responsible for many of the planet's defining features: for our breathable atmosphere, our blue sky, our bountiful oceans, our fertile soils. This is all because of life and because of the way that life has

changed the planetary environments. These are not default features of the planet. Life has created them over time.

Brian Resnick

What is the most stunning example of how life has actually changed the planet?

Ferris Jabr

In the beginning, Earth had essentially no free oxygen in its atmosphere, and the sky was probably a hazy orange. And when cyanobacteria began to oxygenate the atmosphere through the innovation of photosynthesis, the sky probably started shifting toward the blue part of the spectrum.

The entire chemistry of the planet changed. I mean, you suddenly had an oxygen-rich environment, whereas before it was an oxygen-poor environment. That changes absolutely everything.

Brian Resnick

Okay, so to get back to what you were saying before, it's not that Earth evolves in the same way that organisms evolve. But it evolves with a different mechanism, is that right?

Ferris Jabr

Evolutionary biologists will say a planet cannot evolve because it doesn't have a cohesive genome. There's no genetic inheritance going on; there's no sexual reproduction going on.

But there are analogous processes by which changes are passed down from generation to generation that are not genetically encoded.

If we think about a bunch of large mammals, they're transforming their landscape [by walking through it](#) with their immense hefts. They're tearing

down vegetation. They're digging in, uprooting things. They're changing the landscape.

Those changes persist. And so their descendants now are evolving in a new environment changed by their predecessors. These environmental changes are not themselves genetically encoded, but they are being passed from generation to generation, and they are inevitably influencing the evolution that follows.

Brian Resnick

If a fundamental part of life is that it changes the world in which it exists, how are we different for accelerating the climate crisis? Because you look at the history of the Earth and you say, well, life has powerfully changed it. Who's to say what we're doing is necessarily not a natural process?

Ferris Jabr

It's simultaneously humbling and empowering to recognize ourselves as simply the latest chapter in this long evolutionary saga of life changing the planet. It is a basic property of life to change its environment, and we're not an exception to that.

But I do think there's a major distinction between what our species has done and what has happened before in terms of the combined scale and speed and the variety of our changes to the planet. I don't think there's any species or creature before us that has changed the planet on such a large scale so quickly and in so many different ways simultaneously.

We have radically altered the atmosphere, the oceans, and the continents. We've done it in a couple of centuries. That's a huge part of the reason for why the crisis we're going through right now is a crisis. It has so much to do with the scale and the speed of it.

Brian Resnick

What's part four of your argument?

Ferris Jabr

This co-evolution, on the whole, has amplified the planet's capacity for self-regulation and enhanced Earth's resilience. Earth has remained alive for, you know, around 4 billion years, despite repeated catastrophes of unfathomable scale, unlike anything that we have ever experienced in human history. We have to account for that resilience, for that incredible persistence through time.

It is not a deliberate thing. You know, it is not a conscious or collaborative thing. It is simply an inevitable physical process, just as evolution by natural selection is an inevitable physical process.

Even in the mass extinctions in Earth's history, life recedes to its most fundamental and most resilient forms: *microbes*. And then life sprouts from there.

Brian Resnick

Are you sure you're right about all this? Is the scientific community coming around to accept this notion that Earth is indeed alive?

Ferris Jabr

I mean, this book is my personal synthesis, an argument. You know, this is my viewpoint. This is how I have come to see the Earth. There are scientists who agree with me, but I would not say that this is the consensus of modern mainstream science. I think the statement that Earth is alive remains quite controversial and provocative. However, everything else we've been talking about, the co-evolution of life and environment, the fact that life has profoundly changed the planet. These are all well-accepted points.

Brian Resnick

Which part are you most likely wrong about? Or which part do you feel like has the most room for doubt?

Ferris Jabr

We do not have a precise, universally accepted definition of life. We haven't explained it on the most fundamental level. Like 100 years from now, will we have a fundamental explanation for life that we're missing right now? And if we do, will that make thinking of planets as alive defunct? And so, I think open-mindedness is fundamental to any scientific thinking or scientific process. And we have to be open to the idea that a century from now, or even sooner, all of this will be wrong.

And that's part of what I find thrilling: We don't have all of the answers yet. Right? These are incredibly challenging ideas and concepts that we are still working out. If we had figured it out, then we wouldn't be talking about the Gaia hypothesis anymore. The Gaia would have been officially dead a long time ago. But I think the reason that it remains relevant and continues to be debated means that we just haven't figured it out yet.

Brian Resnick

Why is it useful to think of the Earth as alive?

Ferris Jabr

There's a massive difference between thinking of ourselves as living creatures that simply reside on a planet, that simply inhabit a planet, versus being a component of a much larger living entity. When we properly understand our role within the living Earth system, I think the moral urgency of the climate crisis really comes into focus.

All of a sudden it's not just that, *oh, the bad humans have harmed the environment and we need to do something about it.* It's that each of us is literally Earth animated, and we are one part of this much larger, living entity. It's a realization that everything that we are all doing moment to moment, day to day, is affecting this larger living entity in some way.

Brian Resnick

So, the simple point that you're making is that we are Earth, and don't self-harm.

Ferris Jabr

Right, exactly.



The Earth as viewed from the ISS (NASA)

Gaia Hypothesis: Could Earth Really be a Single Organism?

Can a planet like Earth be considered a single living organism? After all, the human body is composed of hundreds of billions of bacteria, and yet we consider the human body to be a single organism. The Gaia Hypothesis (or popularly known as “Gaia Theory”) goes beyond the individual organisms living on Earth, it encompasses all the living and non-living components of Earth’s biosphere and proposes that the complex interacting systems regulate the environment to a very high degree (here’s a biosphere definition). So much so, that the planet may

be viewed as a single organism in its own right. *What's more this hypothesis was developed by a NASA scientist who was looking for life on Mars...*

When you stop to think about it, our planet *does* act like a huge organism. If you look at the interrelationship between plants and atmospherics, animals and humans, rocks and water, a complex pattern of symbiotic processes seem to complement each other perfectly. Should one system be pushed out of balance by some external force (such as a massive injection of atmospheric carbon dioxide after a volcanic event), other processes are stimulated to counteract the instability (more phytoplankton appear in the oceans to absorb the carbon dioxide in the water). Many of these processes could be interpreted as a “global immune system”.

The hypothesis that our planet could be a huge organism was the brain child of British scientist Dr James Lovelock. In the 1960's when Lovelock was working with NASA on methods to detect life on the surface of Mars, his hypothesis came about when trying to explain why Earth has such high levels of carbon dioxide and nitrogen. Lovelock recently defined Gaia as:

“...organisms and their material environment evolve as a single coupled system, from which emerges the sustained self-regulation of climate and chemistry at a habitable state for whatever is the current biota.” – Lovelock J. (2003) The living Earth. Nature 426, 769-770.

So, Lovelock's work points to interwoven ecological systems that promote the development of life currently living on Earth. Naturally, the statement that Earth itself is actually one living organism encompassing the small-scale mechanisms we experience within our biosphere is a highly controversial one, but there are some experiments and tests that have been carried out to support his theory. Probably the most famous model of the Gaia hypothesis is the development of the “Daisyworld” simulation. Daisyworld is an imaginary planet whose surface is either covered in white daisies, black daisies or nothing at all. This imaginary world orbits a sun, providing the only source of energy for the daisies to grow. Black daisies have a very low albedo (i.e. they do not reflect the

sun's light), thereby getting hot and heating up the atmosphere surrounding them. White daisies have a high albedo, reflecting all the light back out of the atmosphere. The White daisies stay cool and do not contribute to atmospheric warming.

When this basic computer simulation runs, a rather complex picture emerges. In the aim of optimizing the growth of daisies on Daisyworld, the populations of white and black daisies fluctuate, regulating the atmospheric temperatures. When the simulation starts, there are huge changes in population and temperature, but the system quickly stabilizes. Should the solar irradiance suddenly change, the white:black daisy ratio compensates to stabilize atmospheric temperatures once more. The simulated Daisyworld plants are self-regulating atmospheric temperature, optimizing their growth.

This is an oversimplified view of what might be happening on Earth, but it demonstrates the principal argument that Gaia is a collection of self-regulating systems. Gaia helps to explain why atmospheric gas quantities have remained fairly constant since life formed on Earth. Before life appeared on our planet 2.5 billion years ago, the atmosphere was dominated by carbon dioxide. Life quickly adapted to absorb this atmospheric gas, generating nitrogen (from bacteria) and oxygen (from photosynthesis). Since then, the atmospheric components have been tightly regulated to optimize conditions for the biomass. Could it also explain why the oceans aren't too salty? Possibly.

This self-regulatory system is not a conscious process; it is simply a [collection of feedback loops](#), all working to optimize life on Earth. The hypothesis also does not interfere with the evolution of species or does it point to a "creator". In its moderate form, Gaia is a way of looking on the dynamic processes on our planet, providing an insight to how the seemingly disparate physical and biological processes are actually interlinked. As to whether Gaia exists as an organism in its own right, it depends on your definition of "organism" (the fact that Gaia cannot reproduce itself is a major drawback for viewing Earth as an organism), but it certainly makes you think...

Is The Earth A Living Organism

October 26, 2022

[Science Journalist](#)

THE LIVING ORGANISM WE CALL EARTH. IS THE PLANET Earth “alive”? Not just in the metaphoric sense of bearing life, but as an actual, living global superorganism? Many ancient peoples never doubted that all nature was part of an Earth Spirit — that the Earth was in fact alive. To the Greeks, the spirit was the earth goddess they called Gaia. The more that modern science learns about life’s secret ways and the planet that biology has conquered, the more tenable becomes a rational version of Gaia. It grows increasingly difficult, in the view of at least some scientists, not to conclude that Earth’s atmosphere, its seas, its lands and all the biota they contain have acted symbiotically — interdependently — through eons as a single living organic complex. The Gaia hypothesis violates the conventional scientific wisdom that life merely adapted to pre-existing terrestrial conditions, that it is essentially a rider on what Buckminster Fuller called “Spaceship Earth. ” By contrast, the Gaia hypothesis suggests that life has played an active role to sustain itself by modifying and controlling the environment on a planet-wide scale — most importantly by regulating Earth’s temperature and its supplies of oxygen and carbon dioxide.

Sulfur finding may hold key to Gaia theory of Earth as living organism

Is Earth really a sort of giant living organism as the Gaia hypothesis predicts? A new discovery may provide a key to answering this question. This key of sulfur could allow scientists to unlock heretofore hidden interactions between ocean organisms, atmosphere, and land — interactions that might provide evidence supporting this famous theory.

Is Earth really a sort of giant living organism as the Gaia hypothesis predicts? A new discovery made at the University of Maryland may provide a key to answering this question. This key of sulfur could allow scientists to unlock heretofore hidden interactions between ocean organisms, atmosphere, and land — interactions that might provide evidence supporting this famous theory.

Newly published work done at the University of Maryland by first author Harry Oduro, together with UMD geochemist James Farquhar and marine biologist Kathryn Van Alstyne of Western Washington University, provides a tool for tracing and measuring the movement of sulfur through ocean organisms, the atmosphere and the land in ways that may help prove or disprove the controversial Gaia theory. Their study appears in this week’s Online Early Edition of the Proceedings of the National Academy of [Sciences](#) (PNAS).

What If the Earth Was One Living Organism? – INSH | Could we all be part of one giant superorganism?

One such critic is an evolutionary biologist named Dr. Ford Doolittle — yup, Dr. Doolittle. He argues that the entire theory violates the scientific method since it only provides ideas, but offers no real explanation of exactly how organisms could act together to maintain a balance of life on Earth.

Imagining Gaia, the Earth, as ‘one great, living organism’

James Lovelock’s hypothesis could unlock a whole-systems approach to protecting the amazing life forms on Earth.

Over 50 years ago, scientist James Lovelock hit upon the idea that Earth is a complex, self-regulating organism. At the suggestion of a friend, novelist William Golding, he called his idea the Gaia hypothesis, after the Greek goddess who symbolizes Earth. Simply put, the Gaia hypothesis says that Earth is a living system and uses similar mechanisms that living creatures use to stay alive, by constantly regulating temperature, chemical and physical inputs and outputs and adaptation through evolution. Lovelock, who turned 101 in 2021, came up with his idea in the 1960s, when NASA asked him to see if his inventions in chemical analysis could detect life on other planets by looking at their atmospheres. Venus, our nearest neighbor at 25 million miles closer to the Sun than Earth, is literally a hot mess, with steady surface temperatures of nearly 900 degrees Fahrenheit and an atmosphere of mostly carbon dioxide laced with bits of sulfur droplets — not hospitable for life forms we know. Mars, 100 million miles further from the Sun than Earth, is a bit less hostile to life, with days of searing heat and nights of deep cold.

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Ecosphere, Biosphere, or Gaia? What to Call the Global Ecosystem on JSTOR

The terms biosphere, ecosphere, and Gaia are used as names for the global ecosystem. However, each has more than one meaning. Biosphere can mean the totality of living things residing on the Earth, the space occupied by living things, or life and life-support systems (atmosphere, hydrospheres, lithosphere, and pedosphere). Ecosphere is used as a synonym of biosphere and as a term for zones in the universe where life as we know it should be sustainable. Gaia is similar to biosphere (in the sense of life and life-support systems) and ecosphere (in the sense of biosphere as life and life-support systems), but, in its most extreme form, refers to the entire planet as a living entity. A case is made for avoiding the term Gaia (at least as a name for the planetary ecosystem), restricting biosphere to the totality of living things, and adopting the ecosphere as the most apt name for the global ecosystem.

Is Earth an organism?

According to Wikipedia, “all known types of organism are capable of some degree of response to stimuli, reproduction, growth and development and self-regulation via homeostasis.” Further, watching a.

An example of this regulation is chemical weathering, whereby carbon dioxide in the atmosphere falls in rain, and reacts with rocks, to form calcium bicarbonate, removing carbon from the short term carbon cycles. The more surface rocks there are which are capable of this reaction, the more CO₂ is removed from the atmosphere.

The Earth became cooler, whether due to Milankovich cycles, volcanic activity, or solar output changes. As this happened, ice began to form at the poles, changing the albedo, and reflecting more radiation back to space, this caused local cooling, and allowed for the growth of the ice sheets. As they spread, the albedo became higher on a larger scale, and the ice sheets eventually covered the two hemispheres, with a band of open ocean at the equator.

Is Planet Earth Alive?

Gaia hypothesis

From Wikipedia, the free encyclopedia

For other uses of "Gaia", see [Gaia \(disambiguation\)](#).



The study of planetary habitability is partly based upon extrapolation from knowledge of the [Earth](#)'s conditions, as the Earth is the only planet currently known to harbour life (*The Blue Marble*, 1972 [Apollo 17](#) photograph).

The **Gaia hypothesis** (/ˈɡaɪ.ə/), also known as the **Gaia theory**, **Gaia paradigm**, or the **Gaia principle**, proposes that living [organisms](#) interact with their [inorganic](#) surroundings on [Earth](#) to form a [synergistic](#) and [self-regulating complex system](#) that helps to maintain and perpetuate the conditions for [life](#) on the planet.

The Gaia hypothesis was formulated by the chemist [James Lovelock](#)^[1] and co-developed by the microbiologist [Lynn Margulis](#) in the 1970s.^[2] Following the suggestion by his neighbour, novelist [William Golding](#), Lovelock named the hypothesis after [Gaia](#), the primordial deity who personified the Earth in [Greek mythology](#). In 2006, the [Geological Society of London](#) awarded Lovelock the [Wollaston Medal](#) in part for his work on the Gaia hypothesis.^[3]

Topics related to the hypothesis include how the [biosphere](#) and the [evolution](#) of organisms affect the stability of [global temperature](#), [salinity](#) of [seawater](#), [atmospheric oxygen](#) levels, the maintenance of a [hydrosphere](#) of liquid water and other environmental variables that affect the [habitability of Earth](#).

The Gaia hypothesis was initially criticized for being [teleological](#) and against the principles of [natural selection](#), but later refinements aligned the Gaia hypothesis with ideas from fields such as [Earth system science](#), [biogeochemistry](#) and [systems ecology](#).^{[4][5][6]} Even so, the Gaia hypothesis continues to attract criticism, and today many scientists consider it to be only weakly supported by, or at odds with, the available evidence.^{[7][8][9][10]}

Overview

[\[edit\]](#)

Gaian hypotheses suggest that organisms [co-evolve](#) with their environment: that is, they "influence their [abiotic](#) environment, and that environment in turn influences the [biota](#) by [Darwinian process](#)". Lovelock (1995) gave evidence of this in his second book, *Ages of Gaia*, showing the evolution from the world of the early [thermo-acidophilic](#) and [methanogenic bacteria](#) towards the oxygen-enriched [atmosphere](#) today that supports more [complex life](#).

A reduced version of the hypothesis has been called "influential Gaia"^[11] in the 2002 paper "Directed Evolution of the Biosphere: Biogeochemical Selection or Gaia?" by Andrei G. Lapenis, which states the [biota](#) influence certain aspects of the abiotic world, e.g. [temperature](#) and atmosphere. This is not the work of an individual but a collective of Russian scientific research that was combined into this peer-reviewed publication. It states the coevolution of life and the environment through "micro-forces"^[11] and biogeochemical processes. An example is how the activity of [photosynthetic](#) bacteria during Precambrian times completely modified the [Earth atmosphere](#) to turn it aerobic, and thus supports the evolution of life (in particular [eukaryotic](#) life).

Since barriers existed throughout the twentieth century between Russia and the rest of the world, it is only relatively recently that the early Russian scientists who introduced concepts overlapping the Gaia paradigm have become better known to the Western scientific community.^[11] These scientists include [Piotr Alekseevich Kropotkin](#) (1842–1921) (although he spent much of his professional life outside Russia), [Rafail Vasil'evich Rizpolozhensky](#) (1862 – c. 1922), [Vladimir Ivanovich Vernadsky](#) (1863–1945), and [Vladimir Alexandrovich Kostitzin](#) (1886–1963).

Biologists and Earth scientists usually view the factors that stabilize the characteristics of a period as an undirected [emergent property](#) or [entelechy](#) of the system; as each individual species pursues its own self-interest, for example, their combined actions may have counterbalancing effects on environmental change. Opponents of this view sometimes reference examples of events that resulted in dramatic change rather than stable equilibrium, such as the conversion of the Earth's atmosphere from a [reducing environment](#) to an [oxygen](#)-rich one at the end of the [Archaean](#) and the beginning of the [Proterozoic](#) periods.

Less accepted versions of the hypothesis claim that changes in the biosphere are brought about through the [coordination of living organisms](#) and maintain those conditions through [homeostasis](#). In some versions of [Gaia philosophy](#), all lifeforms are considered part of one single living planetary being called *Gaia*. In this view, the atmosphere, the seas and the terrestrial crust would be results of interventions carried out by Gaia through the [coevolving](#) diversity of living organisms.

The Gaia paradigm was an influence on the [deep ecology](#) movement.^[12]

Details

[\[edit\]](#)

The Gaia hypothesis posits that the Earth is a self-regulating [complex system](#) involving the [biosphere](#), the [atmosphere](#), the [hydrospheres](#) and the [pedosphere](#), tightly coupled as an evolving system. The hypothesis contends that this system as a whole, called Gaia, seeks a physical and chemical environment optimal for contemporary life.^[13]

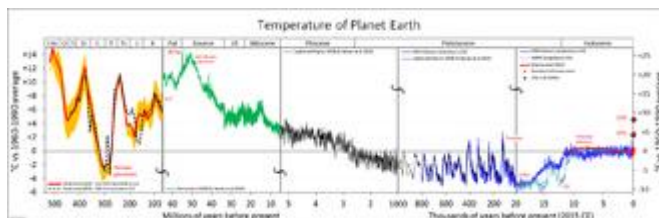
Gaia evolves through a [cybernetic feedback](#) system operated by the [biota](#), leading to broad stabilization of the conditions of habitability in a full homeostasis. Many processes in the Earth's surface, essential for the conditions of life, depend on the interaction of living forms, especially [microorganisms](#), with inorganic elements. These processes establish a global control system that regulates Earth's [surface temperature](#), [atmosphere composition](#) and [ocean salinity](#), powered by the global thermodynamic disequilibrium state of the Earth system.^[14]

The existence of a planetary homeostasis influenced by living forms had been observed previously in the field of [biogeochemistry](#), and it is being investigated also in other fields like [Earth system science](#). The originality of the Gaia hypothesis relies on the assessment that such homeostatic balance is actively pursued with the goal of keeping the optimal conditions for life, even when terrestrial or external events menace them.^[15]

Regulation of global surface temperature

[\[edit\]](#)

See also: [Paleoclimatology](#)



Rob Rohde's palaeotemperature graphs

Since life started on Earth, the energy provided by the [Sun](#) has increased by 25–30%;^[16] however, the surface temperature of the planet has remained within the levels of habitability, reaching quite regular low and high margins. Lovelock has also hypothesised that methanogens produced elevated levels of methane in the early atmosphere, giving a situation similar to that found in petrochemical smog, similar in some respects to the atmosphere on [Titan](#).^[17] This, he suggests, helped to screen out ultraviolet light until the formation of the ozone layer, maintaining a degree of homeostasis. However, the [Snowball Earth](#)^[18] research has suggested that "oxygen shocks" and reduced methane levels led, during the [Huronian](#), [Sturtian](#) and [Marinoan/Varanger](#) Ice Ages, to a world that very nearly became a solid "snowball". These epochs are evidence against the ability of the pre [Phanerozoic](#) biosphere to fully self-regulate.

Processing of the greenhouse gas CO₂, explained below, plays a critical role in the maintenance of the Earth temperature within the limits of habitability.

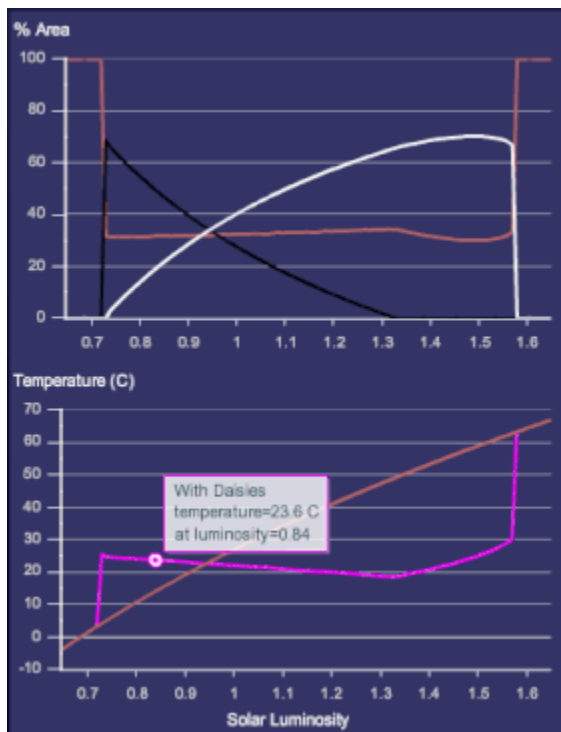
The [CLAW hypothesis](#), inspired by the Gaia hypothesis, proposes a [feedback loop](#) that operates between [ocean ecosystems](#) and the [Earth's climate](#).^[19] The [hypothesis](#) specifically proposes that particular [phytoplankton](#) that produce [dimethyl sulfide](#) are responsive to variations in [climate forcing](#), and that these responses lead to a [negative feedback](#) loop that acts to stabilise the [temperature](#) of the [Earth's atmosphere](#).

Currently the increase in human population and the environmental impact of their activities, such as the multiplication of [greenhouse gases](#) may cause negative feedbacks in the environment to become [positive feedback](#). Lovelock has stated that this could bring an [extremely accelerated global warming](#),^[20] but he has since stated the effects will likely occur more slowly.^[21]

Daisyworld simulations

[\[edit\]](#)

Main article: [Daisyworld](#)



Plots from a standard black and

white [Daisyworld](#) simulation

In response to the criticism that the Gaia hypothesis seemingly required unrealistic [group selection](#) and [cooperation](#) between organisms, James Lovelock and [Andrew Watson](#) developed a mathematical model, [Daisyworld](#), in which [ecological competition](#) underpinned planetary temperature regulation.^[22]

Daisyworld examines the [energy budget](#) of a [planet](#) populated by two different types of plants, black [daisies](#) and white daisies, which are assumed to occupy a significant portion of the surface. The colour of the daisies influences the [albedo](#) of the planet such that black daisies absorb more light and warm the planet, while white daisies reflect more light and cool the planet. The black daisies are assumed to grow and reproduce best at a lower temperature, while the white daisies are assumed to thrive best at a higher temperature. As the temperature rises closer to the value the white daisies like, the white daisies outreproduce the black daisies, leading to a larger percentage of white surface, and more sunlight is reflected, reducing the heat input and eventually cooling the planet. Conversely, as the temperature falls, the black daisies outreproduce the white daisies, absorbing more sunlight and warming the planet. The temperature will thus converge to the value at which the reproductive rates of the plants are equal.

Lovelock and Watson showed that, over a limited range of conditions, this [negative feedback](#) due to competition can stabilize the planet's temperature at a value which supports life, if the energy output of the Sun changes, while a planet without life would show wide temperature changes. The percentage of white and black daisies will continually change to keep the temperature at the value at which the plants' reproductive rates are equal, allowing both life forms to thrive.

It has been suggested that the results were predictable because Lovelock and Watson selected examples that produced the responses they desired.^[23]

Regulation of oceanic salinity

[\[edit\]](#)

Ocean [salinity](#) has been constant at about 3.5% for a very long time.^[24] Salinity stability in oceanic environments is important as most cells require a rather constant salinity and do not generally tolerate values above 5%. The constant ocean salinity was a long-standing mystery, because no process counterbalancing the salt influx from rivers was known. Recently it was suggested^[25] that salinity may also be strongly influenced by [seawater](#) circulation through hot [basaltic](#) rocks, and emerging as hot water vents on [mid-ocean ridges](#). However, the composition of seawater is far from equilibrium, and it is difficult to explain this fact without the influence of organic processes. One suggested explanation lies in the formation of salt plains throughout Earth's history. It is hypothesized that these are created by bacterial colonies that fix ions and heavy metals during their life processes.^[24]

In the biogeochemical processes of Earth, sources and sinks are the movement of elements. The composition of salt ions within our oceans and seas is: sodium (Na^+), chlorine (Cl^-), sulfate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}) and potassium (K^+). The elements that comprise salinity do not readily change and are a conservative property of seawater.^[24] There are many mechanisms that change salinity from a particulate form to a dissolved form and back. Considering the metallic composition of iron sources across a multifaceted grid of thermomagnetic design, not only would the movement of elements hypothetically help restructure the movement of ions, electrons, and the like, but would also potentially and inexplicably assist in balancing the magnetic bodies of the Earth's

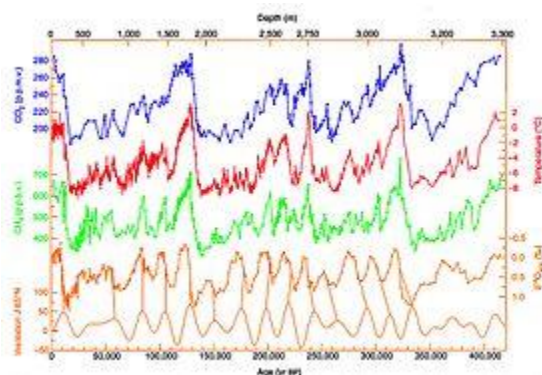
geomagnetic field. The known sources of sodium i.e. salts are when weathering, erosion, and dissolution of rocks are transported into rivers and deposited into the oceans.

The [Mediterranean Sea](#) as being Gaia's kidney is found ([here](#)) by [Kenneth J. Hsu](#), a correspondence author in 2001. Hsu suggests the "[desiccation](#)" of the Mediterranean is evidence of a functioning Gaia "kidney". In this and earlier suggested cases, it is plate movements and physics, not biology, which performs the regulation. Earlier "kidney functions" were performed during the "[deposition](#) of the [Cretaceous](#) ([South Atlantic](#)), [Jurassic](#) ([Gulf of Mexico](#)), [Permo-Triassic](#) ([Europe](#)), [Devonian](#) ([Canada](#)), and [Cambrian/Precambrian](#) ([Gondwana](#)) saline giants."^[26]

Regulation of oxygen in the atmosphere

[\[edit\]](#)

See also: [Geological history of oxygen](#)



Levels of gases in the atmosphere in 420,000 years of ice core data from [Vostok, Antarctica research station](#). Current period is at the left.

The Gaia hypothesis states that the Earth's [atmospheric composition](#) is kept at a dynamically steady state by the presence of life.^[27] The atmospheric composition provides the conditions that contemporary life has adapted to. All the atmospheric gases other than [noble gases](#) present in the atmosphere are either made by organisms or processed by them.

The stability of the atmosphere in Earth is not a consequence of [chemical equilibrium](#). [Oxygen](#) is a reactive compound, and should eventually combine with gases and minerals of the Earth's atmosphere and crust. Oxygen only began to persist in the atmosphere in small quantities about 50 million years before the start of the [Great Oxygenation Event](#).^[28] Since the start of the [Cambrian](#) period, atmospheric oxygen concentrations have fluctuated between 15% and 40% of atmospheric volume.^[29] Traces of [methane](#) (at an amount of 100,000 tonnes produced per year)^[30] should not exist, as methane is combustible in an oxygen atmosphere.

Dry air in the [atmosphere of Earth](#) contains roughly (by volume) 78.09% [nitrogen](#), 20.95% oxygen, 0.93% [argon](#), 0.039% [carbon dioxide](#), and small amounts of other gases including [methane](#). Lovelock originally speculated that concentrations of oxygen

above about 25% would increase the frequency of wildfires and conflagration of forests. This mechanism, however, would not raise oxygen levels if they became too low. If plants can be shown to robustly over-produce O₂ then perhaps only the high oxygen forest fires regulator is necessary. Recent work on the findings of fire-caused charcoal in Carboniferous and Cretaceous coal measures, in geologic periods when O₂ did exceed 25%, has supported Lovelock's contention. ^[citation needed]

Processing of CO₂

[\[edit\]](#)

See also: *Carbon cycle*

Gaia scientists see the participation of living organisms in the [carbon cycle](#) as one of the complex processes that maintain conditions suitable for life. The only significant natural source of [atmospheric carbon dioxide](#) (CO₂) is [volcanic activity](#), while the only significant removal is through the precipitation of [carbonate rocks](#).^[31] Carbon precipitation, solution and [fixation](#) are influenced by the [bacteria](#) and plant roots in soils, where they improve gaseous circulation, or in coral reefs, where calcium carbonate is deposited as a solid on the sea floor. Calcium carbonate is used by living organisms to manufacture carbonaceous tests and shells. Once dead, the living organisms' shells fall. Some arrive at the bottom of shallow seas where the heat and pressure of burial, and/or the forces of plate tectonics, eventually convert them to deposits of chalk and limestone. Much of the falling dead shells, however, redissolve into the ocean below the carbon compensation depth.

One of these organisms is *Emiliana huxleyi*, an abundant [coccolithophore algae](#) which may have a role in the formation of [clouds](#).^[32] CO₂ excess is compensated by an increase of coccolithophorid life, increasing the amount of CO₂ locked in the ocean floor. Coccolithophorids, if the CLAW Hypothesis turns out to be supported (see "Regulation of Global Surface Temperature" above), could help increase the cloud cover, hence control the surface temperature, help cool the whole planet and favor precipitation necessary for terrestrial plants.^[citation needed] Lately the atmospheric CO₂ concentration has increased and there is some evidence that concentrations of ocean [algal blooms](#) are also increasing.^[33]

[Lichen](#) and other organisms accelerate the [weathering](#) of rocks in the surface, while the decomposition of rocks also happens faster in the soil, thanks to the activity of roots, fungi, bacteria and subterranean animals. The flow of carbon dioxide from the atmosphere to the soil is therefore regulated with the help of living organisms. When CO₂ levels rise in the atmosphere the temperature increases and plants grow. This growth brings higher consumption of CO₂ by the plants, who process it into the soil, removing it from the atmosphere.

History

[\[edit\]](#)

Precedents

[\[edit\]](#)



Earthrise taken from *Apollo 8* by astronaut *William Anders*, December 24, 1968

The idea of the Earth as an integrated whole, a living being, has a long tradition. The mythical *Gaia* was the primal Greek goddess personifying the *Earth*, the Greek version of "*Mother Nature*" (from *Ge* = Earth, and *Aia* = *PIE* grandmother), or the *Earth Mother*. James Lovelock gave this name to his hypothesis after a suggestion from the novelist *William Golding*, who was living in the same village as Lovelock at the time (*Bowerchalke*, *Wiltshire*, UK). Golding's advice was based on *Gea*, an alternative spelling for the name of the Greek goddess, which is used as prefix in geology, geophysics and geochemistry.^[34] Golding later made reference to *Gaia* in his *Nobel prize* acceptance speech.

In the eighteenth century, as *geology* consolidated as a modern science, *James Hutton* maintained that geological and biological processes are interlinked.^[35] Later, the *naturalist* and explorer *Alexander von Humboldt* recognized the coevolution of living organisms, climate, and Earth's crust.^[35] In the twentieth century, *Vladimir Vernadsky* formulated a theory of Earth's development that is now one of the foundations of ecology. Vernadsky was a Ukrainian *geochemist* and was one of the first scientists to recognize that the oxygen, nitrogen, and carbon dioxide in the Earth's atmosphere result from biological processes. During the 1920s he published works arguing that living organisms could reshape the planet as surely as any physical force. Vernadsky was a pioneer of the scientific bases for the environmental sciences.^[36] His visionary pronouncements were not widely accepted in the West, and some decades later the *Gaia* hypothesis received the same type of initial resistance from the scientific community.

Also in the turn to the 20th century *Aldo Leopold*, pioneer in the development of modern *environmental ethics* and in the movement for *wilderness* conservation, suggested a living Earth in his biocentric or holistic ethics regarding land.

It is at least not impossible to regard the earth's parts—soil, mountains, rivers, atmosphere etc,—as organs or parts of organs of a coordinated whole, each part with its definite function. And if we could see this whole, as a whole, through a great period of time, we might perceive not only organs with coordinated functions, but possibly also that process of consumption as replacement which in biology we call metabolism, or

growth. In such case we would have all the visible attributes of a living thing, which we do not realize to be such because it is too big, and its life processes too slow.

—*Stephan Harding, Animate Earth*^[37]

Another influence for the Gaia hypothesis and the [environmental movement](#) in general came as a side effect of the [Space Race](#) between the Soviet Union and the United States of America. During the 1960s, the first humans in space could see how the Earth looked as a whole. The photograph [Earthrise](#) taken by astronaut [William Anders](#) in 1968 during the [Apollo 8](#) mission became, through the [Overview Effect](#) an early symbol for the global ecology movement.^[38]

Formulation of the hypothesis

[\[edit\]](#)



[James Lovelock](#), 2005

Lovelock started defining the idea of a self-regulating Earth controlled by the community of living organisms in September 1965, while working at the [Jet Propulsion Laboratory](#) in California on methods of detecting [life on Mars](#).^{[39][40]} The first paper to mention it was *Planetary Atmospheres: Compositional and other Changes Associated with the Presence of Life*, co-authored with C.E. Giffin.^[41] A main concept was that life could be detected in a planetary scale by the chemical composition of the atmosphere. According to the data gathered by the [Pic du Midi observatory](#), planets like Mars or Venus had atmospheres in [chemical equilibrium](#). This difference with the Earth atmosphere was considered to be a proof that there was no life in these planets.

Lovelock formulated the *Gaia Hypothesis* in journal articles in 1972^[1] and 1974,^[2] followed by a popularizing 1979 book *Gaia: A new look at life on Earth*. An article in the [New Scientist](#) of February 6, 1975,^[42] and a popular book length version of the hypothesis, published in 1979 as *The Quest for Gaia*, began to attract scientific and critical attention.

Lovelock called it first the Earth feedback hypothesis,^[43] and it was a way to explain the fact that combinations of chemicals including [oxygen](#) and [methane](#) persist in stable concentrations in the atmosphere of the Earth. Lovelock suggested detecting such combinations in other planets' atmospheres as a relatively reliable and cheap way to detect life.



Lynn Margulis

Later, other relationships such as sea creatures producing sulfur and iodine in approximately the same quantities as required by land creatures emerged and helped bolster the hypothesis.^[44]

In 1971 [microbiologist](#) Dr. [Lynn Margulis](#) joined Lovelock in the effort of fleshing out the initial hypothesis into scientifically proven concepts, contributing her knowledge about how microbes affect the atmosphere and the different layers in the surface of the planet.^[4] The American biologist had also awakened criticism from the scientific community with her advocacy of the theory on the origin of [eukaryotic organelles](#) and her contributions to the [endosymbiotic theory](#), nowadays accepted. Margulis dedicated the last of eight chapters in her book, *The Symbiotic Planet*, to Gaia. However, she objected to the widespread personification of Gaia and stressed that Gaia is "not an organism", but "an emergent property of interaction among organisms". She defined Gaia as "the series of interacting ecosystems that compose a single huge ecosystem at the Earth's surface. Period". The book's most memorable "slogan" was actually quipped by a student of Margulis'.

James Lovelock called his first proposal the *Gaia hypothesis* but has also used the term *Gaia theory*. Lovelock states that the initial formulation was based on observation, but still lacked a scientific explanation. The Gaia hypothesis has since been supported by a number of scientific experiments^[45] and provided a number of useful predictions.^[46]

First Gaia conference

[\[edit\]](#)

In 1985, the first public symposium on the Gaia hypothesis, *Is The Earth a Living Organism?* was held at [University of Massachusetts Amherst](#), August 1–6.^[47] The principal sponsor was the [National Audubon Society](#). Speakers included James Lovelock, [Lynn Margulis](#), [George Wald](#), [Mary Catherine Bateson](#), [Lewis Thomas](#), [Thomas Berry](#), [David Abram](#), [John Todd](#), Donald Michael, [Christopher Bird](#), [Michael Cohen](#), and William Fields. Some 500 people attended.^[48]

Second Gaia conference

[\[edit\]](#)

In 1988, climatologist [Stephen Schneider](#) organised a conference of the [American Geophysical Union](#). The first Chapman Conference on Gaia,^[4] was held in San Diego, California, on March 7, 1988.

During the "philosophical foundations" session of the conference, [David Abram](#) spoke on the influence of metaphor in science, and of the Gaia hypothesis as offering a new and potentially game-changing metaphors, while [James Kirchner](#) criticised the Gaia hypothesis for its imprecision. Kirchner claimed that Lovelock and Margulis had not presented one Gaia hypothesis, but four:

- [CoEvolutionary](#) Gaia: that life and the environment had evolved in a coupled way. Kirchner claimed that this was already accepted scientifically and was not new.
- [Homeostatic](#) Gaia: that life maintained the stability of the natural environment, and that this stability enabled life to continue to exist.
- [Geophysical](#) Gaia: that the Gaia hypothesis generated interest in geophysical cycles and therefore led to interesting new research in terrestrial geophysical dynamics.
- Optimising Gaia: that Gaia shaped the planet in a way that made it an optimal environment for life as a whole. Kirchner claimed that this was not testable and therefore was not scientific.

Of Homeostatic Gaia, Kirchner recognised two alternatives. "Weak Gaia" asserted that life tends to make the environment stable for the flourishing of all life. "Strong Gaia" according to Kirchner, asserted that life tends to make the environment stable, to *enable* the flourishing of all life. Strong Gaia, Kirchner claimed, was untestable and therefore not scientific.^[49]

Lovelock and other Gaia-supporting scientists, however, did attempt to disprove the claim that the hypothesis is not scientific because it is impossible to test it by controlled experiment. For example, against the charge that Gaia was teleological, Lovelock and Andrew Watson offered the [Daisyworld](#) Model (and its modifications, above) as evidence against most of these criticisms.^[22] Lovelock said that the Daisyworld model "demonstrates that self-regulation of the global environment can emerge from competition amongst types of life altering their local environment in different ways".^[50]

Lovelock was careful to present a version of the Gaia hypothesis that had no claim that Gaia intentionally or consciously maintained the complex balance in her environment that life needed to survive. It would appear that the claim that Gaia acts "intentionally" was a statement in his popular initial book and was not meant to be taken literally. This new statement of the Gaia hypothesis was more acceptable to the scientific community. Most accusations of [teleologism](#) ceased, following this conference.^[citation needed]

Third Gaia conference

[\[edit\]](#)

By the time of the 2nd Chapman Conference on the Gaia Hypothesis, held at Valencia, Spain, on 23 June 2000,^[51] the situation had changed significantly. Rather than a discussion of the Gaian teleological views, or "types" of Gaia hypotheses, the focus was upon the specific mechanisms by which basic short term homeostasis was maintained within a framework of significant evolutionary long term structural change.

The major questions were:^[52]

1. "How has the global biogeochemical/climate system called Gaia changed in time? What is its history? Can Gaia maintain stability of the system at one time scale but still undergo vectorial change at longer time scales? How can the geologic record be used to examine these questions?"
2. "What is the structure of Gaia? Are the feedbacks sufficiently strong to influence the evolution of climate? Are there parts of the system determined pragmatically by whatever disciplinary study is being undertaken at any given time or are there a set of parts that should be taken as most true for understanding Gaia as containing evolving organisms over time? What are the feedbacks among these different parts of the Gaian system, and what does the near closure of matter mean for the structure of Gaia as a global ecosystem and for the productivity of life?"
3. "How do models of Gaian processes and phenomena relate to reality and how do they help address and understand Gaia? How do results from Daisyworld transfer to the real world? What are the main candidates for "daisies"? Does it matter for Gaia theory whether we find daisies or not? How should we be searching for daisies, and should we intensify the search? How can Gaian mechanisms be *collaborated* with using process models or global models of the climate system that include the biota and allow for chemical cycling?"

In 1997, Tyler Volk argued that a Gaian system is almost inevitably produced as a result of an evolution towards far-from-equilibrium homeostatic states that maximise [entropy production](#), and Axel Kleidon (2004) agreed stating: "...homeostatic behavior can emerge from a state of MEP associated with the planetary albedo"; "...the resulting behavior of a symbiotic Earth at a state of MEP may well lead to near-homeostatic behavior of the Earth system on long time scales, as stated by the Gaia hypothesis". M. Staley (2002) has similarly proposed "...an alternative form of Gaia theory based on more traditional Darwinian principles... In [this] new approach, environmental regulation is a consequence of population dynamics. The role of selection is to favor organisms that are best adapted to prevailing environmental conditions. However, the environment is not a static backdrop for evolution, but is heavily influenced by the presence of living organisms. The resulting co-evolving dynamical process eventually leads to the convergence of equilibrium and optimal conditions".

Fourth Gaia conference

[\[edit\]](#)

A fourth international conference on the Gaia hypothesis, sponsored by the Northern Virginia Regional Park Authority and others, was held in October 2006 at the Arlington, Virginia campus of George Mason University.^[53]

Martin Ogle, Chief Naturalist, for NVRPA, and long-time Gaia hypothesis proponent, organized the event. Lynn Margulis, Distinguished University Professor in the Department of Geosciences, University of Massachusetts-Amherst, and long-time advocate of the Gaia hypothesis, was a keynote speaker. Among many other speakers: Tyler Volk, co-director of the Program in Earth and Environmental Science at New York University; Dr. Donald Aitken, Principal of Donald Aitken Associates; [Dr. Thomas Lovejoy](#), President of the Heinz Center for Science, Economics and the Environment; [Robert Corell](#), Senior Fellow, Atmospheric Policy Program, American Meteorological Society and noted environmental ethicist, [J. Baird Callicott](#).

Criticism

[\[edit\]](#)

After initially receiving little attention from scientists (from 1969 until 1977), thereafter for a period the initial Gaia hypothesis was criticized by a number of scientists, including [Ford Doolittle](#),^[54] [Richard Dawkins](#)^[55] and [Stephen Jay Gould](#).^[4] Lovelock has said that because his hypothesis is named after a Greek goddess, and championed by many non-scientists,^[43] the Gaia hypothesis was interpreted as a [neo-Pagan religion](#). Many scientists in particular also criticized the approach taken in his popular book *Gaia, a New Look at Life on Earth* for being [teleological](#)—a belief that things are purposeful and aimed towards a goal. Responding to this critique in 1990, Lovelock stated, "Nowhere in our writings do we express the idea that planetary self-regulation is purposeful, or involves foresight or planning by the [biota](#)".

[Stephen Jay Gould](#) criticized Gaia as being "a metaphor, not a mechanism."^[56] He wanted to know the actual mechanisms by which self-regulating homeostasis was achieved. In his defense of Gaia, David Abram argues that Gould overlooked the fact that "mechanism", itself, is a metaphor—albeit an exceedingly common and often unrecognized metaphor—one which leads us to consider natural and living systems as though they were machines organized and built from outside (rather than as [autopoietic](#) or self-organizing phenomena). Mechanical metaphors, according to Abram, lead us to overlook the active or agentic quality of living entities, while the organismic metaphors of the Gaia hypothesis accentuate the active agency of both the biota and the biosphere as a whole.^[57] With regard to causality in Gaia, Lovelock argues that no single mechanism is responsible, that the connections between the various known mechanisms may never be known, that this is accepted in other fields of biology and ecology as a matter of course, and that specific hostility is reserved for his own hypothesis for other reasons.^[43]

Aside from clarifying his language and understanding of what is meant by a life form, Lovelock himself ascribes most of the criticism to a lack of understanding of non-linear mathematics by his critics, and a linearizing form of [greedy reductionism](#) in which all events have to be immediately ascribed to specific causes before the fact. He also

states that most of his critics are biologists but that his hypothesis includes experiments in fields outside biology, and that some self-regulating phenomena may not be mathematically explainable.^[43]

Natural selection and evolution

[\[edit\]](#)

Lovelock has suggested that global biological feedback mechanisms could evolve by [natural selection](#), stating that organisms that improve their environment for their survival do better than those that damage their environment. However, in the early 1980s, [W. Ford Doolittle](#) and [Richard Dawkins](#) separately argued against this aspect of Gaia. Doolittle argued that nothing in the [genome](#) of individual organisms could provide the feedback mechanisms proposed by Lovelock, and therefore the Gaia hypothesis proposed no plausible mechanism and was unscientific.^[54] Dawkins meanwhile stated that for organisms to act in concert would require foresight and planning, which is contrary to the current scientific understanding of evolution.^[55] Like Doolittle, he also rejected the possibility that feedback loops could stabilize the system.

Margulis argued in 1999 that "[Darwin's](#) grand vision was not wrong, *only incomplete*. In accentuating the direct competition between individuals for resources as the primary selection mechanism, Darwin (and especially his followers) created the impression that the environment was simply a static arena". She wrote that the composition of the Earth's atmosphere, hydrosphere, and lithosphere are regulated around "set points" as in [homeostasis](#), but those set points change with time.^[58]

Evolutionary biologist [W. D. Hamilton](#) called the concept of Gaia [Copernican](#), adding that it would take another [Newton](#) to explain how Gaian self-regulation takes place through Darwinian [natural selection](#).^[34]^[better source needed] More recently Ford Doolittle building on his and Inkpen's ITSNTS (It's The Song Not The Singer) proposal^[59] proposed that differential persistence can play a similar role to differential reproduction in evolution by natural selections, thereby providing a possible reconciliation between the theory of natural selection and the Gaia hypothesis.^[60]

Criticism in the 21st century

[\[edit\]](#)

The Gaia hypothesis continues to be broadly skeptically received by the scientific community. For instance, arguments both for and against it were laid out in the journal *Climatic Change* in 2002 and 2003. A significant argument raised against it are the many examples where life has had a detrimental or destabilising effect on the environment rather than acting to regulate it.^{[7][8]} Several recent books have criticised the Gaia hypothesis, expressing views ranging from "... the Gaia hypothesis lacks unambiguous observational support and has significant theoretical difficulties"^[61] to "Suspended uncomfortably between tainted metaphor, fact, and false science, I prefer to leave Gaia firmly in the background"^[9] to "The Gaia hypothesis is supported neither by evolutionary theory nor by the empirical evidence of the geological record".^[62] The [CLAW hypothesis](#),^[19] initially suggested as a potential example of direct

Gaian feedback, has subsequently been found to be less credible as understanding of [cloud condensation nuclei](#) has improved.^[63] In 2009 the [Medea hypothesis](#) was proposed: that life has highly detrimental (biocidal) impacts on planetary conditions, in direct opposition to the Gaia hypothesis.^[64]

In a [2013 book-length evaluation of the Gaia hypothesis](#) considering modern evidence from across the various relevant disciplines, Toby Tyrrell concluded that: "I believe Gaia is a dead end. Its study has, however, generated many new and thought provoking questions. While rejecting Gaia, we can at the same time appreciate Lovelock's originality and breadth of vision, and recognize that his audacious concept has helped to stimulate many new ideas about the Earth, and to champion a holistic approach to studying it".^[65] Elsewhere he presents his conclusion "The Gaia hypothesis is not an accurate picture of how our world works".^[66] This statement needs to be understood as referring to the "strong" and "moderate" forms of Gaia—that the biota obeys a principle that works to make Earth optimal (strength 5) or favourable for life (strength 4) or that it works as a homeostatic mechanism (strength 3). The latter is the "weakest" form of Gaia that Lovelock has advocated. Tyrrell rejects it. However, he finds that the two weaker forms of Gaia—Coevolutionary Gaia and Influential Gaia, which assert that there are close links between the evolution of life and the environment and that biology affects the physical and chemical environment—are both credible, but that it is not useful to use the term "Gaia" in this sense and that those two forms were already accepted and explained by the processes of natural selection and adaptation.^[67]

Anthropic principle

[\[edit\]](#)

As emphasized by multiple critics, no plausible mechanism exists that would drive the evolution of negative feedback loops leading to planetary self-regulation of the climate.^{[8][9]} Indeed, multiple incidents in Earth's history (see the [Medea hypothesis](#)) have shown that the Earth and the biosphere can enter self-destructive positive feedback loops that lead to mass extinction events.^[68]

For example, the [Snowball Earth](#) glaciations appeared to result from the development of [photosynthesis](#) during a period when the [Sun was cooler](#) than it is now. These mechanisms will have some effect, but any understanding of glacial-interglacial cycles requires study of the variations in the Earth's orbit around the sun, the tilt of its axis of rotation, and the 'wobble' in that rotational movement which causes the periodicity in Northern Hemisphere insolation, thereby setting the Earth's thermal regime. Including studies from the fields of mathematics and Earth science, the fields of geology and geography provide insight into the causes of ice ages. Meanwhile, the removal of carbon dioxide from the atmosphere, along with the oxidation of [atmospheric methane](#) by the released oxygen, resulted in a dramatic diminishment of the [greenhouse effect](#).^[note 1] The resulting expansion of the polar ice sheets decreased the overall fraction of sunlight absorbed by the Earth, resulting in a runaway [ice–albedo positive feedback loop](#) ultimately resulting in glaciation over nearly the entire surface of the Earth.^[70] However, volcanic processes at this scale should be understood as relating to the pressure exerted on the Earth's crust, and released during periods of ice sheet

retreat. Breaking out of the Earth from the frozen condition appears to have directly been due to the release of carbon dioxide and methane by volcanos,^[71] although release of methane by microbes trapped underneath the ice could also have played a part.^[72] Lesser contributions to warming would come from the fact that coverage of the Earth by ice sheets largely inhibited photosynthesis and lessened the removal of carbon dioxide from the atmosphere by the weathering of siliceous rocks. However, in the absence of tectonic activity, the snowball condition could have persisted indefinitely.^{[73]:43–68}

Geologic events with amplifying positive feedbacks (along with some possible biologic participation) led to the greatest mass extinction event on record, the [Permian–Triassic extinction event](#) about 250 million years ago. The precipitating event appears to have been volcanic eruptions in the [Siberian Traps](#), a hilly region of [flood basalts](#) in Siberia. These eruptions released high levels of [carbon dioxide](#) and [sulfur dioxide](#) which elevated world temperatures and acidified the oceans.^[74] Estimates of the rise in carbon dioxide levels range widely, from as little as a two-fold increase, to as much as a twenty-fold increase.^{[73]:69–91} Amplifying feedbacks increased the warming to considerably greater than that to be expected merely from the greenhouse effect of carbon dioxide: these include the ice albedo feedback, the increased evaporation of water vapor (another greenhouse gas) into the atmosphere, the release of methane from the warming of [methane hydrate](#) deposits buried under the permafrost and beneath continental shelf sediments, and increased wildfires.^{[73]:69–91} The rising carbon dioxide acidified the oceans, leading to widespread die-off of creatures with calcium carbonate shells, killing mollusks and crustaceans like crabs and lobsters and destroying coral reefs.^[75] Their demise led to disruption of the entire oceanic food chain.^[76] It has been argued that rising temperatures may have led to disruption of the [chemocline](#) separating sulfidic deep waters from oxygenated surface waters, which led to massive release of toxic [hydrogen sulfide](#) (produced by [anerobic](#) bacteria) to the surface ocean and even into atmosphere, contributing to the (primarily methane-driven) collapse of the ozone layer,^[77] and helping to explain the die-off of terrestrial animal and plant life.^[78]

According to the weak [anthropic principle](#), our observation of such stabilizing feedback loops is an observer selection effect.^{[79][80][81]} In all the universe, it is only planets with Gaian properties that could have evolved intelligent, self-aware organisms capable of asking such questions.^{[73]:50} One can imagine innumerable worlds where life evolved with different biochemistries or where the worlds had different geophysical properties such that the worlds are presently dead due to runaway greenhouse effect, or else are in perpetual Snowball, or else due to one factor or another, life has been inhibited from evolving beyond the microbial level.^[note 2]

If no means exists for natural selection to operate at the biosphere level, then it would appear that the anthropic principle provides the only explanation for the survival of Earth's biosphere over geologic time. But in recent years, this strictly reductionistic view has been modified by recognition that natural selection can operate at multiple levels of the biological hierarchy — not just at the level of individual organisms.^[82] Traditional Darwinian natural selection requires reproducing entities that display inheritable properties or abilities that result in their having more offspring than their competitors.

Successful biospheres clearly cannot reproduce to spawn copies of themselves, and so traditional Darwinian natural selection cannot operate. A mechanism for biosphere-level selection was proposed by Ford Doolittle: Although he had been a strong and early critic of the Gaia hypothesis,^[54] he had by 2015 started to think of ways whereby Gaia might be "Darwinised", seeking means whereby the planet could have evolved biosphere-level adaptations. Doolittle has suggested that *differential persistence* — mere survival — could be considered a legitimate mechanism for natural selection. As the Earth passes through various challenges, the phenomenon of differential persistence enables selected entities to achieve fixation by surviving the death of their competitors. Although Earth's biosphere is not competing against other biospheres on other planets, there are many competitors for survival on *this* planet. Collectively, Gaia constitutes the single [clade](#) of all living survivors descended from life's [last universal common ancestor](#) (LUCA).^[81] Various other proposals for biosphere-level selection include sequential selection, entropic hierarchy,^[83] and considering Gaia as a [holobiont](#)-like system.^[84] Ultimately speaking, differential persistence and sequential selection are variants of the anthropic principle,^[83] while entropic hierarchy and holobiont arguments may possibly allow understanding the emergence of Gaia without anthropic arguments.^{[83][84]}

See also

[\[edit\]](#)

-  [Environment portal](#)
-  [Earth sciences portal](#)
-  [Geography portal](#)

- [Anima mundi](#) – Concept in metaphysics
- [Biocoenosis](#) – Interacting organisms living together in a habitat
- [Earth science](#) – Fields of natural science related to Earth
- [Environmentalism](#) – Philosophy about Earth protection
- [Gaianism](#) – Earth-centered philosophical, holistic, and spiritual belief
- [Global brain](#) – Futuristic concept of a global interconnected network
- [Holism](#) – A system as a whole, not just its parts
- [Hylozoism](#) – Philosophical doctrine which holds that all matter is alive
- [Planetary boundaries](#) – Limits not to be exceeded if humanity wants to survive in a safe ecosystem
- [SimEarth](#) – 1990 video game
- [Spiritual ecology](#) – Field in religion, conservation, and academia
- [Superorganism](#) – Group of synergistic organisms

References

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Notes

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1. ^ An para-alternative hypothesis is that the immediate trigger for Snowball Earth may have been a sequence of massive volcanic eruptions that occurred from 717 to 719 million years ago in what is currently the Canadian high arctic. These eruptions presumably lofted massive quantities of sulfur aerosols into the stratosphere, where they reflected incoming solar radiation and had a strong cooling effect.^[69]
2. ^ Dawkins (1982), p. 236: "The Universe would have to be full of dead planets whose homeostatic regulation systems had failed, with, dotted around, a handful of successful, well-regulated planets, of which the Earth is one."

Citations

[\[edit\]](#)

1. ^ [Jump up to:](#)^{a b} Lovelock, J. E. (1972). "Gaia as seen through the atmosphere". *Atmospheric Environment*. **6** (8): 579–580. *Bibcode*:1972AtmEn...6..579L. *doi*:10.1016/0004-6981(72)90076-5.
2. ^ [Jump up to:](#)^{a b} Lovelock, J. E.; Margulis, L. (1974). "*Atmospheric homeostasis by and for the biosphere: the gaia hypothesis*". *Tellus A*. **26** (1–2): 2–10. *Bibcode*:1974Tell...26....2L. *doi*:10.3402/tellusa.v26i1-2.9731. *S2CID* 129803613.
3. ^ "*Wollaston Award Lovelock*". Retrieved 19 October 2015.
4. ^ [Jump up to:](#)^{a b c d} Turney 2003.
5. ^ Schwartzman, David (2002). *Life, Temperature, and the Earth: The Self-Organizing Biosphere*. Columbia University Press. *ISBN* 978-0-231-10213-1.
6. ^ Gribbin, John (1990), "Hothouse earth: The greenhouse effect and Gaia" (Weidenfeld & Nicolson)
7. ^ [Jump up to:](#)^{a b} Kirchner, James W. (2002), "Toward a future for Gaia theory", *Climatic Change*, **52** (4): 391–408, *doi*:10.1023/a:1014237331082, *S2CID* 15776141
8. ^ [Jump up to:](#)^{a b c} Volk, Tyler (2002), "The Gaia hypothesis: fact, theory, and wishful thinking", *Climatic Change*, **52** (4): 423–430, *doi*:10.1023/a:1014218227825, *S2CID* 32856540
9. ^ [Jump up to:](#)^{a b c} Beerling, David (2007). *The Emerald Planet: How plants changed Earth's history*. Oxford: Oxford University Press. *ISBN* 978-0-19-280602-4.
10. ^ Tyrrell 2013.
11. ^ [Jump up to:](#)^{a b c} Lapenis, Andrei G. (2002). "Directed Evolution of the Biosphere: Biogeochemical Selection or Gaia?". *The Professional Geographer*. **54** (3): 379–391. *Bibcode*:2002ProfG..54..379L. *doi*:10.1111/0033-0124.00337. *S2CID* 10796292 – via [Peer Reviewed Journal].
12. ^ Barnhill, David Landis; Gottlieb, Roger S., eds. (2010). *Deep Ecology and World Religions: New Essays on Sacred Ground*. SUNY Press. p. 32.
13. ^ Lovelock 2009, p. 255.
14. ^ Kleidon, Axel. *How does the earth system generate and maintain thermodynamic disequilibrium and what does it imply for the future of the planet?*. Article submitted to the *Philosophical Transactions of the Royal Society* on Thu, 10 Mar 2011

15. ^ Lovelock 2009, p. 179.
16. ^ Owen, T.; Cess, R.D.; Ramanathan, V. (1979). "Earth: An enhanced carbon dioxide greenhouse to compensate for reduced solar luminosity". *Nature*. **277** (5698): 640–
2. *Bibcode*:1979Natur.277..640O. doi:10.1038/277640a0. S2CID 4326889.
17. ^ Lovelock, James (1995). *The Ages of Gaia: A Biography of Our Living Earth*. New York: W. W. Norton & Co. ISBN 978-0-393-31239-3.
18. ^ Hoffman, P.F. 2001. *Snowball Earth theory*
19. ^ Jump up to:^a ^b Charlson, R. J.; Lovelock, J. E; Andreae, M. O.; Warren, S. G. (1987). "Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate". *Nature*. **326** (6114): 655–
661. *Bibcode*:1987Natur.326..655C. doi:10.1038/326655a0. S2CID 4321239.
20. ^ Lovelock 2009, p. ^[page needed].
21. ^ Johnston, Ian (23 April 2012). "'Gaia' scientist James Lovelock: I was 'alarmist' about climate change". NBC News. Archived from *the original* on 13 September 2012. Retrieved 22 August 2012.
22. ^ Jump up to:^a ^b Watson, A.J.; Lovelock, J.E (1983). "Biological homeostasis of the global environment: the parable of Daisyworld". *Tellus*. **35B** (4): 286–
9. *Bibcode*:1983TellB..35..284W. doi:10.1111/j.1600-0889.1983.tb00031.x.
23. ^ Kirchner, James W. (2003). "The Gaia Hypothesis: Conjectures and Refutations". *Climatic Change*. **58** (1–2): 21–
45. doi:10.1023/A:1023494111532. S2CID 1153044.
24. ^ Jump up to:^a ^b ^c Segar, Douglas (2012). *The Introduction to Ocean Sciences* (PDF). Library of Congress. pp. Chapter 5 3rd Edition. ISBN 978-0-9857859-0-1. Archived from *the original* (PDF) on 2016-03-25. Retrieved 2017-02-05.
25. ^ Gorham, Eville (1 January 1991). "Biogeochemistry: its origins and development". *Biogeochemistry*. **13** (3). Kluwer Academic: 199–
239. doi:10.1007/BF00002942. ISSN 1573-515X. S2CID 128563314.
26. ^ "Scientia Marina: List of Issues". scimar.icm.csic.es. Retrieved 2017-02-04.
27. ^ Lovelock 2009, p. 163.
28. ^ Anbar, A.; Duan, Y.; Lyons, T.; Arnold, G.; Kendall, B.; Creaser, R.; Kaufman, A.; Gordon, G.; Scott, C.; Garvin, J.; Buick, R. (2007). "A whiff of oxygen before the great oxidation event?". *Science*. **317** (5846): 1903–
1906. *Bibcode*:2007Sci...317.1903A. doi:10.1126/science.1140325. PMID 17901330. S2CID 25260892.
29. ^ Berner, R. A. (Sep 1999). "Atmospheric oxygen over Phanerozoic time". *Proceedings of the National Academy of Sciences of the United States of America*. **96** (20): 10955–
10957. *Bibcode*:1999PNAS...9610955B. doi:10.1073/pnas.96.20.10955. ISSN 0027-8424. PMC 34224. PMID 10500106.
30. ^ Cicerone, R.J.; Oremland, R.S. (1988). "Biogeochemical aspects of atmospheric methane" (PDF). *Global Biogeochemical Cycles*. **2** (4): 299–
327. *Bibcode*:1988GBioC...2..299C. doi:10.1029/GB002i004p00299. S2CID 56396847.
31. ^ Karhu, J.A.; Holland, H.D. (1 October 1996). "Carbon isotopes and the rise of atmospheric oxygen". *Geology*. **24** (10): 867–
870. *Bibcode*:1996Geo....24..867K. doi:10.1130/0091-7613(1996)024<0867:CIATRO>2.3.CO;2.

32. ^ Harding 2006, p. 65.
33. ^ "Interagency Report Says Harmful Algal Blooms Increasing". 12 September 2007. Archived from [the original](#) on 9 February 2008.
34. ^ Jump up to:^{a b} Lovelock 2009, pp. 195–197.
35. ^ Jump up to:^{a b} Capra, Fritjof (1996). *The web of life: a new scientific understanding of living systems*. Garden City, N.Y: Anchor Books. p. 23. ISBN 978-0-385-47675-1.
36. ^ Weart, S. R. (2003). *The Discovery of Global Warming*. Cambridge: Harvard Press.
37. ^ Harding 2006, p. 44.
38. ^ 100 Photographs that Changed the World by Life - The Digital Journalist
39. ^ Lovelock, J. E. (1965). "A physical basis for life detection experiments". *Nature*. **207** (7): 568–570. Bibcode:1965Natur.207..568L. doi:10.1038/207568a0. PMID 5883628. S2CID 33821197.
40. ^ "Geophysics". Archived from [the original](#) on 2007-05-06. Retrieved 2007-05-05.
41. ^ Lovelock, J. E.; Giffin, C.E. (1969). "Planetary Atmospheres: Compositional and other changes associated with the presence of Life". *Advances in the Astronautical Sciences*. **25**: 179–193. ISBN 978-0-87703-028-7.
42. ^ Lovelock, John and Sidney Epton, (February 8, 1975). "The quest for Gaia". *New Scientist*, p. 304.
43. ^ Jump up to:^{a b c d} Lovelock 2001.
44. ^ Hamilton, W.D.; Lenton, T.M. (1998). "Spora and Gaia: how microbes fly with their clouds". *Ethology Ecology & Evolution*. **10** (1): 1–16. Bibcode:1998EtEcE..10....1H. doi:10.1080/08927014.1998.9522867. Archived from [the original](#) (PDF) on 2011-07-23.
45. ^ Lovelock, J. E. (1990). "Hands up for the Gaia hypothesis". *Nature*. **344** (6262): 100–2. Bibcode:1990Natur.344..100L. doi:10.1038/344100a0. S2CID 4354186.
46. ^ Volk, Tyler (2003). *Gaia's Body: Toward a Physiology of Earth*. Cambridge, Massachusetts: MIT Press. ISBN 978-0-262-72042-7.
47. ^ Joseph, Lawrence E. (November 23, 1986). "Britain's Whole Earth Guru". *The New York Times Magazine*. Retrieved 1 December 2013.
48. ^ Bunyard, Peter (1996), *Gaia in Action: Science of the Living Earth* (Floris Books)
49. ^ Kirchner, James W. (1989). "The Gaia hypothesis: Can it be tested?". *Reviews of Geophysics*. **27** (2): 223–235. Bibcode:1989RvGeo..27..223K. doi:10.1029/RG027i002p00223.
50. ^ Lenton, TM; Lovelock, JE (2000). "Daisyworld is Darwinian: Constraints on adaptation are important for planetary self-regulation". *Journal of Theoretical Biology*. **206** (1): 109–14. Bibcode:2000JThBi.206..109L. doi:10.1006/jtbi.2000.2105. PMID 10968941. S2CID 5486128.
51. ^ Simón, Federico (21 June 2000). "GEOLOGÍA Enfoque multidisciplinar La hipótesis Gaia madura en Valencia con los últimos avances científicos". *El País* (in Spanish). Retrieved 1 December 2013.
52. ^ American Geophysical Union. "General Information Chapman Conference on the Gaia Hypothesis University of Valencia Valencia, Spain June 19-23, 2000

- (Monday through Friday)". AGU Meetings. Archived from [the original](#) on 4 June 2012. Retrieved 7 January 2017.
53. ^ Official Site of Arlington County Virginia. "[Gaia Theory Conference at George Mason University Law School](#)". Archived from [the original](#) on 2013-12-03. Retrieved 1 December 2013.
 54. ^ [Jump up to:](#)^{a b c} Doolittle, W. F. (1981). "Is Nature Really Motherly". *The Coevolution Quarterly*. Spring: 58–63.
 55. ^ [Jump up to:](#)^{a b} Dawkins 1982.
 56. ^ Gould S.J. (June 1997). "[Kropotkin was no crackpot](#)". *Natural History*. **106**: 12–21.
 57. ^ Abram 1991.
 58. ^ Margulis 1998.
 59. ^ Doolittle WF, Inkpen SA. Processes and patterns of interaction as units of selection: An introduction to ITSNTS thinking. [PNAS April 17, 2018 115 \(16\) 4006-4014](#)
 60. ^ Doolittle, W. Ford (2017). "[Darwinizing Gaia](#)". *Journal of Theoretical Biology*. **434**: 11–19. [Bibcode:2017JThBi.434...11D](#). [doi:10.1016/j.jtbi.2017.02.015](#). [PMID 28237396](#).
 61. ^ Waltham, David (2014). [Lucky Planet: Why Earth is Exceptional – and What that Means for Life in the Universe](#). Icon Books. ISBN 9781848316560.
 62. ^ Cockell, Charles; Corfield, Richard; Dise, Nancy; Edwards, Neil; Harris, Nigel (2008). [An Introduction to the Earth-Life System](#). Cambridge (UK): Cambridge University Press. ISBN 9780521729536.
 63. ^ Quinn, P.K.; Bates, T.S. (2011), "[The case against climate regulation via oceanic phytoplankton sulphur emissions](#)", *Nature*, **480** (7375): 51–56, [Bibcode:2011Natur.480...51Q](#), [doi:10.1038/nature10580](#), [PMID 22129724](#), [S2CID 4417436](#)
 64. ^ Ward, Peter (2009). *The Medea Hypothesis: Is Life on Earth Ultimately Self-Destruction?*. Princeton University Press. ISBN 978-0-691-13075-0.
 65. ^ Tyrrell 2013, p. 209.
 66. ^ Tyrrell, Toby (26 October 2013), "[Gaia: the verdict is...](#)", *New Scientist*, **220** (2940): 30–31, [doi:10.1016/s0262-4079\(13\)62532-4](#)
 67. ^ Tyrrell 2013, p. 208.
 68. ^ "[Gaia's evil twin: Is life its own worst enemy?](#)". *The New Scientist* (cover story). Vol. 202, no. 2713. 17 June 2009. pp. 28–31.
 69. ^ Poppick, Laura (5 April 2019). "[Snowball Earth: The times our planet was covered in ice](#)". *Astronomy*. Kalmbach Media. Retrieved 6 December 2023.
 70. ^ Harland, W. B. (1964-05-01). "Critical evidence for a great infra-Cambrian glaciation". *Geologische Rundschau*. **54** (1): 45–61. [Bibcode:1964GeoRu..54...45H](#). [doi:10.1007/BF01821169](#). ISSN 1432-1149. [S2CID 128676272](#).
 71. ^ Crowley, T.J.; Hyde, W.T.; Peltier, W.R. (2001). "CO 2 levels required for deglaciation of a 'near-snowball' Earth". [Geophysical Research Letters](#). **28** (2): 283–6. [Bibcode:2001GeoRL..28..283C](#). [doi:10.1029/2000GL011836](#).
 72. ^ Boyd, E.S.; Skidmore, M.; Mitchell, A.C.; Bakermans, C.; Peters, J.W. (2010). "Methanogenesis in subglacial sediments". *Environmental Microbiology Reports*. **2** (5): 685–692. [Bibcode:2010EnvMR...2..685B](#). [doi:10.1111/j.1758-2229.2010.00162.x](#). [PMID 23766256](#).

73. [^] [Jump up to:^{a b c d}](#) Mann, Michael (2023). *Our Fragile Moment*. New York: Hachette Book Group. [ISBN 9781541702899](#).
74. [^] Hulse, D; Lau, K.V.; Sebastiaan, J.V.; Arndt, S; Meyer, K.M.; Ridgwell, A (28 Oct 2021). "[End-Permian marine extinction due to temperature-driven nutrient recycling and euxinia](#)". *Nat Geosci.* **14** (11): 862–867. [Bibcode:2021NatGe..14..862H](#). [doi:10.1038/s41561-021-00829-7](#). [S2CID 240076553](#).
75. [^] McKinney, M. L. (1987). "Taxonomic selectivity and continuous variation in mass and background extinctions of marine taxa". *Nature*. **325** (6100): 143–145. [Bibcode:1987Natur.325..143M](#). [doi:10.1038/325143a0](#). [S2CID 13473769](#).
76. [^] Twitchett RJ, Looy CV, Morante R, Visscher H, Wignall PB (2001). "Rapid and synchronous collapse of marine and terrestrial ecosystems during the end-Permian biotic crisis". *Geology*. **29** (4): 351–354. [Bibcode:2001Geo....29..351T](#). [doi:10.1130/0091-7613\(2001\)029<0351:RASCOM>2.0.CO;2](#). [ISSN 0091-7613](#).
77. [^] Lamarque, J.-F.; Kiehl, J. T.; Orlando, J. J. (2007). "[Role of hydrogen sulfide in a Permian-Triassic boundary ozone collapse](#)". *Geophysical Research Letters*. **34** (2). [Bibcode:2007GeoRL..34.2801L](#). [doi:10.1029/2006GL028384](#).
78. [^] Kump, Lee R.; Pavlov, Alexander; Arthur, Michael A. (2005). "Massive Release of Hydrogen Sulfide to the Surface Ocean and Atmosphere During Intervals of Oceanic Anoxia". *Geology*. **33** (5): 397–400. [Bibcode:2005Geo....33..397K](#). [doi:10.1130/G21295.1](#).
79. [^] Nicholson, Arwen E.; Wilkinson, Davin M.; Williams, Hywel T. P.; Lenton, Timothy M. (2018). "Alternative mechanisms for Gaia". *Journal of Theoretical Biology*. **457**: 249–257. [Bibcode:2018JThBi.457..249N](#). [doi:10.1016/j.jtbi.2018.08.032](#). [hdl:10871/40424](#). [PMID 30149011](#).
80. [^] Fellgett, P. B. (1988). "[GAIA and the Anthropic Principle](#)". *Quarterly Journal of the Royal Astronomical Society*. **29**: 85. [Bibcode:1988QJRAS..29...85F](#). Retrieved 8 December 2023.
81. [^] [Jump up to:^{a b}](#) Doolittle, W. Ford. "[Is the Earth an organism?](#)". Aeon. Aeon Media Group Ltd. Retrieved 8 December 2023.
82. [^] Shavit, Ayelet. "[Altruism and Group Selection](#)". *Internet Encyclopedia of Philosophy*. University of Tennessee at Martin. Retrieved 9 December 2023.
83. [^] [Jump up to:^{a b c}](#) Arthur, Rudy; Nicholson, Arwen (2022). "[Selection principles for Gaia](#)". *Journal of Theoretical Biology*. **533**: 110940. [arXiv:1907.12654](#). [Bibcode:2022JThBi.53310940A](#). [doi:10.1016/j.jtbi.2021.110940](#). [PMID 34710434](#). Retrieved 11 December 2023.
84. [^] [Jump up to:^{a b}](#) zu Castell, W.; Lüttge, U.; Matyssek, R. (2019). "[Gaia — A Holobiont-like System Emerging From Interaction](#)". In Wegner, L.; Lüttge, U. (eds.). *Emergence and Modularity in Life Sciences*. Springer, Cham. pp. 255–279. [doi:10.1007/978-3-030-06128-9_12](#). [ISBN 978-3-030-06128-9](#).

Cited sources

[\[edit\]](#)

- Abram, David (1991). "[The Mechanical and the Organic: On the Impact of Metaphor in Science](#)". In Schneider, Stephen; Boston, Penelope (eds.). *Scientists On Gaia*. Cambridge, Massachusetts: MIT Press. Archived from [the original](#) on 2012-02-23 – via [Wildethics.org](#).

- Dawkins, Richard (1982). *The Extended Phenotype: the Long Reach of the Gene*. Oxford University Press. [ISBN 978-0-19-286088-0](#).
- Harding, Stephan (2006). *Animate Earth*. Chelsea Green Publishing. [ISBN 978-1-933392-29-5](#).
- Lovelock, James (2001). *Homage to Gaia: The Life of an Independent Scientist*. Oxford: Oxford University Press. [ISBN 978-0-19-860429-7](#).
- Lovelock, James (2009). *The Vanishing Face of Gaia: A Final Warning*. New York: Basic Books. [ISBN 978-0-465-01549-8](#).
- Margulis, Lynn (1998). *Symbiotic Planet: A New Look at Evolution*. London: Weidenfeld & Nicolson. [ISBN 978-0-297-81740-6](#).
- Turney, Jon (2003). *Lovelock and Gaia: Signs of Life*. Revolutions in Science. UK: Icon Books. [ISBN 978-1-84046-458-0](#).
- Tyrrell, Toby (2013). *On Gaia: A Critical Investigation of the Relationship between Life and Earth*. Princeton: Princeton University Press. [ISBN 978-0-691-12158-1](#).

Further reading

[\[edit\]](#)

- Abram, David (1990). *"The Perceptual Implications of Gaia"*. In Badiner, A. H. (ed.). *Dharma Gaia: A Harvest of Essays in Buddhism and Ecology*. Parallax Press. Archived from [the original](#) on 2013-10-31 – via Wildethics.org.
- Bondi, Roberto (2006). *Blu come un'arancia. Gaia tra mito e scienza*. Torino, Utet: Prefazione di Enrico Bellone. [ISBN 978-88-02-07259-3](#).
- Bondi, Roberto (2007). *Solo l'atomo ci può salvare. L'ambientalismo nuclearista di James Lovelock*. Torino, Utet: Prefazione di Enrico Bellone. [ISBN 978-88-02-07704-8](#).
- Jaworski, Helan (1928). *Le Géon ou la Terre vivante*. Paris: Librairie Gallimard.
- Joseph, Lawrence E. (1990). *Gaia: The Growth of an Idea*. New York: St. Martin's Press. [ISBN 978-0-31-204318-6](#).
- Kleidon, Axel (2004). "Beyond Gaia: Thermodynamics of Life and Earth system functioning". *Climatic Change*. **66** (3): 271–319. doi:[10.1023/B:CLIM.0000044616.34867.ec](#). S2CID [55295082](#).
- Lovelock, James (1983). *"Gaia as seen through the atmosphere"*. In Westbroek, P.; deJong, E. W. (eds.). *Biominalization and Biological Metal Accumulation*. D. Reidel Publishing Company. pp. 15–25 – via jameslovelock.org.
- Lovelock, James (2000). *Gaia: A New Look at Life on Earth*. Oxford: Oxford University Press. [ISBN 978-0-19-286218-1](#).
- Lovelock, James (16 January 2006). *"The Earth is about to catch a morbid fever"*. *The Independent*. Archived from [the original](#) on 2006-04-08.
- Lovelock, James (2007). *The Revenge of Gaia: Why the Earth Is Fighting Back: and How We Can Still Save Humanity*. Santa Barbara CA: Allen Lane. [ISBN 978-0-7139-9914-3](#).
- Marshall, Alan (2002). *The Unity of Nature: Wholeness and Disintegration in Ecology and Science*. River Edge, NJ: Imperial College Press. [ISBN 978-1-86094-330-0](#).
- Schneider, Stephen Henry (2004). *Scientists debate Gaia: the next century*. Cambridge, Massachusetts: MIT Press. [ISBN 978-0-262-19498-3](#).

- Staley, M. (September 2002). "Darwinian selection leads to Gaia". *J. Theor. Biol.* **218** (1): 35–46. [Bibcode:2002JThBi.218...35S](#). [doi:10.1006/jtbi.2002.3059](#). [PMID 12297068](#).
- Thomas, Lewis G. (1974). *The Lives of a Cell; Notes of a Biology Watcher*. New York: *Viking Press*. ISBN 978-0-670-43442-8.

External links

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[Library resources](#) about

Gaia hypothesis

-
- [Resources in your library](#)
 - [Resources in other libraries](#)
 - Lovelock, James (2006), interviewed in *How to think about science*, CBC Ideas (radio program), broadcast January 3, 2008. [Link](#)
 - "Lovelock: 'We can't save the planet'" BBC Sci Tech News
 - [Interview: Jasper Gerard meets James Lovelock](#)
 - [Clips of interview with James Lovelock from 2010](#) at the [Wayback Machine](#) (archived 3 March 2016)

Earth science

From Wikipedia, the free encyclopedia



The rocky side of a mountain creek in [Costa Rica](#)

Earth science or **geoscience** includes all fields of [natural science](#) related to the planet [Earth](#).^[1] This is a branch of science dealing with the physical, chemical, and biological complex constitutions and synergistic linkages of Earth's four spheres: the [biosphere](#), [hydrosphere/cryosphere](#), [atmosphere](#), and [geosphere](#) (or [lithosphere](#)). Earth science can be considered to be a branch of [planetary science](#) but with a much older history.

Geology

[\[edit\]](#)



Layers of [sedimentary rock](#) in [Makhtesh Ramon](#)

[Geology](#) is broadly the study of Earth's structure, substance, and processes. Geology is largely the study of the [lithosphere](#), or Earth's surface, including the [crust](#) and [rocks](#). It includes the physical characteristics and processes that occur in the lithosphere as well as how they are affected by [geothermal energy](#). It incorporates aspects of chemistry, physics, and biology as elements of geology interact. [Historical geology](#) is the application of geology to interpret [Earth history](#) and how it has changed over time.

[Geochemistry](#) studies the chemical components and processes of the Earth. [Geophysics](#) studies the physical properties of the Earth. [Paleontology](#) studies fossilized biological material in the lithosphere. [Planetary geology](#) studies geoscience as it pertains to extraterrestrial bodies. [Geomorphology](#) studies the origin of landscapes. [Structural geology](#) studies the deformation of rocks to produce mountains and lowlands. Resource geology studies how energy resources can be obtained from minerals. [Environmental geology](#) studies how pollution and contaminants affect soil and

rock.^[2] [Mineralogy](#) is the study of minerals and includes the study of mineral formation, [crystal structure](#), hazards associated with minerals, and the physical and chemical properties of minerals.^[3] [Petrology](#) is the study of rocks, including the formation and composition of rocks. [Petrography](#) is a branch of petrology that studies the typology and classification of rocks.^[4]

Earth's interior

[\[edit\]](#)



A [volcanic](#) eruption is the release of stored energy from below Earth's surface.^[5]

Main article: [Structure of Earth](#)

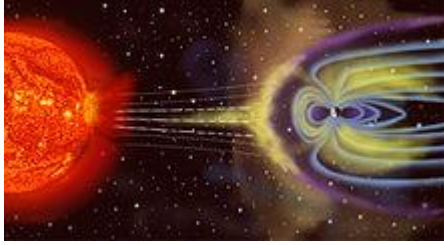
[Plate tectonics](#), [mountain ranges](#), [volcanoes](#), and [earthquakes](#) are [geological](#) phenomena that can be explained in terms of physical and chemical processes in the Earth's crust.^[6] Beneath the Earth's crust lies the [mantle](#) which is heated by the [radioactive decay](#) of [heavy elements](#). The mantle is not quite solid and consists of [magma](#) which is in a state of semi-perpetual [convection](#). This convection process causes the lithospheric plates to move, albeit slowly. The resulting process is known as plate tectonics.^{[7][8][9][10]} Areas of the crust where new crust is created are called *divergent boundaries*, those where it is brought back into the Earth are *convergent boundaries* and those where plates slide past each other, but no new lithospheric material is created or destroyed, are referred to as [transform](#) (or conservative) boundaries.^{[8][10][11]} [Earthquakes](#) result from the movement of the lithospheric plates, and they often occur near convergent boundaries where parts of the crust are forced into the earth as part of subduction.^[12]

Plate tectonics might be thought of as the process by which the Earth is resurfaced. As the result of [seafloor spreading](#), new crust and lithosphere is created by the flow of magma from the [mantle](#) to the near surface, through fissures, where it cools and solidifies. Through [subduction](#), oceanic crust and lithosphere vehemently returns to the convecting mantle.^{[8][10][13]} Volcanoes result primarily from the melting of subducted crust material. Crust material that is forced into the [asthenosphere](#) melts, and some portion of the melted material becomes light enough to rise to the surface—giving birth to volcanoes.^{[8][12]}

Atmospheric science

[\[edit\]](#)

Main article: [Atmospheric science](#)



The [magnetosphere](#) shields the surface of Earth from the charged particles of the [solar wind](#).
(*image not to scale.*)

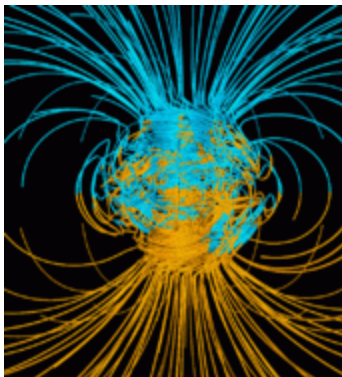
Atmospheric science initially developed in the late-19th century as a means to forecast the weather through [meteorology](#), the study of weather. [Atmospheric chemistry](#) was developed in the 20th century to measure [air pollution](#) and expanded in the 1970s in response to [acid rain](#). [Climatology](#) studies the [climate](#) and [climate change](#).^[14]

The [troposphere](#), [stratosphere](#), [mesosphere](#), [thermosphere](#), and [exosphere](#) are the five layers which make up Earth's atmosphere. 75% of the mass in the atmosphere is located within the troposphere, the lowest layer. In all, the atmosphere is made up of about 78.0% [nitrogen](#), 20.9% [oxygen](#), and 0.92% [argon](#), and small amounts of other gases including CO₂ and water vapor.^[15] Water vapor and CO₂ cause the Earth's atmosphere to catch and hold the Sun's energy through the [greenhouse effect](#).^[16] This makes Earth's surface warm enough for liquid water and life. In addition to trapping heat, the atmosphere also protects living organisms by shielding the Earth's surface from [cosmic rays](#).^[17] The [magnetic field](#)—created by the internal motions of the core—produces the [magnetosphere](#) which protects Earth's atmosphere from the [solar wind](#).^[18] As the Earth is [4.5 billion](#) years old,^{[19][20]} it would have lost its atmosphere by now if there were no protective magnetosphere.

Earth's magnetic field

[\[edit\]](#)

This section is an excerpt from [Earth's magnetic field](#).[\[edit\]](#)



Computer simulation of [Earth's](#) field in a period of normal polarity between reversals.^[21] The lines represent magnetic field lines, blue when the field points towards the center and yellow when away. The rotation axis of Earth is centered and vertical. The dense clusters of lines are within Earth's core.^[22]

Earth's magnetic field, also known as the geomagnetic field, is the **magnetic field** that extends from **Earth's interior** out into space, where it interacts with the **solar wind**, a stream of **charged particles** emanating from the **Sun**. The magnetic field is generated by **electric currents** due to the motion of **convection currents** of a mixture of molten **iron** and **nickel** in **Earth's outer core**: these convection currents are caused by heat escaping from the core, a natural process called a **geodynamo**.

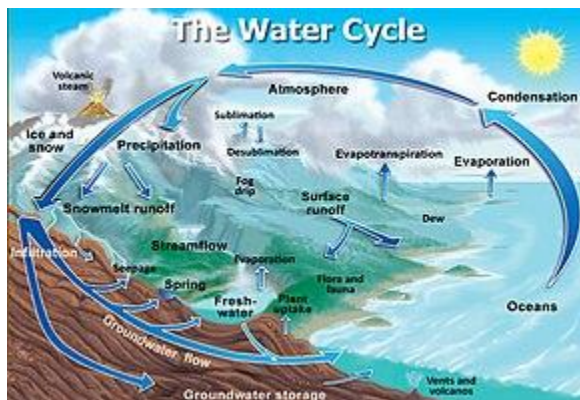
The magnitude of Earth's magnetic field at its surface ranges from 25 to 65 μT (0.25 to 0.65 G).^[23] As an approximation, it is represented by a field of a **magnetic dipole** currently tilted at an angle of about 11° with respect to **Earth's rotational axis**, as if there were an enormous **bar magnet** placed at that angle through the center of Earth. The **North geomagnetic pole** (**Ellesmere Island**, **Nunavut**, Canada) actually represents the South pole of Earth's magnetic field, and conversely the **South geomagnetic pole** corresponds to the north pole of Earth's magnetic field (because opposite magnetic poles attract and the north end of a magnet, like a compass needle, points toward Earth's South magnetic field.)

While the North and South **magnetic poles** are usually located near the geographic poles, they slowly and continuously move over geological time scales, but sufficiently slowly for ordinary **compasses** to remain useful for navigation. However, at irregular intervals averaging several hundred thousand years, **Earth's field reverses** and the **North** and **South Magnetic Poles** abruptly switch places. These reversals of the **geomagnetic poles** leave a record in rocks that are of value to **paleomagnetists** in calculating geomagnetic fields in the past. Such information in turn is helpful in studying the motions of continents and ocean floors. The **magnetosphere** is defined by the extent of Earth's magnetic field in space or **geospace**. It extends above the **ionosphere**, several tens of thousands of kilometres into **space**, protecting Earth from the charged particles of the **solar wind** and **cosmic rays** that would otherwise strip away the upper atmosphere, including the **ozone layer** that protects Earth from **harmful ultraviolet radiation**.

Hydrology

[[edit](#)]

Main article: [Hydrology](#)



Movement of water through the **water cycle**

Hydrology is the study of the hydrosphere and the [movement of water on Earth](#). It emphasizes the study of how humans use and interact with freshwater supplies. Study of water's movement is closely related to [geomorphology](#) and other branches of Earth science. Applied hydrology involves engineering to maintain aquatic environments and distribute water supplies. Subdisciplines of hydrology include [oceanography](#), [hydrogeology](#), [ecohydrology](#), and [glaciology](#). Oceanography is the study of oceans.^[24] Hydrogeology is the study of [groundwater](#). It includes the mapping of groundwater supplies and the analysis of groundwater contaminants. Applied hydrogeology seeks to prevent contamination of groundwater and [mineral springs](#) and make it available as [drinking water](#). The earliest exploitation of groundwater resources dates back to 3000 BC, and hydrogeology as a science was developed by hydrologists beginning in the 17th century.^[25] Ecohydrology is the study of ecological systems in the [hydrosphere](#). It can be divided into the physical study of aquatic ecosystems and the biological study of aquatic organisms. Ecohydrology includes the effects that organisms and aquatic ecosystems have on one another as well as how these ecosystems are affected by humans.^[26] Glaciology is the study of the cryosphere, including [glaciers](#) and coverage of the Earth by ice and snow. Concerns of glaciology include access to glacial freshwater, mitigation of glacial hazards, obtaining resources that exist beneath frozen land, and addressing the effects of climate change on the cryosphere.^[27]

Ecology

[\[edit\]](#)

Main article: [Ecology](#)

Ecology is the study of the [biosphere](#). This includes the study of nature and of how living things interact with the Earth and one another and the consequences of that. It considers how living things use resources such as [oxygen](#), [water](#), and [nutrients](#) from the Earth to sustain themselves. It also considers how humans and other living creatures cause changes to nature.^[28]

Physical geography

[\[edit\]](#)

Main article: [Physical geography](#)

Physical geography is the study of [Earth's systems](#) and how they interact with one another as part of a single self-contained system. It incorporates astronomy, mathematical geography, meteorology, climatology, geology, geomorphology, biology, biogeography, pedology, and soils geography. Physical geography is distinct from [human geography](#), which studies the human populations on Earth, though it does include human effects on the environment.^[29]

Methodology

[\[edit\]](#)



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Methodologies vary depending on the nature of the subjects being studied. Studies typically fall into one of three categories: observational, experimental, or theoretical. Earth scientists often conduct sophisticated computer analysis or visit an interesting location to study earth phenomena (e.g. Antarctica or [hot spot](#) island chains).

A foundational idea in Earth science is the notion of [uniformitarianism](#), which states that "ancient geologic features are interpreted by understanding active processes that are readily observed." In other words, any geologic processes at work in the present have operated in the same ways throughout geologic time. This enables those who study [Earth history](#) to apply knowledge of how the Earth's processes operate in the present to gain insight into how the planet has evolved and changed throughout long history.

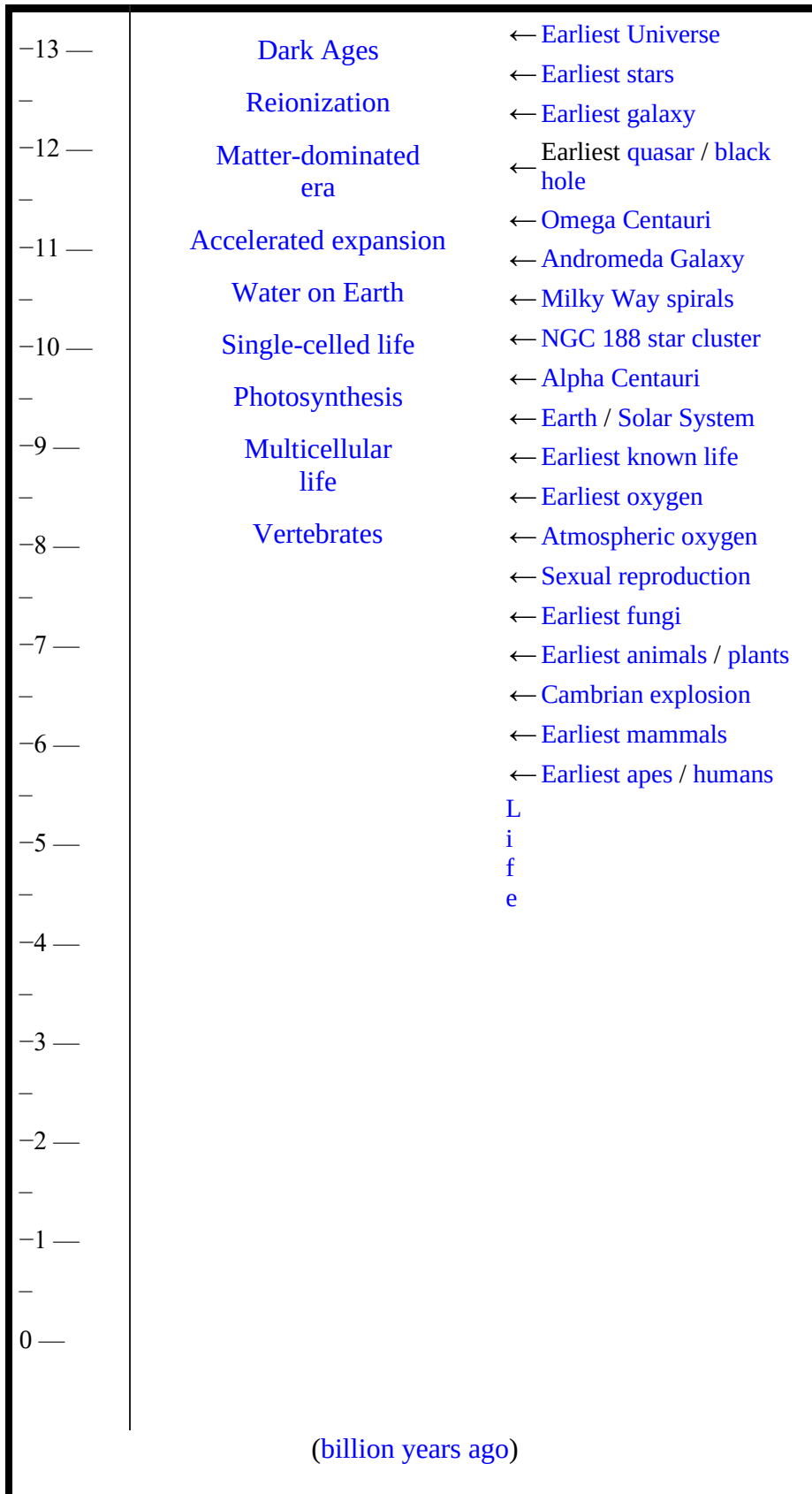
Earth's spheres

[\[edit\]](#)

[Nature timeline](#)

This box:

- [view](#)
- [talk](#)
- [edit](#)



In Earth science, it is common to conceptualize the Earth's surface as consisting of several distinct layers, often referred to as spheres: the [lithosphere](#), the [hydrosphere](#), the [atmosphere](#), and the [biosphere](#), this concept of spheres is a useful tool for understanding the Earth's surface and its various processes^[30] these correspond to [rocks](#), [water](#), [air](#) and [life](#). Also included by some are the [cryosphere](#) (corresponding to [ice](#)) as a distinct portion of the hydrosphere and the [pedosphere](#) (corresponding to [soil](#)) as an active and intermixed sphere. The following [fields of science](#) are generally categorized within the Earth sciences:

- [Geology](#) describes the [rocky](#) parts of the [Earth's crust](#) (or [lithosphere](#)) and its historic development. Major subdisciplines are [mineralogy](#) and [petrology](#), [geomorphology](#), [paleontology](#), [stratigraphy](#), [structural geology](#), [engineering geology](#), and [sedimentology](#).^{[31][32]}
- [Physical geography](#) focuses on [geography](#) as an Earth science. Physical geography is the study of Earth's seasons, climate, atmosphere, soil, streams, landforms, and oceans. Physical geography can be divided into several branches or related fields, as follows: [geomorphology](#), [biogeography](#), [environmental geography](#), [palaeogeography](#), [climatology](#), [meteorology](#), [coastal geography](#), [hydrology](#), [ecology](#), [glaciology](#).^[citation needed]
- [Geophysics](#) and [geodesy](#) investigate the [shape of the Earth](#), its reaction to forces and its [magnetic](#) and [gravity fields](#). Geophysicists explore the [Earth's core](#) and [mantle](#) as well as the [tectonic](#) and [seismic](#) activity of the lithosphere.^{[32][33][34]} Geophysics is commonly used to supplement the work of [geologists](#) in developing a comprehensive understanding of crustal geology, particularly in mineral and petroleum exploration. [Seismologists](#) use [geophysics](#) to understand plate tectonic movement, as well as predict seismic activity.
- [Geochemistry](#) is defined as the study of the processes that control the abundance, composition, and distribution of chemical compounds and isotopes in geologic environments. Geochemists use the tools and principles of chemistry to study the composition, structure, processes, and other physical aspects of the Earth. Major subdisciplines are [aqueous geochemistry](#), [cosmochemistry](#), [isotope geochemistry](#) and [biogeochemistry](#).
- [Soil science](#) covers the outermost layer of the Earth's crust that is subject to [soil formation](#) processes (or [pedosphere](#)).^[35] Major subdivisions in this field of study include [edaphology](#) and [pedology](#).^[36]
- [Ecology](#) covers the interactions between organisms and their environment. This field of study differentiates the study of Earth from the study of other planets in the [Solar System](#), Earth being its only planet teeming with life.
- [Hydrology](#), [oceanography](#) and [limnology](#) are studies which focus on the movement, distribution, and quality of the water and involves all the components of the hydrologic cycle on the Earth and its atmosphere (or [hydrosphere](#)). "Sub-disciplines of hydrology include hydrometeorology, surface water hydrology, hydrogeology, watershed science, forest hydrology, and water chemistry."^[37]

- [Glaciology](#) covers the [icy](#) parts of the Earth (or [cryosphere](#)).
- [Atmospheric sciences](#) cover the [gaseous](#) parts of the Earth (or [atmosphere](#)) between the surface and the [exosphere](#) (about 1000 km). Major subdisciplines include meteorology, climatology, [atmospheric chemistry](#), and [atmospheric physics](#).

Earth science breakup

[\[edit\]](#)

Main article: [Outline of Earth sciences](#)

Atmosphere

- [Atmospheric chemistry](#)
- [Geography](#)
 - [Climatology](#)
 - [Meteorology](#)
- [Hydrometeorology](#)
- [Paleoclimatology](#)

Biosphere

- [Biogeochemistry](#)
- [Biogeography](#)
- [Ecology](#)
 - [Landscape ecology](#)
- [Geoarchaeology](#)
- [Geomicrobiology](#)
- [Paleontology](#)
 - [Palynology](#)
 - [Micropaleontology](#)

Hydrosphere

- [Hydrology](#)
 - [Hydrogeology](#)
- [Limnology](#) (freshwater science)
- [Oceanography](#) (marine science)
 - [Chemical oceanography](#)
 - [Physical oceanography](#)
 - [Biological oceanography](#) (marine biology)
 - [Geological oceanography](#) (marine geology)
 - [Paleoceanography](#)

Lithosphere (geosphere)

- [Geology](#)
 - [Economic geology](#)
 - [Engineering geology](#)

- Environmental geology
- Forensic geology
- Historical geology
 - Quaternary geology
- Planetary geology and planetary geography
- Sedimentology
- Stratigraphy
- Structural geology
- Geography
 - Human geography
 - Physical geography
- Geochemistry
- Geomorphology
- Geophysics
 - Geochronology
 - Geodynamics (see also Tectonics)
 - Geomagnetism
 - Gravimetry (also part of Geodesy)
 - Seismology
- Glaciology
- Hydrogeology
- Mineralogy
 - Crystallography
 - Gemology
- Petrology
 - Petrophysics
- Speleology
- Volcanology

Pedosphere

- Geography
- Soil science
 - Edaphology
 - Pedology

Systems

- Earth system science
- Environmental science
- Geography
 - Human geography
 - Physical geography
- Gaia hypothesis
- Systems ecology

- [Systems geology](#)
- Others**

- [Geography](#)
 - [Cartography](#)
 - [Geoinformatics \(GIScience\)](#)
 - [Geostatistics](#)
 - [Geodesy and Surveying](#)
 - [Remote Sensing](#)
 - [Hydrography](#)
- [Nanogeoscience](#)

See also

[\[edit\]](#)

-  [Earth sciences portal](#)
-  [Environment portal](#)
-  [Ecology portal](#)
-  [World portal](#)

- [American Geosciences Institute](#)
- [Earth sciences graphics software](#)
- [Four traditions of geography](#)
- [Glossary of geology terms](#)
- [List of Earth scientists](#)
- [List of geoscience organizations](#)
- [List of unsolved problems in geoscience](#)
- [Making North America](#)
- [National Association of Geoscience Teachers](#)
- [Solid-earth science](#)
- [Science tourism](#)
- [Structure of the Earth](#)

References

[\[edit\]](#)

1. [^] ["Earth sciences | Definition, Topics, & Facts | Britannica". *www.britannica.com*. Retrieved 2023-08-19.](#)
2. [^] [Smith & Pun 2006](#), pp. 14–16.
3. [^] [Haldar 2020](#), p. 109.
4. [^] [Haldar 2020](#), p. 145.
5. [^] [Encyclopedia of Volcanoes. London: Academic Press. 2000. ISBN 9780080547985.](#)

6. ^ ["Earth's Energy Budget"](#). ou.edu. [Archived](#) from the original on 2008-08-27. Retrieved 2007-06-20.
7. ^ [Simison 2007](#), paragraph 7
8. ^ [Jump up to:^{a b c d} Adams & Lambert 2006](#), pp. 94–95, 100, 102
9. ^ [Smith & Pun 2006](#), pp. 13–17, 218, G-6
10. ^ [Jump up to:^{a b c} Oldroyd 2006](#), pp. 101, 103, 104
11. ^ [Smith & Pun 2006](#), p. 331
12. ^ [Jump up to:^{a b} Smith & Pun 2006](#), pp. 325–26, 329
13. ^ [Smith & Pun 2006](#), p. 327
14. ^ Wallace, John M.; Hobbs, Peter V. (2006). *Atmospheric Science: An Introductory Survey* (2nd ed.). Elsevier Science. pp. 1–3. [ISBN 9780080499536](#).
15. ^ [Adams & Lambert 2006](#), pp. 107–08
16. ^ [American Heritage](#), p. 770
17. ^ Parker, Eugene (March 2006), [Shielding Space](#) (PDF), *Scientific American*, archived from [the original](#) (PDF) on 2016-01-01, retrieved 2017-05-24
18. ^ [Adams & Lambert 2006](#), pp. 21–22
19. ^ [Smith & Pun 2006](#), p. 183
20. ^ ["How Did Scientists Calculate the Age of Earth?"](#). education.nationalgeographic.org. Retrieved 2023-08-19.
21. ^ Glatzmaier, Gary A.; Roberts, Paul H. (1995). "A three-dimensional self-consistent computer simulation of a geomagnetic field reversal". *Nature*. **377** (6546): 203–209. [Bibcode:1995Natur.377..203G](#). [doi:10.1038/377203a0](#). [S2CID 4265765](#).
22. ^ Glatzmaier, Gary. ["The Geodynamo"](#). University of California Santa Cruz. Retrieved 20 October 2013.
23. ^ Finlay, C. C.; Maus, S.; Beggan, C. D.; Bondar, T. N.; Chambodut, A.; Chernova, T. A.; Chulliat, A.; Golovkov, V. P.; Hamilton, B.; Hamoudi, M.; Holme, R.; Hulot, G.; Kuang, W.; Langlais, B.; Lesur, V.; Lowes, F. J.; Lühr, H.; Macmillan, S.; Mandea, M.; McLean, S.; Manoj, C.; Menvielle, M.; Michaelis, I.; Olsen, N.; Rauberg, J.; Rother, M.; Sabaka, T. J.; Tangborn, A.; Tøffner-Clausen, L.; Thébaud, E.; Thomson, A. W. P.; Wardinski, I.; Wei, Z.; Zvereva, T. I. (December 2010). ["International Geomagnetic Reference Field: the eleventh generation"](#). *Geophysical Journal International*. **183** (3): 1216–1230. [Bibcode:2010GeoJI.183.1216F](#). [doi:10.1111/j.1365-246X.2010.04804.x](#). [hdl:20.500.11850/27303](#).
24. ^ Davie, Tim; Quinn, Nevil Wyndham (2019). *Fundamentals of Hydrology* (3rd ed.). Routledge. pp. 1–2. [ISBN 9780203798942](#).
25. ^ Hölting, Bernward; Coldewey, Wilhelm G. (2019). "Introduction". [Hydrogeology](#) (8th ed.). Springer. pp. 1–3. [doi:10.1007/978-3-662-56375-5](#). [ISBN 9783662563755](#). [Archived](#) from the original on 2022-08-16. Retrieved 2022-08-16.
26. ^ Wood, Paul J.; Hannah, David M.; Sadler, Jonathan P. (2007). "Ecohydrology and Hydroecology: An Introduction". *Hydroecology and Ecohydrology: Past, Present and Future*. Wiley. pp. 1–6. [ISBN 9780470010174](#).
27. ^ Knight, Peter (1999). [Glaciers](#). Taylor & Francis. p. 1. [ISBN 9780748740000](#).
28. ^ Ricklefs, Robert E.; Miller, Gary L. (2000). *Ecology* (4th ed.). W. H. Freeman. pp. 3–4. [ISBN 9780716728290](#).
29. ^ Petersen, James F.; Sack, Dorothy; Gabler, Robert E. (2014). *Fundamentals of Physical Geography*. Cengage Learning. pp. 2–3. [ISBN 9781285969718](#).

30. ^ [Earth's Spheres Archived](#) August 31, 2007, at the [Wayback Machine](#). ©1997–2000. Wheeling Jesuit University/NASA Classroom of the Future. Retrieved November 11, 2007.
31. ^ [Adams & Lambert 2006](#), p. 20
32. ^ [Jump up to:^a ^b Smith & Pun 2006](#), p. 5
33. ^ ["WordNet Search – 3.1"](#). [princeton.edu](#). [Archived](#) from the original on 2019-05-15. Retrieved 2010-10-13.
34. ^ ["NOAA National Ocean Service Education: Global Positioning Tutorial"](#). [noaa.gov](#). [Archived](#) from the original on 2005-05-08. Retrieved 2007-11-17.
35. ^ [Elissa Levine, 2001, The Pedosphere As A Hub](#) broken link?
36. ^ [Gardiner, Duane T. "Lecture 1 Chapter 1 Why Study Soils?". ENV320: Soil Science Lecture Notes. Texas A&M University-Kingsville. Archived from the original on 2018-02-09. Retrieved 2019-01-07.](#)
37. ^ [Craig, Kendall. "Hydrology of the Watershed"](#). [Archived](#) from the original on 2017-01-11. Retrieved 2017-04-04.

Sources

[\[edit\]](#)

- [Adams, Simon; Lambert, David \(2006\). Earth Science: An illustrated guide to science. New York: Chelsea House. ISBN 978-0-8160-6164-8.](#)
- [Halder, S. K. \(2020\). Introduction to Mineralogy and Petrology \(2nd ed.\). Elsevier Science. ISBN 9780323851367.](#)
- [American Heritage dictionary of the English language \(4th ed.\). Boston: Houghton Mifflin Company. 1992. ISBN 978-0-395-82517-4.](#)
- [Simison, W. Brian \(2007-02-05\). "The mechanism behind plate tectonics". Archived from the original on 2007-11-12. Retrieved 2007-11-17.](#)
- [Smith, Gary A.; Pun, Aurora \(2006\). How Does the Earth Work? Physical Geology and the Process of Science. Upper Saddle River, NJ: Pearson Prentice Hall. ISBN 978-0-13-034129-7.](#)
- [Oldroyd, David \(2006\). Earth Cycles: A historical perspective. Westport, CT: Greenwood Press. ISBN 978-0-313-33229-6.](#)

Further reading

[\[edit\]](#)

- [Allaby M., 2008. Dictionary of Earth Sciences, Oxford University Press, ISBN 978-0-19-921194-4](#)
- [Korvin G., 1998. Fractal Models in the Earth Sciences, Elsevier, ISBN 978-0-444-88907-2](#)
- ["Earth's Energy Budget". Oklahoma Climatological Survey. 1996–2004. Archived from the original on 2007-11-17. Retrieved 2007-11-17.](#)
- [Miller, George A.; Christiane Fellbaum; and Randee Tengi; and Pamela Wakefield; and Rajesh Poddar; and Helen Langone; Benjamin Haskell \(2006\). "WordNet Search 3.0". WordNet a lexical database for the English language. Princeton, NJ: Princeton University/Cognitive Science Laboratory. Archived from the original on 2011-01-01. Retrieved 2007-11-10.](#)

- ["NOAA National Ocean Service Education: Geodesy"](#). National Oceanic and Atmospheric Administration. 2005-03-08. [Archived](#) from the original on 2005-05-08. Retrieved 2007-11-17.
- Reed, Christina (2008). *Earth Science: Decade by Decade*. New York: Facts on File. [ISBN 978-0-8160-5533-3](#).
- Tarbuck E. J., Lutgens F. K., and Tasa D., 2002. *Earth Science*, Prentice Hall, [ISBN 978-0-13-035390-0](#)

Physicists Propose How To Test If The Universe Is Finely Tuned For Life



It sure looks made for us, but then it would. - Image credit: Triff/Shutterstock.com© IFL Science

A new paper has set out ways that we can test the anthropic principle, or whether the universe has been "finely tuned" for life. Surprisingly, it may be possible to have answers to this age-old question in a pretty short timescale.

There is a problem (or not, for fans of being alive) within physics, in that the universe appears finely tuned for life – at least of the kind we find on Earth – to emerge and thrive.

If gravity was substantially weaker than it is (and it's [already pretty weak](#), just ask any magnet), stars and planets would not have formed. If it was just a little

weaker, or electromagnetism slightly stronger, stars would be cooler and not explode to produce the heavier elements needed for life to exist. There are countless other examples. Mess around with the values of physics even slightly, and life as we know it in this universe would not exist.

"The cliché that 'life is balanced on a knife-edge' is a staggering understatement," physicist Paul Davies famously [wrote of the problem](#). "No knife in the universe could have an edge that fine."

Naturally, scientists and philosophers have attempted to tackle this problem in different ways. You could argue that the universe is not really fine-tuned for life. Perhaps if the constants had been different, a different sort of life would have emerged (by [different processes](#)) to ask why the universe appears to be so finely tuned for its existence.

One idea is that asking the question "Why is the universe so finely tuned for us?" is a kind of survivor bias, or the observer selection effect, sometimes termed the anthropic principle.

"Suppose the evolution of life and intelligence requires a set of exceedingly unlikely coincidences: planets at just the right distance from an unusually stable star in the galactic life zone, with a stabilizing moon and a comet-deflecting Jovian, just the right chemical diversity, a fantastically unlikely chemical coincidence producing cells, a long list of low-probability evolutionary steps leading up to a generalist species forced by environmental conditions to become a super-generalist intelligent species," [writes](#) Anders Sandberg of the Institute for Futures Studies. "Yet every intelligent species in the universe would have these coincidences under their belt. Conversely, knowing we exist does not tell us whether intelligence is common."

In short, any observers would find themselves in a universe that seems just right for them. If the conditions were not right, they would not be alive. They are alive, so the conditions must have been right for life. Extensions of the idea propose that we are simply in a [multiverse](#) with many possible values for various constants, and are in the part of it in which life is possible.

This is a pretty difficult idea to test, but, according to a new paper, it is possible, and we could have answers surprisingly soon.

The authors focused on dark matter, the mysterious substance that makes up most of the universe's matter, according to the standard dark energy/cold dark matter model of physics. The search for dark matter has, so far, yielded zero particles that fit the required bill.

One idea for dark matter was weakly interacting massive particles (WIMPs). This idea was favored because it was predicted by [supersymmetry](#), and was expected to be produced in an abundance that would explain observations at the beginning of the universe. As such, their existence would not require the anthropic principle in order to explain why it (and we) are here.

However, we have not found WIMPs at the predicted energies, and physicists are increasingly turning to axions and "fuzzy axions" as an alternative explanation. [Axions](#) were first proposed to explain charge parity violation (or CP violation) and are predicted to be extremely light.

If they do make up dark matter, they are predicted to have been produced at specific masses during "high-scale inflation" in the early universe. If axion dark matter is found, or signs of it through upcoming observations, we could see it as a test of the anthropic principle.

"The point is, that the presence of high-scale inflation and ultralight axions with masses $m > 10^{-19}$ eV would imply that dark matter 'must' be an axion: for typical initial conditions, we'd end up with way too much dark matter, and we'd desperately need the anthropic principle to constrain it," Nemanja Kaloper, a physicist from the Department of Physics and Astronomy at the University of California, Davis, explained in a [statement](#).

"To find that axion is not dark matter, we'd infer that the initial conditions were not just unlikely (which can be fixed anthropically) but extremely unlikely, which really does not even fall under the domain of anthropic reasoning."

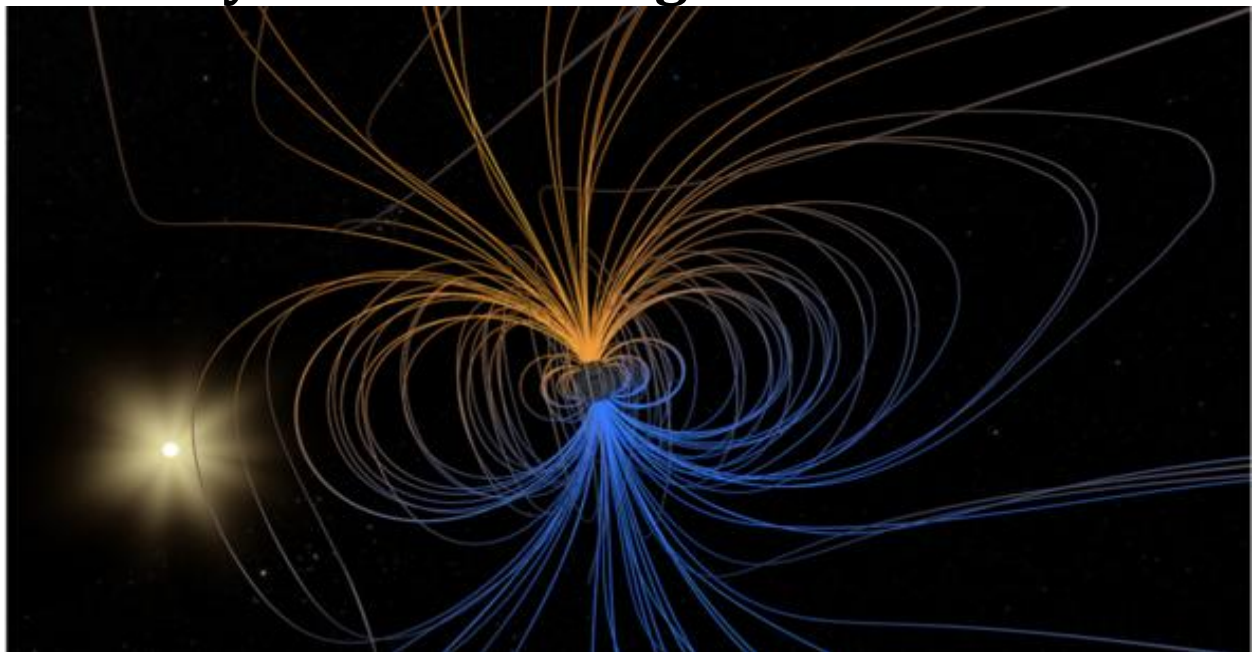
While finding dark matter seems like a long shot – we have been looking for a while, after all – the upcoming Lite Satellite for the Study of B-mode Polarization (LiteBIRD), set for launch by Japan in 2032, could provide evidence for or against the anthropic principle.

"It is possible that the LiteBIRD satellite discovers primordial gravity waves close to the current limits, which match high-scale inflation," Kaloper explained. "Most cosmologists would feel this confirms high-scale inflation."

"It is also possible that we discover signs of ultralight axions by surveying supermassive black holes in the universe. The axions affect the spin-to-mass ratio of black holes, and this could be observed," Kaloper continued. "Finally, it is possible that future direct dark matter searches discover that dark matter is predominantly not made up of ultralight axions. In which case, we'd think that the anthropic principle fails."

The study will be published in the Journal of Cosmology and Astroparticle Physics and a preprint is available on [arXiv](#).

NASA on high alert over massive 'dent' anomaly in Earth's magnetic field



model of the Earth's magnetic field.© NASA

NASA has been tracking an evolving "dent" in Earth's magnetic field which stretches out between South America and southwest Africa.

Dubbed the South Atlantic Anomaly, the region of lower magnetic intensity in the field has [concerned researchers](#) for years.

Earth's magnetic field acts like a protective shield around the planet, repelling and trapping charged particles from the Sun, according to NASA.

But the weakened magnetic field within the anomaly allows these particles to dip closer to the surface than normal.

The region can be hazardous for NASA's low-Earth orbit satellites and spacecraft that travel through it.

The agency said that if a satellite is hit by a high-energy proton, it can short-circuit and glitch temporarily. Permanent damage can also be caused if a key component is hit.

In order to avoid losing satellites, NASA shuts down non-essential components as they pass through the anomaly, described by some researcher as a "dent."

The agency said observations in recent years have shown that the region is expanding and continuing to weaken.

In 2020, researchers found that it has also split into two lobes, creating more issues for the agency's satellite missions.

A large reservoir of dense rock located 1,800 miles below Africa is believed to be what is disturbing the field's generation, resulting in the weakening effect.

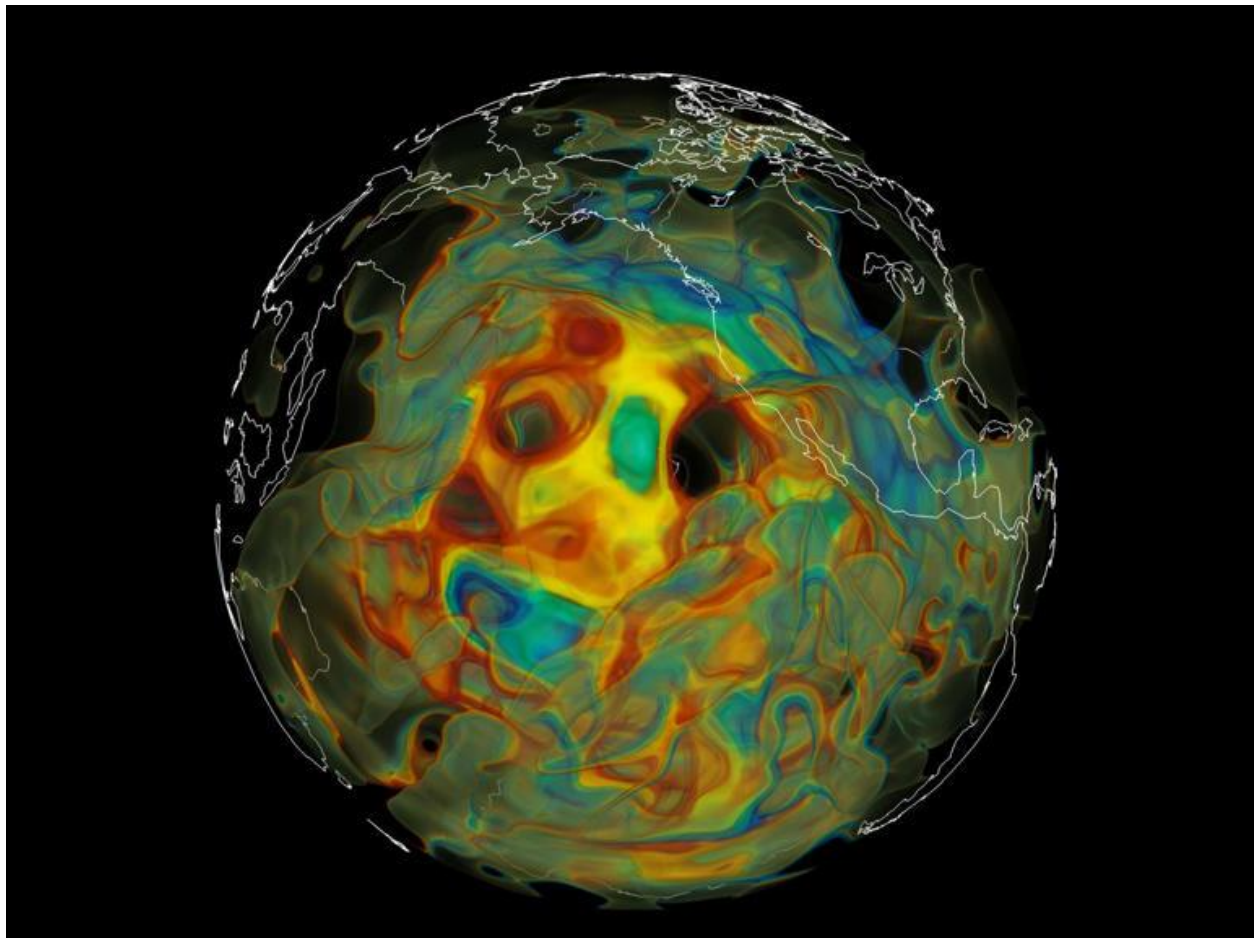
A 2020 study suggested the strange phenomenon could be a recurrent magnetic event that may have affected Earth 11 million years ago.

南半球版



Hao Xiaoguang's vertical world map Associated Press / Alamy Stock Photo

Geopolitics is also at play in this modern Chinese map from 2013. The vertical depiction shows Asia at the centre of the world, also highlighting the poles as opposed to hiding them away in the usual manner like “some embarrassing great aunt”, says Bonnett. The effect is to emphasise Asia as the seat of global power and to mark increasingly ice-free polar waters as sites for economic opportunity. Political boundaries have always changed, says Bonnett. However, that is increasingly true of natural features as well. “I don’t think we’ve ever lived at a time where the physical natural map of the world is changing so fast,” he says.



This map shows the structure of the planet’s mantle below the Pacific Ocean based on reflected seismic waves
Princeton University

Maps can extend from above Earth to below it. This tangle of colours indicates the structure of the planet’s mantle below the Pacific Ocean based on reflected seismic waves rippling through this region. Produced in 2015 by a team of geoscientists using a supercomputer to crunch the numbers from thousands of earthquakes, it depicts the speed of the waves as they move through different

materials that are at different pressures and temperatures within the planet. The slowest speeds are in red and orange, while the fastest are in green and blue. A particular area of interest for Bonnett is the ring of blue on the left side of the map marking the fast-moving tectonic feature known as the Tonga microplate. This image is just one view of a larger project to create a 3D map of Earth's entire mantle.

How the Earth's most isolated tree met its tragic end



The tree's extraordinary will to survive captivated explorers and scientists alike. During a well excavation in 1938-1939, researchers discovered its roots reached 118 feet underground to access water. "One must see the Tree to believe its existence," wrote Commander Michel Lesourd in 1939 "What is its secret? How can it still be living in spite of the multitudes of camels which trample at its sides?"

The answer lay in local customs that treated the tree as sacred. Desert travelers respected an unwritten rule never to harm it, with the acacia becoming what Lesourd called "a living lighthouse" for caravans traveling between Agadez and Bilma. The tree was so significant it appeared on maps at a scale of 1:4,000,000 – one of only two trees deemed important enough to mark.

Sadly, modern machinery proved more destructive than centuries of desert winds and passing caravans. In 1973, an intoxicated Libyan truck driver crashed into the tree and killed it. Today, the tree's remains rest in the Niger National Museum in Niamey, while a metal sculpture marks its original location in the vast Sahara – a memorial to what was once described by the *Smithsonian Magazine* as "the most isolated tree in the world."

Largest Organism in The World Could Officially Be The Oldest Living Thing



Green Aerial Outline of Pando© Provided by ScienceAlert

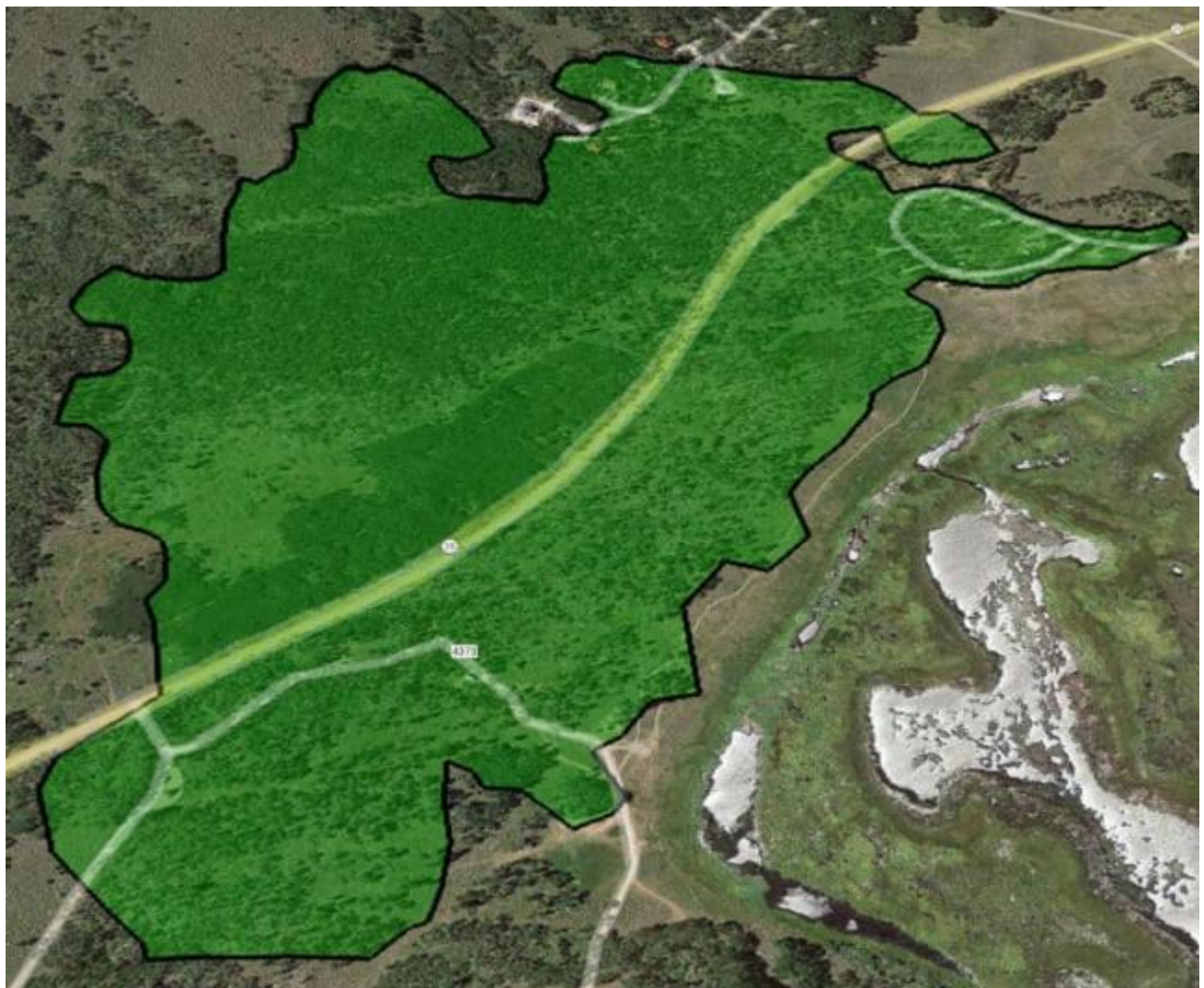
Age might well be just a number, but for a plant in Utah known affectionately as Pando, it could be a digit that leaves all other living things in the dust.

Sequencing hundreds of samples of material collected from the vast network of quaking aspen (*Populus tremuloides*), a team of

scientists in the US has estimated the 106-acre (43-hectare) wood may have started as a lonely seedling long before the end of the [last ice age](#), some 34,000 years ago.

Incredibly, less conservative estimates confirm it's possible that the tree may have even sprouted tens of thousands of years before that.

Though [the study](#) is yet to be peer reviewed, its conclusions [help confine speculations](#) over how long this one clonal organism has stood in place, which have ranged wildly from several thousand to more than a million years.



Pando stretches across 106 acres, 103 of which are visible from above. (Friends of Pando)

Pando already attracts attention from biologists for its impressive size, considered by some to be the single largest organism on the planet.

Though the aspen appears to be 47,000 distinct trees rising above the soil, all share the same genetic heritage and the one web of interconnected roots, effectively making them all chips off the same ol' block.

The record holder for a solitary tree's age is an [unnamed bristlecone pine](#) in California's White Mountains, thought to be a smidge over 5,000 years old.



Bristlecone pines are some of the longest-lived non-cloning plants. (Piriya Photography/Getty Images)

Yet clonal organisms like Pando – a name that translates into 'I spread' – [play by different rules](#). Its genome of chromosome triplets doesn't mix easily with others within its species, limiting the plant's reproduction to asexual clones that remain connected while rooting its way through the environment.

Whether we consider creeping populations of near-identical cells to be one individual or an army of closely-related units, clonal organisms have a knack for persisting in one place where their

sexually-reproductive cousins easily wither. Asexual reproduction has allowed some species of fungi to [survive for centuries](#) in one place as a single ongoing mass, for example.

Pando has already been suspected of [being extremely old](#). To place harder limits on its actual age, the research team collected around 500 pieces of root, leaf, and bark from its trees, as well as specimens from other, unrelated aspen, and sequenced their DNA.

Applying analytical techniques to pick out changes that have emerged over time, the researchers identified 4,000 genetic variations across the various samples. The patterns of their mutations told an intriguing story, one their models suggest dates back anywhere from 16,000 to 80,000 years.

"You would expect that the trees that are spatially close are also closer genetically," University of Chicago geneticist Rozenn Pineau told Helena Kudiabor at [Nature](#).

"But this is not exactly what we find. We found a spatial signal, but that is much weaker than what we expected."

Further studies on why its history of mutations has spread in this way and how Pando protects its genome to avoid accumulations of less-helpful genes could tell us why the plant and others like it live to such a ripe old age.

With fears that Pando's [days might be numbered](#), it's critical we learn as much as we can about the plant's ability to [handle whatever humans](#) and [the natural world](#) might throw at it.

Similar studies on other clonal organisms may even push the aspen from its perch. There's a patch of *Posidonia oceanica* seagrass off the Spanish island of Formentera which some venture might be [more than 200,000 years old](#).

We can only hope Pando sticks around to reach such a number.

The world's oldest forest dating hundreds of millions of years old has been discovered



The forest is believed to be about 386m years old, which makes it older than the Amazon© David McNew/Getty Images

There are some pretty old forests in this world – but the one which dates back the furthest is actually in [upstate New York](#), of all places.

A network of trees that is thought to have once sprawled about 400 kilometres (250 miles) was found in Cairo, USA, at the bottom of a sandstone quarry.

The forest is believed to be about 386 million years old, which makes it older than the [Amazon rainforest](#), India's legendary jungles and the remote forests of southeast Asia.

A team led by scientists at Binghamton University, New York State Museum and Cardiff University mapped about 3,000 square metres of the forest in the foothills of the Catskill Mountains in the Hudson Valley in 2019.

The forest contains early plants called cladoxyloids, which are similar to ferns, and *Achaeopteris* trees, which have fronds for branches.

A single example of a third type of tree was also uncovered, which remained unidentified but could possibly have been a lycopod.

All these trees reproduced using only spores rather than seeds.

Dr Christopher Berry, a paleobotanist at Cardiff University, said in 2019: "You are walking through the roots of ancient trees.

"Standing on the quarry surface we can reconstruct the living forest around us in our imagination.

"This would have looked like a fairly open forest with small to moderate sized coniferous-looking trees with individual and

clumped tree-fern like plants of possibly smaller size growing between them.

"In order to really understand how trees began to draw down carbon dioxide from the atmosphere, we need to understand the ecology and habitats of the very earliest forests, and their rooting systems.

"These remarkable findings have allowed us to move away from the generalities of the importance of large plants growing in forests, to the specifics of which plants, in which habitats, in which types of ecology were driving the processes of global change.

"We have literally been able to drill into the fossil soil between the trees and are now able to investigate geochemical changes to the soil with our colleagues at Sheffield University.

"We are really getting a handle on the transition of the Earth to a forested planet."

Oldest Plants in the World

Across the world, some plants have defied time, surviving for thousands and even tens of thousands " of years. These ancient organisms have withstood climate changes, natural disasters, and the test of centuries, adapting in incredible ways to ensure their survival. From resilient trees and clonal shrubs to hardy mosses and unique desert plants, each of these botanical wonders tells a story of persistence and adaptability. Many of these plants are found in extreme environments, which have shaped their unique characteristics and lifespans. By understanding these ancient species, we gain insights into the

remarkable resilience of life and the hidden history written within each leaf and branch. Here's a look at some of the oldest plants still alive on Earth today.



Pando (*Populus tremuloides*)

Pando, also known as "The Trembling Giant," is a clonal colony of quaking aspens estimated to be 80,000 years old. Located in Utah, it is considered the heaviest and oldest living organism in terms of its extensive root system. Despite appearing as individual trees, each trunk is genetically identical and connected to a massive underground root network. Over millennia, Pando has survived by continually sending up new shoots even as older ones die off.

Climate change and grazing threats have, however, put Pando at risk in recent years. Conservationists are working to protect this ancient organism from further harm. Pando's remarkable age and size make it one of the most extraordinary examples of plant longevity.

Pando: The world's largest tree and heaviest living organism

Pando is an ancient quaking aspen tree (*Populus tremuloides*) with 47,000 genetically identical stems, or tree trunks, connected to a vast underground root system. Each stem is a clone of the one next to it and originates from a single seed that started growing up to 80,000 years ago during the [last ice age](#).

Pando — Latin for "I spread" — is the largest known tree on Earth and the heaviest living organism on record. The colony extends over 106 acres (43 hectares) and weighs an estimated 6,500 tons (5,900 metric tons), which is equivalent to 40 blue whales or three times the [world's largest single-stem tree](#) — California's General Sherman giant sequoia (*Sequoiadendron giganteum*).

Researchers realized that Pando is a single organism in the 1970s, and geneticists have since confirmed that what looks to the untrained eye like a forest is actually one giant clone, according to the U.S. [Forest Service](#). A recent DNA analysis of hundreds of tree samples suggested Pando is between 16,000 and 80,000 years old, making it one of the oldest living organisms in the world — although that research, which was published Oct. 24, 2024 to the [preprint database bioRxiv](#), has not yet been peer reviewed.

Some of Pando's stems are more than 130 years old, according to the Forest Service, and the plant should continuously regenerate

the parts of itself that wither and die. But that hasn't been the case in recent years.

Pando reproduces asexually, creating clones of itself rather than mixing its DNA with that of other trees. The root system produces genetically identical shoots that grow upward, filling in the gaps between stems and keeping the plant alive for thousands of years. But according to a [2018 study](#), aerial images taken of Pando over a period of 72 years show stark signs of decline, including larger gaps in the canopy and aging stems that aren't being replaced by younger ones.



The Pando aspen clone extends across 106 acres. (Image credit: Jon G. Fuller/VWPics/Alamy)

"Imagine walking into a town of 50,000 people where everybody in town was 85 years old," [Paul Rogers](#), an adjunct associate professor of ecology at Utah State University and director of the [Western Aspen Alliance](#), told [National Geographic](#) in 2022. "That's sort of the issue with Pando."

The main culprits for this decline are [animals that eat aspen shoots](#), according to the 2018 study. Mule deer and cattle that graze in Utah's Fishlake National Forest are chomping off the tops of saplings and killing new growth quicker than the plant can compensate for. Wolves, bears and cougars used to keep the deer population in check, but humans have now eliminated most of these predators.

Pests and diseases are also attacking Pando, with root rot as well bacterial and fungal infections affecting the stems, according to the Forest Service. "Another thought is that the Pando is just old and doesn't have the energy reserves to send up suckering [fresh new shoots]," Kurt Robins, a district ranger of Fishlake National Forest, [said in a video](#).

Aspen stands like Pando support highly diverse animal and plant communities and form an integral part of the ecosystem. "We look at the aspen as a keystone species for what they provide on the landscape."



Methuselah Tree (*Pinus longaeva*)

© Image Editorial Credit: Dcjrjr / Wikimedia Commons

The Methuselah Tree, a bristlecone pine in California, is estimated to be around 4,850 years old. Growing in the White Mountains, this tree thrives at high altitudes with cold, harsh climates.

Methuselah's remarkable age is due in part to its slow growth and ability to survive with minimal nutrients. Its wood is dense and resistant to decay, allowing it to persist for millennia even as parts of the tree die off. The tree has witnessed countless seasons

and changes in climate. Named after the biblical figure, it stands as a symbol of endurance. Methuselah's longevity is unmatched among non-clonal plants.



Jomon Sugi (*Cryptomeria japonica*)

© Image Editorial Credit: Chris 73 / Wikimedia Commons

The Jomon Sugi, a cryptomeria tree found in Japan's Yakushima Island, is estimated to be between 2,000 and 7,200 years old. This tree is Japan's oldest and largest conifer, with a height and trunk girth that commands respect. The humid, forested environment of Yakushima has provided an ideal setting for the tree's growth. Over the centuries, it has withstood numerous typhoons, earning it a legendary status among locals.

The Jomon Sugi is a protected national treasure, drawing thousands of visitors each year. Its ancient bark and roots have weathered the test of time. The tree is both a symbol of resilience and a reminder of nature's wonders.



Zion Curtain Juniper (*Juniperus osteosperma*)

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The Zion Curtain Juniper, found in Utah's high desert, is estimated to be over 1,600 years old. This ancient tree has survived in an environment where other plants struggle due to

extreme drought and rocky soil. Junipers like the Zion Curtain adapt by growing slowly and using water very efficiently. Its twisted branches and dense, resilient bark are symbols of its endurance through centuries. This juniper also plays an essential ecological role, providing shelter and food for wildlife. Despite its age, it continues to grow and thrive, withstanding the region's harsh conditions. The Zion Curtain Juniper is a reminder of the resilience needed to survive in arid landscapes.



Siberian Larch (*Larix sibirica*)

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Found in the cold forests of Siberia, the Siberian Larch has an estimated age of up to 2,500 years. This resilient conifer grows in some of the harshest climates, withstanding extreme cold and nutrient-poor soil. Its thick bark and needle-like leaves help conserve water and protect against freezing temperatures. Despite these challenges, the Siberian Larch has flourished, becoming a symbol of strength in Siberia  s wilderness. It also provides shelter for animals and helps stabilize the soil in its region. In winter, its needles turn yellow and fall, a rare trait among conifers, enabling it to save energy during the colder months. The Siberian Larch is a testament to adaptation and survival.



Kauri Tree (*Agathis australis*)

© Image Editorial Credit: Michael Beckmann / Wikimedia Commons

The Kauri Tree, native to New Zealand, is estimated to be over 2,000 years old. This towering tree grows in the subtropical forests of the North Island and is one of the largest trees in the world. Its thick, rough bark and expansive canopy create a natural shelter for numerous species. Kauri trees produce a highly resistant wood, which has helped ancient specimens survive for millennia.

However, the species is now threatened by disease and human activities, and conservation efforts are underway. Kauri trees are revered in Māori culture, symbolizing strength and longevity. These magnificent trees are a reminder of the ancient and diverse ecosystems found in New Zealand.



The Olive Tree of Vouves (*Olea europaea*)

© Image Editorial Credit: Eric Nagle / Wikimedia Commons

The Olive Tree of Vouves, located on the Greek island of Crete, is estimated to be between 2,000 and 3,000 years old. This ancient olive tree still produces olives, and its twisted trunk has become a symbol of resilience and heritage. It is considered one of the

oldest olive trees in the world and continues to flourish despite its age. The tree has been scientifically analyzed, and its age is celebrated with an annual festival. Over the centuries, it has provided food and oil for countless generations. The Olive Tree of Vouves is also a symbol of peace and longevity in Greek culture. This ancient tree is a living reminder of Crete's deep agricultural history.



General Sherman Tree (*Sequoiadendron giganteum*)

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The General Sherman Tree, a giant sequoia located in California's Sequoia National Park, is estimated to be around 2,200 years old. This colossal tree is the largest living tree by volume, with its massive trunk and towering height. Despite its incredible size, General Sherman grows in a relatively limited area where sequoias thrive. Its thick bark helps protect it from wildfires, which have allowed it to survive countless blazes. The tree's age and size make it a popular tourist attraction and a symbol of longevity. Giant sequoias are known for their impressive height and width, with some branches thicker than ordinary tree trunks. General Sherman is a testament to the enduring strength of ancient trees in North America.



Patriarca da Floresta (*Cariniana legalis*)

© Image Editorial Credit: Bruna Leone Gagetti / Wikimedia Commons

Found in Brazil, Patriarca da Floresta is an ancient tree with an estimated age of over 3,000 years. This species, known as the Jequitibã-Rosa, is native to the Atlantic Forest and is one of the tallest trees in Brazil. It plays a critical ecological role, providing food and shelter for numerous species in its ecosystem. The tree's dense wood and resilient bark have helped it survive

fires and human encroachment. Due to its age and size, Patriarca da Floresta is considered a national treasure. It also symbolizes the endangered state of Brazil's forests and the importance of conservation. This ancient tree has become an icon of preservation and natural history in Brazil.



Baobab of Sagole (*Adansonia digitata*)

© Image Editorial Credit: Ferdinand Reus / Wikimedia Commons

The Baobab of Sagole, located in South Africa, is estimated to be over 1,200 years old. Known for its iconic swollen trunk, this baobab is the largest in South Africa and one of the oldest known baobabs. It has been used by indigenous communities for centuries as a source of food, water, and shelter. Baobabs are uniquely adapted to store water in their massive trunks, helping

them survive droughts. The tree's hollow interior has provided refuge for both people and wildlife throughout its long life. Sadly, many ancient baobabs have been dying in recent years due to climate change. The Baobab of Sagole remains a powerful symbol of Africa's unique natural heritage.



Alerce (*Fitzroya cupressoides*)

© Image Editorial Credit: PatagoniaArgentina / Wikimedia Commons

The Alerce, also known as the Patagonian cypress, is native to Chile and Argentina, with some specimens estimated to be around 3,600 years old. This slow-growing tree is one of the oldest and largest in South America. Its thick, reddish bark helps it withstand forest fires, while its dense wood is resistant to decay. The Alerce thrives in the cool, temperate rainforests of Patagonia, where it forms dense, towering forests. These trees have been used historically by local populations for timber, but deforestation has placed them at risk. Alerces are now protected, allowing them to continue their ancient growth. They are a cherished part of South American biodiversity, representing both resilience and the need for conservation.

The underused energy source under the Earth's surface that could mean a carbon-free future



Scientists have discovered vast underground reserves of a clean energy source capable of replacing fossil fuels and helping feed the world for centuries.© Pixabay

A recent scientific discovery could change the course of the global energy crisis: **under the earth's surface** there are vast reserves of **natural hydrogen, a clean and sustainable resource**.

According to a study published in Science Advances, these reserves could be the key to **replacing fossil fuels** and **feeding the world for the next 200 years**.

Until recently it was believed that hydrogen **could not accumulate underground** due to its volatile nature, but recent **research has shown otherwise**.

Computer models suggest the planet is home to approximately **6.2 trillion tons of hydrogen** trapped in rocks and underground deposits, a figure **26 times greater than known oil reserves**.

The promise of natural hydrogen

Hydrogen, known for being a **clean, emissions-free energy source**, can power vehicles, industrial processes and generate electricity.

According to Geoffrey Ellis, a geochemist at the U.S. Geological Survey and lead author of the study, even a small fraction of these reserves- about 2%- would be **enough to meet global energy demand** and move toward **a carbon-free future**.

The first signs of significant accumulations of natural hydrogen have been found in places such as **West Africa and a chrome mine in Albania**.

These discoveries have opened up new possibilities for the use of this resource, provided that **technologies are developed** that allow the reserves to be **located and extracted efficiently**.

Hydrogen as an energy source: Challenges and opportunities

While calculations indicate there is **more than enough hydrogen** to meet the planet's energy needs, scientists acknowledge much of the reserves may be **too deep or found in inaccessible locations**.

Some deposits may be **too small to justify extraction**. But these limitations do not negate hydrogen's transformative potential.

A crucial advantage of natural hydrogen is its **stability in the reservoirs** where it is found, eliminating the need for costly storage and transportation systems. In addition, its ability **to release twice as much energy** as known natural gas reserves makes it an attractive alternative for a variety of energy sectors.

A future powered by hydrogen

With global demand for hydrogen expected to increase fivefold by 2050, experts predict the resource will account for **up to 30% of energy supply** in some sectors.

Most hydrogen is **currently produced artificially** through processes such as electrolysis, but the **discovery of natural reserves** could significantly reduce costs and accelerate the transition to clean energy.

In the coming months, researchers hope to more precisely identify **hydrogen deposits in the United States** and other countries, ushering in a new energy era. If these findings are confirmed, **natural hydrogen could become the key to abandoning fossil fuels** and tackling climate change once and for all.

Earth's Rotation Is Slowing Down, And Could Explain Why We Have Oxygen



Earth's rotation is slowing down, and it could be why we have oxygen for life

Ever since its formation around 4.5 billion years ago, Earth's rotation has been gradually slowing down, and its days have gotten progressively longer as a result.

While Earth's slowdown is not noticeable on human timescales, it's enough to work significant changes over eons. One of those changes is perhaps the most significant of all, at least to us: lengthening days are linked to the oxygenation of Earth's atmosphere, according to a study from 2021.

Specifically, the blue-green algae (or cyanobacteria) that emerged and proliferated about 2.4 billion years ago would have been able to produce more oxygen as a metabolic by-product because Earth's days grew longer.

"An enduring question in Earth sciences has been how did Earth's atmosphere get its oxygen, and what factors controlled when this oxygenation took place," [microbiologist Gregory Dick](#) of the University of Michigan explained in 2021.

"Our research suggests that the rate at which Earth is spinning – in other words, its day length – may have had an important effect on the pattern and timing of Earth's oxygenation."

There are two major components to this story that, at first glance, don't seem to have a lot to do with each other. The first is that Earth's spin is slowing down.

The reason Earth's spin is slowing down is [because the Moon](#) exerts a gravitational pull on the planet, which causes a rotational deceleration since [the Moon](#) is gradually pulling away.

We know, based on the fossil record, that days were just 18 hours long 1.4 billion years ago, and half an hour shorter than they are today 70 million years ago. Evidence suggests that we're gaining 1.8 milliseconds a century.

The second component is something known as the [Great Oxidation Event](#) – when cyanobacteria emerged in such great quantities that Earth's atmosphere experienced a sharp, significant rise in oxygen.

Without this oxidation, scientists think life as we know it could not have emerged; so, although cyanobacteria may [cop a bit of side-eye today](#), the fact is we probably wouldn't be here without them.

There's still a lot we don't know about this event, including such burning questions as why it happened when it did and not sometime earlier in Earth's history.

It took scientists working with cyanobacterial microbes to connect the dots. In the Middle Island Sinkhole in Lake Huron, microbial mats can be found that are thought to be an analog of the cyanobacteria responsible for the Great Oxidation Event.

Purple cyanobacteria that produce oxygen via photosynthesis and white microbes that metabolize sulfur, compete in a microbial mat on the lakebed.

At night, the white microbes rise to the top of the microbial mat and do their sulfur-munching thing. When day breaks, and the Sun rises high enough in the sky, the white microbes retreat and the purple cyanobacteria rise to the top.

"Now they can start to photosynthesize and produce oxygen," [said geomicrobiologist Judith Klatt](#) of the Max Planck Institute for Marine Microbiology in Germany.

"However, it takes a few hours before they really get going, there is a long lag in the morning. The cyanobacteria are rather late risers than morning persons, it seems."

This means the window of daytime in which the cyanobacteria can pump out oxygen is very limited – and it was this fact that caught the attention of oceanographer Brian Arbic of the University of Michigan. He wondered if changing day length over Earth's history had had an impact on photosynthesis.

"It's possible that a similar type of competition between microbes contributed to the delay in oxygen production on the early Earth," [Klatt explained](#).

To demonstrate this hypothesis, the team performed experiments and measurements on the microbes, both in their natural environment and a laboratory setting. They also performed detailed modelling studies based on their results to link sunlight to microbial oxygen production, and microbial oxygen production to Earth's history.

"Intuition suggests that two 12-hour days should be similar to one 24-hour day. The sunlight rises and falls twice as fast, and the oxygen production follows in lockstep," [explained marine scientist Arjun Chennu](#) of the Leibniz Centre for Tropical Marine Research in Germany.

"But the release of oxygen from bacterial mats does not, because it is limited by the speed of molecular diffusion. This subtle uncoupling of oxygen release from sunlight is at the heart of the mechanism."

These results were incorporated into global models of oxygen levels, and the team found that lengthening days were linked to the increase in Earth's oxygen -

not just the Great Oxidation Event, but another, second atmospheric oxygenation called the [Neoproterozoic Oxygenation Event](#) around 550 to 800 million years ago.

"We tie together laws of physics operating at vastly different scales, from molecular diffusion to planetary mechanics. We show that there is a fundamental link between day length and how much oxygen can be released by ground-dwelling microbes," [Chennu said](#).

"It's pretty exciting. This way we link the dance of the molecules in the microbial mat to the dance of our planet and its Moon."

The research has been published in [Nature Geoscience](#).

Finland Discovers Vast Geothermal Energy Source That Could Last 20 Million Years

Finland Discovers Vast Geothermal Energy Source That Could Last 20 Million Years

Why it matters: [Euroweeklynews](#) reports that Finland has uncovered a groundbreaking geothermal energy source that could power the country for millions of years, marking a significant advancement in renewable energy technology and setting a new precedent for sustainable power generation in Europe.

The Big Picture: [Ecoticias](#) reports that the discovery brings multiple benefits:

- 2,600 MW annual electricity production
- 95% reduction in emissions
- Powers 130 homes initially
- Supports 2030 carbon neutrality goal

Technical Implementation: The project showcases innovative approaches:

- Advanced drilling technologies
- District heating network integration
- Geoenergy Leap project support
- European [Just Transition Fund](#) backing

Environmental Impact: The initiative demonstrates significant sustainability gains:

- Near-zero emissions compared to fossil fuels
- Year-round energy availability
- Minimal environmental footprint
- Scalable clean energy solution

Looking Forward: While the Vantaa plant represents just the beginning, Finland's discovery could revolutionize renewable energy across Europe. The technology's potential for replication, particularly in urban areas, suggests broader applications beyond Finland's borders.

Hidden Metal Highways Discovered Beneath Earth's Ancient Continents



Hidden Metal Highways Discovered Beneath Earth's Ancient Continents | The Daily Galaxy --Great Discoveries Channel© Daily Galaxy

In a groundbreaking study, researchers have uncovered a hidden network of “metal highways” beneath the Earth’s ancient continental cores. These geological formations, shaped over millions of years, serve as pathways for critical metals such as **copper**, **rare earth elements**, and **cobalt**—essential components for advancing a green economy. The discovery provides a new understanding of how these vital resources accumulate and offers valuable insights for sustainable exploration of untapped reserves.

The Groundbreaking Study

This transformative [research](#), led by **Dr. Chunfei Chen** and his team at **Macquarie University**, was published on January 8, 2025, in the prestigious journal *Nature*. The study builds on years of high-pressure experiments conducted by Macquarie University's **Earth Evolution research group**. The research received support from multiple institutions, including the **Australian Research Council** and Macquarie University.

Dr. Chen, during his postdoctoral work, focused on the behavior of carbonate-rich melts—molten material deep beneath the Earth's surface. His team identified how these melts, which form at depths of around 200 kilometers beneath the continental crust, are responsible for transporting and concentrating critical metals along the margins of ancient continental cores.

According to the study, the edges of these continental cores—thick, bowl-shaped sections of tectonic plates—are hotspots for volcanic activity and metal deposition. The findings align with observations from Geoscience Australia and the Australian National University, which have long speculated on the unusual metal concentrations in these regions.

How Earth's Metal Highways Work

The study provides a detailed explanation of how these hidden pathways form and operate. Beneath ancient continents, carbonate-rich melts flow upward and outward from the centers of thick continental cores toward their edges. **Dr. Chunfei Chen** explained:

"These cores are the thickest, bowl-shaped, parts of tectonic plates. Melts that form below their centers will flow upwards and outwards towards the edges, so that volcanic activity is common around their edges."

As these melts rise, their composition changes significantly. Initially rich in silica, critical metals, and sulfur, they lose silica along the way. This loss triggers a chemical reaction that causes metals to drop out of the melt and accumulate in linear patterns along the continental margins.

Professor Stephen Foley, a distinguished geologist at **Macquarie University**, highlighted the importance of this process:

“The initial melts can carry lots of critical metals and sulfur, but our new results show that these are dropped by the melt as it loses silica. This causes concentrations of critical metals and sulfur in linear arrangements around the edges of thick continental cores.”

This process effectively transforms the edges of ancient continental cores into natural repositories for critical metals, creating a “highway” for these valuable resources to move and deposit over millions of years.

Why this Discovery Matters

The implications of this study are immense, especially in the context of the global transition to renewable energy and a **green economy**. Technologies like electric vehicles, wind turbines, and solar panels rely heavily on critical metals such as copper and rare earth elements. Yet, the current supply of these metals is insufficient to meet the growing demand.

Dr. Chen’s findings bring previously unexplored regions into focus, offering new opportunities for mining operations to locate untapped reserves. By targeting the edges of ancient continental cores, geologists can explore areas that have long been overlooked, reducing the reliance on traditional mining sites that are increasingly depleted.

Moreover, the study underscores the interconnectedness of deep Earth processes and surface ecosystems. The formation and distribution of critical metals are not random but are deeply influenced by tectonic activity and the movement of molten materials within the [Earth’s mantle](#).

Future Exploration and Sustainability

This discovery also has the potential to reshape the mining industry’s approach to sustainability. By identifying specific geological processes responsible for metal accumulation, exploration efforts can become more targeted and less invasive.

Instead of widespread, environmentally damaging mining practices, operations can focus on areas with the highest potential yield.

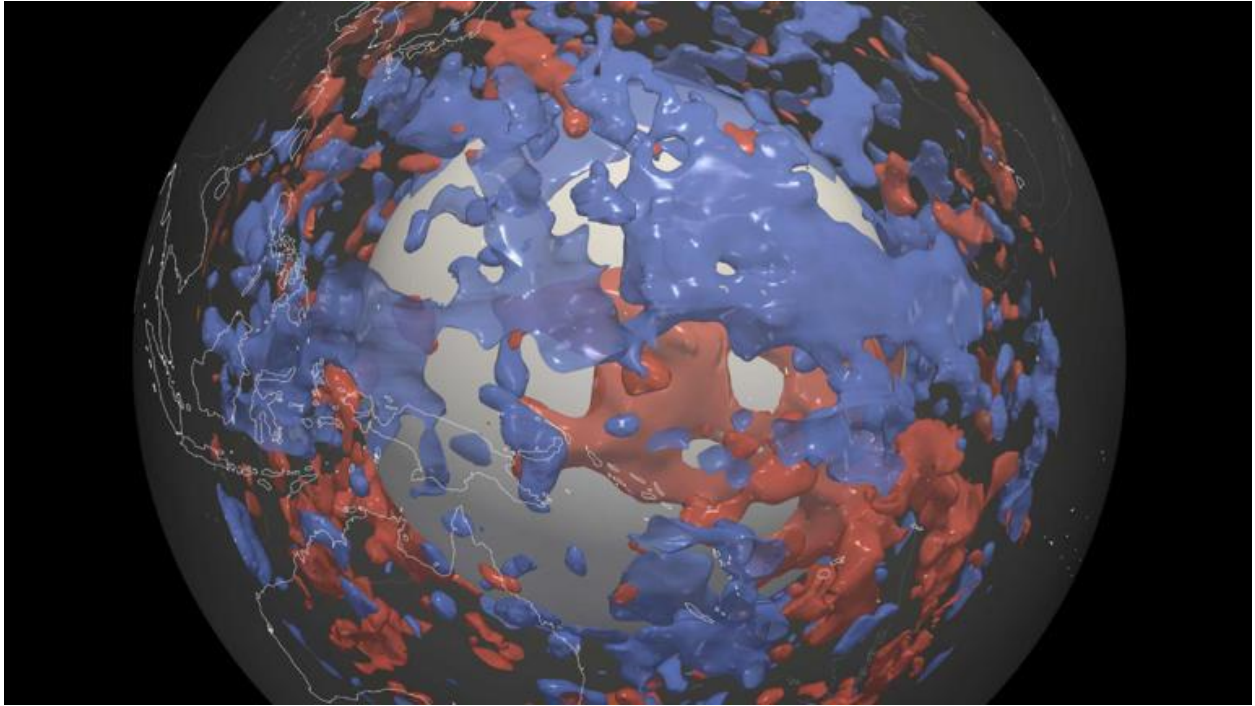
Scientists discover 'sunken worlds' hidden deep within Earth's mantle that shouldn't be there

Potential patches of Earth's ancient crust, sometimes called "sunken worlds," may have just been discovered deep within the mantle, thanks to a new way of mapping [the inside of our planet](#). However, these mysterious blobs appear in places they should not, leaving researchers scratching their heads.

For decades, scientists have been building up a better picture of [Earth's interior](#) by using seismographs — 3D images created by measuring how seismic waves from earthquakes reverberate deep within our planet. This method has helped scientists identify ancient sections of the planet's crust, known as subducted slabs, that have been pulled into the mantle through subduction zones where [tectonic plates](#) meet. For example, in October 2024, researchers announced the discovery of a section of seafloor that had [sunk deep into the mantle below Easter Island](#).

In a study published Nov. 4, 2024, in the journal [Scientific Reports](#), researchers revealed that they had discovered "numerous" potential subducted slabs throughout Earth's mantle, using a new type of seismographic imaging. (Little information about the size, shape and exact locations of the blobs has been revealed so far.)

However, unlike previously identified subducted slabs, which are found in areas where tectonic plates currently collide or have previously smashed together, some of the new anomalies are located in places where no known tectonic activity has ever occurred, such as below the western Pacific Ocean. As a result, it is unclear how they ended up there.



The new model shows blobs within Earth's mantle where seismic waves travel slower than usual (blue), which suggests they may be subducted slab chunks. (Image credit: Sebastian Noe/ETH Zurich)

There are other potential explanations for the newly mapped blobs. For example, they may be made of crust-like material left over from the mantle's creation 4 billion years ago. Or they may consist of some other similarly dense material that has grown within the mantle over the past few hundred million years.

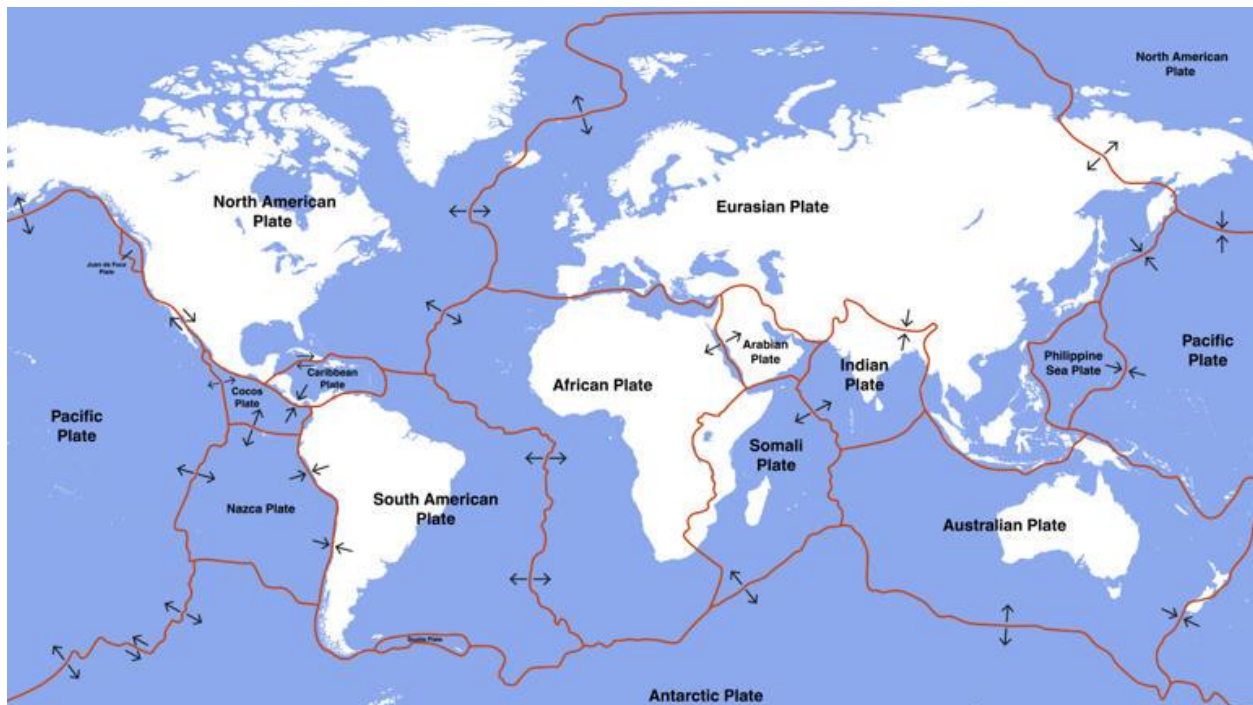
However, these are just alternative theories. At the moment, the identity of these blobs remains a "major mystery," ETH Zurich representatives wrote in the statement.

Finding "sunken worlds"

Until now, everything we know about Earth's innards has come from stitching together different seismographs created from different individual earthquakes across the globe. But in the new study, researchers used a new method, known as full-waveform inversion, which uses computer models to combine these seismographs into a single clear image.

This is a computationally intensive method, and to pull it off, researchers had to run the model on the Piz Daint [supercomputer](#) at the Swiss National

Supercomputer Center in Lugano — formerly Europe's most powerful computer — to crunch the numbers.



The newly discovered blobs are located far from any current or past fault lines between tectonic plates. (Image credit: Getty Images)

Study co-author [Andreas Fichtner](#), a seismologist at ETH Zurich who created the full-waveform model used in the new research, compared the use of full-waveform inversion to medical imaging advancements. Imagine a doctor has been studying the circulatory system for decades, Fichtner said. "Then, if you give [them] a new, better examination tool, [they] suddenly see an artery in the buttock that doesn't really belong there," Fichtner explained. "That's exactly how we feel about the new findings."

Researchers think the newly discovered blobs may be subducted slabs, largely because seismic waves travel through them both at the same speed. But this does not guarantee that they are the same thing, and more research is needed to assess whether they are actually alike.

"We have to calculate the different material parameters that could generate the observed speeds of the different wave types," Schouten said. "Essentially, we have to dive deeper into the material properties behind the wave speed."

Every human being originated from this one African country

In the world of genetic research, the last twenty years have witnessed remarkable progress. (CREDIT: CC BY-SA 3.0)© The Brighter Side of News

Over the past two decades, genetic research has undergone transformative advancements, marked by an extraordinary surge in [genomic data](#) collection. This effort has gathered information from hundreds of thousands of individuals, spanning both modern populations and ancient lineages.

Such a wealth of data offers unprecedented opportunities to unravel the origins of human genetic diversity. By piecing together these findings, researchers are steadily moving toward the creation of a comprehensive global map of [human genealogy](#).

Achieving this ambitious goal has long been hindered by two critical challenges: integrating genome sequences from various databases and creating algorithms robust enough to process these enormous datasets.



Map of Africa showing modern day Sudan in relation to other African countries. (CREDIT: Google Maps)© The Brighter Side of News

However, a newly devised method, unveiled by researchers from the [University of Oxford's Big Data Institute](#), promises to surmount these challenges. This method offers the capability to seamlessly integrate data from multiple sources and can scale to accommodate millions of genome sequences.

Dr. Yan Wong, an evolutionary geneticist at the Big Data Institute and one of the lead authors, elucidated, "We have essentially erected an immense family tree—a [genealogy for all of humanity](#)—that faithfully models the historical processes underlying the genetic diversity observable in modern humans. This genealogy affords us the opportunity to discern the relationship between every individual's genetic sequence and that of every other individual, across all genomic loci."

Given that specific genomic regions are inherited solely from one parent, either the mother or the father, the ancestry of each point on the genome can be conceptualized as a tree.

NOVEMBER 14, 2024

Study finds four global policies could eliminate >90% of plastic waste and 30% of linked carbon emissions by 2050

by [University of California - Santa Barbara](#)



Credit:

Magda Ehlers from Pexels

A study released in *Science* determines that just four policies can reduce mismanaged plastic waste—plastic that isn't recycled or properly disposed of and ends up as pollution—by 91% and plastic-related greenhouse gases by one-third.

The policies are:

- Mandate new products be made with 40% post-consumer recycled plastic
- Cap new plastic production at 2020 levels
- Invest significantly in [plastic waste](#) management—such as landfills and waste collection services
- Implement a small fee on plastic packaging

This policy package also delivers climate benefits, reducing emissions equivalent to taking 300 million gasoline-powered vehicles off the road for one year.

The [study](#), "Pathways to reduce global plastic waste mismanagement and greenhouse gas emissions by 2050," by researchers at the University of California Berkeley and the University of California Santa Barbara, comes in advance of negotiations in Busan, Republic of Korea (November 25–December 1), where delegates from more than 190 countries are expected to iron out the final details of the world's first legally binding treaty on plastic pollution.

"This is it. These upcoming negotiations in Busan are our one chance to come together as a planet and fix this problem," said Dr. Douglas McCauley, Professor at UC Santa Barbara, Adjunct Professor at UC Berkeley. "One of the most exciting discoveries in this research is that it is actually possible to nearly end plastic pollution with this Treaty. I'm cautiously optimistic, but we can't squander this once-in-a-lifetime opportunity."

If no action is taken in Busan, annual plastic consumption will rise 37% between 2020 and 2050, and plastic pollution will nearly double across the same period.

"This study demonstrates how far we have come in not just quantifying the manifold problems surrounding plastics, but also in identifying and evaluating potential solutions," said Dr. Roland Geyer, Professor of Industrial Ecology, Bren School of Environmental Science & Management at UC Santa Barbara. "I am very proud of what our team was able to achieve in time for the final round of negotiations for the Global Plastics Treaty."

By continuing with business as usual, the world would generate enough litter between 2011 and 2050 to cover Manhattan in a heap of plastic ten times the height of the Empire State Building.

In a business-as-usual future, [greenhouse gas emissions](#) related to plastic would jump 37% from 2020 levels to 3.35 gigatons of carbon dioxide equivalent in 2050—this is the same as nearly 9,000 natural gas-fired power plants operating for one year or the energy use for more than 436 million homes for one year.

"There are multiple pathways available to negotiators, but it does require ambition," said Sam Pottinger, Senior Research Data Scientist, Eric and Wendy Schmidt Center for Data Science and Environment at UC Berkeley.

"The impact that we're really hoping to see on the treaty is that it is data-informed. As the treaty comes to its final conclusion before ratification, we want folks to be aware of how much progress they've actually made, at least according to the best science that we have available right now."

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Countries in the Global South will continue to bear the greatest burden of the plastic crisis. Financing mechanisms created in the treaty could drive much-needed investment into [waste management](#) and recycling infrastructure in these regions to reduce plastic pollution—thus helping to solve a major global environmental justice issue.

"I'm optimistic about a [sustainable future](#)," said Dr. Nivedita Biyani, Researcher of Global Plastic Modeling, Benioff Ocean Science Laboratory at UC Santa Barbara.

"This policy work shows that we can reach minimal mismanaged plastic waste if we can come together in action. This provides policymakers with a novel tool that isn't prescriptive—they can combine various policies as they see fit. Going forward, I think a mechanism to gather data on plastic production and trade will be a key factor. We need supply chain transparency here."

The study is built on insights from an AI-generated [tool](#) developed by a team of plastic researchers, data scientists, and AI researchers at the Benioff Ocean Science Laboratory and Bren School of Environmental Science & Management at University of California Santa Barbara, and the Eric and Wendy Schmidt Center for Data Science & Environment at University of California Berkeley.

The tool uses machine learning to combine information about [population growth](#) and economic trends to forecast the future of plastic production, pollution and trade.

More information: A. Samuel Pottinger et al, Pathways to reduce global plastic waste mismanagement and greenhouse gas emissions by 2050, *Science* (2024). DOI: [10.1126/science.adr3837](https://doi.org/10.1126/science.adr3837). www.science.org/doi/10.1126/science.adr3837

Journal information: *Science*

Provided by [University of California - Santa Barbara](#)

Kola Borehole facts — the real ‘Journey to the Center of the Earth’

To date, the Kola Superdeep Borehole is the deepest point humans have ever made into the Earth. But how did they do it, and why?

Published: Jan 02, 2024



Image of the welded metal cap to the Kola borehole in Russia.

- Around the same time the world’s major powers were vying to make history in space, a very different scientific battle was also unfolding.
- Rather than stretching upwards, this battle competed to get as deep into the Earth as possible.

- The Soviet Union eventually won this battle with the Kola Superdeep Borehole, which managed to get as close to the Earth's mantle as anyone before or since.

The strive for scientific excellence has been an important driver of human development. Throughout human history, it has led to some of the most important advancements in knowledge that, arguably, might not have ever been manifested without some good old-fashioned competition. One such field was the race to get as [close to the Earth's mantle](#) as possible.

This race between major world powers ultimately led to the best effort our species has managed to date, the impressive Kola Superdeep Borehole. But what is it, and why is it so significant? Let's find out.

1. There is more than just one borehole there

[The Kola Borehole](#) is a series of boreholes, not just one. Several boreholes were drilled there, the deepest reaching its record depth in 1989. This borehole is called SG-3 and is the deepest in the world. The Kola Superdeep Borehole reached over 7.5 miles (~12 kilometers), penetrating rocks over 2.5 billion years old.

This age dates back to the transition between the Archean and the Proterozoic periods of the Earth's geological record. At this time, the Earth was very different from today, with the early surface largely covered with water. The earliest known life forms existing during the Archean were microbial mats called stromatolites that thrived in shallow waters.

The life forms that existed were mostly prokaryotes, comprising archaea and eubacteria. Photosynthetic processes, especially those of early cyanobacteria, emerged in the mid to late Archean era. These photosynthetic processes led to a permanent change in the ocean and atmosphere during and after the Archean era.

[Biggest/Wikimedia Commons](#)

One of the most surprising findings during the Kola Superdeep Borehole project was the discovery of evidence of early life. At around 3.7 miles (~6 kilometers) depth, microscopic plankton fossils were recovered from the borehole samples. These rocks would be about 2.5 billion years old, making them some of the oldest fossils ever discovered on Earth.

Another interesting discovery was the presence of large amounts of hydrogen gas at depth. The drilling mud that flowed from the borehole was described as "boiling" with hydrogen. It has since been discovered that most of this gas was probably created through a process [called serpentinization](#).

This is the process of hot water in the Earth's crust (hydrothermal) altering minerals in rocks, transforming Fe-Mg (iron-magnesium) silicates such as olivine, pyroxene, or amphiboles contained in ultramafic (high-silica content) rocks into serpentine minerals. One of the byproducts of this process is the production of free hydrogen.

2. It is the deepest thing humans have ever dug

Drilling began on the [Kola Superdeep Borehole](#) on May 24, 1970, using the Uralmash-4E drilling rig and later the Uralmash-15000 series rig.

In 1979, the Kola borehole became the deepest human-made hole in history when it surpassed the previous record held by the Bertha Rogers hole in Washita County, Oklahoma, U.S., at a recorded depth of 31,440 feet (9,583 meters).

The Kola borehole reached 40,230 feet (12,262 meters) in 1989, making it the deepest human-made hole on Earth. As of 2023, it remains the [deepest known hole](#) created by human beings. To put that into perspective, the borehole is deeper than the Mariana Trench and deeper than Mount Everest is tall.

In terms of true vertical depth, it remains the deepest borehole in the world. It also held the record for being the longest borehole in the world for 20 years, but in 2008, it was surpassed by the Al Shaheen Oil Well in Qatar, which measures 40,318 feet (12,289 meters) along the well bore.

[Trevor/Atlas Obscura](#)

The Kola Borehole was abandoned in 1992 after drilling encountered temperatures of 356 degrees Fahrenheit, °F (180 degrees Celsius, °C), exceeding the expected 212 degrees Fahrenheit (100 degrees Celsius). This surprisingly high temperature is caused by the heat flow from the much hotter mantle below the Earth's crust. On average, temperatures rise about 72–87 °F for each mile (25–30 °C/kilometers) of depth.

At these depths, the rock density means that it acts more like a thick plastic than rock, making drilling almost impossible. It has been compared to keeping a pit in the center of a pot of hot soup. These high temperatures can also cause damage to equipment. As the [Smithsonian explains](#), the hotter it gets and the more moisture in the environment, the more difficult it is to maintain the bore.

3. The borehole changed our ideas of the crust's composition

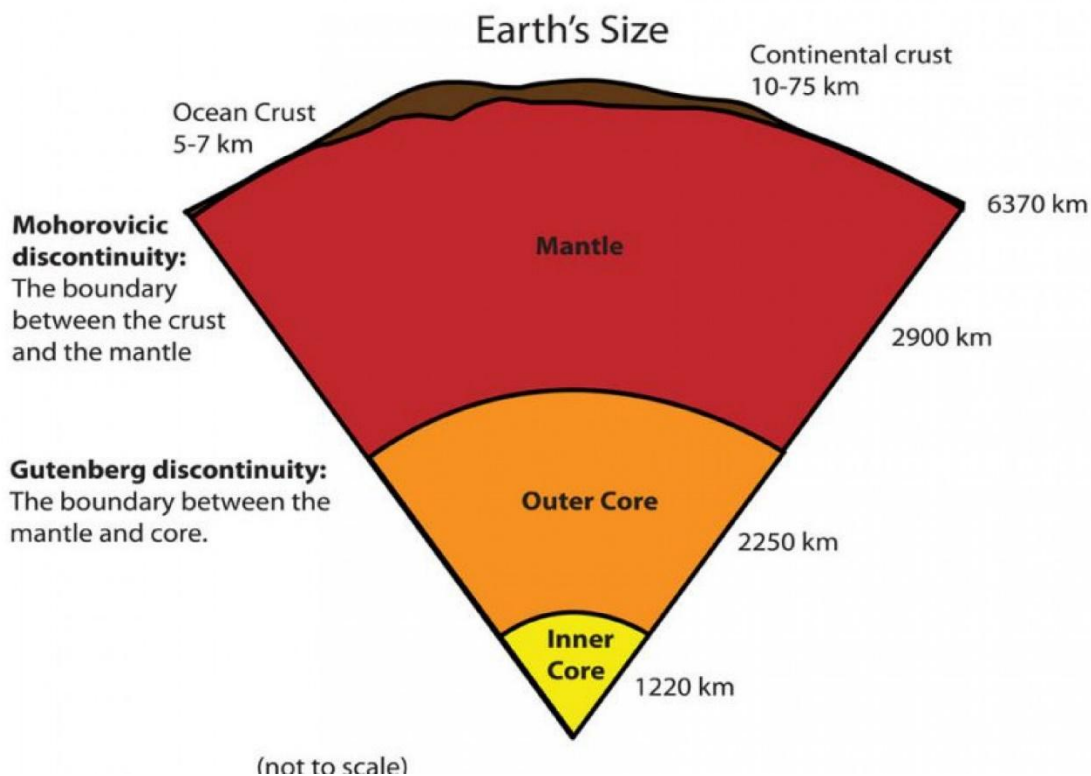


Image of the Earth's main layers.

[National Geographic](#)

The study of the Earth often relies on surface observations and seismic studies. However, the Kola borehole enabled geologists to directly examine the structure of the crust, putting their theories to the test.

One of the most surprising discoveries was the absence of the expected transition from granite to basalt between three and six kilometers below the surface. This transition, known as the [“Conrad discontinuity,”](#) was previously believed to exist based on seismic-reflection surveys.

Although a discontinuity has been detected beneath all of the continents, the drill at Kola never encountered the proposed layer of basalt. Instead, it found that the granitic rock extended beyond the twelve-kilometer point.

This discovery led scientists to realize that the seismic-reflection results were due to a metamorphic change in the rock, caused by intense heat and pressure, rather than a change in rock type as they had previously thought.

The project has been likened to geology's “space race”



4.Kola Borehole has been likened to the Space Race.

[peepo/iStock](#)

For around 50 years or so now, scientists have been engaged in a project to reach as far below the [Earth's crust as possible](#)—ideally, to the Earth's mantle. The scale and complexity of this task are so great that it has been likened to the global “Space Race” back in the 1950s and 1960s.

The mantle comprises 40 percent or more of the planet, which has a radius of 4,000 miles (~6,400 kilometers). It is located just below the Earth's crust and above the Earth's core and is thought to have a thickness of 1,800 miles (~2,800 kilometers). On the other hand, the crust is a relatively small part of the planet, averaging between three to 25 miles (~40 kilometers) in thickness.

The mantle is the major engine driving the planet's constant evolution and contains a geological record of much of the Earth's history.

If we could physically get some direct measurements and samples of the mantle, this would dramatically increase our understanding of how it works and, by proxy, give a better understanding of the Earth's system as a whole. To this end, scientists in the United States attempted to reach the mantle in 1958 with “Project Mohole” by drilling through the Pacific Ocean floor off Guadalupe, Mexico. However, funding was discontinued in 1966 before the drillers reached the mantle.

In 1970, Soviet geologists took on the challenge and set their drills over the Kola Peninsula, which protrudes eastward from the Scandinavian landmass. This, as we now know, would become the most successful of all attempts, reaching the deepest so far.

5. It required some very specialist equipment

The project employed a drilling technique [called rotary drilling](#), and it used a branching structure, meaning the main borehole had several side holes branching off at various depths. This technique is widely used in the oil and gas industry.

It employs a rotary drill bit attached to a drill string and a series of drill pipes that transmit rotational force to the bit from the surface. The drill bit is usually lubricated using special fluids called muds. These are circulated through the drill pipe and out of the drill bit and provide cooling, pressure control, cutting removal, and lubrication to aid the drill process.

Various drill bits are often made from tough materials like tungsten carbide or diamond. As the borehole deepened, challenges arose with torque, drill string weight, and temperature. These issues required innovative engineering solutions.

The Kola project had the unique feature of a branching structure, making the borehole resemble a sort of tree branch or root-like structure underground. At specific depths, side holes branched off from the main borehole. This allowed for a more thorough exploration of the Earth's crust without starting a new borehole from the surface.

6. The borehole was finally sealed in 2008

Years after being mothballed, the borehole was finally sealed in 2008. Today, among the ruins of the support facilities on site, the only evidence of the site's scientific significance is a small, now rusted metal cap. The cap is so nondescript you could be forgiven for not even noticing it if you ever visited the site for yourself.

This is a very real shame, as the technical and scientific achievement that the [Kola borehole](#) represents cannot be underestimated. It is probably one of the Soviet Union's greatest contributions to scientific study ever. That being said, it is still revered as one of the Soviet Union's most precious scientific relics, and rightfully so.

And that's your lot for today.

The Kola Superdeep Borehole is still, today, the deepest our species has ever ventured into the bowels of the Earth. While [some other projects planned](#) will attempt to beat it, for now, it remains one of the most impressive scientific exploratory drilling endeavors ever attempted.

Kola Superdeep Borehole

Coordinates:  69°23'46.39"N 30°36'31.20"E



The Kola Superdeep Borehole in 2007.



Finland

Murmansk Oblast in north Russia, near

Kola Peninsula

Кольский полуостров



Kola Peninsula as a part of [Murmansk Oblast](#)



Location of Murmansk Oblast within Russia

Geography

Location	Far northwest Russia
Adjacent to	• Barents Sea • White Sea
Area	100,000 km ² (39,000 sq mi)
Length	370 km (230 mi)
Width	244 km (151.6 mi)
Highest elevation	1,191 m (3907 ft)
Highest point	Mount Chasnachorr

Administration

Russia

The **Kola Superdeep Borehole** (Russian: Кольская сверхглубокая скважина, *Kolskaya sverkhglubokaya skvazhina*) was a very deep hole dug on the [Kola Peninsula](#) in Russia during 1970-1992 and closed by 2008. It was dug in order to learn more about [the inside](#) of the [Earth](#). Digging started on May 24, 1970. The work continued until 1992,^[1] or 1994.^[2] The borehole was kept open until 2005.^[3] SG-3, the deepest part of the hole, reached 12,261 meters or 7.6 miles below the surface in 1989. That is the deepest hole ever made and is still the [deepest man-made point](#) on Earth.^[2]

For a long time, SG-3 was also the longest hole by distance from its opening. In 2008, the [Al Shaheen BD-04A oil well](#) in [Qatar](#) reached +27 meters or 89 feet farther^{[4][5]} and, in 2011, the [Odoptu OP-11 oil well](#) off [Sakhalin](#) got +83 m or 272 ft farther.^[6]

Making the hole



A Soviet [stamp](#) from 2021 with a picture of the hole.

The hole was made with different machines at different times. The Soviets started making the hole with the [Uralmash-4E](#). Later, they used the [Uralmash-15000](#). At first, they wanted to get to 15,000 m or 9.3 mi below the surface. The machines broke the earlier record for the deepest hole on June 6, 1979. The prior record had been held by the 9,583-meter (31,440 ft) [Bertha Rogers](#) hole in [Washita County, Oklahoma](#), in the [United States](#).^[7] The machines got to 12,000 m or 7.5 mi below the surface in 1983. Then the Soviet Union celebrated (took special note of) this for about a year without going any deeper.^[1] On September 27, 1984, the machine broke at a depth of 12,066 m or 39,587 ft; its [drill string](#) twisted off and was left in the hole. When the Soviets started to make the hole again, they had to start from 7,000 m (23,000 ft).^[1]

The greatest depth was reached in 1989. The people making the hole thought that they would get to 13,500 m (8.4 mi) by the end of 1990 and, at last, get to 15,000 m by 1993.^{[8][9]} They were not able to go any deeper, though, because they had made an error, and the end of the hole was 180 °C or 356 °F in place of the 100 °C or 212 °F they had hoped for. Their machines stopped making any holes at all in 1992.^[1] The last studies were stopped in 2005 and the place was completely closed and left alone in 2008.^[3]

What we learned



The hole itself in 2012. It has been [welded](#) shut, so that solid metal covers the hole and keeps people out.

The Kola hole got about $\frac{1}{3}$ of the way through the [Baltic Shield](#), the part of the [Earth's crust](#) (its outer level of rock) below the [Kola Peninsula](#). ([People who study the Earth](#) think it's about 35 kilometers or 22 miles deep at the place where the hole was made.) The rocks at the bottom of the deepest hole were [more than 2½ billion years old](#).^[10]

The people who made the hole said they wanted to learn about the different levels of the [Baltic Shield](#), how [sound](#) and heat move under the ground, or what kinds of rocks make up the deep [crust](#), and to create new skills and tools for going deep into the Earth. One of the most important things they found was they had made an error about the kinds of rocks underground. When they looked at how sound waves moved through the Earth, they thought there should be a change from [granite](#) to [basalt](#) rocks at about 7 km (4.3 mi) below the surface. In fact, the sound waves had changed because the heat and pressure made the granite act differently. Also, this special kind of granite was broken into pieces and full of water. The water did not come from above but had been trapped in the deep crust by solid rock.^[11] Another important discovery was that the mud from the deep hole was "boiling" with [hydrogen](#) gas.^[12]

Scientists discover enormous reservoir hidden in Cascades — more than twice the amount of water in Lake Mead



The Oregon Cascades hold at least 81 cubic kilometers of water beneath their volcanic rocks, scientists find. © tomwachs/Getty Images

A hidden reservoir of groundwater more than twice the size of Lake Mead is buried inside the Oregon Cascades, a new study reports.

Scientists found that the underground aquifer holds at least 19.4 cubic miles (81 cubic kilometers) of water below the surface of the mountain range. The finding could impact both water use and scientists' understanding of volcanic processes in the region.

"It is a continental-size lake stored in the rocks at the top of the mountains, like a big water tower," study co-author [Leif Karlstrom](#), an Earth scientist at the University of Oregon, [said in a statement](#). "That there are similar large volcanic aquifers north of the Columbia Gorge and near Mount Shasta likely make the Cascade Range the largest aquifer of its kind in the world."

The Cascade mountain range extends for about 700 miles (1,100 kilometers) from Northern California to British Columbia, Canada, and has been built up by volcanic activity over millions of years. Within Oregon, the High Cascades, whose volcanic rocks date back 8 million years, is home to smooth slopes and ongoing volcanic activity, while the older Western Cascades that dates to 45 million years ago is filled with canyons and valleys carved by flowing streams. The researchers used the gradual shift between these two zones to study how volcanic processes have affected the region over time.

In the study, published Jan. 13 in the journal [PNAS](#), the researchers measured how the temperature of rocks in the mountain range changes with depth. Deeper rock tends to be hotter because it's under more pressure and closer to Earth's hot interior, but the team found several areas where the temperature remained constant, even as the depth increased. That implied the rock was being cooled, which they attributed to water permeating the rock.

"We initially set out to better understand how the Cascade landscape has evolved over time, and how water moves through it," study co-author [Gordon Grant](#), a hydrologist with the U.S. Forest Service, said in the statement. "But in conducting this basic research, we discovered important things that people care about: the incredible volume of water in active storage in the Cascades and also how the movement of water and the hazards posed by volcanoes are linked together."

Deep-permeating waters could affect the types of volcanism observed in the region. When water comes in contact with magma, it quickly evaporates into steam, which can increase the pressure underground and lead to explosive volcanic eruptions.

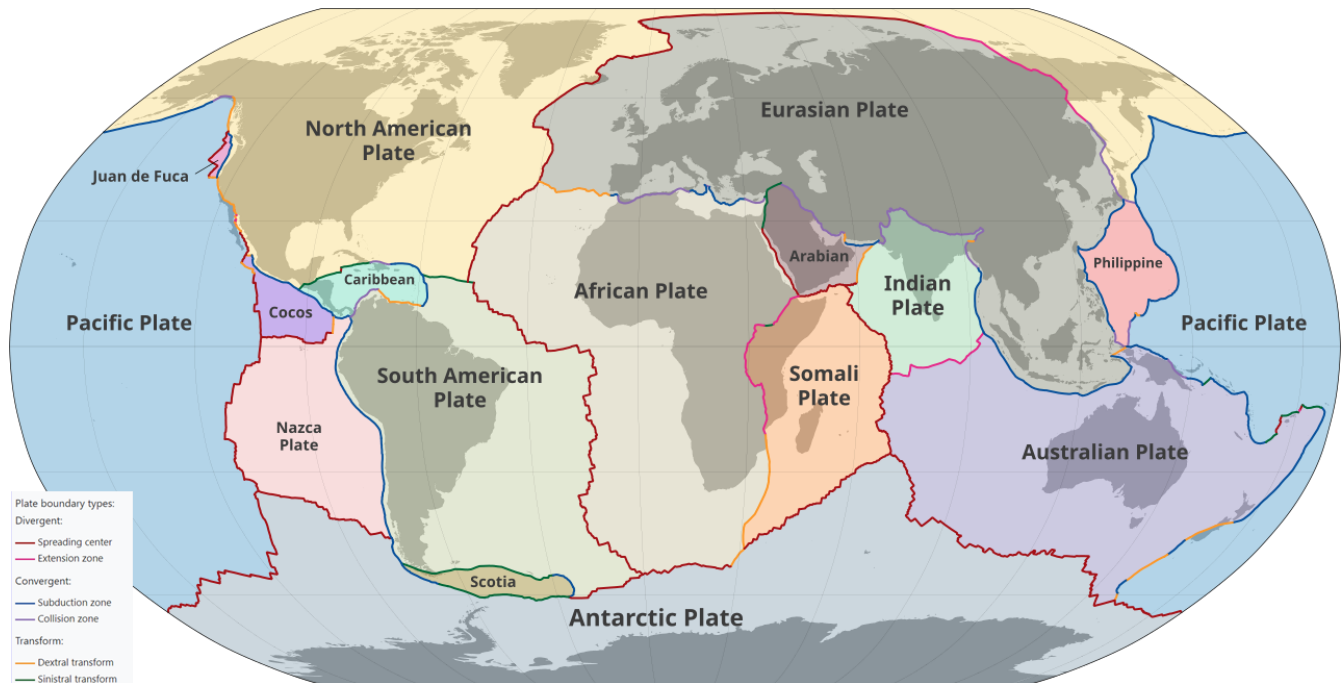
The water stored in the aquifer could potentially be a valuable resource for human consumption, though further research on the impacts of drought and climate change on the reservoir will be necessary to properly manage its use, the researchers wrote.

"This region has been handed a geological gift, but we really are only beginning to understand it," Grant said in the statement. "If we don't have any snow, or if we have a run of bad winters where we don't get any rain, what's that going to mean? Those are the key questions we're now having to focus on."

Making Sense Of The World, One Map At A Time

Map Of The World's Tectonic Plates

Last Updated: September 5, 2024



Map created by [M.Bitton](#)

This map shows the major tectonic plates that make up [Earth's lithosphere](#).

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Tectonic plates are massive slabs of solid rock that float on the semi-fluid asthenosphere beneath them and move relative to one another.

The movement of these plates can cause earthquakes, volcanic activity, mountain building, and ocean trench formation.

Here is an overview of each major plate shown in the map:

1. Pacific Plate

- **Location:** The largest tectonic plate, located beneath the Pacific Ocean.
- **Characteristics:** Contains both oceanic crust (mostly basaltic) and a small section of continental crust.
- **Interactions:** It interacts with many other plates, leading to the formation of the “Ring of Fire,” a zone known for earthquakes and volcanic activity around the Pacific Ocean.

2. North American Plate

- **Location:** Covers most of North America, parts of the Atlantic Ocean, and part of Siberia in Russia.
- **Characteristics:** Includes both continental and oceanic crust.
- **Interactions:** The western boundary with the Pacific Plate is a transform boundary (San Andreas Fault), where many earthquakes occur.

3. South American Plate

- **Location:** Covers the continent of South America and parts of the Atlantic Ocean.
- **Characteristics:** Predominantly continental crust with some oceanic crust.
- **Interactions:** The west coast is a convergent boundary with the Nazca Plate, forming the Andes Mountains and causing frequent earthquakes.

4. African Plate

- **Location:** Covers the continent of Africa and surrounding oceanic crust.
- **Characteristics:** Includes both continental and oceanic crust.
- **Interactions:** Contains a divergent boundary (East African Rift) where the Somali Plate is splitting away, potentially forming a new ocean basin.

5. Eurasian Plate

- **Location:** Covers Europe and Asia, extending into the Atlantic Ocean.
- **Characteristics:** Mostly continental crust.
- **Interactions:** Collides with the Indian Plate, creating the Himalayas.

6. Indian Plate

- **Location:** Mostly covers the Indian subcontinent and part of the Indian Ocean.
- **Characteristics:** Predominantly continental crust.
- **Interactions:** Converges with the Eurasian Plate, leading to the uplift of the Himalayan Mountains.

7. Australian Plate

- **Location:** Covers Australia, New Zealand, and surrounding ocean areas.
- **Characteristics:** Contains both continental and oceanic crust.
- **Interactions:** Converges with the Pacific Plate, causing significant tectonic activity in New Zealand.

8. Antarctic Plate

- **Location:** Covers Antarctica and the surrounding oceanic crust.

- **Characteristics:** Primarily oceanic with some continental crust.
- **Interactions:** Divergent boundaries with many other plates, leading to mid-ocean ridge formation.

9. Nazca Plate

- **Location:** West of South America, beneath the Pacific Ocean.
- **Characteristics:** Oceanic crust.
- **Interactions:** Converges with the South American Plate, creating the Andes Mountains and deep ocean trenches.

10. Cocos Plate

- **Location:** Located off the west coast of Central America.
- **Characteristics:** Oceanic crust.
- **Interactions:** Subducts beneath the Caribbean Plate, causing volcanic activity in Central America.

11. Caribbean Plate

- **Location:** Beneath the Caribbean Sea.
- **Characteristics:** Oceanic crust with some continental crust.
- **Interactions:** Interacts with the North American Plate, South American Plate, and Cocos Plate, causing earthquakes and volcanic activity.

12. Philippine Plate

- **Location:** Beneath the Philippine Sea.
- **Characteristics:** Oceanic crust.
- **Interactions:** Interacts with the Pacific Plate, Eurasian Plate, and Indo-Australian Plate, leading to tectonic activity in the Philippines and surrounding regions.

13. Arabian Plate

- **Location:** Covers the Arabian Peninsula.
- **Characteristics:** Mostly continental crust.
- **Interactions:** Divergent boundary with the African Plate forming the Red Sea and convergent boundary with the Eurasian Plate forming the Zagros Mountains.

14. Somali Plate

- **Location:** East of the African Plate, covering the Horn of Africa.
- **Characteristics:** Continental crust.
- **Interactions:** Diverging from the African Plate along the East African Rift.

15. Scotia Plate

- **Location:** Between the South American Plate and the Antarctic Plate.
- **Characteristics:** Oceanic crust.
- **Interactions:** Transform boundaries with both the South American and Antarctic Plates.

16. Juan de Fuca Plate

-
- **Location:** Off the west coast of North America.
- **Characteristics:** Oceanic crust.
- **Interactions:** Subducts beneath the North American Plate, creating the Cascade Range volcanoes.

These interactions at the plate boundaries result in various geological phenomena like earthquakes, volcanic eruptions, and the creation of mountain ranges and oceanic trenches.

Plate Boundary Types

Plate boundaries are the edges where two tectonic plates meet, and their interactions can cause various geological phenomena.

The types of plate boundaries are primarily classified into three main categories:

Divergent, Convergent, and Transform.

Each of these boundaries can result in specific geological features and processes.

1. Divergent Boundaries

Divergent boundaries occur where two tectonic plates are moving away from each other. This process allows magma from the mantle to rise to the surface, creating new crust.

Spreading Center:

This is the most common type of divergent boundary. Spreading centers occur mainly along mid-ocean ridges, where two oceanic plates are pulling apart from each other.

As they move apart, magma rises from beneath the Earth's crust to fill the gap, creating new oceanic crust. The Mid-Atlantic Ridge is a prime example of a spreading center.

Extension Zone:

An extension zone occurs when a continental plate is being pulled apart, leading to thinning of the crust.

This process can create rift valleys, such as the East African Rift, where the African Plate is splitting into the Nubian and Somali plates. This area is also characterized by volcanic activity and earthquakes.

2. Convergent Boundaries

Convergent boundaries occur where two tectonic plates are moving towards each other. This type of interaction can result in one plate being forced beneath another, or both plates crumpling together.

Subduction Zone:

A subduction zone is formed when an oceanic plate converges with either another oceanic plate or a continental plate. The denser oceanic plate is forced down into the mantle beneath the lighter plate in a process called subduction.

This leads to the formation of deep ocean trenches (like the Mariana Trench) and volcanic arcs (like the Andes or the Cascade Range). Subduction zones are also associated with powerful earthquakes and tsunamis.

Collision Zone:

A collision zone occurs when two continental plates converge, leading to the crumpling and folding of the Earth's crust. Since both plates are of similar density, they push against each other, forming large mountain ranges.

The Himalayan Mountains, formed by the collision between the Indian Plate and the Eurasian Plate, are a classic example.

3. Transform Boundaries

Transform boundaries occur where two tectonic plates slide past each other horizontally. This type of boundary is characterized by lateral movement, rather than vertical movement.

Dextral Transform:

A dextral (or right-lateral) transform fault is a type of transform boundary where the opposite side of the fault moves to the right. A well-known example is the San Andreas Fault in California.

In this fault, if you stand on one side and look across to the other side, it appears to move to the right.

Sinistral Transform:

A sinistral (or left-lateral) transform fault is a type of transform boundary where the opposite side of the fault moves to the left. An example is the Dead Sea Transform fault system, which runs through the Middle East.

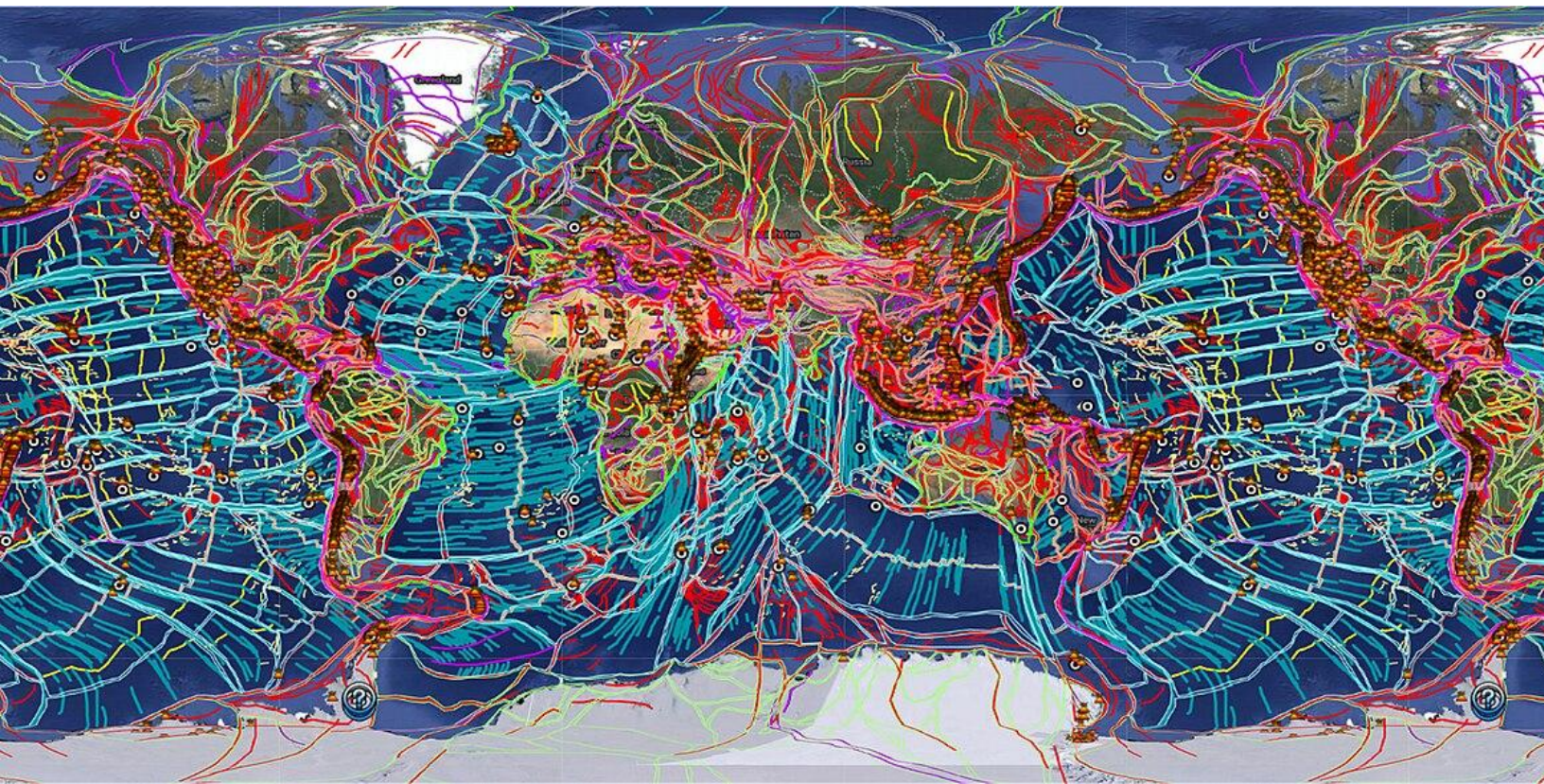
Here, the Arabian Plate moves northwards relative to the African Plate, causing left-lateral displacement.

Summary

- **Divergent Boundaries:** Plates move apart (Spreading Center and Extension Zone).

- **Convergent Boundaries:** Plates move towards each other (Subduction Zone and Collision Zone).
- **Transform Boundaries:** Plates slide past each other (Dextral Transform and Sinistral Transform).

And while the map above looks great it's actually a vast oversimplification. The map below in contrast includes all the details:



Map created by [Jpvandijk](#)

This Map is extracted from the publically available Google MyMaps Map which was launched in 2023.

It is an Appendix to the publication of van Dijk (2023) and shows the tectonic elements (faults, thrusts, subduction zones, passive margins, rift

zones, sutures) of the Earth and the subdivision into 1,180 Plates, also called “Terranes”.

These are divided into 3 domains: Continental Blocks, Oceanic Plates, and Mobile Zones.

Legend: Green:

- Terrane (microplate) boundaries in the Continental Blocks
- Cyan: Terranes of the Oceanic Plates
- Orange: terranes inside the Mobile Belts
- Blue: Oceanic transform faults;
- Red: Fault zones in the Continental and Mountain belt domain;
- Purple: Main subduction zones and suture zones;
- Orange dots: volcanoes.

The related scientific publication is: van Dijk, J.P. (2023); *The New Global Tectonic Map – Analyses and Implications*. Terra Nova, 2023, 27 pp. <https://doi.org/10.1111/ter.12662>. The Map is available at: https://www.google.com/maps/d/viewer?mid=1dXnQlelic4WjA4xKnYFL3F-0_BtzltY&ll. The link to the publication: https://www.researchgate.net/publication/371505776_The_New_Global_Tectonic_Map-Analyses_and_Implications

Like these maps? Please help us by sharing them:

Scientists Found Ancient Tectonic Plates in the Middle of Continents—Where They Shouldn't Be

- The modern understanding of the plate tectonic cycle predicts that remnants of submerged plates will be found near subduction zones.
- However, a new high-resolution model shows that these remnants can also be found far from subduction zones, complicating this-long held geologic narrative.
- The researchers theorize that these far-off remnants could either be deposits of silica-rich material that have hung around since the formation of the mantle four billion years ago, or areas where iron-rich rocks have accumulated via convection over billions of years.

Some things in science are frustratingly inaccessible to direct human observation. Pretty much anything beyond our [Solar System](#) must be measured using advanced techniques, and the intricacies of the quantum realm are also largely explored through technological intermediaries. In much the same way, the mysteries of our very planet's composition are often similarly and annoyingly out of reach.

However, just like astronomers and quantum physicists, geologists have developed ingenious methods of exploring the subject of their field (our planet's interior) without needing some very big, very *impossible* instrument. One of these methods is by setting up seismographic stations to measure seismic waves as they travel through the [Earth](#)—every moment of refraction, diffraction, and reflection of those shock waves tells us something about the interior of the planet. Using this method, scientists can develop models of the Earth's interior that show where submerged plates formed along subduction zones (which is when a plate goes under, or subducts, another plate).

Using the Piz Daint supercomputer in Lugano, Switzerland and a technique known as full-wave inversion (which essentially gathers *all* waveforms into one massive model), [scientists](#) from the California Institute of Technology and ETH Zurich created a new high-resolution model of the lower mantle. However, what they found initially didn't make any sense. The model displayed remnants of

submerged plates located under oceans and in the middle of continents, which—according to our current understanding of the plate tectonic cycle—are all too far from any subduction zone. The results of the study were published [in the journal *Scientific Reports*](#).

One example of these areas is in the western [Pacific](#), where the presence of a submerged plate should be impossible, as there's been no subduction zone nearby in recent geologic history. And yet, this new model clearly highlights the remnants of submerged plates. Andreas Fichtner, the senior author on the study from ETH Zurich, likens the discovery to a doctor finding a new blood vessel thanks to advanced imaging technology.

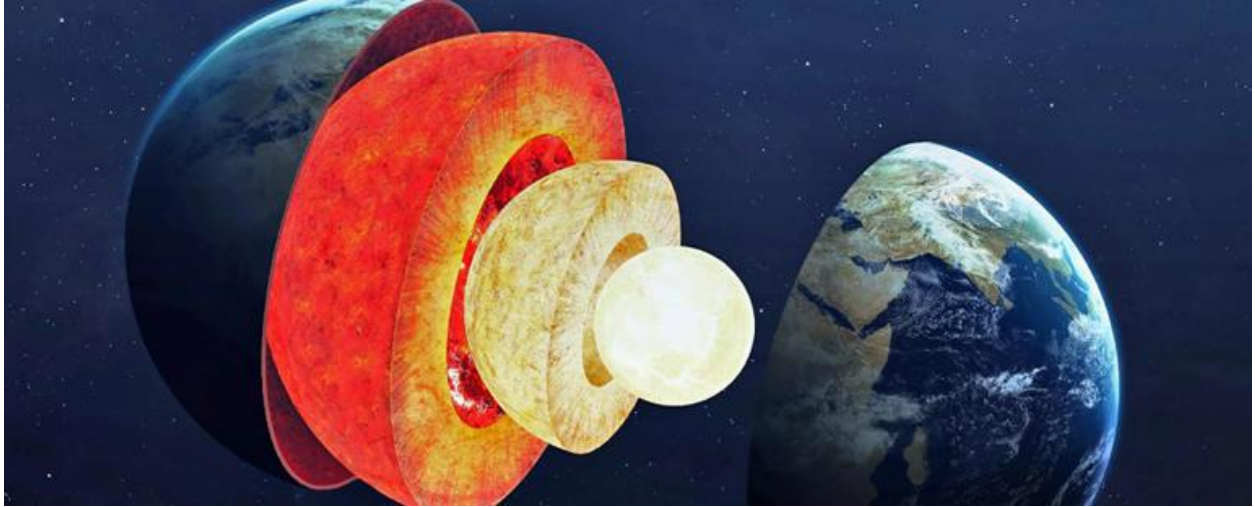
"[With] a new, better examination tool, [the doctor] suddenly sees an artery in the buttock that doesn't really belong there," Fichtner [said in a press statement](#). "That's exactly how we feel about the new findings."

While this [discovery](#) has required the authors to rethink our current understanding of Earth's composition, they do have a few ideas as to what the source of this tectonic anomaly might be.

"It could be either ancient, silica-rich material that has been there since the formation of the [mantle](#) about 4 billion years ago and has survived despite the convective movements in the mantle," Thomas Schouten, first author of the study from ETH Zurich, said in a press statement, "or zones where iron-rich rocks accumulate as a consequence of these mantle movements over billions of years."

However, one of the shortcomings of using an indirect method of observation is that many questions remain, especially regarding what [materials](#) could be impacting these seismic wave velocities. The researchers hope that even better models will be able to divine the material properties behind these head-scratching enigmas deep below the Earth's surface.

Scientists Found Signs of a Hidden Structure Inside Earth's Core



Earth's Innermost Inner Core

While most of us take the ground beneath our feet for granted, written within its complex layers, like the pages of a book, is Earth's history. Our history.

Research shows there are little-known chapters in that history, deep within Earth's past. In fact, Earth's inner core appears to have another even more inner core within it.

"Traditionally we've been taught the Earth has four main layers: the crust, the mantle, the outer core and the inner core," Australian National University geophysicist Joanne Stephenson [explained in 2021](#).

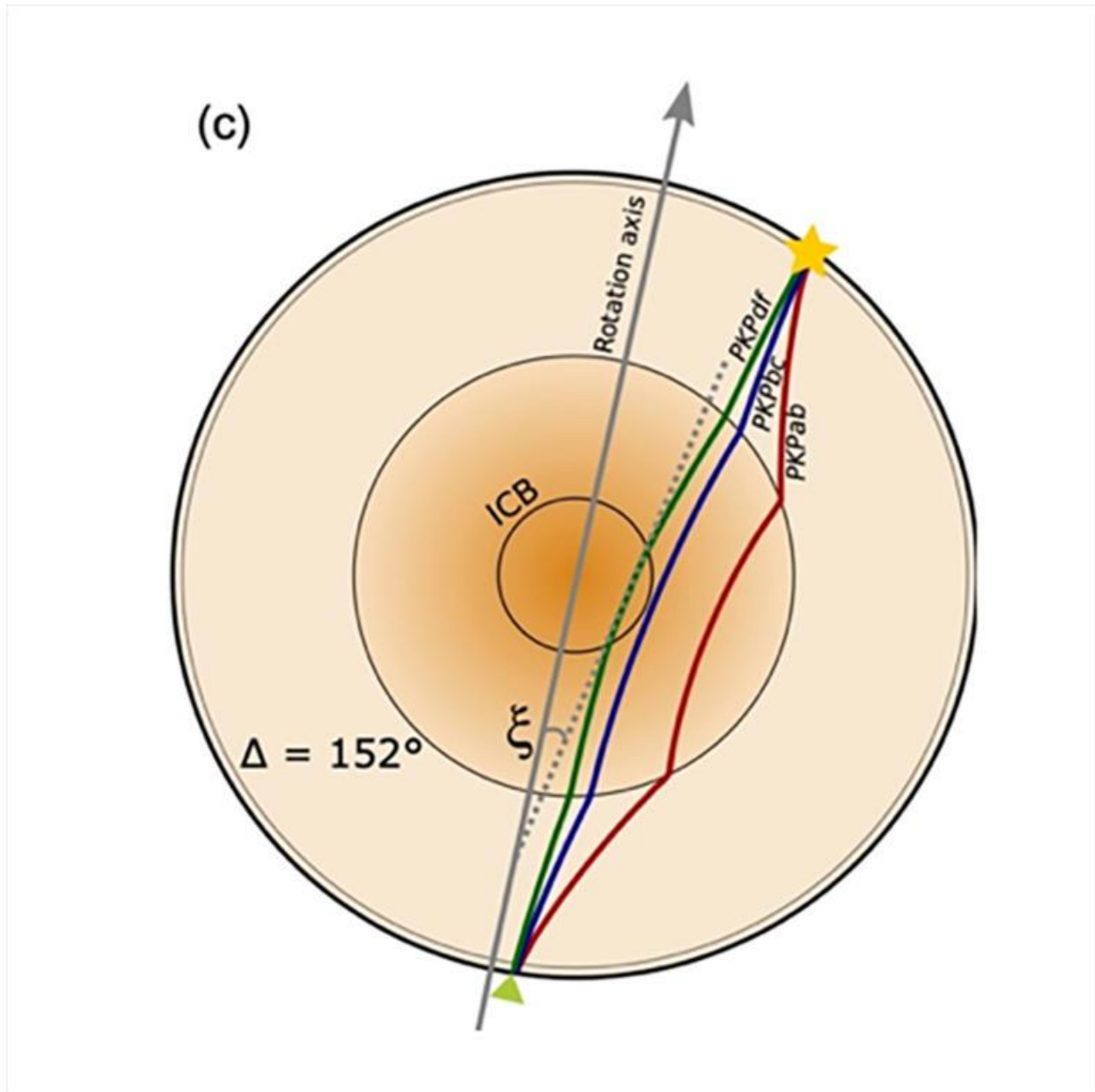
Our knowledge of what lies beneath Earth's crust has been inferred mostly from what volcanoes have divulged and what seismic waves have whispered.

From these indirect observations, scientists have calculated that the scorchingly hot inner core, with temperatures surpassing 5,000 degrees Celsius (9,000 Fahrenheit), makes up only 1 percent of Earth's total volume.

But a few years ago, Stephenson and colleagues found evidence Earth's inner core may actually have two distinct layers.

"It's very exciting – and might mean we have to re-write the textbooks!" [Stephenson explained at the time](#).

The team used a search algorithm to trawl through and match thousands of models of the inner core with observed data across many decades about how long seismic waves take to travel through Earth, gathered by the International Seismological Centre.



Differences in seismic wave paths through layers of Earth. (Stephenson xxxxxx)

Differences in seismic wave paths through layers of Earth. (Stephenson et al., *Journal of Geophysical Research: Solid Earth*, 2021)

So what's down there? The team looked at some models of the inner core's [anisotropy](#) – how differences in the make-up of its material alters the properties of seismic waves – and found some were more likely than others.

While some models suggest the material of the inner core channels seismic waves faster parallel to the equator, others indicate the mix of materials allows for faster waves more parallel to Earth's rotational axis. Even then, there are arguments about the exact degree of difference at certain angles.

The study here didn't show much variation with depth in the inner core, but it did find there was a change in the slow direction to a 54-degree angle, with the faster direction of waves running parallel to the axis.



Earth's inner core may actually have two distinct layers. (alexlmx/Canva Pro)

"We found evidence that may indicate a change in the structure of iron, which suggests perhaps two separate cooling events in Earth's history," Stephenson [said](#).

"The details of this big event are still a bit of a mystery, but we've added another piece of the puzzle when it comes to our knowledge of the Earth's inner core."

These findings may explain why [some experimental evidence](#) has been inconsistent with our current models of Earth's structure.

The presence of an innermost layer has been suspected before, with hints that iron crystals that compose the inner core have different structural alignments.

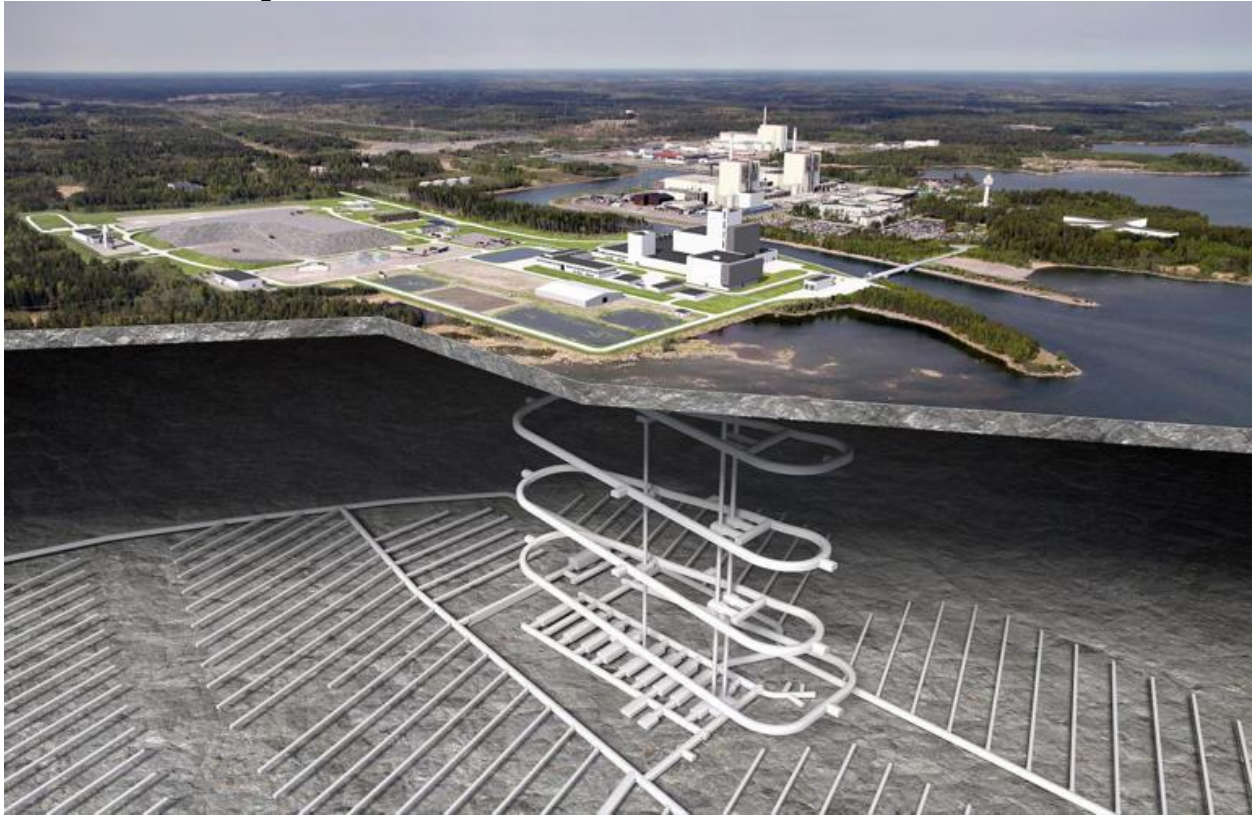
"We are limited by the distribution of global earthquakes and receivers, especially at polar antipodes," [the team wrote](#) in their paper, explaining the missing data decreases the certainty of their conclusions.

But their conclusions align with other studies on the anisotropy of the innermost inner core.

Future research may fill in some of these data gaps and allow scientists to corroborate or contradict their findings, and hopefully translate more stories written within this early layer of Earth's history.

This research was published in the [*Journal of Geophysical Research*](#).

Sweden begins construction of massive underground nuclear vault that will last 100,000 years



Rendering of Sweden's nuclear waste storage facility (SKB handout)

Sweden has broken ground on its ambitious \$11 billion nuclear waste repository, where highly radioactive material will rest in an underground maze of tunnels stretching 60 kilometers - longer than the New York City subway's longest line. The sprawling network, which resembles an elaborate waterpark park design minus the fun, will take a decade to build before accepting its first radioactive deposits.

Barron's reports that the \$11 billion project at Forsmark, 140 kilometers north of Stockholm, will start with two years of surface prep - including water treatment facilities and forest clearing - before workers begin excavating into bedrock to a depth of 1,640 feet.

Nuclear waste management company SKB will oversee this complex burial, where spent fuel will be sealed in copper and iron capsules designed to safely contain radioactivity for 100,000 years. Each massive canister will be welded shut and lowered through the elaborate underground network. Engineers will surround them with bentonite clay, a natural material that expands when wet to create a watertight, earthquake-resistant seal. When complete in the 2080s, the facility will house more than 6,000 canisters of spent nuclear fuel.

BOING BOING

SEARCHSTORE

MENU

There's 22 million gallons of nuclear waste under a concrete dome on a Pacific Island, and it's sinking

THOM DUNN 4:45 AM TUE NOV 12, 2019



The [*Los Angeles Times*](#) has a harrowing new story about Enewetak Atoll in the Marshall Islands. Japanese forces invaded the small Pacific nation and its residents during World War I, and the United States did the same during World War II under that classic guise of "liberation." But the US was hardly acting altruistically, at the time nor since then. The islands' location made it a prime strategic military base in the Pacific. It was also isolated enough to make it a convenient nuclear testing site—if you disregarded the 72,000 people who lived there, of course.

Between 1946 and 1962, US military experiments produced **108 megatons** of nuclear yield in the Marshall Islands— **about 80%** of the country's total radioactive waste output from nuclear testing. That's the

equivalent **1.6 atomic bombs dropped every day for 12 years**. And after the US decided to gradually cede control of the land back to the Marshallese people, we just kind of ... left it all behind. We were kind enough to pour a bunch of concrete on top of the **22 million gallons** of nuclear waste left behind on one specific island, creating the **Runit Dome**.

But that dome is still there. And the concrete is starting to crack. And sea levels are rising rapidly, particularly in the Pacific, further accelerating that erosion process. Now the Dome—affectionately and appropriately called "The Tomb" by the locals—is threatening to leach all of that nuclear waste into the land and the ocean.

308.1K

Anduril CEO on Building a New Ohio Plant, an IPO, Working With Trump

I realize that an island-sized nuclear waste dump called "The Tomb" in the middle of the Pacific Ocean sounds like some straight-up Godzilla sci-fi shit. But I assure you, this is real. I actually wrote **an article about Enewetak Atoll** about 4 years ago, as part of a larger campaign about climate change. This new LA Times piece goes much further, however, as it reveals some new details that really pour salt into that gaping Imperialist nuclear wound:

A Times review of thousands of documents, and interviews with U.S. and Marshallese officials, found that the American government withheld key pieces of information about the dome's contents and its weapons testing program before the two countries signed a compact in 1986 releasing the U.S. government from further liability. One example: The United States did not tell the Marshallese that in 1958, it shipped 130 tons of soil from its atomic testing grounds in Nevada to the Marshall Islands.

Are you kidding me?

U.S. authorities also didn't inform people in Enewetak, where the waste site is located, that they'd conducted a dozen **biological weapons tests** in the atoll, including experiments with an aerosolized bacteria designed to kill enemy troops.

Are you fucking kidding me?

The problem with nuclear waste

Nuclear energy produces less carbon dioxide than any other any source (including solar, wind, and geothermal). But nuclear waste is extremely poisonous, and leaks are inevitable. And there are problems surrounding what to do with the byproducts of nuclear power plants.

World's deadliest spot: the horror of Lake Karacha

NOV 8, 2024



By NASA, Jan Rieke (color correction, borders and labels) - NASA World Wind screenshot (Landsat Global Mosaic visual layer), Public Domain, [Link](#)

Standing for just one hour at the shore of Russia's [Lake Karachay](#) ("black water") in 1990 would have killed you. Before it was buried beneath

concrete and stone, the lake held an apocalyptic secret: over 50 times more radioactive material than was released in the Chernobyl disaster.

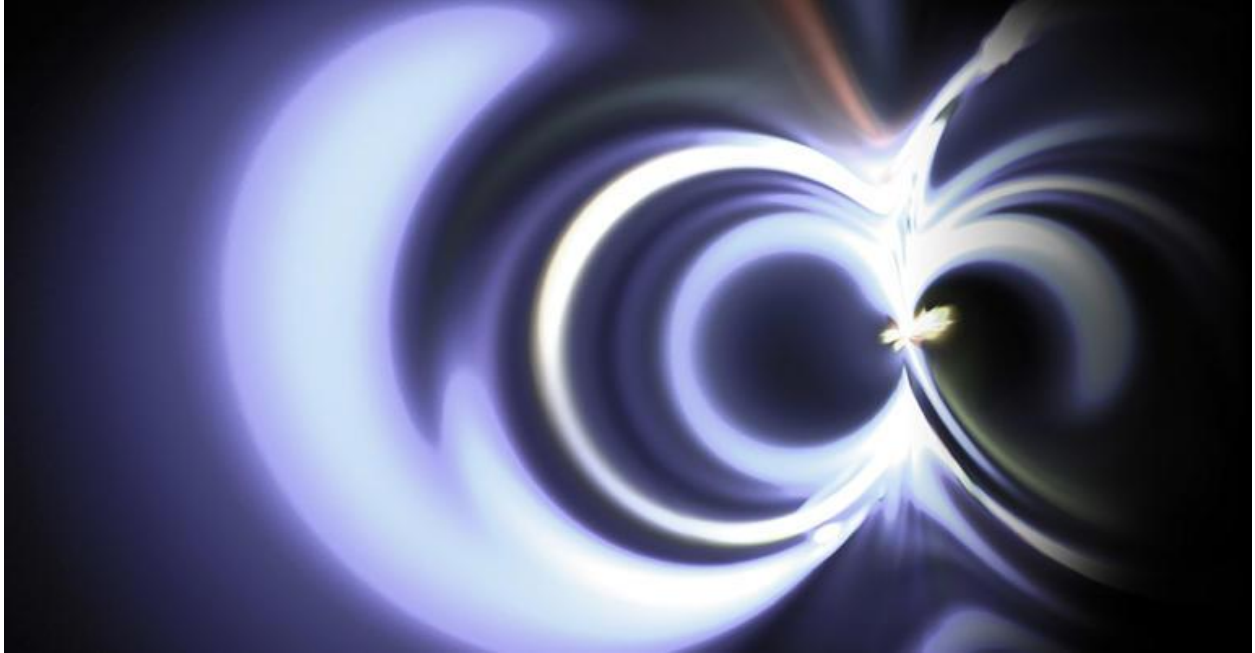
For decades, the Soviet Union's Mayak nuclear facility — built in secrecy between 1946-1948 as part of Stalin's nuclear weapons program — used this small lake in the Ural Mountains as a convenient dumping ground for its most dangerous nuclear waste, creating what the Worldwatch Institute would later describe as "the most polluted spot on Earth." To spread the good cheer, the 1957 Kyshtym Disaster (an explosion in underground storage vats) forced officials to start dumping the radioactive schmutz in other areas, including the nearby Techa River.

The lake became even more deadly when it started drying up in 1968, exposing radioactive sediment on the shoreline. Winds swept up the contaminated dust and carried it across the countryside, irradiating half a million people. In nearby villages like Metlino, doctors worked overtime treating what they could only call the "special disease" — the compassionate servants in the Politburo forbade them from mentioning radiation in their diagnoses.

The lake bed itself was a monument to nuclear horror — its sediment, nearly 11 feet deep, was composed almost entirely of high-level radioactive waste. Between 1978 and 1986, as the deadly reality of the situation became clear, workers risked their lives to dump almost 10,000 hollow concrete blocks into the lake to keep the radioactive sediment from shifting. The project to finally bury the lake completely would take until 2015, when the last layer of rock and soil transformed Lake Karachay from a liquid nightmare into what officials euphemistically termed "a near-surface permanent and dry nuclear waste storage facility."

While the lake is now sealed, the site remains one of the most contaminated places on Earth, with massive amounts of radioactive material contained beneath its surface, and will remain dangerous for generations, requiring ongoing monitoring and management. I'm sure President Putin will make sure it stays safe at any cost.

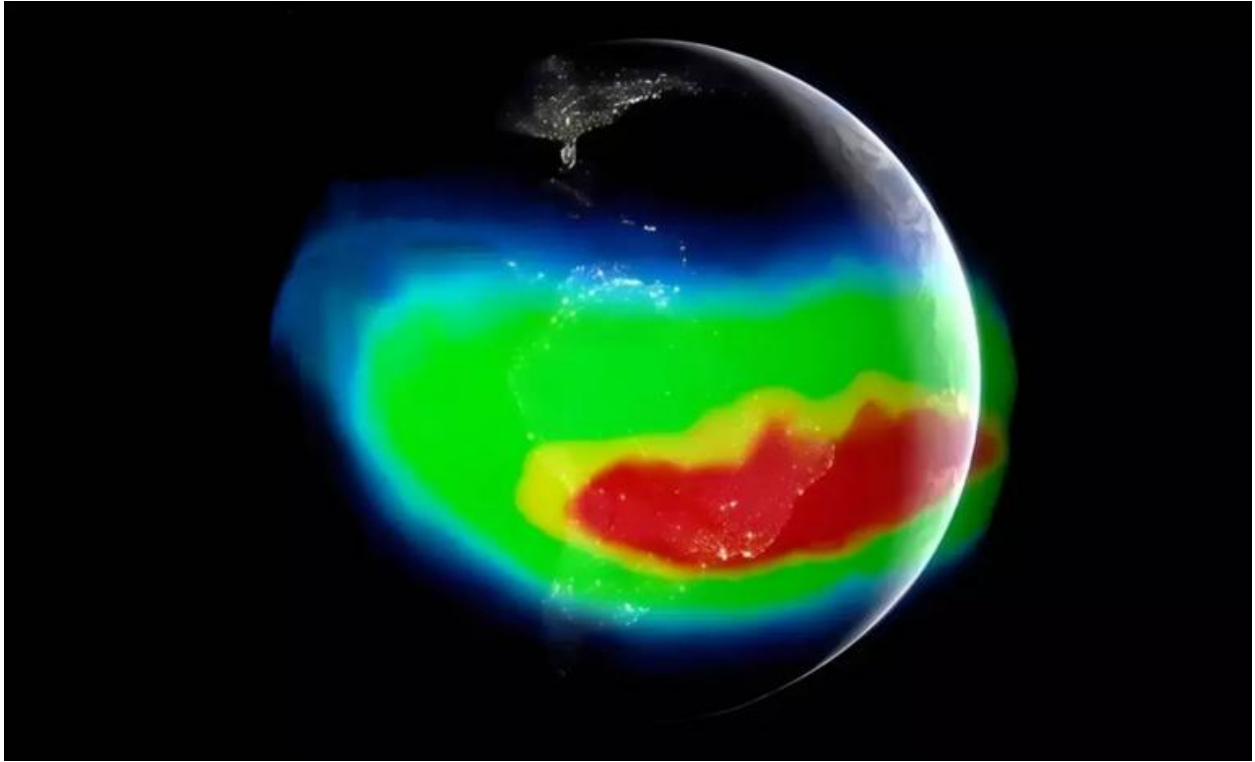
NASA Scientists Warn of Potential Threat After 'Dent' in Earth's Magnetic Field



NASA Scientists Warn of Potential Threat After 'Dent' in Earth's Magnetic Field© Sean Cate

A massive and evolving weak spot in Earth's magnetic field, known as the South Atlantic Anomaly (SAA), has caught the attention of NASA scientists. This "dent" in our planet's magnetic shield poses significant risks to satellites, space exploration, and possibly the future of humanity if left unmonitored. Stretching from South America to southwest Africa, the SAA continues to grow and shift, raising alarms about its potential implications for life and technology on Earth.

The South Atlantic Anomaly



The Earth's magnetic field acts as a shield, protecting the planet from harmful solar radiation and charged particles. However, the SAA is an area [where this field weakens](#), allowing particles to dip closer to the Earth's surface than normal. First identified in 1958, the anomaly spans over 4.3 million square miles and has shown consistent signs of expansion and intensification.

"The SAA is a dynamic feature of our magnetic field that must be continuously observed," said Terry Sabaka, a geophysicist at NASA's Goddard Space Flight Center. Recent data shows that the anomaly has begun splitting into two distinct lobes, complicating predictions and mitigation efforts.

Impact on Satellites and Spacecraft



Satellites and spacecraft that pass through the SAA face heightened exposure to radiation from charged solar particles. These particles can cause malfunctions in onboard computers, data collection systems, and other sensitive equipment. *"The SAA has forced us to shut down non-essential spacecraft components to prevent catastrophic damage,"* noted a NASA spokesperson.

Even the [International Space Station](#) (ISS), which regularly travels through the SAA, has experienced minor disruptions. Instruments like the GEDI (Global Ecosystem Dynamics Investigation) lose data during such encounters, though astronauts remain safe within the station's protective shielding.

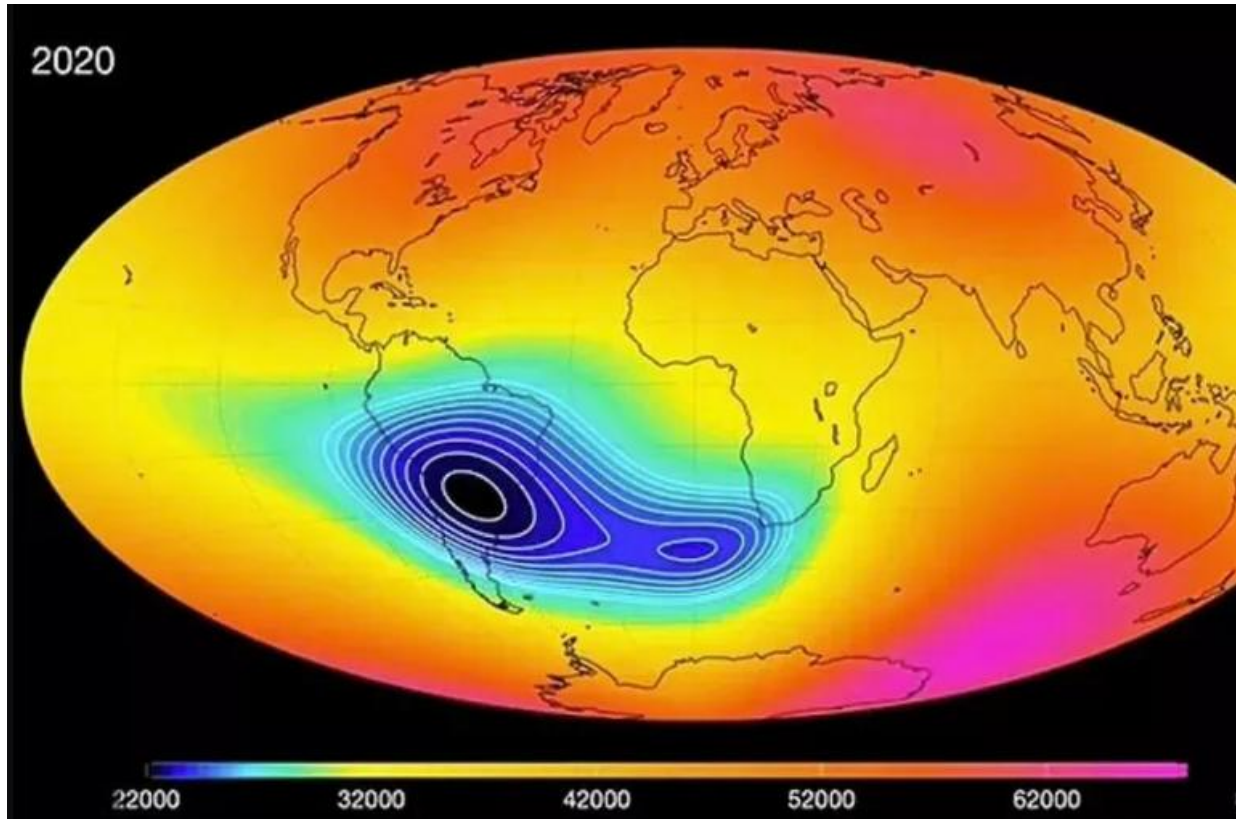
The Source of the Anomaly



The SAA [originates from](#) processes deep within Earth's outer core, where molten, iron-rich materials generate the magnetic field through the geodynamo effect. Irregularities in this flow, combined with the tilt of Earth's magnetic axis, create the anomaly. Additionally, dense rock formations in the mantle, such as the African Large Low Shear Velocity Province, amplify the weakening effect.

"The magnetic field is a complex system influenced by many factors," explained NASA [heliophysicist](#) Ashley Greeley. *"Understanding these processes helps us make better predictions about the anomaly's behavior".*

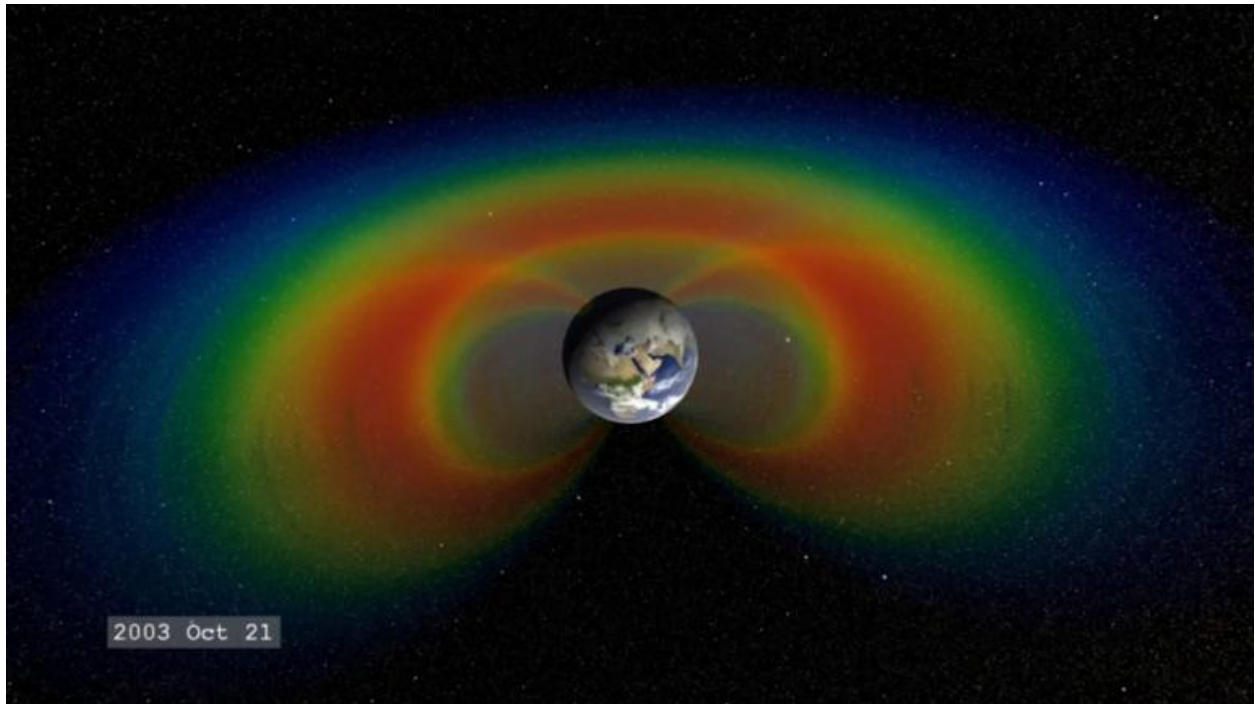
A History of Change and Future Risks



The anomaly's movement and intensification are not new phenomena. Research indicates that similar events may have occurred as far back as [11 million years](#). However, recent measurements show the SAA is weakening by about 7% every four years and drifting northwest.

Some scientists have speculated that the anomaly could signal an impending magnetic field pole reversal, where the north and south poles swap places. The last such event occurred 780,000 years ago, though temporary reversals have been recorded more recently.

Space Technology at Risk



The implications of the SAA extend beyond satellite malfunctions. High-energy proton strikes within the anomaly can cause irreversible damage to critical infrastructure, including GPS systems, weather monitoring satellites, and communication networks. With humanity's growing reliance on space-based technology, the risks posed by the SAA could escalate into widespread disruption of everyday life.

"Satellites are integral to global operations, from food production to emergency services," said geophysicist [Weijia Kuang](#). "A malfunction caused by the SAA could have cascading effects on these systems".

Human Exploration and the SAA



The anomaly poses additional challenges for future space missions. With organizations like NASA and SpaceX planning crewed missions to Mars, the increased magnetic field radiation exposure within the SAA becomes a critical safety concern. As a precaution, spacecraft traversing the region often power down critical systems to minimize damage.

"The more we explore space, the more we must account for anomalies like the SAA," said Sabaka. "Failure to do so could jeopardize both missions and lives".

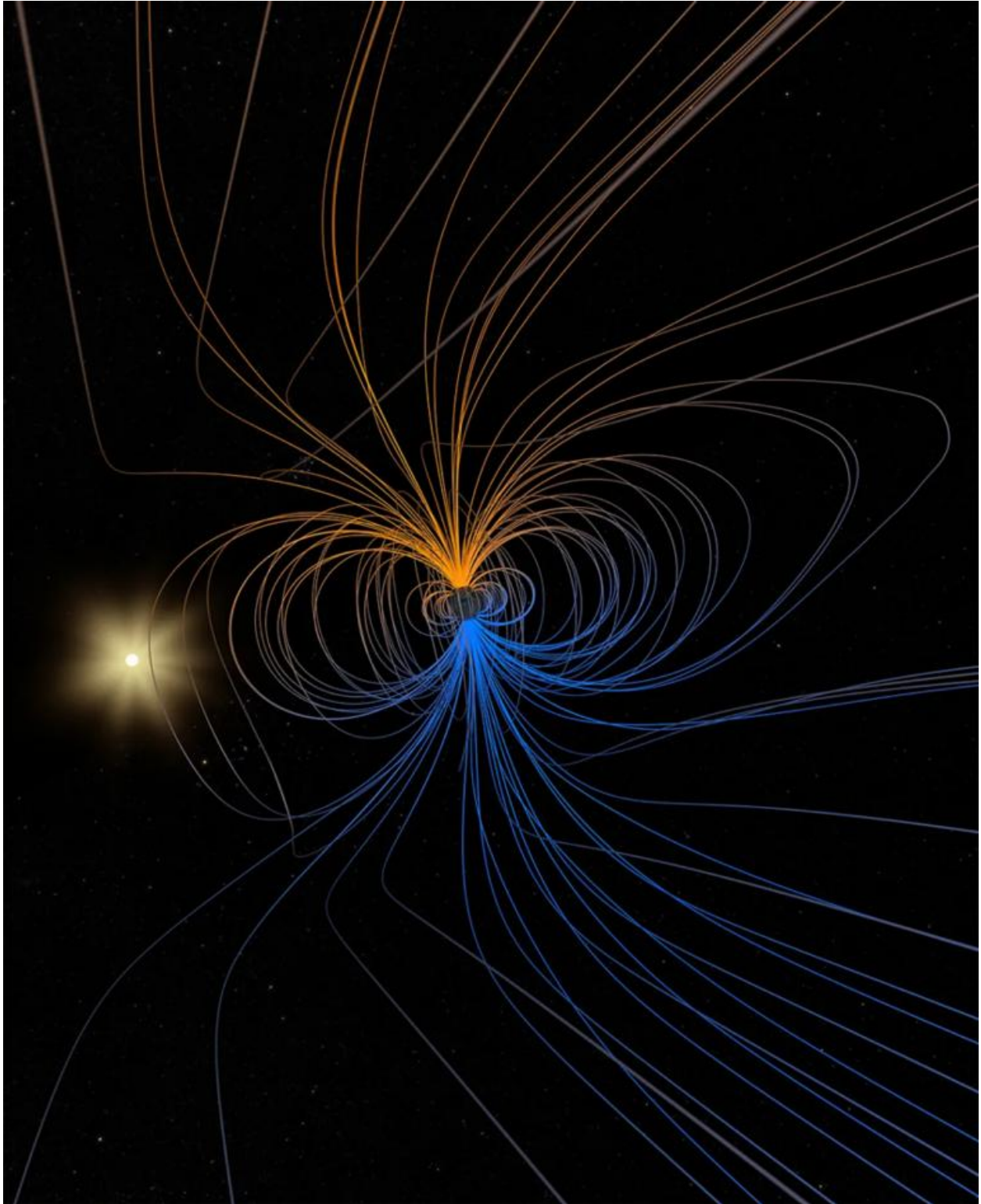
Monitoring and Mitigation Efforts



To better understand and predict the SAA's evolution, NASA collaborates with the European Space Agency (ESA) and other research organizations. The ESA's Swarm satellite constellation provides precise measurements of magnetic field signals, helping scientists map changes in the anomaly over time.

NASA's Solar, Anomalous, and Magnetospheric Particle Explorer ([SAMPEX](#)) also monitored particle radiation levels within the SAA from 1992 to 2012. These findings have informed satellite designs, ensuring they are better equipped to withstand the anomaly's effects.

Preparing for an Uncertain Future



While the South Atlantic Anomaly currently poses limited risks to life on Earth's surface, its impact on technology and space exploration is significant. As the anomaly evolves, continued monitoring and advanced modeling are essential to mitigate potential threats.

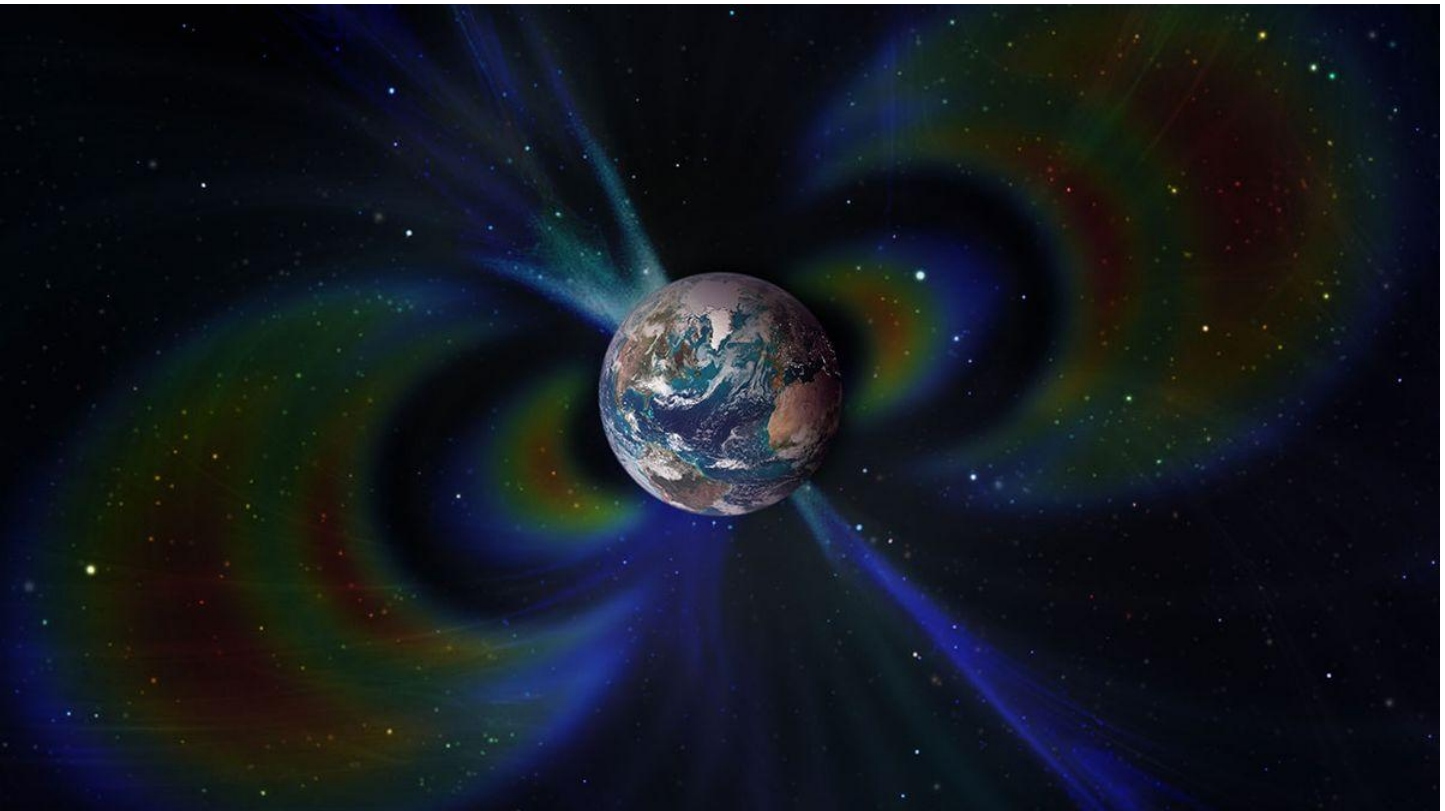
"This is not just an issue for scientists; it's a challenge for humanity as a whole," said [Jürgen Matzka](#) from the German Research Centre for Geosciences. *"Understanding and addressing the SAA's effects is crucial to safeguarding our technological future".*

The post NASA Scientists Warn of Potential Threat After 'Dent' in Earth's Magnetic Field appeared first on [The Hearty Soul](#).

'A force more powerful than gravity within the Earth': How magnetism locked itself inside our planet

published May 26, 2024

"As the magma cooled to form what is today the world's solid outer crust, magnetism was locked into minerals containing iron, such as magnetite."



The image of an atom, with electrons swarming around a central nucleus bulging with protons and neutrons, is as iconic in our perception of science as the DNA helix or the rings of Saturn. But however much we scratch the surface of these scientific fundamentals, we can go even deeper, focusing that microscope further and discovering even more forces that govern our world.

In his new book "[CHARGE: Why Does Gravity Rule?](#)", theoretical physicist [Frank Close](#) explores the fundamental forces that govern our world, posing questions along the way that seek to explain how the delicate balance of positive and negative charges paved the way for gravity to shape our universe.

In this excerpt, he explains how magnetism, the most tangible fundamental forces, was discovered, where it comes from and how it got its name.

The force within

Magnetism is a manifestation of electricity, and vice versa. Electricity and magnetism were imprinted into our surroundings from the beginning. Five billion years ago when the new-born Earth was a hot plasma of swirling electrical currents, these flows created magnetic fields. As the magma cooled to form what is today the world's solid outer crust, [magnetism](#) was locked into minerals containing iron, such as magnetite.

Today, the [Earth's liquid core](#) is still a terpsichorean frenzy of electric currents, which generate a magnetic field. This extends into the atmosphere and far beyond, invisible to our normal senses. But in spreading from its source in the molten core to the heavens above, it first permeates the Earth's crust. This is where it leaves a tangible imprint, evidence that there exists a force more powerful than gravity at work within the Earth whose influence extends very far.

Way back in the earliest Precambrian, four billion years ago, as the surface cooled, atomic elements accumulated in the strata. The most stable of these, iron, is today one of the most abundant elements in the crust. Igneous rocks formed from volcanic lava. These rocks have the property that in the presence of a magnetic field, their atoms of iron act like soldiers on parade as they themselves become magnetic. This is exploited in popular demonstrations where the magnetic field of a bar magnet can be made visible.

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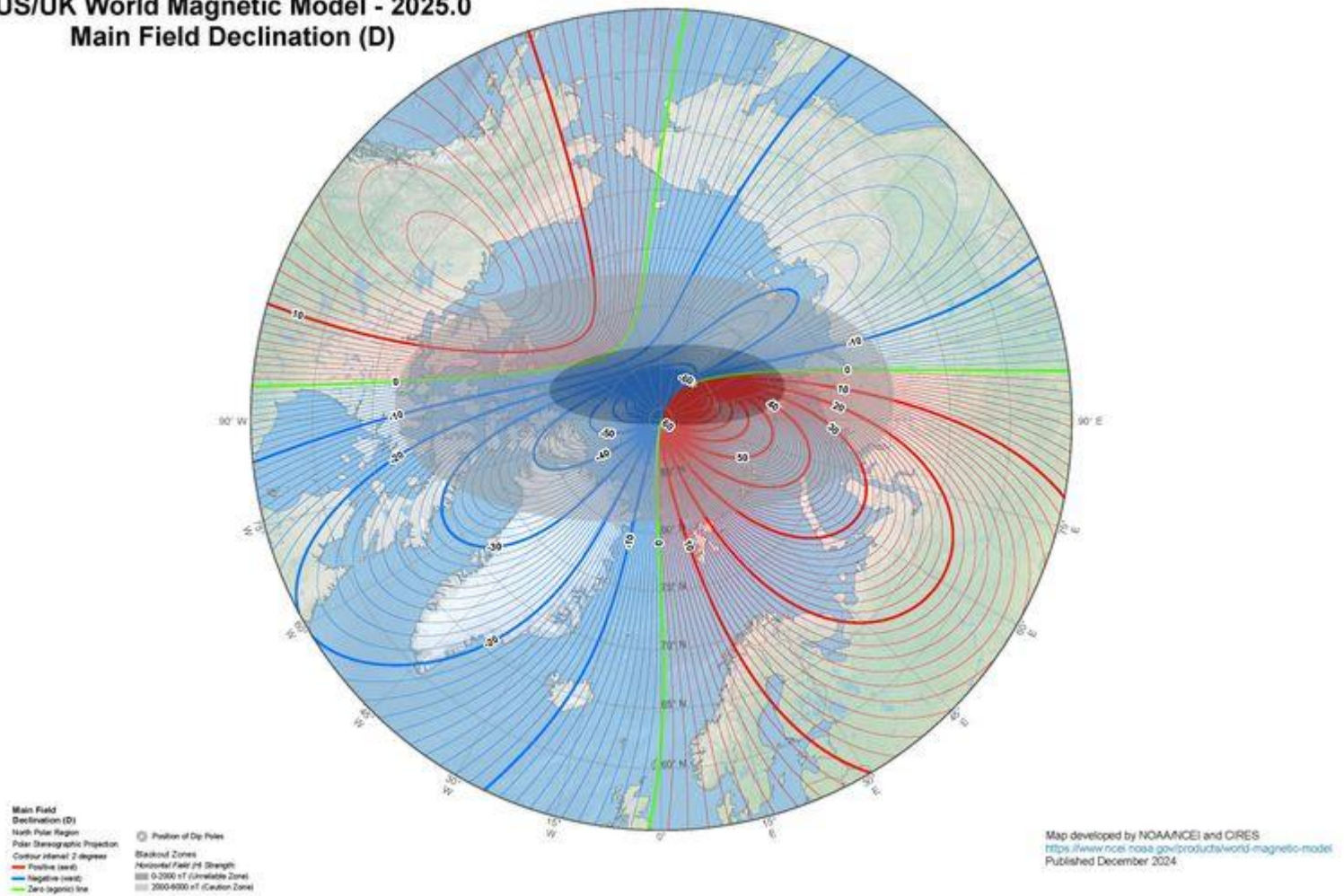
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PUBLISHED December 18, 2024

US/UK World Magnetic Model - 2025.0
Main Field Declination (D)



Earth's Magnetic North Pole Officially Has A New Position

Feast your eyes on the World Magnetic Model 2025, one of the key tools developed to model the change in Earth's magnetic field.

Image credit: NOAA/NCEI.

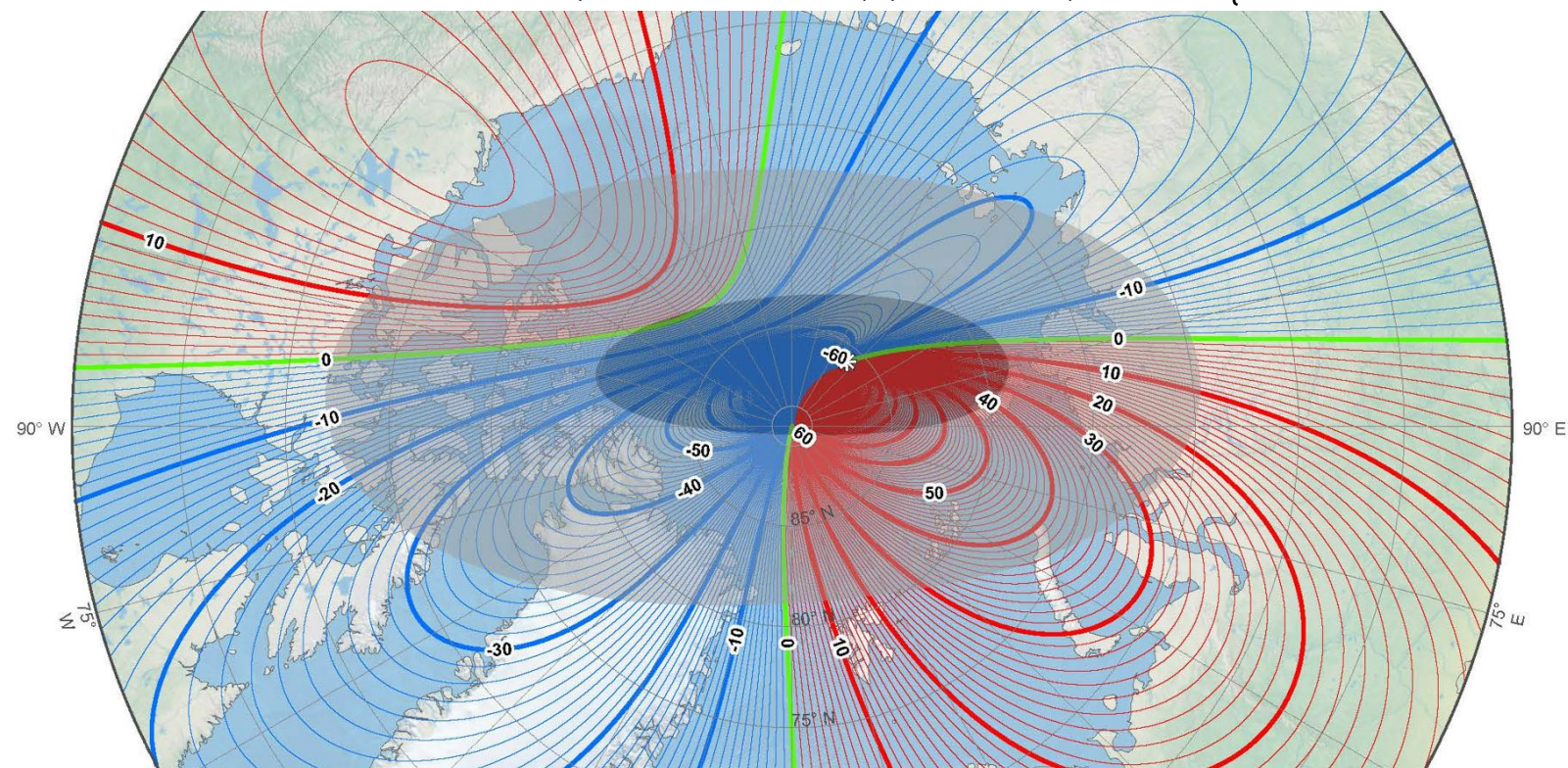
Hoping to keep tabs on the magnetic north's wandering ways, the World Magnetic Model 2025 has been released this week, revealing the latest official predicted placement of Earth's magnetic fields. This version will remain valid until late 2029, during which time we can expect to see the magnetic north pole slowly edge further toward Russia.

Earth's magnetic north pole is different from the geographic North Pole. The latter (the so-called "True North") directly points toward the geographic North Pole, a fixed point on the Earth's surface located at 90° North latitude where the Earth's axis of rotation meets the surface.

Meanwhile, the magnetic north pole is an ever-changing point that's dictated by liquid metals sloshing around Earth's outer core. These molten metals are conductive and in constant motion due to the planet's rotation and heat-driven convection. In tune with the principles of electromagnetism, the movement creates electric currents, which generate a magnetic field with two poles.

Since the magnetic poles are constantly moving, albeit very slowly, the NOAA and the British Geological Survey (BGS) have to regularly revise their models.

On December 17, they [released the latest update](#), including the new World Magnetic Model High Resolution (WMMHR2025). WMMHR2025 offers a significant improvement in spatial resolution – approximately 300 kilometers (186 miles) at the equator – compared to the standard model's resolution of 3,300 kilometers (2,050 miles) at the equator.



A closer look at the map above shows the north dip magnetic pole (marked by a bold white asterisk) is now closer to Siberia than it is to Canada.

Image credit: NOAA/NCEI

The update is extremely important for technology that relies on the Earth's magnetic field, namely the Global Positioning System (GPS) and other satellite-based navigation systems used elsewhere in the world.

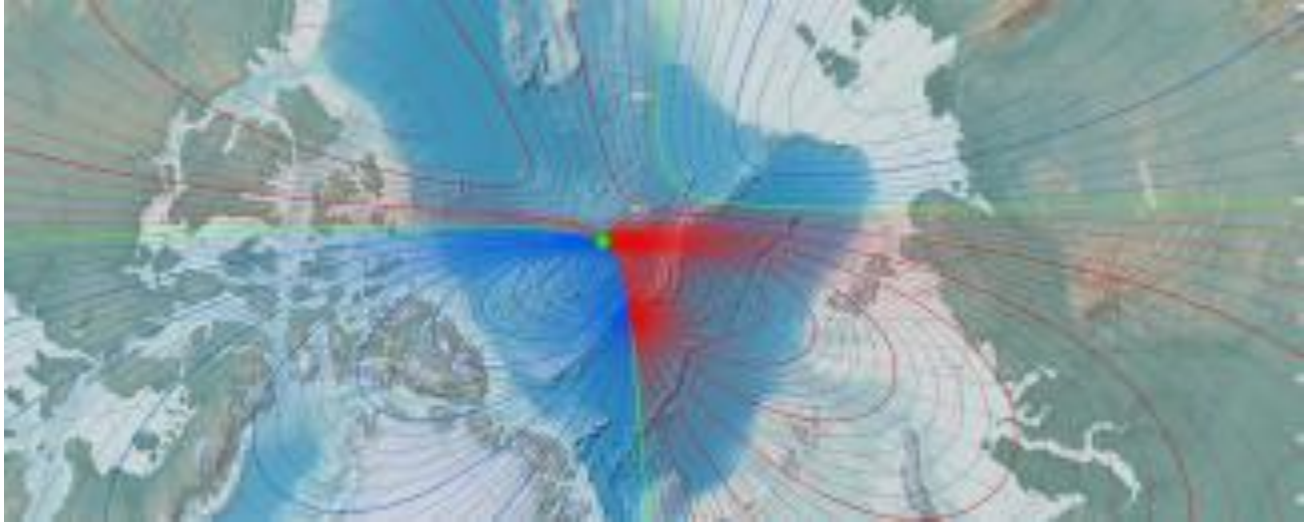
The new version is of timely importance too as the magnetic north pole's movement [seems to be accelerating](#).

Since the 1830s, the north magnetic pole of Earth has relocated some 2,250 kilometers (1,400 miles) across the upper stretches of the Northern Hemisphere from Canada towards Siberia. Between 1990 and 2005, the rate of pole movement increased from less than 15 kilometers (9.3 miles) per year to around 50 to 60 kilometers (31 to 37 miles) per year.

"The WMM is officially released today, ensuring users can have the most up-to-date information so they can continue to navigate accurately for the next five years," Dr William Brown, global geomagnetic field modeler at BGS, said in a [statement](#).

"The current behaviour of magnetic north is something that we have never observed before. Magnetic north has been moving slowly around Canada since the 1500s but, in the past 20 years, it accelerated towards Siberia, increasing in speed every year until about five years ago, when it suddenly decelerated from 50 to 35 km per year, which is the biggest deceleration in speed we've ever seen," added Dr Brown.

Tracking Changes in Earth's Magnetic Poles



Courtesy of NOAA NCEI

As Earth's [magnetic field](#) varies over time, the positions of the North and South Magnetic Poles gradually change. [Magnetic declination](#)—the angle between magnetic North and true North—at a given location also changes over time. Our [Historical Magnetic Declination Map Viewer](#) displays locations of the geomagnetic poles and historical declination lines calculated for the years 1590–2020.

Earth's Magnetic History

Sir James Clark Ross first discovered the North Magnetic Pole in northern Canada in 1831. Since 1831, the pole has been moving across the Canadian Arctic toward Russia. NCEI scientists with the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder calculated the movement of both the North and South Magnetic Poles from 1590 to 2025 using two models: [gufm1](#) and [IGRF](#). Gufm1 incorporates thousands of magnetic observations taken by mariners engaged in merchant and naval shipping. The IGRF is the product of a collaborative effort between magnetic field modelers and the institutes involved in collecting and disseminating magnetic field data from satellites and from

observatories and surveys around the world. A survey in 2007 by a Canadian–French international collaboration determined that the North Magnetic Pole was moving approximately north-northwest at 55 km per year. According to the latest IGRF, the Pole is currently moving in the same direction but at a slightly reduced speed of about 45 km per year.

NCEI and CIRES scientists created an [animation](#) showing changes in declination location and the “[wandering](#)” of the [North Magnetic Pole](#) over the last 50 years. Watch how the isogonic lines converge at the Pole. View historic data back to 1590 with our [Map Viewer](#).

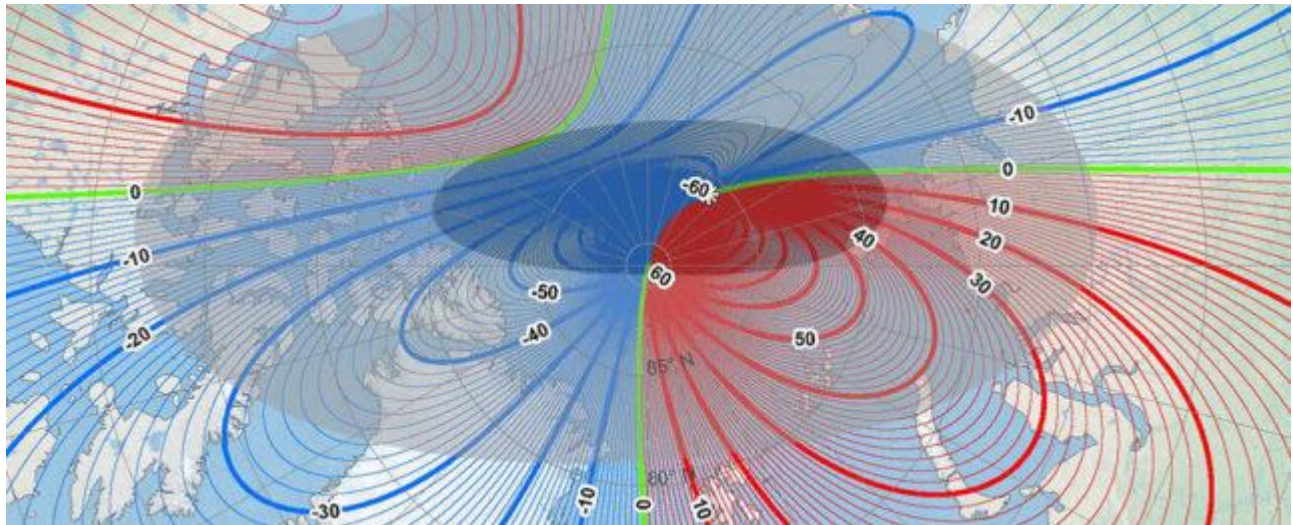
Plates and Polarity: Synchronicity

Earth’s magnetic field has been slowly changing throughout its existence. When the tectonic plates form along the oceanic ridges, the magnetic field that exists is “frozen” into the rock as they cool below about 700°C. The slowly moving plates act as a kind of tape recorder leaving information about the strength and direction of past magnetic fields. By sampling these rocks and using radiometric dating techniques, it has been possible to reconstruct the history of Earth's magnetic field for roughly the last 160 million years. If one “plays the tape backwards,” the record shows Earth’s magnetic field strengthening, weakening, and often changing polarity. Magnetic North and South Poles have even reversed or “flipped,” which is known as geomagnetic pole reversal.

Geomagnetic pole reversals have happened throughout Earth's history. The last one occurred 780,000 years ago. Though they sound scary, pole flips can take a long time to occur and pose no immediate threat. Scientists have determined that, in the short-term, there is no real change to Earth’s environment and no threat to life due to a pole flip.

The Magnetic North Pole Has Officially Changed Position

PHYSICS 20 December 2024

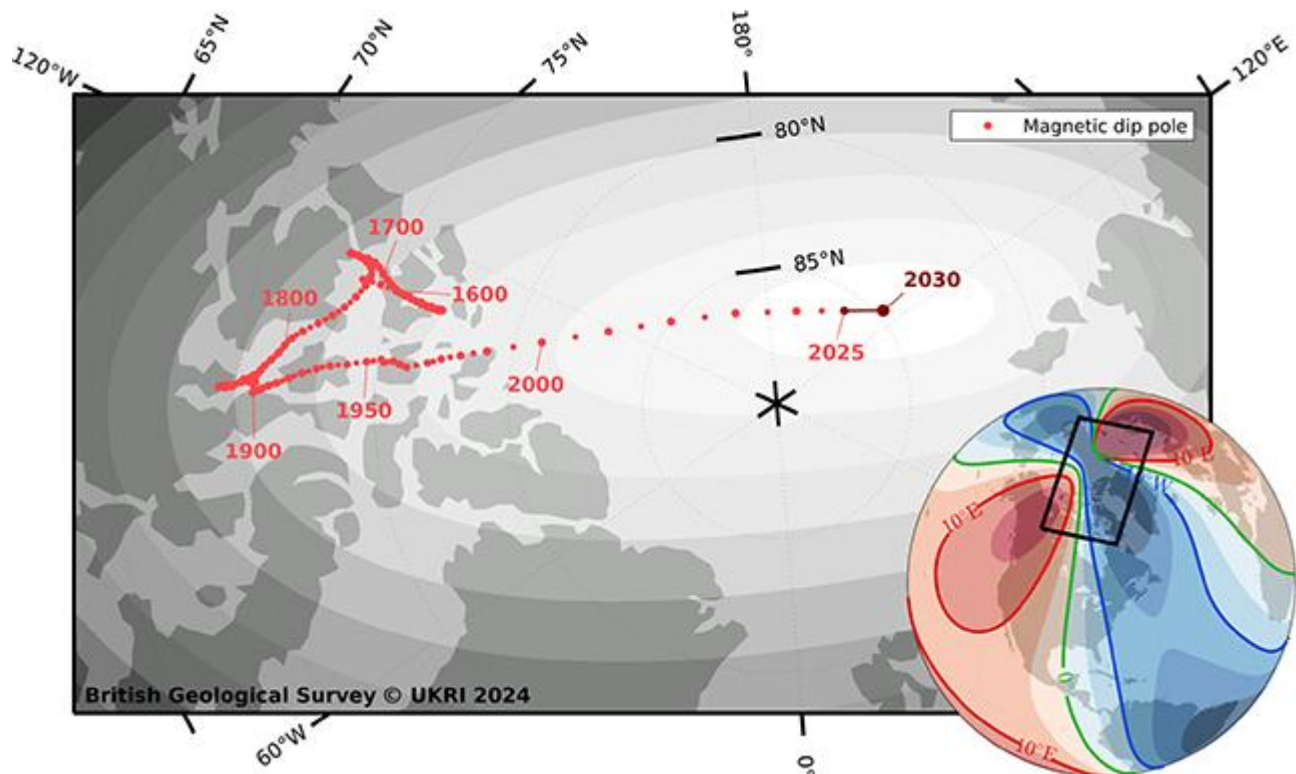


There's a new World Magnetic Model. ([NOAA/NCEI/BGS](#))

It's time to recalibrate the navigation systems on ships, airplanes, and (given the time of year) Santa's sleigh: the position of the [magnetic North Pole](#) is officially being changed, continuing its shift away from Canada and towards Siberia.

Experts from the US National Oceanic and Atmospheric Administration (NOAA) and the British Geological Survey (BGS) have joined forces – as they do every five years – to produce a new, more accurate [World Magnetic Model](#) (WMM).

While the geographical North Pole stays fixed in place (at the very summit of the Earth's rotational axis), the WMM pinpoints the magnetic North Pole – where Earth's magnetic field points straight down, a perfectly vertical magnetic field.



Magnetic north has shifted a lot over the centuries. (BGS)

And as the iron and nickel [inside our planet shift](#), so does Earth's magnetic field, meaning the North (and South) Poles are also constantly on the move. If you're using a compass or a GPS system, knowing exactly where these points are is crucial.

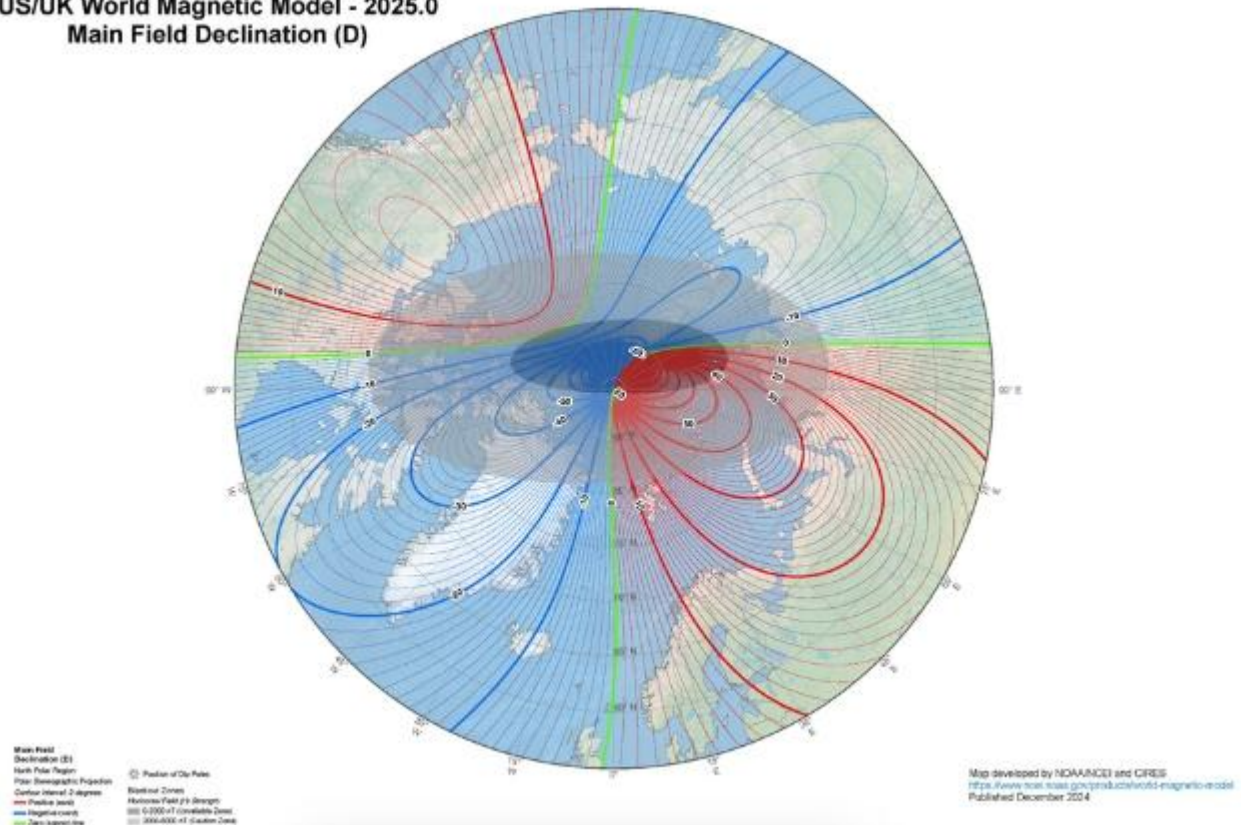
"The current behaviour of magnetic north is something that we have never observed before," [says](#) global geomagnetic field modeller William Brown, from BGS.

"Magnetic north has been moving slowly around Canada since the 1500s but, in the past 20 years, it accelerated towards Siberia, increasing in speed every year until about five years ago, when it suddenly decelerated from 50 to 35 kilometers [\[31 to 22 miles\]](#) per year, which is the biggest deceleration in speed we've ever seen."

[Research suggests](#) that two giant magnetic lobes – one under Canada and one under Siberia – are what's driving the shifting of magnetic north. Sometimes the shifts are dramatic enough that [an emergency update](#) is required, outside of the usual 5-year cycle.

Now we have a more accurate map of magnetic north, one that should be good for another half a decade. For the first time, a [higher resolution](#) map is also available, which offers more than 10 times more detail: it has a spatial resolution of about 300 km at the equator compared to the standard 3,300 km.

US/UK World Magnetic Model - 2025.0
Main Field Declination (D)



The 2025 World Magnetic Model. (NOAA/NCEI)

According to the BGS team, traveling 8,500 km (5,282 miles) from South Africa to the UK in a straight line would leave you 150 km (93 miles) off course by the end, if you used the old WMM compared to the new WMM for your navigation.

That's how much difference it can make, and mapping and logistics companies, together with governments and official agencies, will now be making updates.

However, we won't have to apply any updates to our own phones or sat navs – it'll all happen automatically.

The magnetic North Pole was first discovered by [Sir James Clark Ross](#) in northern Canada back in 1831.

Since then, researchers have gradually been able to track it with more precision, using ground measurements taken all across the globe as well as readings from [satellites in space](#).

Earth's Magnetic North Pole Just Officially Moved—and Scientists Just Updated Its Position



Earth's Magnetic North Pole Just Officially Moved—and Scientists Just Updated Its Position | The Daily Galaxy --Great Discoveries Channel© Daily Galaxy

The **magnetic north pole** is on the move, and its latest shift has significant implications for global **navigation systems**. Scientists have released an updated **World Magnetic Model (WMM)**, revealing that the pole is now closer to **Siberia** than it was five years ago and continues its drift toward **Russia**. This update is crucial for ensuring the accuracy of **GPS systems** used by planes, ships, and even smartphones. But why does magnetic north move, and what does this mean for our understanding of Earth's **magnetic field**?

Why Magnetic North Matters: The Science Behind the Drift

Unlike the **geographic North Pole**, which remains fixed, the magnetic north pole is determined by Earth's ever-shifting **magnetic field**. This field is generated by the churning of molten metals in Earth's **core**, creating a dynamic and unpredictable **magnetosphere**. Over the past few decades, the movement of magnetic north has been anything but steady.

- **Unprecedented Speed Changes:** In the 1990s, the pole's drift accelerated dramatically, reaching speeds of up to 34.2 miles (55 kilometers) per year. By 2015, it slowed to about 21.7 miles (35 kilometers) per year, a change that baffled scientists.

- **Impact on Navigation:** The **World Magnetic Model**, updated every five years, is essential for maintaining the accuracy of **GPS systems**. Without these updates, errors in navigation could accumulate, affecting everything from commercial flights to **military operations**.

Dr. Arnaud Chulliat, a senior research scientist at the University of Colorado, Boulder, explains, "The more you wait to update the model, the larger the error becomes. Our forecast is mostly an extrapolation given our current knowledge of the **Earth's magnetic field**."

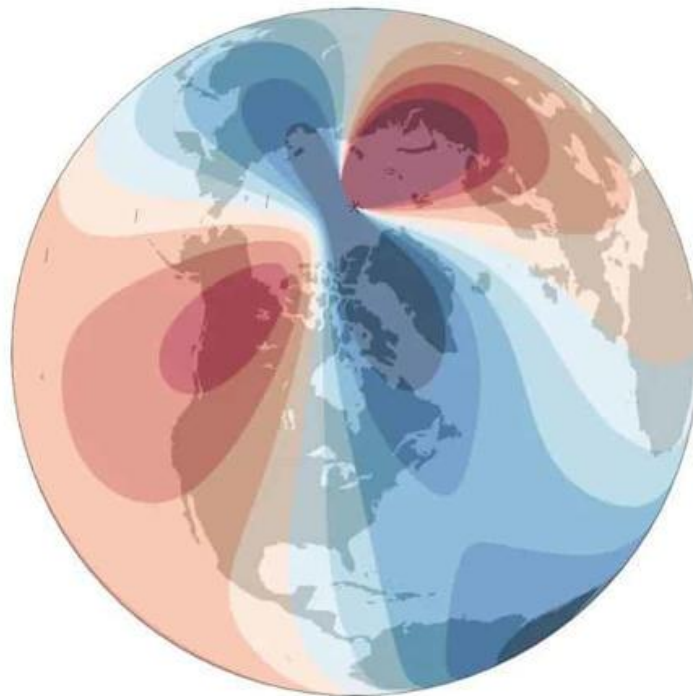
The New World Magnetic Model: What's Changed?

On December 17, scientists released two versions of the WMM: the standard model and a **high-resolution version**. While the high-resolution model offers greater precision, most consumer **GPS devices** rely on the standard model, which remains sufficient for everyday use.

- **Standard Model:** With a spatial resolution of approximately 2,051 miles (3,300 kilometers) at the equator, this version is widely used in commercial and **military navigation systems**.

- **High-Resolution Model:** Offering a resolution of about 186 miles (300 kilometers) at the equator, this version is more powerful but requires specialized hardware to utilize.

Dr. William Brown, a geophysicist with the **British Geological Survey**, notes, "Major airlines will upgrade the navigation software across their entire fleets of aircraft to load in the new model. But for most people, the switch isn't necessary."



This image shows magnetic declination, or the angle between magnetic and geographic north, according to the World Magnetic Model released in 2025. Red is magnetic north to the east of geographic north; blue is to the west. BGS/UKRI/Wessel, P./W. H. F. Smith© Daily Galaxy

Magnetic North vs. True North: A Tale of Two Poles

The **geographic North Pole**, or "**true north**," is a fixed point where all lines of longitude converge. In contrast, the magnetic north pole is the northernmost point of Earth's **magnetic field**, which is constantly in motion due to the convective activity in Earth's **core**.

- **Historical Drift:** Since its discovery in 1831 by British explorer Sir James Clark Ross, magnetic north has drifted from northern **Canada** toward Russia. By 2000, it had left Canadian shores entirely.
- **Impact on Technology:** A weakened magnetic field during a reversal could disrupt **radio communication**, scramble **navigation systems**, and endanger **satellites**.
- **Effects on Wildlife:** Migratory animals that rely on the magnetic field for navigation, such as **whales**, **butterflies**, and **sea turtles**, could face challenges during a reversal.

While life on Earth has survived multiple **magnetic reversals**, modern technology has never experienced one. "It would certainly be an interesting time for engineers to adapt our technology to," says Brown. "But hopefully, they'd have a slow, centuries-long buildup to prepare."

Earth's Magnetic North Pole: Unveiling Its Slowing Drift and Surprising Impacts on Technology

Earth's magnetic north pole is on the move—and in surprising ways. With the release of the World Magnetic Model 2025, scientists reveal new details about its unpredictable journey and why it has slowed down after decades of rapid acceleration. What drives these shifts deep within Earth, and how does it affect the technology we rely on every day?



Earth's North Magnetic Pole Officially Shifts© Provided by Ever-Growing

Unlike the geographic North Pole, which remains fixed at 90° latitude, the magnetic north pole is constantly on the move. First identified in 1831 on Canada's Boothia Peninsula, the pole has since traveled more than 1,400 miles toward Siberia. In the 1990s, its movement accelerated to an unprecedented 37 miles per year. Currently located at 86.5°N and 164.0°E, the pole's motion has recently slowed. This wandering behavior is driven by turbulent flows of molten iron in Earth's outer core. By studying these dynamics, scientists aim to unlock new insights into the inner workings of our planet.

Sharper Insights with the World Magnetic Model 2025

The World Magnetic Model (WMM) has long been the standard for mapping Earth's magnetic field, but the 2025 update offers a significant upgrade. Resolution has improved from 2,050 to 186 miles, enabling much more precise tracking of magnetic variations. This is especially critical for areas like the South Atlantic Anomaly, where the magnetic field is abnormally weak, exposing satellites to increased radiation. These improved data help protect satellites and mitigate the impact of magnetic disruptions on modern technology. Enhanced precision benefits navigation systems and even military operations, ensuring accuracy in critical scenarios.

Magnetic Precision Drives Modern Technology

Magnetic north plays a vital role in the functionality of everyday technology. From smartphone apps to autonomous vehicles, accurate magnetic data ensures seamless operation. Even GPS systems, often considered infallible, can be impacted by magnetic shifts, affecting air travel, shipping routes, and military missions. Errors in tracking magnetic north can result in significant consequences, from grounded planes to misrouted cargo. The WMM2025 ensures that technology remains reliable, minimizing costly disruptions.

Unraveling Earth's Core Mysteries

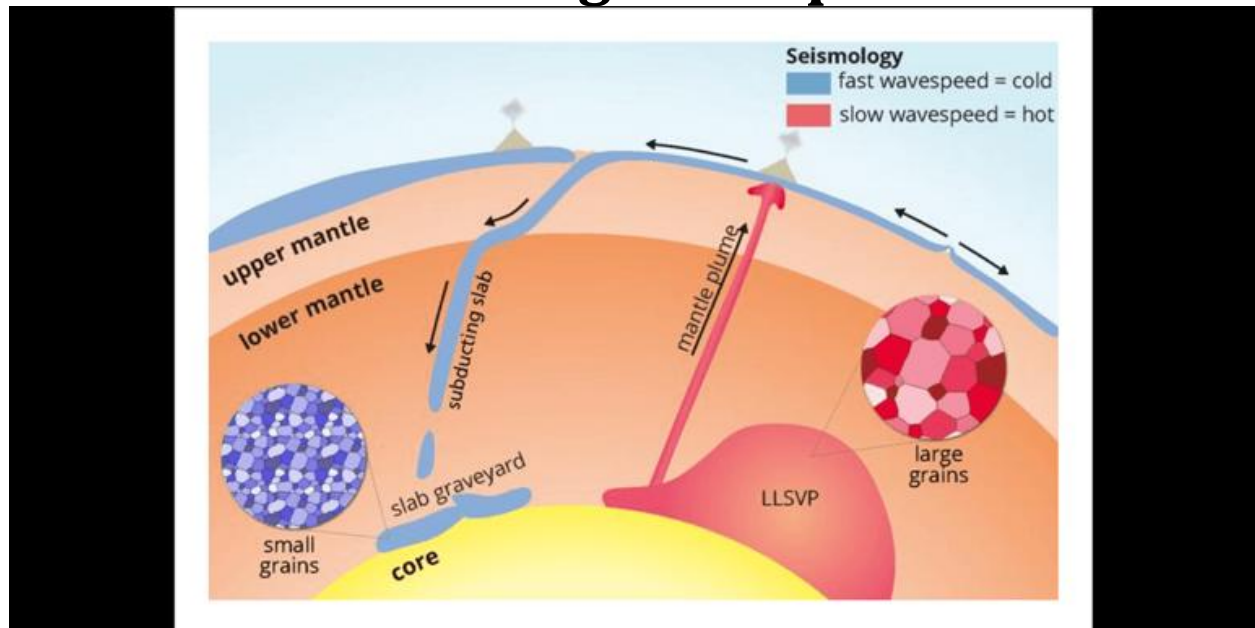
After decades of rapid movement, the magnetic pole has recently slowed to about 22 miles per year. Scientists link this change to Taylor columns—large, rotating fluid structures in Earth's outer core that influence magnetic dynamics. With the enhanced precision of WMM2025, researchers hope to decode these complex processes further.

Understanding these shifts is not just crucial for Earth—it offers a glimpse into planetary survival. Mars, for instance, lost its magnetic field billions of years ago, leaving its surface vulnerable to solar winds. Could Earth face a similar fate? The WMM2025 data provides critical insights into this pressing question.

How might these magnetic shifts reshape our understanding of Earth and other planets? Share your thoughts in the comments.

Based on content from www.dailygalaxy.com and own research.

Giant Ancient Hot Spot “Islands” Found In Earth’s Mantle Using Earthquake Data



Schematic of a Large Low Velocity Seismic Province and neighboring subduction zone, with the difference in response to earthquakes attributed to grain size. - Image Credit: Utrecht University© IFL Science

Earth’s mantle behaves like a slow-moving fluid, but that hasn’t stopped two vast regions at its base from maintaining a separation from the rest. These continent-sized areas are hotter than the rest of the mantle – and according to new research, have maintained that status for at least half a billion years. The same areas could be responsible for volcanoes that occur away from plate boundaries.

The knowledge that heat flows from a hot location to a cold one must surely go back hundreds of thousands of years. A scientifically rigorous description dates to Newton. Yet we continue to be surprised at the way regions of heat can maintain themselves relative to surrounding conditions.

In the 1990s, seismologists discovered two hot zones within Earth’s mantle: one under most of Africa, Spain, and part of the Atlantic; the other under the Pacific

Ocean. "Nobody knew what they are, and whether they are only a temporary phenomenon, or if they have been sitting there for millions or perhaps even billions of years," said study co-author Professor Arwen Deuss of Utrecht University in a [statement](#). The age was particularly significant – it's one thing for temporary warm areas to arise, such as when an area exposed to the Sun remains warmer than its neighbor as dusk sets in. If that heat difference is retained long-term, there is more explaining to do.

"These two large islands are surrounded by a graveyard of tectonic plates which have been transported there by a process called 'subduction', where one tectonic plate dives below another plate and sinks all the way from the Earth's surface down to a depth of almost three thousand kilometres," Deuss added.

The areas are known as [Large Low Seismic Velocity Provinces](#) (LLSVPs) because seismic waves slow down as they pass through, a product of vibrations produced by the higher temperatures interfering with transmission. They sit at the bottom of the mantle, where it meets the outer core.

Deuss and colleagues investigated the seismic interference LLSVPs provide. "Against our expectations, we found little damping in the LLSVPs," first author Dr Sujania Talavera-Soza said. Even though the LLSVPs change the frequency of the waves as they pass through, the authors found, they don't affect the volume much. This is in contrast to the surrounding cold slabs, which cause considerable damping. The results contrast with the upper mantle where, Talavera-Soza said; "We found exactly what we expected: it is hot, and the waves are damped."

The team explained the differences in transmission as a consequence of the grain size of particles within the LLSVPs, which Deuss said is "much more important" than temperature. "Subducting tectonic plates that end up in the slab graveyard consist of small grains because they recrystallize on their journey deep into the Earth. A small grain size means a larger number of grains and therefore also a larger number of boundaries between the grains." This leads to more damping than in the large-grained LLSVPs, as energy is lost every time a wave crosses the boundary between grains.

If the LLSVPs grains are so large, the authors concluded, these zones must be very old, since grains grow slowly – particularly in rigid blocks like the LLSVPs. Instead of being mixed in with the rest of the mantle as textbooks say, the LLSVPs remain aloof, holding onto their heat over hundreds of millions of years. Looking

at it the other way, a different chemical composition or variation in grain size would assist in maintaining long-term temperature differences.

Indeed, the LLSVPs may even be remnants of when the mantle first formed out of the [magma ocean](#) that once covered Earth. Nevertheless, the grains modeled for the LLSVPs are hardly giants, being around 1 millimeter (0.04 inches) across, which is still about ten times larger than the authors suspect for neighboring regions.

Large as the LLSVPs are, phenomena hundreds of kilometers beneath our feet mostly interests us when it affects the surface. The authors think they may be doing that, in the form of [mantle plumes](#), where bubbles of hot material rise to the surface to produce volcanic regions, [most famously Hawaii](#). "We think that those mantle plumes originate at the edges of the LLSVPs," Deuss said.

Although earthquakes are common, only a few are large and deep enough to make the whole planet shake and provide the clarity needed to resolve the effects of LLSVPs, surrounding slab graveyards, and upper mantle behavior. However, with a database stretching back to 1975, the authors say that enough have been observed to interpret with confidence.

Coincidentally, the work is published soon after the first evidence for a similar sustained difference in temperature in the Martian mantle, which may have [caused the difference](#) in altitude between the red planet's hemispheres.

The study is published in the journal [Nature](#).

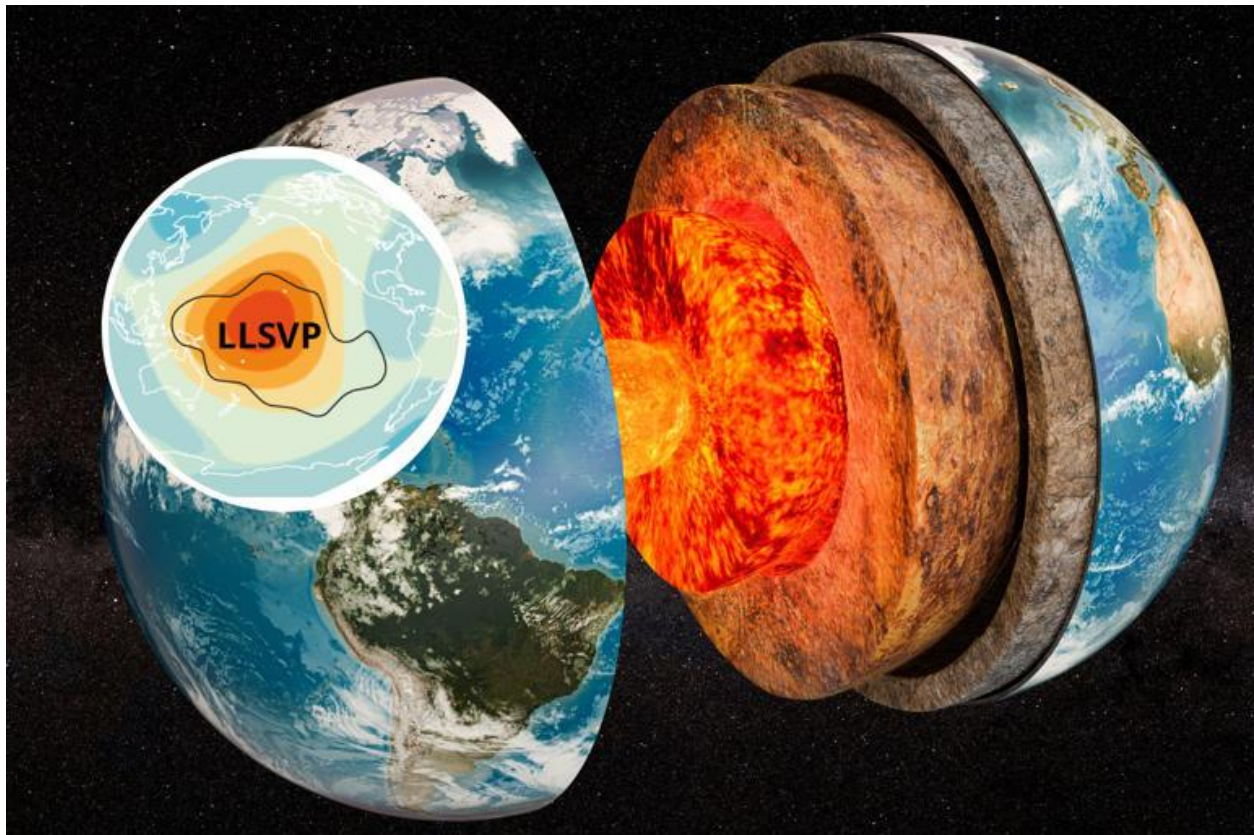
Mysterious 'Supercontinents' Inside Earth Challenge Mantle Theory

Two enormous continent-sized "islands" found buried deep inside the Earth's mantle are challenging our ideas about our planet's inner workings.

These unexpected regions of the Earth's innards appear to be hotter and older than other structures nearby that are known to be sunken tectonic plates, possibly being around 500 million years old, according to a new paper in the journal *Nature*.

This indicates that the Earth's mantle might not work the way we think it does, and may be less fast-flowing or well-mixed than anticipated.

These ancient buried "super-continents"—known to scientists as large low-seismic-velocity provinces (LLSVPs)—were found lurking below Africa and the Pacific Ocean, entombed some 1,200 miles below the surface of the Earth.



Stock image of the interior of our planet (main) and location of one of the LLSVPs (inset). ISTOCK / GETTY IMAGES PLUS / Utrecht University© ISTOCK / GETTY IMAGES PLUS / Utrecht University

They were discovered after geophysicists analyzed the waves of earthquakes traveling through these regions of the Earth. As ultrasound can reveal structures deep within our bodies, so can measuring subtle changes to the speed and direction of seismic waves reveals what lies deep beneath our feet.

"Nobody knew what they are, and whether they are only a temporary phenomenon, or if they have been sitting there for millions or perhaps even billions of years," study co-author and seismologist professor Arwen Deuss of Utrecht University in the Netherlands said in a statement.

"These two large islands are surrounded by a graveyard of tectonic plates which have been transported there by a process called 'subduction', where one tectonic plate dives below another plate and sinks all the way from the Earth's surface down to a depth of almost three thousand kilometers."

Plate subduction is a geological process where one tectonic plate moves beneath another as they converge. This typically occurs at plate boundaries, where two

plates collide, with the denser plate—typically an oceanic plate—being forced downward into the mantle beneath the less dense plate.

According to the new research, these sunken supercontinents appear to be different from the surrounding remains of subducted crust, as they are much hotter.

"We have known for years that these islands are located at the boundary between the Earth's core and mantle. And we see that seismic waves slow down there," Deuss said.

"The waves slow down because the LLSVPs are hot, just like you can't run as fast in hot weather as you can when it's colder."

However, the hot temperature of the LLSVPs cannot fully explain the properties of the seismic waves they were hearing emanating from these regions deep within the Earth.

The researchers suggest that the buried supercontinent regions must also be made of much larger mineral grains than the buried subducted crust, which would explain the difference in the waves they observed.

"Subducting tectonic plates that end up in the slab graveyard consist of small grains because they recrystallize on their journey deep into the Earth. A small grain size means a larger number of grains and therefore also a larger number of boundaries between the grains," Deuss explained.

"Due to the large number of grain boundaries between the grains in the slab graveyard, we find more damping, because waves lose energy at each boundary they cross. The fact that the LLSVPs show very little damping, means that they must consist of much larger grains."

Just like mineral structures on Earth's surface, like crystals or stalactites, larger mineral grains within the Earth take a lot longer to grow. This therefore indicates that the LLSVPs are much older than the sunken tectonic plates surrounding them.

These larger grains and subsequent older structures also imply that they are not involved in the convection or flow of the mantle, meaning that the mantle may not be as well-mixed as we first thought.

This discovery is hoped to help geophysicists better understand how volcanoes around the world evolve.

"And also to understand other phenomena at the Earth's surface, such as volcanism and mountain building," Deuss said.

"The Earth's mantle is the engine that drives all these phenomena. Take, for example, mantle plumes, which are large bubbles of hot material that rise from the Earth's deep interior as in a lava lamp."

When these plumes reach the surface, they result in volcanoes forming, spewing forth lava like they recently [have in Hawaii](#) and in [Iceland](#).

"We think that those mantle plumes originate at the edges of the LLSVPs."

Do you have a tip on a science story that *Newsweek* should be covering? Do you have a question about geophysics? Let us know via science@newsweek.com.

Reference

Talavera-Soza, S., Cobden, L., Faul, U. H., & Deuss, A. (2025). Global 3D model of mantle attenuation using seismic normal modes. *Nature*. <https://doi.org/10.1038/s41586-024-08322-y>

Planet Earth's Core May Be "Leaking" Iron



Illustration of Earth's core structure: the outer crust, the rocky mantle, the liquid outer core, and the solid inner core. -
Image credit: Vadim Sadovski/Shutterstock.com© IFL Science

Think Earth is just a static rock? Dive deep, and you'll find a dynamic world where metals leak, water seeps, and its insides churn.

Inside the belly of planet Earth, a giant solid ball of metal is surrounded by a swooshing layer of liquid iron and nickel, making up the two innermost stages of Earth's geological layers. These furiously hot metals might not always stay put, though.

A study, published in the journal [Nature Geoscience](#) in 2020, suggested that iron isotopes might migrate into the rocky mantle, the next geological layer of Earth that starts at around 2,900 kilometers (1,800 miles) below Earth's surface.

It's extremely tricky to get [samples of Earth's deep mantle](#) simply because of its extreme depth. So, instead, the scientists reached their findings by carrying out experiments and geodynamic modeling that showed how iron alloy liquids react under extremely high temperatures of 2,000°C (3,632°F) and intense pressure, much like the conditions of Earth's interior.

The experiments demonstrated how iron isotopes migrate based on temperature gradients, with heavier isotopes migrating towards cooler regions. This effect, they said, is likely to cause metallic core material to infiltrate parts of the lowermost mantle.

"If true, the results suggest iron from the core has been leaking into the mantle for billions of years," Charles Lesher, lead author of the 2020 study and professor emeritus of geology at UC Davis and professor of earth system petrology at Aarhus University in Denmark, said in a [statement](#).

This isn't the only part of the Earth's interior that's surprisingly dynamic. Just as material is likely to move from the core outwards, other materials are heading from the surface into the lower depths.

Other scientists have suggested that [water from the Earth's surface](#) is being driven into the rocky mantle due to tectonic plate shifts.

A [2014 study](#) suggested that the mantle transition zone, around 410 to 660 kilometers (255 to 410 miles) deep, contains a girthy layer that's dense in ringwoodite. This vibrant blue mineral contains water, but not in the form of a liquid, gas (like vapor), or solid (like ice). Instead, it incorporates water in another molecular form within its crystal structure.

Nevertheless, ringwoodite does indicate the presence of a [lot of water down there](#). The researchers estimated that if just 1 percent of rock in the mantle transition zone is HO, that would be equivalent to nearly three times the amount of water in our oceans. In other words, most of the water on Earth might be inside its mantle, trapped within the crystal structure of ringwoodite.

All of these insights point to a greater truth about our planet. Viewed from the surface – or even [from space](#) – Earth can seem like a giant, unchanging monolith. But when you step back or look deeper, you realize this old rock is actually [an ever-changing blob](#), constantly shifting in a state of flux.

NASA Spots Giant California Lava Flows From Space

The [NASA Earth Observatory](#) has unveiled a new image of the Sáttítla Highlands in Northern California, showcasing the region's volcanic history and its impressive ancient lava flows.

Captured on October 7, 2024, by the Operational Land Imager (OLI) aboard Landsat 8, the photograph includes the bare lava fields and volcanic formations that form part of the newly designated Sáttítla Highlands National Monument.

At the heart of this landscape lies the Medicine Lake Volcano, a massive dormant shield [volcano](#) whose past activity shaped much of the region's terrain and may do so again within our lifetime.



Satellite image shows lava flows of the Sáttítla Highlands. This newly designated national monument has a rich volcanic history and could wake up in the not-so-distant future. Wanmei Liang/NASA Earth Observatory© Wanmei Liang/NASA Earth Observatory

Why This Matters

On 7 January, the Biden administration announced it was establishing two new national monuments—Chuckwalla and the Sáttítla Highlands—both of which are in California.

The designations were designed to protect the "scientific, cultural, ecological and historical importance" of the areas, the administration said in a statement.

Spanning over 224,000 acres, the Sáttítla Highlands include portions of the ancestral homelands of Indigenous tribes such as the Modoc and Pit River peoples.

This latest image provides an impressive view of the newly protected area, with several large lava flows visible.

What to Know

The Medicine Lake Volcano, one of the two largest in the Cascades Volcanic Arc, has erupted nine times in the past 5,000 years. Some eruptions began explosively, spewing ash across vast distances before transitioning to slow lava flows.

One of the most iconic features, the Glass Mountain flow, is a 5.4-square-mile lava deposit formed approximately 1,000 years ago.

These geological wonders, visible in the satellite image, reveal the region's fiery history and ongoing potential for volcanic activity, monitored closely by the California Volcano Observatory.

Though the volcano is considered dormant, the U.S. Geological Survey categorizes it as a "high threat volcano" that could erupt in human lifetimes.

The new Sáttítla Highlands National Monument encompasses volcanic terrain, including cinder cones—steep, conical hills made of solidified lava—and lava tubes—tunnels created by ancient lava flows.

These features contribute to the area's striking appearance and serve as important habitats for rare species like the northern spotted owl and Cascades frog.

Additionally, the porous volcanic rock plays a critical role in recharging aquifers that supply water to Northern California.



Aerial view west across the upper part of Medicine Lake Volcano. Glass Mountain flow, draped over the east side of the volcano, is the youngest lava flow at the volcano. USGS© USGS

Why Was the Sáttítla Highlands Designated as a National Monument?

The Sáttítla Highlands hold deep cultural and spiritual significance for Indigenous communities, reflected in the name "Sáttítla," meaning "obsidian place" in the Ajumawi language. Obsidian is a black volcanic glass; deposits found here were historically used by Indigenous peoples to craft tools.

Over 80 plant species in the area have traditional uses in medicine, food and rituals.

Beyond its cultural importance, the region's unique biodiversity and geology make it a treasure trove for scientific research. The highlands are home to rare

flora and fauna, many of which depend on old-growth conifers or volcanic habitats.

The national monument designation aims to preserve these resources for future generations. It will be managed by the Department of Agriculture's U.S. Forest Service.

During his tenure, Biden created a total of 10 national monuments and enlarged several more.

What Are People Saying

In its announcement on 7 January, the White House said: "At the new monument's core sits the Medicine Lake Volcano, a massive dormant volcano covering an expanse roughly 10 times that of Mount St. Helens in Washington.

"The protection of the Sáttítla Highlands conserves a diverse array of natural and scientific resources, ensuring that the cultural, historical, and scientific values of this area, shaped by its volcano, endure for the benefit of all Americans."

Scientists Uncover Mysterious Underground Supercontinent That May Be as Old as Earth Itself



Scientists Uncover Mysterious Underground Supercontinent That May Be as Old as Earth Itself | The Daily Galaxy -- Great Discoveries Channel© Daily Galaxy

Deep beneath Earth's surface, two massive structures—dubbed **low-shear velocity provinces (LLSVPs)**—are reshaping scientists' understanding of the planet's history. Located beneath Africa and the Pacific Ocean, these colossal "supercontinents" of rock and mineral are buried thousands of miles below the Earth's crust, deep within the mantle. While their precise origins and purpose remain enigmatic, new research suggests they may be as old as the Earth itself, providing a stunning glimpse into the planet's ancient past.

According to seismologist **Arwen Deuss** of Utrecht University in the Netherlands, understanding these structures requires listening to the Earth's internal vibrations. "When there is a big earthquake, the whole Earth will expand and contract like a bell," Deuss explained in an interview with *New Scientist*. "Earth becomes a musical instrument."

This “music” offers a rare opportunity for scientists to analyze the composition of the LLSVPs, which appear to slow down sound waves as they travel through the mantle. These signals, generated by earthquakes, allow researchers to peer deep into the Earth’s core, where the LLSVPs sit like ancient islands surrounded by a “graveyard” of tectonic plates.

A Graveyard of Subducted Plates

The immense **LLSVPs** are not isolated. Instead, they are encased in layers of subducted tectonic plates—fragments of Earth’s crust that have been transported down into the mantle over millions of years. Deuss describes the surrounding region as a “**slab graveyard**,” a result of subduction, the geological process where one tectonic plate dives beneath another and is pulled toward the Earth’s core.

“These two large islands are surrounded by a graveyard of tectonic plates which have been transported there by a process called ‘subduction,’” **Deuss said**. “One tectonic plate dives below another plate and sinks all the way from the Earth’s surface down to a depth of almost three thousand kilometers,” or about 1,900 miles.

This surrounding layer of fragmented plates provides context for the LLSVPs’ surprising characteristics. While these structures are known to be extremely hot, the sound waves passing through them retain their energy, unlike waves traveling through the surrounding subducted plates. Scientists initially believed the heat of the **LLSVPs** would “dampen” sound waves and cause them to lose energy, but the opposite is true.

Ancient Crystals and Earth’s Deep History

The key to understanding the **LLSVPs** may lie in their grain size. According to **Deuss and her team**, these massive structures are likely composed of larger, less numerous mineral grains. “Grain size” refers to the size of the crystals making up the rock. The larger the grains, the fewer the boundaries between them. It is these boundaries that normally absorb energy and dampen sound waves.

Because the **LLSVPs** have fewer grain boundaries, they allow sound waves to travel through them without significant loss of energy.

This grain size discovery also reveals clues about the LLSVPs' age. Crystals take vast amounts of time to grow to such enormous sizes, meaning the structures are far older than the surrounding subducted plates. "Nobody knew what they are, and whether they are only a temporary phenomenon, or if they have been sitting there for millions or perhaps even billions of years," Deuss said.

The new findings suggest that these mysterious superstructures could be among the oldest features on Earth, possibly dating back to the planet's early formation. If true, they represent a rare and tangible connection to Earth's primordial history.

Earth as a Musical Instrument

One of the most fascinating aspects of this discovery is how scientists are able to study these structures—by listening to the "music" of the Earth. Earthquakes send sound waves rippling through the planet, and these waves behave differently depending on the materials they pass through. By analyzing these **seismic vibrations**, scientists can determine the density, composition, and even temperature of materials buried deep within the mantle.

"Earth becomes a musical instrument," **Deuss explained**. The seismic "notes" produced by the planet offer valuable insights into its inner workings, much like the resonance of a bell reveals its quality and structure.

This innovative approach has allowed researchers to uncover the unique properties of the LLSVPs, which continue to defy conventional geological understanding.

A Glimpse Into the Deep Past

The two massive **LLSVPs** beneath [Africa](#) and the Pacific Ocean stand as silent witnesses to Earth's ancient history. Encased in a graveyard of tectonic plates and composed of grains that have taken eons to grow, these structures may hold the answers to questions about the planet's early formation and evolution.

Through innovative seismic techniques, scientists are beginning to unravel the mysteries of these “**supercontinents**” deep within the Earth. As research continues, the LLSVPs may offer a rare glimpse into the dynamic processes that have shaped our planet from its earliest days to the present.

Mystery structures discovered deep inside the Earth leaving scientists baffled

[Scientists](#) have discovered structures that scatter seismic waves deep inside the mantle of [Planet Earth](#) everywhere and it is leaving them baffled.

Research suggests our planet's mantle, which is the layer sandwiched between the core and crust, is filled with zones that slow down seismic waves which are caused by [earthquakes](#).

It was already known that ultra-low velocity zones (ULVZs) are near hotspots, which are regions of mantle where hot rock moves up forming volcanic islands, but new mysterious earthquake waves suggest this might be more widespread than initially thought.

[Speaking to LiveScience](#), Michael Thorne, a geologist and geophysicist at the University of Utah, said: "Here's one of the most extreme features that we see anywhere inside the planet and we don't know what they are, where they're coming from, what they're made of, [or] what role they play inside the Earth.

"There are a lot of open questions we don't have answers to yet."



Mystery structures discovered deep inside the Earth are causing waves which is leaving scientists baffled / (Rost-9D, iStock)

This all came to light when researchers were working on a different study.

Scientists were looking to examine how PKP waves caused by very large earthquakes could travel through the middle of Earth to the other side of the core through the mantle, the liquid outer core, and then the mantle again.

Another strange type of wave, called precursor PKP waves, can sometimes come before PKP waves and scientists were researching features of these.

Findings from this study suggested something was dramatically slowing the earthquake waves to scatter energy.

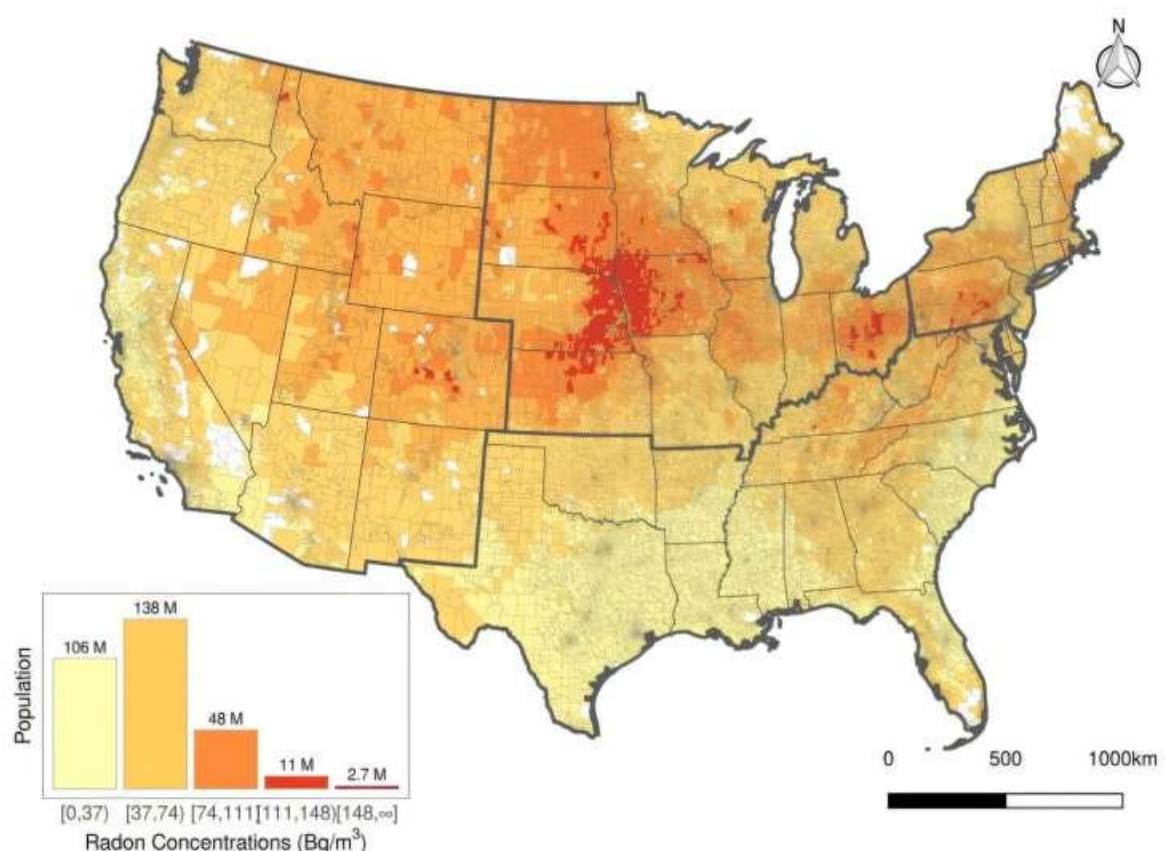
A large ULVZ was found in the area studied by the team of scientists under the western Pacific; the team also found signs of a number ULVZs when looking elsewhere under North America, North Africa, East Asia, Papua New Guinea and the Pacific Northwest.

Thorne said this suggests they're being actively generated.

While this will likely be researched further, better understanding is reported as having the potential to improve geologists' grasp of volcanic hotspots as well as how the mantle moves.

JANUARY 21, 2025 [REPORT](#)

Improved radon gas mapping finds nearly 25% of Americans living in highest risk areas



Average predicted community-level radon concentrations at screening floor across contiguous United States during 2001 to 2021. Credit: *Proceedings of the National Academy of Sciences* (2025). DOI: 10.1073/pnas.2408084121

Researchers from Harvard T.H. Chan School of Public Health have assembled a national database with millions of multi-day indoor radon measurements from 2001 to 2021. Findings reveal that nearly 25% of the U.S. population may be exposed to radon concentrations exceeding 148 Bq/m³, a level associated with cancer risks.

Radioactive radon gas emerges from natural radioactive decay processes in underground uranium. Uranium-238 decays and eventually generates radon gas, which can migrate upwards, working its way into buildings.

Radon gas pollution is the second leading cause of lung cancer in the United States, claiming an estimated 21,000 lives per year (220,000 globally), with exposure linked to multiple other risks such as breast cancer, stroke and stomach cancer.

The US Environmental Protection Agency (EPA) recommends installing a radon mitigation system when the concentration in living space reaches or exceeds 148 Bq/ m³. Efforts to map radon levels to identify where communities are at most risk and require interventions have historically provided county-wide averages based on very little data.

Public health agencies have been recommending improvements in radon mapping because population growth, climate change, housing construction practices, and mitigation efforts have shifted the pattern of radon risk over time.

Regulations adopted in 35 states have mandated radon measurement and disclosure during property transactions, with tens of millions being recorded in the last few decades. The accumulated data provides an opportunity for revisiting the distribution of radon risk around the country.

In the study, "High-resolution national radon maps based on massive indoor measurements in the United States," [published](#) in the *Proceedings of the National Academy of Sciences*, researchers compiled a [national database](#) with millions of radon measurement data points from 2001 to 2021, and used predictive modeling to map radon exposures across communities in the lower 48 states.

Approximately 4.48 million radon measurements, along with 186 radon-related contributing factors, were used to train a random forest algorithm to extrapolate zip-code-based community risk.

The predictive contributing factors associated with the measurements included geological parameters (uranium concentration in bedrock, soil composition), meteorological conditions (temperature, [soil moisture](#), barometric pressure), socioeconomic indicators (median household income), and a key architectural feature regarding the size and age of homes and if the location has a basement.

This extensive set of predictors was essential for capturing the diverse influences on radon levels across different communities and environments as they correlate with exposure.

Validation methods confirmed that the random forest model effectively captured the variations in [radon concentrations](#) driven by the 186 contributing factors with a mean absolute error of 22.6 Bq/m³ for zip code-level observations.

Once validated, the trained model was utilized to extrapolate radon concentration estimates for zip-codes lacking any direct measurements by leveraging the known predictor values in those areas.

Average radon concentration across the contiguous United States was estimated at 53.3 Bq/m³, slightly higher than the EPA's estimate of 48.1 Bq/m³. Regional variations were much more significant. Five radon zones were established based on predicted average concentrations.

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Zone 1 (below 37 Bq/m³) includes the entire central valley of California, stretching up to the Pacific Northwest of the state, most of Texas, almost all of Louisiana and Mississippi, southern Arkansas, and the south half of the Eastern Seaboard. Louisiana and Texas had the lowest state averages, at 24.7 Bq/m³ and 29.7 Bq/m³

Zone 2 (37–74 Bq/m³) cuts across the country, keeping just south of Colorado and Kansas, as it crosses Oklahoma, northern Texas, New Mexico and Arizona, circling the Central Valley of California and covering the Pacific Northwest from Oregon to Washington.

Zone 3 (74–111 Bq/m³) dominates most of Colorado's land area (but not the population centers) along with Utah, northern Nevada, up through Idaho, Montana, Wyoming, then western Pennsylvania, North Carolina, New York, New Jersey, and parts of Maryland

Zone 4 (111–148 Bq/m³) concentrates around some areas of Colorado and a large swath of territory running down from Canada into Wisconsin, parts of Illinois, parts of Iowa, and portions of Ohio.

Zone 5 (above 148 Bq/m³) covers much of South Dakota, North Dakota, Nebraska, parts of Iowa, eastern Pennsylvania and central Ohio. South Dakota had the highest population-weighted average radon concentration at 128.3 Bq/m³, followed by Nebraska (119.2 Bq/m³). Areas around the city of Newark in Ohio had the highest predicted average radon concentration in the nation at 246 Bq/m³.

On average, about 3.7 million people reside in Zone 5 year-round. Much of the average Zone 4 territory becomes Zone 5 during winter, putting the seasonal peak at nearly 10 million. One contributing factor to the seasonality is reduced ventilation while heating homes for winter, trapping and concentrating radon gas in basements and recirculated air.

Even within low-radon zones, certain homes or communities may experience higher radon concentrations depending on several factors that contribute to radon gas contact and emissions.

The primary driver of radon prevalence was uranium content in soil. High uranium geological basements (shales, granites, glacial deposits) correlated with high radon zones.

High-permeability soils, such as sandy or gravelly soils, allow radon gas to migrate upward more easily and into homes. If there is shallow bedrock, rainwater can pull the soluble uranium isotopes down to the bedrock, where it concentrates and then begins the journey up again as radon gas.

Much of the low radon map overlays well with traditional flood zones, in part because basements are rare in these areas, and homes are often built on raised foundations, allowing for additional ventilation.

Colder regions where basements are common tend to have higher radon levels as foundation (and basement wall) imperfections are prime points of entry for the gas. Radon infiltrates and then accumulates in the poorly ventilated basement spaces, often exceeding aboveground levels by a broad margin.

The study found that 83.8 million people, or 26.8% of the population, live in homes where radon concentrations can exceed 148 Bq/m³. Surprisingly, most of these residences are located in otherwise low-radon regions (Zones 1 and 2), highlighting the need for comprehensive testing nationwide.

Zone 2 alone accounts for 33.4 million residents exposed to high radon levels, with another 20 million in Zone 3. These scattered hot spots have a big impact on the number of people affected as they are in higher-density residential areas that have overlapping contributing factors.

Slight overall decreases in [radon gas](#) were observed in some previously high-radon zones, possibly reflecting stronger mitigation practices, radon awareness and evolving building codes.

The new model could be used to design community-specific building codes or increase homeowner mitigation efforts to prevent radon entry. It could also be used to assess residential exposure to radon in population health studies aimed at improving understanding of radon's health effects.

More information: Longxiang Li et al, High-resolution national radon maps based on massive indoor measurements in the United States, *Proceedings of the National Academy of Sciences* (2025). DOI: [10.1073/pnas.2408084121](https://doi.org/10.1073/pnas.2408084121)

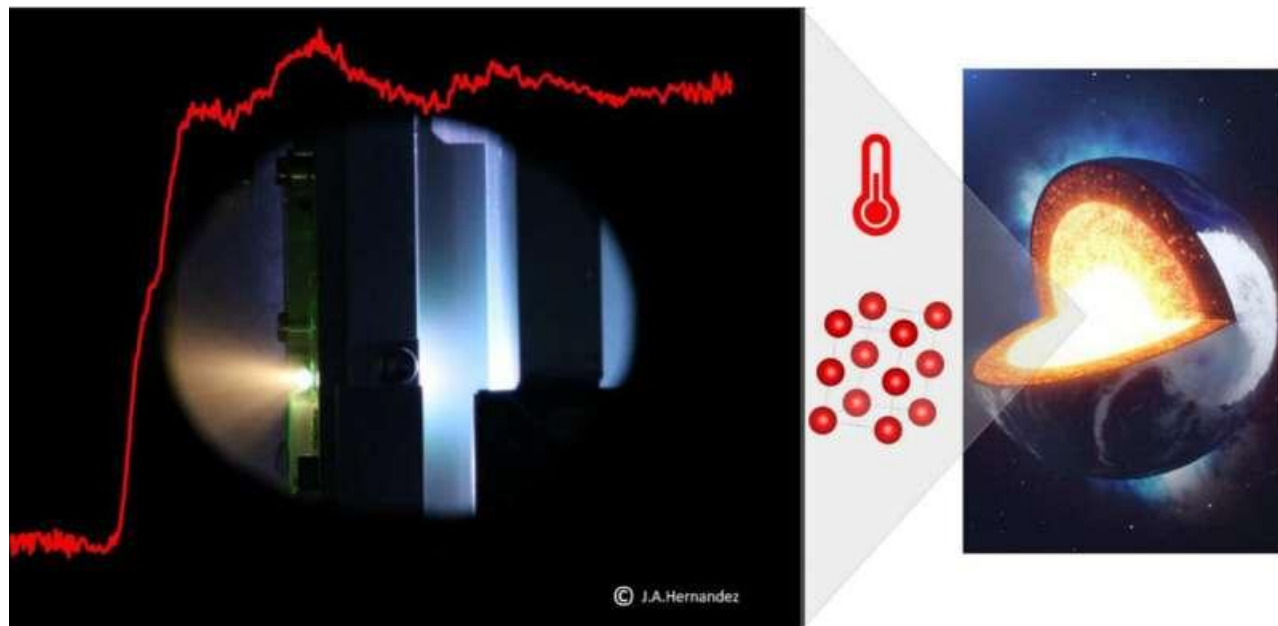
Journal information: [Proceedings of the National Academy of Sciences](#)

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JANUARY 21, 2025 **FEATURE**

Melting temperature and phase stability of iron under core-like conditions shed light on Earth's geodynamics

by Ingrid Fadelli , Phys.org



A laser-driven shock event in iron at the High Power Laser Facility (HPLF), where X-ray absorption spectroscopy (XAS) was used to determine the melting temperature and microscopic structure of iron at pressures relevant to Earth science. Credit: Jean-Alexis Hernandez, European Synchrotron Radiation Facility.

Iron is one of the main elements found in the Earth's inner core, which is characterized by extremely high temperatures and pressures. Determining how iron behaves in these extreme conditions could thus help to advance the current understanding of our home planet's structure and geodynamics.

Researchers at the European Synchrotron Radiation Facility in Grenoble, the Polytechnic Institute of Paris and other institutes worldwide carried out a study examining the [melting temperature](#) and phase stability of shock-compressed iron at high temperatures and pressures using ultrafast X-ray absorption spectroscopy.

Their findings, [published](#) in *Physical Review Letters*, shed new light on the melting curve and structural phase of iron under extreme conditions.

"The goal of this study was to explore the microscopic behavior of iron under extreme pressure and temperature conditions, up to the multi-Mbar and thousands of Kelvin ranges,

using ultrafast synchrotron X-ray absorption spectroscopy," Sofia Balugani, first author of the paper, told Phys.org.

"This research is crucial for understanding the properties of the Earth's core, which is primarily composed of iron with small amounts of lighter elements."

As iron is the primary component of the Earth's core, its properties (e.g., its melting temperature at the pressures found in the proximity of the Earth's inner core boundary) set an upper limit for the melting temperature at this specific boundary, which separates the inner and outer core.

Determining the melting temperature at this pressure can in turn aid the study of geodynamics, offering insight into the process via which the outer core, which is liquid, crystallizes to form the solid inner core.

"There is also significant debate regarding the structural phase of iron under these extreme conditions," Balugani said.

"We set [out] to gather both structural and electronic data of iron at these conditions. The team is still working on interpreting the electronic structure information of iron under these extreme conditions, as this area of research is entirely new."

Balugani and her colleagues carried out their experiment at the European Synchrotron Radiation Facility in France, specifically within its new High-Power Laser Facility. This research site hosts various advanced technologies, combining high-power lasers with an energy above 40J with an energy-dispersive ID24-ED beamline, optimized for ultra-fast (≈ 100 ps) X-ray absorption spectroscopy.

"The high-power laser is focused onto a multi-layered target, ablating the first layer (typically a polymer) to create a hot plasma," explained Balugani.

"This plasma expands and generates a shock wave, propagating at supersonic speeds through the iron sample. The shock wave induces [extreme pressure](#) and temperature conditions in the iron. Simultaneously, the X-rays are synchronized to capture the XAS spectrum of iron at the moment the shock wave exits the sample corresponding to the peak pressure and temperature in iron."

The ultra-fast (≈ 100 ps) X-ray absorption spectroscopy measurements collected by the researchers yielded detailed information about the structural phase of iron at extremely high pressures and temperatures.

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In addition to measuring the bulk temperature of iron near its melting curve at 240 GPa, the researchers were able to determine the structural changes that this element undergoes in conditions that mirror those found in the Earth's core.

"Temperature is a particularly difficult parameter to measure in both shock and static compression experiments," said Balugani.

"In shock compression, the thermal self-emission from the heated sample is typically captured and fitted to the Planck black body model to estimate the temperature. However, this method has limitations, particularly for opaque samples like metals, where only the surface temperature can be measured."

Notably, shock compression measurements collected using conventional approaches are also only reliable above 3,000 K. In contrast, the methods used by the researchers allowed them to measure the phase diagram of iron under conditions mimicking those at the depths of the Earth, which they could then use to extrapolate its melting temperature at the inner core boundary, where the pressure is known to be 330 GPa.

"I believe this work has paved the way for a new method to determine reliable bulk temperatures of metals using XAS, which could be applied to experimentally constrain the melting curves of various metals," said Balugani.

"Additionally, we determined that the phase of pure iron at 240 GPa and 5,345 K, just before melting, is hexagonal close-packed (hcp), rather than the body-centered cubic (bcc) structure predicted by many theoretical studies."

This study by Balugani and her colleagues could have important implications for the future study of the Earth's geodynamics. The measurements collected by the researchers could ultimately advance the understanding of our planet's inner structure and its thermal history.

"Seismological data has observed shear softening under Earth's core conditions, which has been attributed to the bcc (body-centered cubic) phase of pure iron by some [theoretical studies](#)," said Balugani. "In our study, we ruled out the bcc phase of iron at 240 GPa and 5,345 K, near the melting curve."

The researchers' findings set new constraints on the melting curve of iron under extreme conditions, disproving some earlier theoretical predictions.

Nonetheless, their measurements do not exclude the possibility that a phase other than the bcc phase may become more favorable when iron is alloyed with lighter elements, both in the Earth's core or in other pressure-temperature regions of the iron phase diagram.

"It would now be fascinating to explore iron alloys under these [extreme conditions](#) and conduct similar experiments," added Balugani.

"There is already significant progress being made in this area, and hopefully, we will soon gain a better understanding of the Earth's core. With technologic advancements in high-power laser facilities, it will also be possible to explore even more extreme regions of the iron and iron alloys phase diagram."

By examining iron and iron alloys at even more extreme temperatures and pressures, the researchers could better understand the structure of telluric exoplanets (e.g., super-Earths).

In addition, their future works could contribute to nuclear fusion research, for which [iron](#) plays a key role, as it is the main component of the stainless steel used to conduct inertial confinement fusion studies.

More information: S. Balugani et al, New Constraints on the Melting Temperature and Phase Stability of Shocked Iron up to 270 GPa Probed by Ultrafast X-Ray Absorption Spectroscopy, *Physical Review Letters* (2024). DOI: [10.1103/PhysRevLett.133.254101](https://doi.org/10.1103/PhysRevLett.133.254101)
Journal information: [Physical Review Letters](#)

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JANUARY 15, 2025

Over 97 million US residents exposed to unregulated contaminants in their drinking water, analysis reveals

by [Silent Spring Institute](#)



Credit: Unsplash/CC0 Public Domain

Nearly a third of people in the U.S. have been exposed to unregulated contaminants in their drinking water that could impact their health, according to a [new analysis](#) by scientists at Silent Spring Institute. What's more, Hispanic and Black residents are more likely than other groups to have unsafe levels of contaminants in their drinking water and are more likely to live near pollution sources.

The findings, published in the journal *Environmental Health Perspectives*, add to growing concern about the quality of drinking water in the United States and the disproportionate impact of contamination on [communities of color](#).

Close to 100 contaminants are currently regulated under the U.S. Safe Drinking Water Act. This means public water utilities must test for these contaminants and take steps to ensure levels don't exceed certain limits by installing new treatment systems and taking other measures.

"Yet, we know there are thousands of other [harmful chemicals](#) that are not regulated that make their way into groundwater and [surface waters](#), and some of these chemicals can ultimately end up in drinking water supplies," says co-author Laurel Schaider, a senior scientist at Silent Spring Institute.

Schaider and her team looked at data from the U.S. Environmental Protection Agency (EPA) collected between 2013 and 2015 under its Unregulated Contaminant Monitoring Rule program. The team analyzed data from 4,815 public water systems and found 27%—serving 97 million residents—had detectable levels of at least one of the following chemicals:

- 1,4-dioxane, a solvent classified by EPA as a probable human carcinogen, also found in consumer products
- PFAS (per- and polyfluoroalkyl substances), non-stick chemicals widely used in [consumer products](#), associated with cancer, thyroid disease, [high cholesterol](#) and other health problems
- chlorodifluoromethane (Freon 22), an ozone-depleting gas previously used as a refrigerant and used in the production of fluoropolymers (e.g. Teflon)
- 1,1-dichloroethane, a solvent used in paints, plastics, and pesticides associated with cancer.

Communities with a higher proportion of Hispanic and Black residents generally were more likely to be exposed to these unregulated contaminants in their drinking water and were more likely to be situated close to pollution discharge sites including [wastewater treatment plants](#), airports and military training areas, and industrial sites.

"Our findings show that the percentage of Hispanic and Black residents in a community is a consistent predictor of poorer water quality," says lead author Aaron Maruzzo, a scientist at Silent Spring Institute.

These racial disparities could not be explained by income or other measures of socioeconomic status, he says, suggesting that factors such as racism and the historical

practice of redlining that led to the disproportionate siting of industrial facilities in communities of color could be playing a role.

The study builds on [previous research](#) by Silent Spring, which found Hispanic residents are more likely to be exposed to higher levels of nitrate in their drinking water.

EPA set a legal limit on nitrate decades ago to protect infants from a fatal condition known as "blue baby syndrome.". Newer evidence suggests exposure to nitrate at levels below the federal standard can also increase the risk of colorectal and bladder cancer.

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A 2023 [study](#), co-authored by Schaider, looked at community water systems in 18 states and found those with a higher proportion of Hispanic and Black residents had higher levels of PFAS in their drinking water.

The new Silent Spring analysis is the first to look at disparities in exposure to PFAS and other unregulated contaminants in all U.S. states, as well as Tribal lands and U.S. territories.

In addition, recent testing shows PFAS are significantly more widespread in drinking water than previously thought, so the number of residents impacted by contaminants at the time the data were collected is an underestimate, says Schaider.

In April 2024, EPA announced drinking water standards for six PFAS chemicals. The study's findings underscore the need for federal action to regulate more [contaminants](#) and provide communities of color with more resources to address the impacts of pollution.

"Ultimately, we need to do a better job at protecting source waters and reducing discharges of pollutants into water bodies that feed into our drinking water supplies," says Schaider.

More information: Socioeconomic disparities in exposures to PFAS and other unregulated industrial drinking water contaminants in U.S. public water systems, *Environmental Health Perspectives* (2025). DOI: [10.1289/EHP14721](https://doi.org/10.1289/EHP14721)

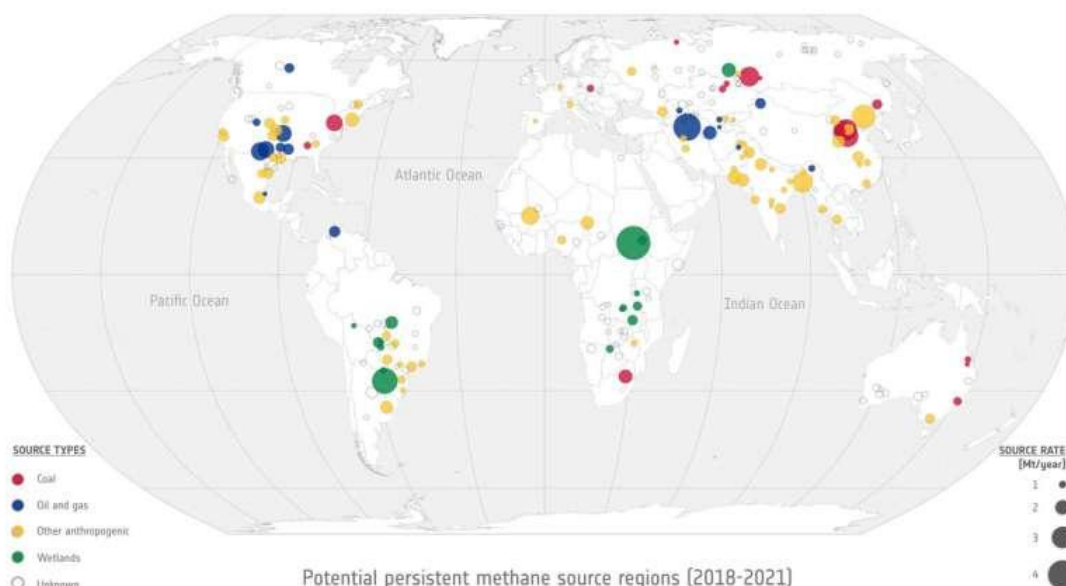
Journal information: [Environmental Health Perspectives](#)

Provided by [Silent Spring Institute](#)

FEBRUARY 3, 2025

Satellite data analysis uncovers top 10 persistent methane sources

by [European Space Agency](#)



A study by the University of Bremen has identified 217 potential persistent methane source regions, estimated their emissions and created a global map of their distribution. The data was from the Copernicus Sentinel-5P satellite, taken over the four-year period 2018–2021. It identifies some of the major regions that emit methane on a persistent, continuous basis. Credit: ESA Climate Change Initiative GHG Project (contains modified Copernicus Sentinel data, 2024)

A list of the top 10 global regions where natural or anthropogenic sources emit methane on a continuous, "persistent" basis was recently [published](#) in *Atmospheric Chemistry and Physics*.

The study analyzed data and measured emissions from hundreds of potential sources of methane based on [satellite data](#).

Data from the Copernicus Sentinel-5P mission was used to study and estimate methane emissions at 217 potential locations, as shown on the map above.

The paper focused on sources that emit methane gradually over time, in contrast to "super-emitters"—typically oil and gas operations, [coal mines](#) or poorly managed landfills—which release disproportionately large amounts of methane but not on a continuous basis.

Measuring the problem

Sentinel-5P, the result of a close collaboration between ESA, the European Commission, the Netherlands Space Office and industry, carries the state-of-the-art Tropomi instrument, which is used to map trace gases including methane.

The study is based on a new methane concentration dataset and an algorithm developed by the University of Bremen as part of the ESA Climate Change Initiative Greenhouse Gas Project, as well as the ESA Earth System Science Hub projects, Methane CAMP and SMART-CH4.

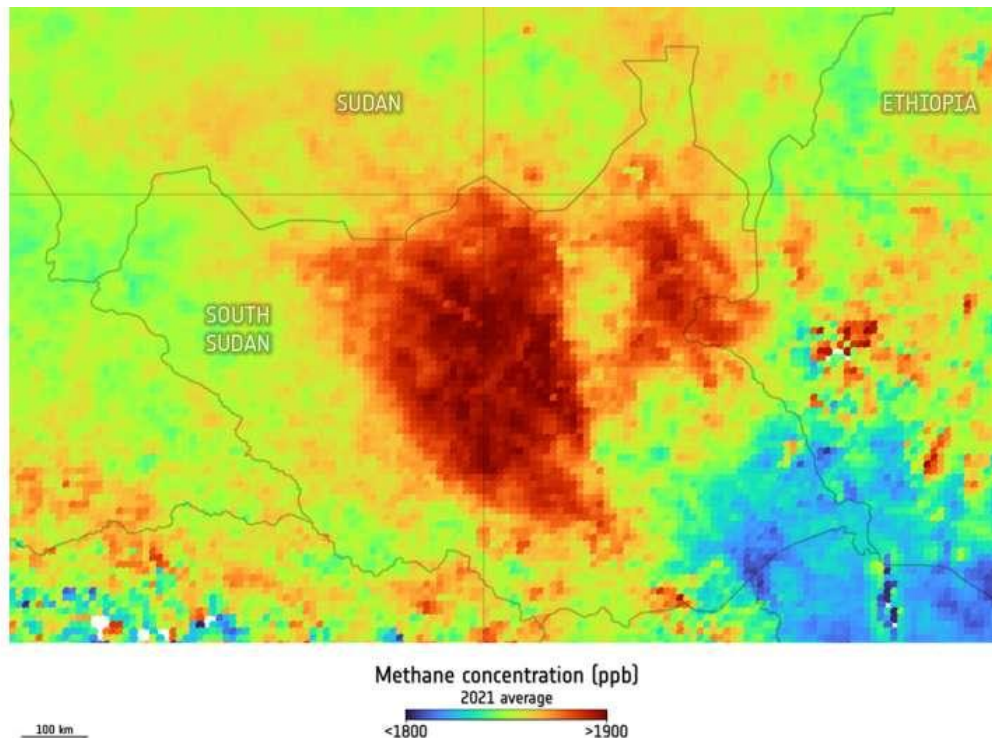
According to Claus Zehner, ESA's Mission Manager for Sentinel-5P, "Sentinel-5P is currently the only satellite that provides the feasibility to detect [methane sources](#) on a global scale and on a daily basis."

Researchers analyzed concentrations of methane (parts per billion) for 2018–2021. A location was classified as a potential persistent emitter if levels of methane were consistently higher than the surrounding area.

One of the paper's authors, Michael Buchwitz, Senior Scientist at the University of Bremen, explained, "The aim was not to identify specific events, where methane is only released for a short period of time. Instead, the aim was to identify sources that emit almost continuously during the four years that were analyzed. This includes natural sources such as wetlands, but also coal mining areas or large oil and gas fields."

Natural emitters

Wetlands are the most important natural sources of methane as microbes found in wetland soil emit high levels of the gas. The two natural sources indicated in the study's top 10 are both wetlands: the Sudd wetlands in southern Sudan and the Iberá wetlands in Argentina.



Sudan atmospheric methane map 2021 average. Credit: European Space Agency

The Sudd wetlands are a well-known methane source. Increased methane concentrations were detected across the Sudd region in 2020 and have been attributed to heavier rainfall and increased water flow from the White Nile. The region spans 500 km north to south and 200 km east to west, covering some 57,000 sq km, although it can double in size during rainy season.

The Iberá wetlands, in the Corrientes province of Argentina, is about half the size of Sudd and is an important freshwater source in South America. It is listed as the third biggest potential persistent methane source in the study.

Anthropogenic sources

The study also identified potential persistent methane emissions related to human activity. The biggest anthropogenic source was from the oil and gas fields on the west coast of Turkmenistan.

Several oil and gas persistent emission sites were identified in North America, including the Permian Basin, which is America's highest producing oil field, spanning the border between Texas and New Mexico.

The top 10 persistent emitting sources included three coal fields in Shanxi province in China, as well as Kuznetsk, one of the largest coal mining areas in Russia.

The study also looked at other anthropogenic sources, which include landfills, wastewater, digestive gas from ruminant animals such as cattle, sheep and goats, as well as manure, rice and energy buildings.

Region	Emissions (million tonnes per year)	Source
South Sudan – Sudd	4.5	Wetland
Turkmenistan – coast	3.5	Oil and gas
Argentina – Ibera	3.3	Wetland
China – Liaoning	2.9	Other anthropogenic sources
China – Shanxi 1	2.6	Coal
China – Shanxi 2	2.6	Coal
China – Shanxi 3	2.4	Coal
Bangladesh – Dhaka	2.4	Other anthropogenic sources
Russia – Kuznetsk Basin	2.4	Coal
USA – Permian Delaware	2.2	Oil and gas

Ten

highest potential persistent methane emitting regions 2018–2021. Credit: European Space Agency

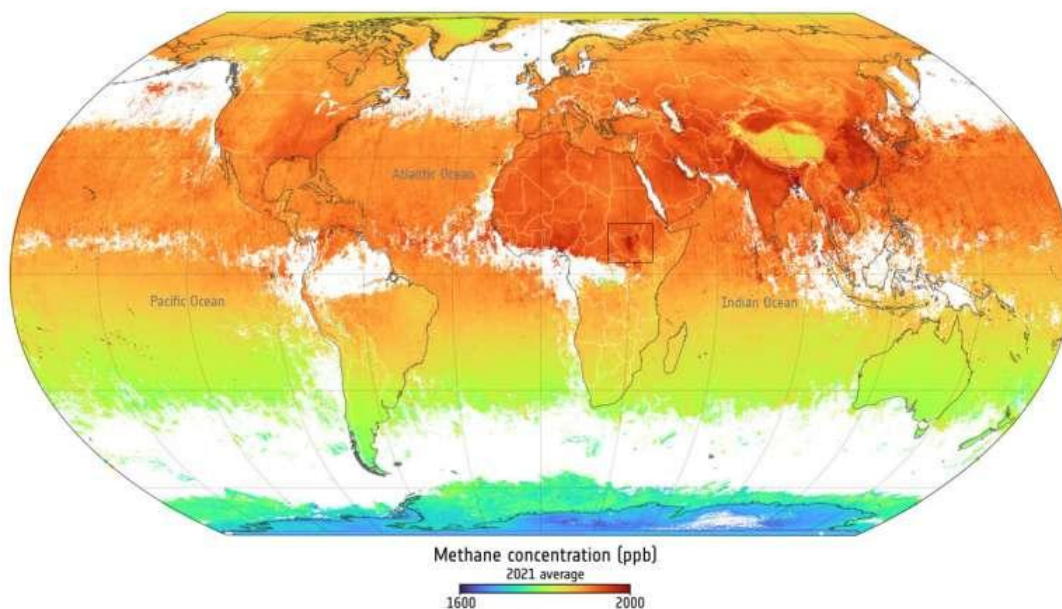
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Why is methane important?

Methane is the second most important greenhouse gas after carbon dioxide and is naturally present in the air we breathe. But its increasing concentration in the atmosphere is an important factor in [global warming](#).

Until 1850, levels were recorded at between 680 and 790 parts per billion, or ppb, according to data from NOAA Global Monitoring Laboratory. In the past decade, methane levels in Earth's atmosphere have reached almost three times the levels in 1850 to more than 1900 ppb. High-emitting and persistent methane sources make up a large share of global methane emissions and the Global Methane Budget 2024 shows there has been a significant rise in anthropogenic methane emissions in the past two decades.



The data used in this map of the global atmospheric methane average in 2021 was retrieved from the Copernicus Sentinel-5P satellite, using the WFMD retrieval algorithm developed at the University of Bremen (Schneising et al., 2023). Areas in dark red have the highest methane concentrations of around 1900 parts per billion, while blue areas show lower methane concentration in the atmosphere of around 1700 parts per billion. Credit: ESA Climate Change Initiative GHG Project (contains modified Copernicus Sentinel data, 2024)

Methane has a more powerful warming effect than carbon dioxide, although it has a much shorter duration in the atmosphere before it decomposes. Over a 20-year timescale, each kilogram of methane emitted has a global warming potential more than 80 times more potent than carbon dioxide. Reducing [methane](#) emissions is therefore an important strategy for tackling the causes of global warming.

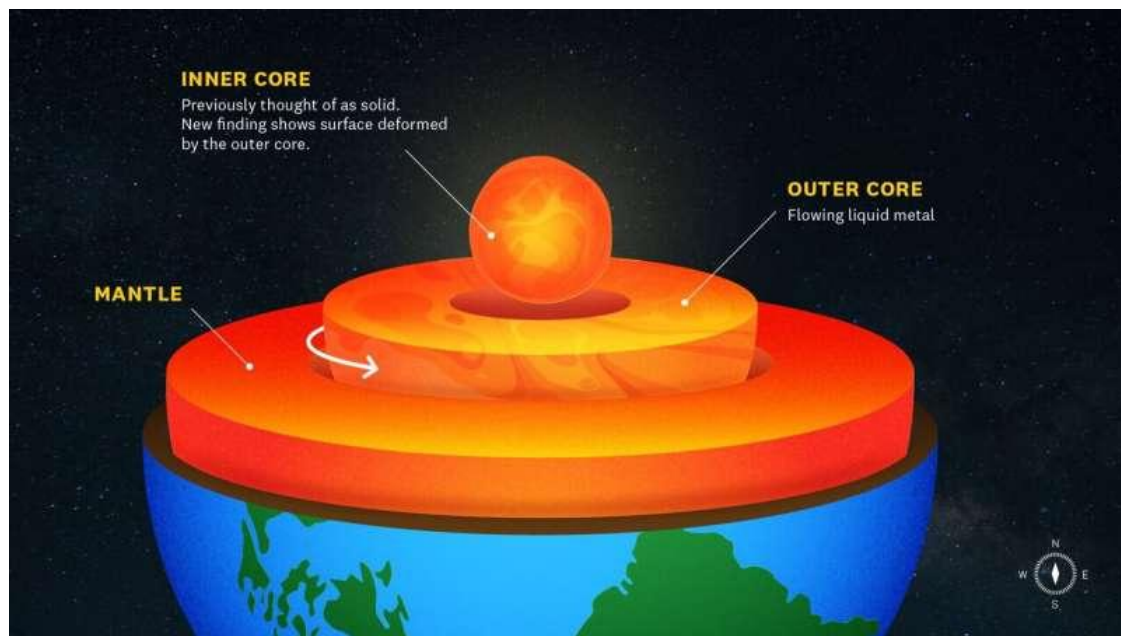
More information: Steffen Vanselow et al, Automated detection of regions with persistently enhanced methane concentrations using Sentinel-5 Precursor satellite data, *Atmospheric Chemistry and Physics* (2024). DOI: [10.5194/acp-24-10441-2024](https://doi.org/10.5194/acp-24-10441-2024)

Journal information: [Atmospheric Chemistry and Physics](#)
 Provided by [European Space Agency](#)

FEBRUARY 10, 2025

Earth's inner core is less solid than previously thought: Study reveals structural transformation

by [University of Southern California](#)



The Earth's internal layers including the mantle, outer core and inner core. New research shows the inner core undergoes structural transformation likely caused by outer core disturbance. Credit: USC Graphic/Edward Sotelo

The surface of the Earth's inner core may be changing, as shown by a new study by USC scientists that detected structural changes near the planet's center, published in [Nature Geoscience](#).

The changes of the [inner core](#) have long been a topic of debate for scientists. However, most research has been focused on assessing rotation. John Vidale, Dean's Professor of Earth Sciences at the USC Dornsife College of Letters, Arts and Sciences and principal investigator of the study, said the researchers "didn't set out to define the physical nature of the inner core."

"What we ended up discovering is evidence that the near surface of Earth's inner core undergoes structural change," Vidale said. The finding sheds light on the role topographical activity plays in rotational changes in the inner core that have minutely altered the length of a day and may relate to the ongoing slowing of the inner core.

Redefining the inner core

Located 3,000 miles below the Earth's surface, the inner core is anchored by gravity within the molten liquid outer core. Until now, the inner core was widely thought of as a solid sphere.

The original aim of the USC scientists was to further chart [the slowing of the inner core](#). "But as I was analyzing multiple decades' worth of seismograms, one dataset of seismic waves curiously stood out from the rest," Vidale said. "Later on, I'd realize I was staring at evidence the inner core is not solid."

The study utilized seismic waveform data—including 121 repeating earthquakes from 42 locations near Antarctica's South Sandwich Islands that occurred between 1991 and 2024—to give a glimpse of what takes place in the inner core.

As the researchers analyzed the waveforms from receiver-array stations located near Fairbanks, Alaska, and Yellowknife, Canada, one dataset of seismic waves from the latter station included uncharacteristic properties the team had never seen before.

"At first the dataset confounded me," Vidale said. It wasn't until his [research](#) team improved the resolution technique did it become clear the seismic waveforms represented additional physical activity of the inner core.

Deformed inner core

The physical activity is best explained as temporal changes in the shape of the inner core. The new study indicates that the near surface of the inner core may undergo viscous deformation, changing its shape and shifting at the inner core's shallow boundary.

The clearest cause of the structural change is interaction between the inner and outer core. "The molten outer core is widely known to be turbulent, but its turbulence had not been observed to disrupt its neighbor the inner core on a human timescale," Vidale said. "What we're observing in this study for the first time is likely the outer core disturbing the inner core."

Vidale said the discovery opens a door to reveal previously hidden dynamics deep within Earth's core, and may lead to better understanding of Earth's thermal and magnetic field.

More information: John Vidale, Annual-scale variability in both the rotation rate and near surface of Earth's inner core, *Nature Geoscience* (2025). DOI: [10.1038/s41561-025-01642-2](https://doi.org/10.1038/s41561-025-01642-2). www.nature.com/articles/s41561-025-01642-2

Journal information: [Nature Geoscience](#)
Provided by [University of Southern California](#)

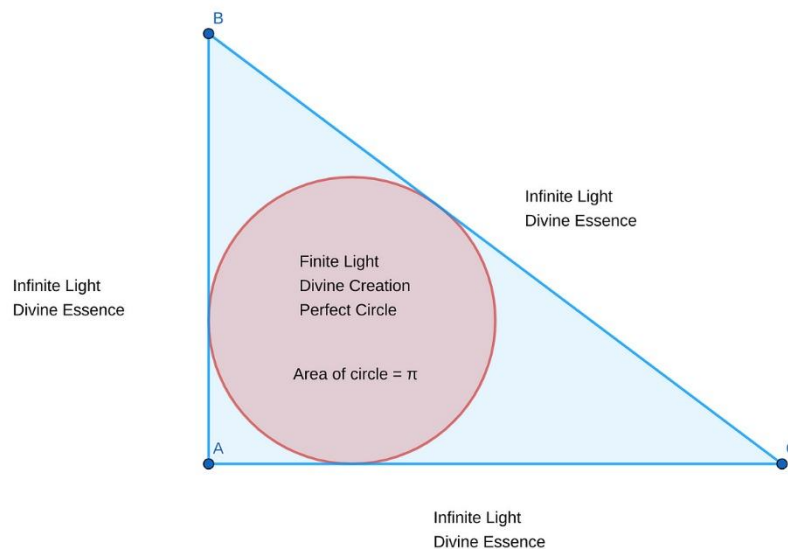
The Egyptian Triangle 3-4-5

When gematria and sacred geometry meet, a divine language

[SALAH-EDDIN GHERBI](#)

JAN 21, 2025

The Egyptian Triangle 3-4-5 is an interesting triangle that carries deep esoteric significance. The area of the circle inscribed in the triangle equals precisely the number π (3.14). This remarkable relationship hints at a deeper symbolic understanding of geometry as a bridge between the finite and the infinite, the measurable and the transcendent. Part of their thought in ancient Egypt was that π was not a number but a symbol of cosmic order, the cyclical nature of existence, the eternal nature of being, and the infinite wisdom in creation. The latter signifies wholeness and unity and brings us to the key to the mysteries of the universe as defined by π .



The value of Pi is defined as the perfect circle delimited by the boundaries of the triangle 3-4-5. The Divine creation and its content can be interpreted as the red circle.

According to the Kabbala, the entire creation began as a perfect circle. God "constricted" His infinite light into a perfect circle to make room for the creation. Pi (π) was used to bring this circle (Tzimtzum) wholly and perfectly. In the words of the sixteenth-century Safed Kabbalist R. Isaac Luria:

Before the emanated beings were emanated and the created beings created, a lofty, undifferentiated light filled all existence, and there was no cleared space... That [light] is called the Light of the Infinite ('ôr 'ên sof). When it arose in His undifferentiated will to create worlds... He then constricted Himself, the Infinite, at His core point... and He constricted that light, and it was distanced to the sides surrounding the middle point. Then there remained a cleared space and an empty atmosphere and hollowness... Then there was a place in which beings could be emanated and created... ('Ēṣ ḥayyim, 1:2)

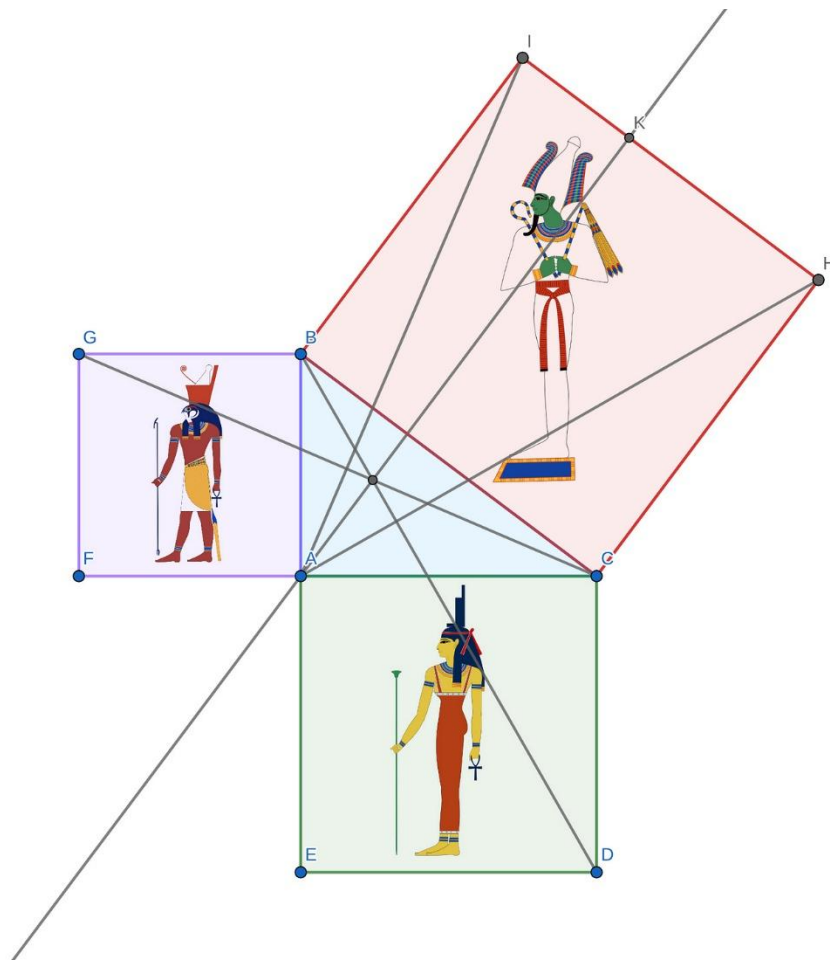
Sacred geometry, as naturally embedded in the 3-4-5 triangle, is the perfect example of how mathematics was once regarded as a divine language meant to decipher the harmonious intermingling of physical structures from those metaphysical principles of which they were composed.

Plutarch first describes the Egyptian 3-4-5 triangle in *Moralia* Vol. V:

“The upright, therefore, may be likened to the male, the base to the female, and the hypotenuse to the child of both, and so Ausar [Osiris] may be regarded as the origin, Auset [Isis] as the recipient, and Heru [Horus] as perfected result.”

The short side of the right-angle triangle is named “Ausar,” which corresponds to Osiris, the Father. The longer side is named “Auset,” corresponding to Isis, the Mother. And finally, the hypotenuse is called “Heru,” or Horus, the Son.

The ancient Egyptians saw this geometric figure as the prime matter or the One Substance that contains everything—all the elements that make matter and stages of consciousness¹.



Egyptian Triangle 3-4-5 / 47th Problem of Euclid

The 47th problem of Euclid.

The Pythagorean triangle 3-4-5 is a geometric figure representing the universal harmony in the microcosm and macrocosm. As

above, so below. The human being is a mirror of the eternal creative energy, the pure light of the nondual Spirit. Each triangle is attributed to each principle of the three-ness, a trinity well known in Ancient Egypt as Osiris, Isis, and Horus the child.

1. Osiris is the triangle of edge length 3, representing the three vital principles: salt, sulphur, and mercury.
2. Isis is the triangle 4, which was the expression of the four basic elements: fire, water, air, and earth.
3. Horus the child, the body (salt) incarnates the nondual spirit through the union process between the father and the mother. The Father, passing his vital principle through the mother, continues to live in the child. Horus represents the five stages of the development of life: minerals, plants, animals, humans, and enlightened ones.

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The Theorem of Pythagoras speaks about this beautiful process within:

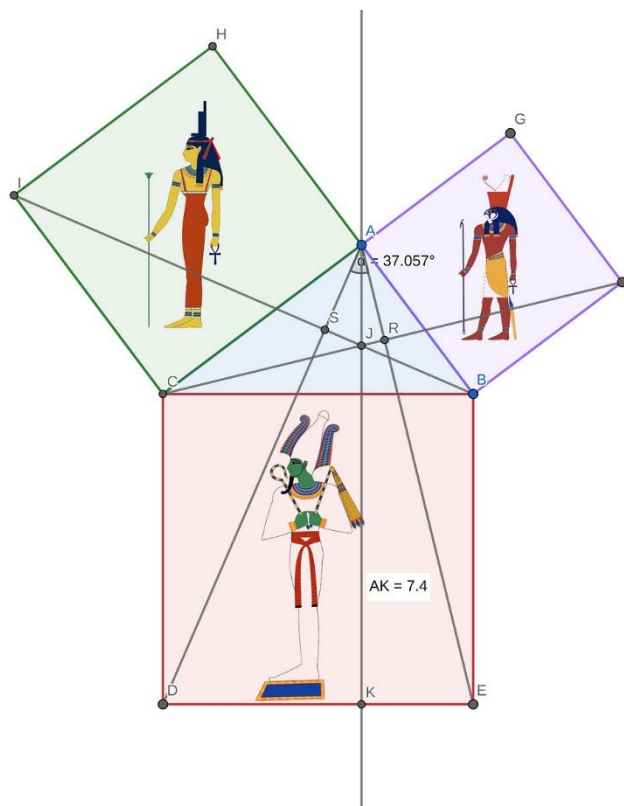
$$32 \text{ (Father)} + 42 \text{ (Mother)} = 52 \text{ Child}$$

As Plutarch describes:

“Three is the first perfect odd number: four is a square whose side is the even number two; but five is in some ways like to its father, and in some ways like to its mother, being made up of three and two. And panta, (all), is a derivative of pente (five), and they speak of counting as ‘numbering by fives.’ Five makes a square of itself.”

In this particular triangle, the segment [AK] represents the descent of pure light (spirit) into matter and has a side length equal to 7.4. It is the line of balance between the triad, passing through the

right angle A and extending perpendicularly to the side [BC] and then to the side [ED]. Interestingly, the angle SAR, which can be seen as the light cone projected, is about 37 degrees. If we had to break the light cone projected into two parts with the angles SAJ (23.385 degrees) and JAR (13.671 degrees), the latter would be about 37% of the original angle SAR (37.057 degrees). So, the prime number 37 seems to be a central key number in the Egyptian Triangle 3-4-5.



The descent of pure light into matter involves the key number 37, measured as the angle of the light cone projected SAR in degrees and the side length [AK] of 7.4, which is one-fifth of 37.

The angle SAJ could refer to the precession angle of Earth, approximately valued at 23.4 degrees.

The side length [AK] equal to 7.4 is a numerical code well encoded in the Bible, particularly in the first verse of Genesis. The expanded

form of this verse in Hebrew Gematria is 5476 (using the Mispar Shemi Method). The first verse can be written in its expanded form, and the total sum of the Hebrew letters is the square of 74, which is 5476. For example, Alef is 111, and the numerical value of its full name is: $111 = 1 + 10 + 100 =$ אלף.

First verse:

5476 = בראשית ברא אלהים את השמים ואת הארץ:

The first verse in its expanded form (full standard):

- 1819 = בראשית
- 1033 = ברא
- 291 = אלהים
- 517 = את
- 546 = השמים
- 539 = ואת
- 731 = הארץ:

$$731 + 539 + 546 + 517 + 291 + 1033 + 1819 = 5476 = 74^2$$

The number 74 is also the standard gematria value of Jesus in English.

- J = 10
- E = 5
- S = 19
- U = 21
- S = 19

$$10 + 5 + 19 + 21 + 19 = 74$$

The number 74 is the numerical value associated with the central line (represented by the segment [AK] in our illustration) in the triangle 3-4-5, representing the stillness and equilibrium of every aspect of the divine creation. Further mention of this particular line in the next articles will be called **the transcended line** or **the descent of light** into the physical world. The first verse mentions, in the beginning, that Elohim created the heavens and the earth. No doubt it began with the number Pi (π), which is at the core of the universe because everything is composed of cycles that spin, orbit, rotate, or oscillate. Pi (π) defines all the cycles of the spinning and orbiting of atoms, planets, solar systems, galaxies, etc.



This article invites us to meditate upon a simple geometric figure that embodies the entire universe and the original coding of the number Pi (π) as the boundaries were defined for God's creation.

Are we experiencing a simulation of an expanded universe that is already bounded by the parameter Pi (π) from the beginning? At the origin of the coding of such a wonderfully ordered cosmic play, we can dive in enough to start to see some of the important correlations between the words, geometry, and the alphabetical letters, either in Hebrew, Greek, English, or any other language. There is more to explore, which is the point of the Quantum Blueprint.