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# Journey to the Center of the Earth

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## We know more about the edge of the universe than about the core of our planet. Could a crazy mission get to the bottom of things?

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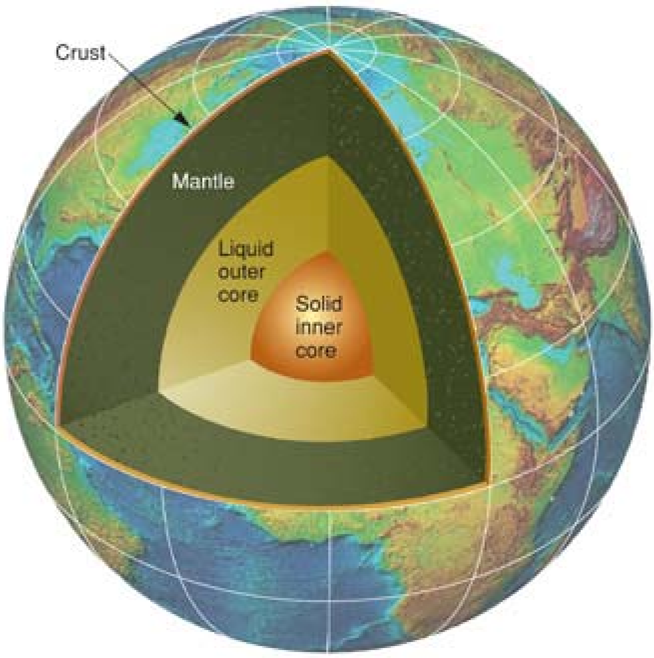


The earth's layers.

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Lawrence Livermore National Labs

In 1970 Russian geologists started drilling into the Kola Peninsula, near Finland, hoping to learn more about Earth's enigmatic insides. After 22 years of digging, work had to stop when the crust turned gooey under the drill bit; at 356 degrees Fahrenheit, the underground rock was much hotter than expected at that depth. The result of the scientists' grand effort: a tunnel as wide as a cantaloupe extending all of 7.6 miles down.

The Kola borehole is by far the deepest one ever dug, yet it reaches a mere 0.2 percent of the way to the core. The rest of Earth's interior remains as frustratingly out of reach as it was three centuries ago, when astronomer Edmond Halley suggested that our planet was hollow and filled with life. His ideas seem laughable today, but the truth is, when it comes to the inner Earth, no one knows anything for sure. Might a massive crystal sit at the center? What about a natural nuclear reactor? Are we so sure that the textbook diagram of the Earth sliced open, with nested layers of yellow, orange, and red, reflects reality?

The questions are so compelling that they inspired one geophysicist to draw up blueprints for a journey to the center of Earth. Nobody is doing it just yet; it would require cracking open the ground and pouring in thousands of tons of liquid metal. But that and other far-fetched ideas may inspire the ambitious projects necessary to catch a glimpse of the core—a place just 3,950 miles below our feet and yet, in many ways, less accessible than the edge of the visible universe, 13.8 billion light-years away.

Geophysicists try to explore the architecture of Earth by studying seismic waves that shimmy through the planet. Every year more than a thousand earthquakes register at hundreds of seismic stations, sometimes making their way completely across the globe. The waves travel at differing speeds depending on the materials they flow through, which provides clues about the topography of the interior: Faster-moving waves, for instance, generally indicate denser rock. (It's a bit like trying to identify a murder victim by examining the damage to the bullet.) The seismological data are combined with information about Earth's internal density derived from the laws of gravity and with results from extreme-pressure experiments in which materials are squeezed between diamonds to pressures of millions of pounds per square inch.

From all of this indirect evidence, scientists have been able to conjure complex, if often still speculative, ideas about the world below. Here is the picture so far.

**The Crust** The thin skin of Earth ranges from three miles thick (under some parts of the ocean) to 40 miles thick (under the continents). The crust encompasses the brittle and shifting continental plates; it becomes scarred with mountains when the plates grind together or with deep ocean basins when the plates pull apart.

**The Mantle** This deep layer of warm rock accounts for two-thirds of the mass of our planet. The solid but pliable rock churns in slow motion, drawing heat from Earth's center up toward the crust. There is enough turnover so that rock is constantly cycling through; pieces of crust have probably reached all the way down to the bottom of the mantle, about 1,700 miles below the surface. The underside of the mantle—the boundary between it and the liquid outer core—is probably rugged terrain. Think of it as the Earth's surface turned upside down. The boundary's mountains may approach the height of the Himalayas, and the constant activity may cause "avalanches," flows of rock that cascade along the slopes of those inverted peaks.

**The Outer Core** Made of molten iron, nickel, and other ingredients yet to be determined, the churning liquid outer core may have the viscosity of water, streaming at possibly one to several miles per week with the turbulence of a gargantuan, slow-moving washing machine.

**The Inner Core** At the center of this spherical body of liquid is the inner core, a ball of iron alloy one-third the size of the moon. This metal ball is broiling hot at 11000 degrees Fahrenheit, comparable to the surface of the sun, but it remains solid because of the enormous weight of all the rest of Earth bearing down on it.

Life thrives on this planet partly because it is protected by the powerful magnetic field generated in the outer core. The swirling motions of the liquid metals there create the conditions for what is known as a geodynamo—a geologic electric generator. How this dynamo was initiated and how it works is mysterious, but it seems that the circulation of liquid metal through a magnetic field (which must have begun eons ago) causes a feedback loop of electricity and magnetism and unleashes a powerful electric current hundreds of miles wide. This current fills the core and is the source of tremendous magnetism; its poles, located roughly at the ends of Earth's axis, mark magnetic north and south. Dangerous cosmic rays are deflected by the magnetic field back out into space, and our atmosphere remains robust because of this protection.

Although most geophysicists feel confident that they understand the topography of the inner Earth within a resolution of several hundred miles, it is possible that our assumptions from seismic data could be as inaccurate as were our assumptions about other planets when earthbound telescopes were our only source of observation. "If we have only remote information—the information we get from indirect methods—then we get only part of the picture," says David Stevenson, a professor of planetary science at Caltech.

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This is where the speculative, often offbeat, theories come in. As recently as 1995, geophysicists at the Carnegie Institution of Washington proposed that the inner core was actually a gigantic crystal. This strange but educated guess came in response to strong evidence that seismic waves traveling through the inner core along the axis of the magnetic poles complete their trip through Earth about four seconds more quickly than do waves traveling from one side of the equator to the other. An iron crystal would account for this marked "grain" in the inner core, and the extreme temperature and pressure at the planet's center happen to be ideal conditions for crystal growing.

As scientists have learned more about the properties of iron, however, the sleek crystal hypothesis has been challenged by an opposite idea: that the iron core is a lumpy, layered wad. "The inner core could be comparable to the Earth's surface but with more subdued variations," says geophysicist John Vidale of the University of Washington. "And there is some evidence that there are variations in the properties inside of it." Although the inner core is mostly or entirely solid, it probably does flow slowly over time, like a glacier. Variations in its composition may mean that some parts melt more easily than others, causing lumpiness and, after eons of flow, layering. Some researchers calculate that the layers in the inner core are tens of miles thick, Vidale says.

> Stevenson's idea is to open a crack in Earth's crust with a controlled blast and pour in 100,000 tons of liquid iron, along with a few refrigerator-size probes.

At the bottom of those layers may lie yet another surprise. After perusing the records of hundreds of thousands of earthquakes, geophysicists at Harvard University speculate that there may be an inner inner core, a 360-mile-wide nugget at the very center that has its own grain, slightly askew to the rest of the inner core. This could be the oldest part of our planet, a relic of Earth's formation 4.6 billion years ago—or, less exciting, it could be iron crystals packed together in an odd way. Evidence for the inner-inner core is mounting.

Perhaps the oddest theory about our planet's inner workings comes from an independent geophysicist, J. Marvin Herndon, who imagines that instead of a stable ball of iron at Earth's center, there could be a natural nuclear reactor chugging away. He believes that uranium may have settled into the core—enough to sustain nuclear fission—and that the resulting reactor is the energy source for the geomagnetic field. "The whole idea of Earth having an inner core that's nickel-iron metal goes back 60 years," says Herndon. "It's still being promoted because people are afraid to even consider that it might not be correct. Most people are afraid to go against the consensus mentality."

Although Herndon's idea is considered to be fringe by those in the field, even his harshest critics admit that it cannot be entirely dismissed—we simply do not know enough. "It's very easy to create wild theories that do not violate what we observe," says Stevenson, who has outspokenly opposed Herndon's reactor concept. "There is nothing that Herndon predicts that is necessary." Then again, he admits, "That's not the same thing as saying I know for certain he is wrong."

Testing Herndon's wild idea, along with many other hypotheses, will require new and better tools designed for deep Earth exploration. If there is indeed significant radioactivity in the core, for instance, we would expect subatomic particles called neutrinos (by-products of radioactive decay) to be emitted and make their way to the surface. Although neutrino detectors already exist, their accuracy is limited. It is currently difficult to determine whether any given neutrino originated from space or escaped Earth's core. Detectors designed specifically to find so-called geoneutrinos may be up and running in 10 to 20 years.

Studying the origin of Earth's magnetic field is even tougher. For example, scientists don't understand why the magnetic field is as strong as it is, or why the field reverses polarity—the North Pole becomes the South Pole and vice versa—every several hundreds of thousands of years, briefly vanishing in between. Some impressive computer models have replicated this effect, but those matches, while impressive, fall far short of explaining things.

Several labs around the world have attempted to create large physical models of the core by tumbling molten metal in barrel-size copper spheres. The hope is to get a lab-size geodynamo going under small-scale conditions that mimic those inside Earth. A lab at the École Normale Supérieure in Paris has created a geodynamo in this way, and the scientists there were able to observe flips in polarity, although critics say that the experiment does not replicate the core's conditions closely enough to be trumpeted as a true success. "It's quite clear that the core is a more hostile environment than the surface of the sun," says Dan Lathrop, a geophysicist at the University of Maryland, pointing out the difficulty in accurately re-creating the core. Lathrop is building a 10-foot-sphere version of this kind of experiment that some believe will be the first model to convincingly imitate Earth's geodynamo.

Earth's interior conditions are so extreme that mimicking them, whether with molten globes or with rock samples crushed between tiny diamonds, may not be possible for many years. Some potentially decisive experiments may never be practical enough to execute. "We can't really come up with a rotating convection state that would be truly capable of showing a dynamo because convection is always too weak," Lathrop says. "We would have to build an experiment that is 100 feet in diameter. That would be a big experiment." Not only would Lathrop and his colleagues need an enormous apparatus, but to truly model the core they would also need to re-create gravity's downward pull, a contributing element to the physics of inner Earth.

"There's no way to replicate that in an experiment unless you were to put a black hole at the center," says Lathrop. "So we need a laboratory black hole. I've asked my students to try to figure out how to do this, but so far they haven't come up with anything."

Even a gargantuan artificial core with a black hole at its center—cool as that sounds—would still be only a simulation. Better yet would be direct evidence, the kind we could get only if we actually trekked down to Earth's center. With this in mind, Stevenson drew up a proposal that was published in the journal Nature. His idea is to open a crack in Earth's crust with a controlled blast and then pour in 100,000 tons of liquid iron, along with a few refrigerator-size probes. According to his calculations, gravity should pull the heavy iron, and the probes with it, down to the core in about one week. (The path behind would naturally seal itself up.) The probes could communicate with the surface via seismic waves, sending back readings on the constituents and properties of the mantle and core. Although Stevenson's proposal was mostly meant as a provocation, many in the field agree it is plausible.

So why not give it a whirl? "It's too damn expensive," Stevenson says. He has worked with NASA designing space missions to explore the geophysics of other planets in our solar system, so he has some insight into how much these things cost. Constructing a probe that could survive the heat and pressure of the core and send back information would be a major undertaking, not to mention the expensive bureaucracy that would go along with taking on such a high-profile project. "In all likelihood the effort required to start it would be comparable to the Manhattan Project or a space mission. It could be billions of dollars."

Which is not to say that it should not be done. Our fantastic ideas usually cannot compare to the truths uncovered when scientists get their hands on the curtain and pull it back. "One of the enduring messages of planetary exploration," Stevenson says, "is when we actually go somewhere, we are surprised."