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Continental IMPACT

Although we know that continents constantly move across the surface of Earth, we don't know why they first began to drift. A new theory proposes that violent impacts from celestial bodies could have kicked off the process 2.5 billion years ago

Earth's continents are always moving. This continental drift, part of the theory of plate tectonics, is so fundamental to geology that it's easy to forget that the concept was a fringe theory just a few decades ago. It's only recently that a majority of geologists accepted the idea that Earth's crust consists of plates that move in relation to one another and that this motion can explain earthquakes, volcanic eruptions and the formation of mountain ranges—some of the most important phenomena encountered in geology. Today the idea is largely undisputed. But there is a fundamental question about plate tectonics that has not been answered: How did the movement of continents begin?

Vicki L. Hansen, a geologist at the University of Minnesota Duluth, recently published her hypothesis that the movement may have started over 2.5 billion years ago. Hansen suspects that powerful impacts in several places on Earth from so-called bolides—objects such as comets and asteroids that crash into planets and moons—could have caused large amounts of molten magma from Earth's mantle to flow to the surface. This would have set off subduction, a crucial process in plate tectonics in which one continental plate slides beneath another.

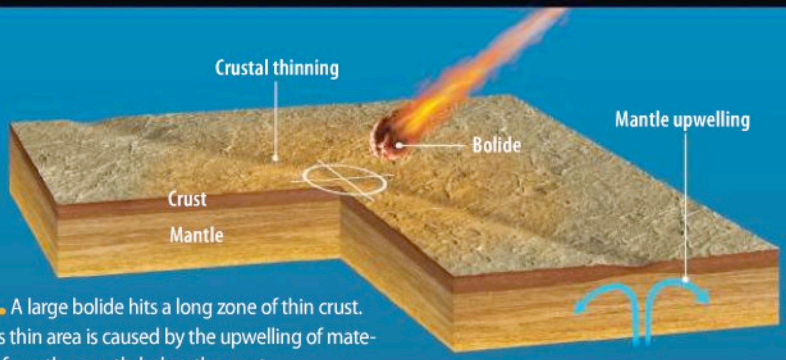
A New Movement

In 1915 German meteorologist, geophysicist and astronomer Alfred

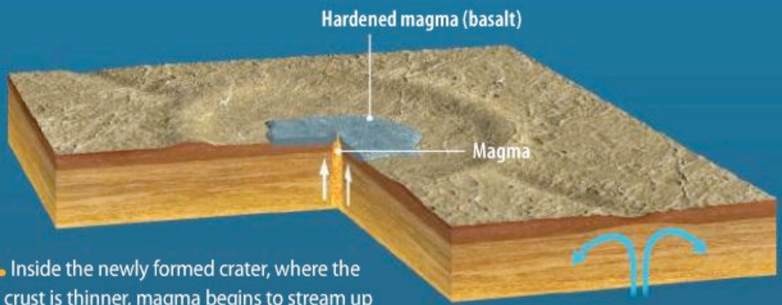
Vicki L. Hansen of the University of Minnesota Duluth believes objects impacting Earth could have set its surface in motion.

How a Bolide Sets Plates in Motion

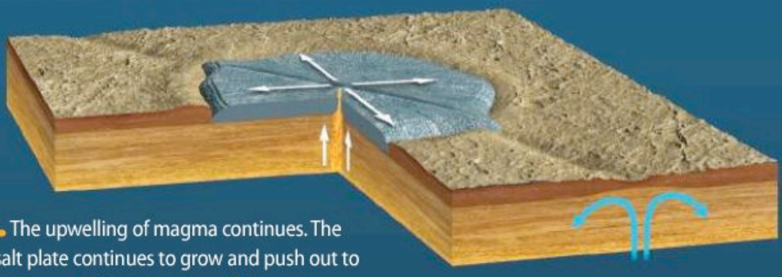
More than 2.5 billion years ago, Earth was much hotter than it is today, and its crust could have been uniform. According to Vicki L. Hansen's hypothesis, a bolide—an impacting object—could have smashed a gigantic hole in the crust and let upwelling magma flow to the surface to kick off plate tectonics as we know it.



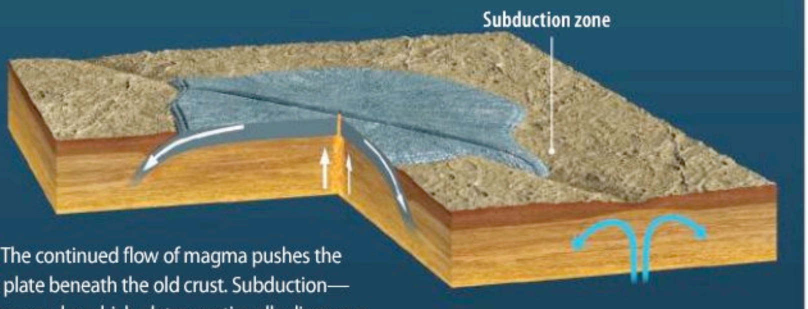
1. A large bolide hits a long zone of thin crust. This thin area is caused by the upwelling of material from the mantle below the crust.



2. Inside the newly formed crater, where the old crust is thinner, magma begins to stream up to the surface, where it hardens into basalt. This creates a new basalt plate, which spreads as magma continues to stream to the surface.



3. The upwelling of magma continues. The basalt plate continues to grow and push out to the sides until it hits the edge of the crater.



4. The continued flow of magma pushes the new plate beneath the old crust. Subduction—the process by which plates continually disappear back into the mantle—has begun.

Wegener presented his idea, now known as the theory of continental drift, that the continents are in motion and had once, in the distant past, formed a single supercontinent. Bringing together observations from several fields—the interlocking appearance of the African and South American coastlines, the identical plants and animals found fossilized on both sides of the Atlantic, the strikingly similar mountain ranges and rock formations on separate continents—Wegener asserted that the continents had once been a single landmass, which he dubbed Pangaea, and were now separate because they had broken and moved apart.

Wegener's contemporaries greeted his ideas with great skepticism. Although many scientists believed that the continents could have been connected, the reigning hypothesis was that they had been linked by land bridges, which had since sunk into the oceans. The idea that the continents moved seemed far-fetched, especially because Wegener couldn't explain how or why it happened. His suggestion that the continents plowed through the ocean floor as they moved was dismissed as impossible. And the explanations he offered for why the continents were moving—that the motion might be driven by centrifugal or magnetic forces—were similarly discounted.

Wegener worked on his theory right up to his death in 1930, but the notion of continental drift wasn't accepted during his lifetime. A turning point came in the decades after World War II. Because of military interest in submarine navigation, and with the aid of new sonar technology, geologists meticulously mapped the bottom of the oceans for the first time. The results astonished them. They discovered underwater mountain ranges extending for hundreds of miles across the globe.

In the centers of these ranges, dubbed mid-ocean ridges, geologists found evidence of new rocks forming from magma flowing to the surface and cooling. They also discovered undersea trenches, often where the

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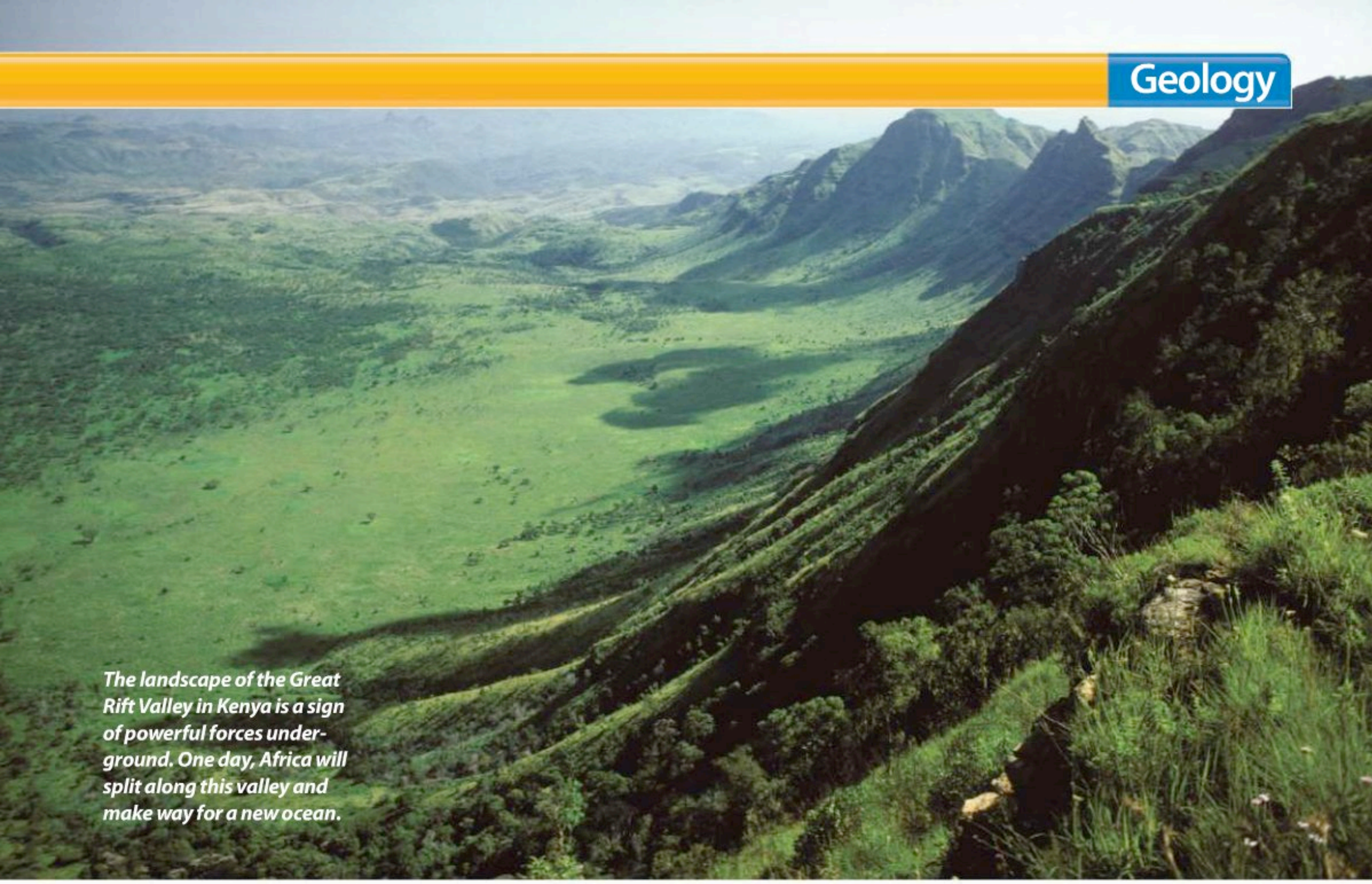


The landscape of the Great Rift Valley in Kenya is a sign of powerful forces underground. One day, Africa will split along this valley and make way for a new ocean.

continents met the oceans, and some of these trenches were more than six miles deep. At the same time that these discoveries were being made, seismologists were developing methods to more precisely locate earthquakes, which proved to be concentrated near the newly discovered mid-ocean ridges and deep-sea trenches. Perhaps, researchers thought, the earth was moving most dramatically in these places where the deep ocean met the continents.

Another decisive breakthrough came in the 1960s, when research vessels were first sent out to drill into the seafloor. One important project started in 1968, when the *Glomar Challenger* set sail on the first of 15 years of voyages for the international Deep Sea Drilling Project, which studied the seafloor below the ocean sediments.

Ocean research, such as that of the Deep Sea Drilling Project, gave scientists the pieces to assemble the

Alfred Wegener's theory was not accepted until decades after his death.

The Father of Plate Tectonics

German meteorologist, geophysicist and astronomer Alfred Wegener (1880–1930) was the first to propose, in 1915, that the continents had once been joined together as a single supercontinent and had broken apart and spread to create the continents as we know them. In his major work *The Origin of Continents and Oceans*, he based his theory on the geological and paleontological similarities among the continents and on the fact that their shapes fit together like puzzle pieces.

Wegener was a multitalented man. In 1906, together with his brother, he broke the world record for balloon flights by staying up for 52 hours, and as a young man, he took part in several expeditions to the Greenland ice cap. Later, the ice killed him—he died on an expedition to Greenland in 1930.

One of Wegener's greatest challenges was his inability to explain the force behind continental drift (he believed that it was centrifugal or magnetic). Therefore, his hypothesis was not confirmed until 30 years after his death, when geologists discovered a mechanism by which continents could move.

FROM TOP: ALAMY/IMAGESELECT; SPL/FOCI

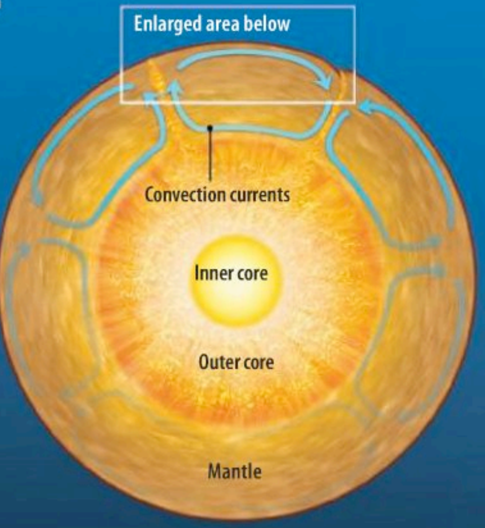
modern theory of plate tectonics. The very bottom layer of the ocean floor is composed of a hardened magma known as basalt, which contains magnetic minerals. When the basalt cools and hardens, researchers discovered, these minerals line up with Earth's magnetic field, which periodically reverses its polarity. (The reversals are becoming more frequent. They once happened roughly every million years, but in more recent times, they happen about every 200,000 years.) As a result, this deep-ocean basalt contains a record of the planet's magnetic field, and these reversals have been particularly useful for studying Earth's history. Geologists use them for, among other things, dividing the ancient past into periods. We now live in a period of magnetization known as the Brunhes chron. About 700,000 years ago, however, during the Matuyama chron, north-south magnetization was the opposite of the way it is today.

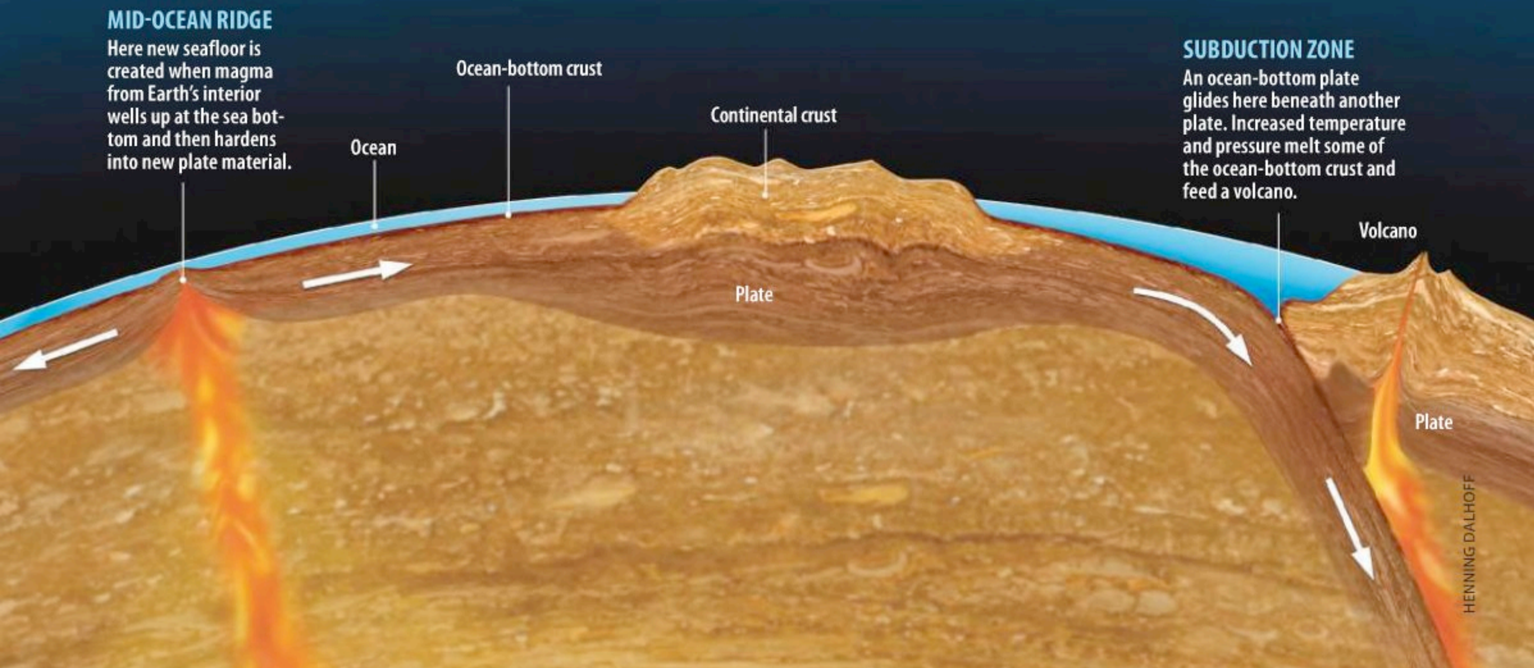
The Deep Sea Drilling Project found that the magnetic reversals form a very characteristic pattern in undersea basalt: The basalt located right next to a mid-ocean ridge contains the patterns of the most recent magnetic period. The farther away from the ridge, the older the patterns in the basalt.

Earth's Heat Fuels Continental Drift

The theory of plate tectonics, including continental drift, explains how the oceans came into being, why earthquakes and volcanic eruptions occur on Earth, and how mountain ranges arise. This central theory of geology is based on the idea that the outermost layer of our planet, the crust, consists of rigid plates, with the continents lying atop them. These plates move, carrying the continents with them as they drift over the surface of Earth.

Plate tectonics is powered by convection currents in Earth's mantle, which in turn are caused by heat being produced within the planet's core and mantle. As material in the mantle warms up, it rises toward the surface of the planet. Some of this material escapes—the magma spilling out of the mid-ocean ridges is one example—but some remains trapped beneath the crust and moves laterally, cooling and sinking as it goes. These currents help push tectonic plates, causing them to diverge and free more magma in some places and to collide and begin subduction in others. It is at plate boundaries that most earthquakes and volcanic activity occur, and it is also at these boundaries that mountain ranges form.




MID-OCEAN RIDGE
Here new seafloor is created when magma from Earth's interior wells up at the sea bottom and then hardens into new plate material.

SUBDUCTION ZONE
An ocean-bottom plate glides here beneath another plate. Increased temperature and pressure melt some of the ocean-bottom crust and feed a volcano.

HENNING DALHOFF

Scientists on the project also found that even the oldest areas of the seafloor are, geologically speaking, fairly young—200 million years old at most, as opposed to Earth itself, which is more than four billion years old.

These ongoing discoveries have led geologists to theorize that new seafloor must be constantly produced at each mid-ocean ridge, from which it spreads out to both sides.

Mid-Ocean Action

Today geologists know that Earth's 30-to-60-mile-thick oceanic plates and 60-to-160-mile-thick continental plates are rigid bodies consisting of the crust and uppermost layer of the mantle and that they move atop another layer of the mantle that is softer and more plastic.

Heat and pressure within our planet cause rock within the mantle to flow like a liquid. This forms an ocean of rock on which the plates move. When the plates resting atop the mantle diverge, the release of pressure can cause the mantle to melt and well up to the surface, where it hardens into basalt. This new basalt is constantly being pushed aside by new magma welling up from below, causing the plates to grow and move. When upwelling magma rises beneath a continent, the land will break in the middle and, later, an ocean will fill the gap—as occurred between Africa and South America and as is slowly under way today in the East African Rift System.

When a basalt plate in motion collides with a plate topped by a continent (which consists of more-buoyant rock, such as granite) or with a younger oceanic basalt plate, the basalt will sink under the other plate and eventually be reabsorbed into the mantle. This process, called subduction, explains why the seafloor is so young: The older seafloor is continually being pushed back into the mantle. Subduction occurs at the deep-sea trenches, where the seafloor plates on their downward path unleash powerful earthquakes. In addition, the plates partially melt and send magma back up to the surface. Behind the deep-sea trenches, this magma either forms volcanic mountain ranges on land (the Andes, for instance) or chains of volcanic islands in the sea (like the Philippines).

The continents, on the other hand, remain atop the plates because of their lower density and move with those plates. Sometimes the continents, too, can collide, as is the case with India, which rammed into Asia 40 million to 50 million years ago, creating the Himalayas by doing so.

Drill samples from research ships can provide valuable information about the seafloor—including evidence of new seafloor being made.

Vessels such as the Japan Agency for Marine-Earth Science and Technology's* D/V Chikyu *investigate the seafloor.

A Bolide Started It All?

Geologists now understand the processes that drive plate tectonics and know that it has been under way for billions of years. But its origin remains a mystery. There has especially been a lack of ideas to explain how subduction got started.

This is where Hansen's new hypothesis comes into the picture. Imagine a younger Earth, 2.5 billion years ago. At that point, the planet was significantly different. Judging by the impacts scientists have identified on the moon and Mars, Earth was probably under steady bombardment by bolides. Earth may also have been covered by a comparatively uniform crust, with few differences in density or strength from place to place. In the mantle beneath the crust, however, there could have been currents similar to those of today, and these currents could have caused areas of the crust to become thinner as it stretched over the slowly moving mantle. These

FROM TOP: IODP; JAMSTEC

conditions—bombardment by bolides, a mostly uniform crust, and areas of localized thinning—serve as the starting point for Hansen's hypothesis.

If one of those many bolides had hit an especially thin part of the crust, and the impact made a crater more than 600 miles in diameter, Hansen believes that it could have started subduction, which has never stopped since. In addition to making the crust thinner where it struck, the bolide's impact would have led to local heating of the mantle, which would have caused magma to surge upward. This magma would have burst through the crust and up to the surface, where it would have hardened into a dense, rigid basalt plate. As the process continued, this new basalt would have spread outward from the impact site, similar to the process by which the seafloor moves today.

Hansen goes on to imagine that continued spreading would force the basalt plate in the crater out to the sides. At some point, that plate would collide with the hard rim of the crater, which would not budge. The basalt plate would begin to sink beneath the rim of the crater, and subduction would be under way.

Hansen is not sure exactly when this process would have begun—she says only that the most likely period was at least 2.5 billion years ago. But she does say that the combination of circumstances that she lists in her hypothesis could have occurred many times in different spots around the globe. So subduction could have started many times. And in every case, the die was cast: After the first impact occured, the weakness would have expanded. Subduction is like a virus, Hansen says. Once it starts, it can very easily spread.

How It Will End

In another 250 million years, geologists predict, the continents could once again

An Undersea Map of Continental Drift

After World War II, geologists discovered chains of undersea mountains thousands of miles long. In the middle of these mid-ocean ridges are continual flows of hot magma coming from Earth's interior.

When this lava hardens, it becomes basalt, a volcanic rock containing magnetic minerals, and these minerals line up with Earth's magnetic field. (The orientation of the magnetic field reverses at regular time intervals.) Using the rocks' magnetic orientation at various locations, geologists were able to date those rocks' age. Seafloor sediments can also be dated, and the evidence was clear: At the mid-ocean ridges, the magnetized areas and seafloor sediments from the ancient past spread out symmetrically from each ridge. The rocks are youngest adjacent to the ridge and get older the farther they are from it. These observations supported the idea that new seafloor is continuously being created and that seafloor plates are constantly moving away from the mid-ocean ridges. Geologists had found the force that drives plate tectonics.

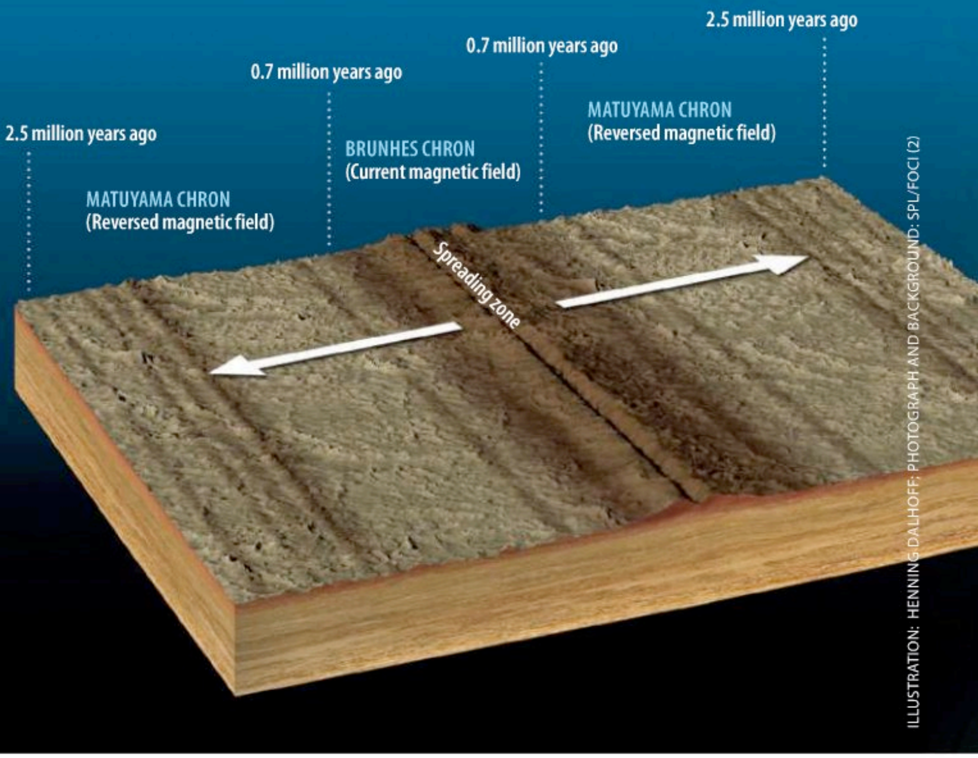


ILLUSTRATION: HENNING DALHOFF; PHOTOGRAPH AND BACKGROUND: SPL/FOCI (2)

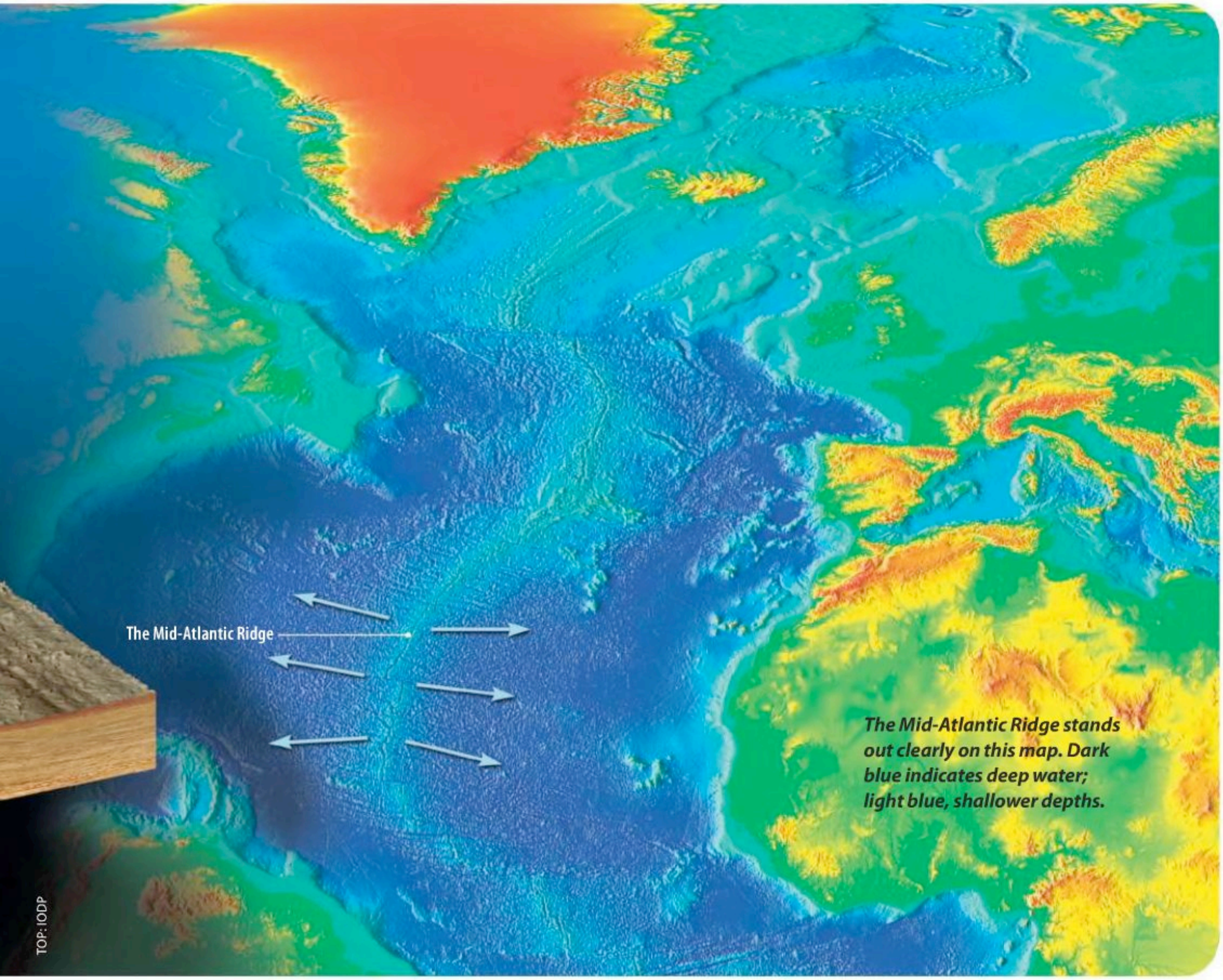
Extreme heat along the Mid-Atlantic Ridge creates hydrothermal vents.

come together into a supercontinent, only to break apart. But over the very long term—hundreds of millions or even billions of years—the plates could stop moving.

This is because, in the larger scheme of things, ever since Earth was formed 4.6 billion years ago, its core has been cooling. Very slowly, to be sure (partially because the decay of radioactive elements in Earth has continued to produce heat, thus delaying the process), but it is cooling nonetheless. The currents in the mantle are the planet's way of throwing off heat. And when they one day stall because heat production within the planet's core and mantle has dropped off, that will be the end of plate tectonics (and possibly all life on Earth).

Volcanic material called basalt is shown here inside a research vessel's drill core.

For now, Hansen's hypothesis about the origins of subduction has been fairly well received by other geologists, but she points out that it must still be tested. She compares it with the theory that the moon was created by a collision between Earth and a heavenly body the size of Mars early in our planet's history. This hypothesis was put forth in the 1960s and '70s and at first was treated as absolute nonsense. But later, data appeared that supported it, and now it is the reigning hypothesis of how the moon came to be. Hansen's theory—like Wegener's before it—will have to undergo a similar process. ■



The Mid-Atlantic Ridge stands out clearly on this map. Dark blue indicates deep water; light blue, shallower depths.

TOP: IODP