The Flap Over Magnetic Flips

What happens when Earth's magnetic field reverses itself?

By RICHARD MONASTERSKY

The way Carlo Laj tells it, the 1980s were a dead time for scientists studying Earth's peculiar habit of flipping its magnetic field every few hundred thousand years. Laj and other paleomagnetists spent the decade roving the world, accumulating records of times when the magnetic field reversed itself, switching north pole for south and then back again. But even as their databases grew, the study of geomagnetic reversals foundered for lack of new theories to guide the research.

"The community was slowly going to sleep," says Laj, a geophysicist at the Centre des Faibles Radioactivités in Gif-sur-Yvette, France.

Two years ago, however, Laj's group and Bradford M. Clement of Florida International University in Miami sent out a wake-up call that roused the paleomagnetic community and packed the halls of scientific conferences dealing with geomagnetic reversals. Working independently, Clement and Laj's team concluded that the magnetic field, quite unexpectedly, had displayed a persistent pattern of behavior during recent reversals — a finding that promised to reveal fundamental insights into the workings of the planet's deep interior.

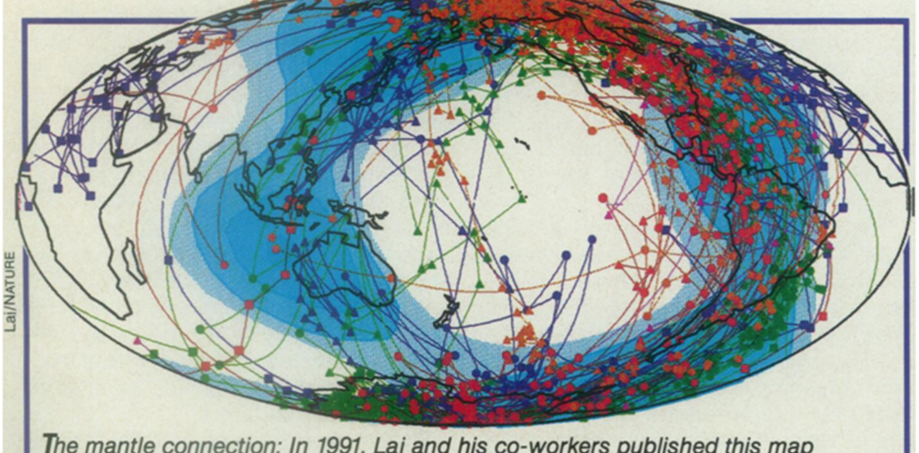
Their far-reaching claims sparked a heated debate that simmers to this day. One after another, scientific teams across the world have joined the fray, with some groups supporting the 1991 observations while others attack Clement and Laj's proposal on a variety of fronts.

"This is one of the hottest things going on today in the earth sciences," offers Kenneth A. Hoffman, a geophysicist at California Polytechnic State University in San Luis Obispo.

Clement and Laj made their discoveries by taking a detailed look at what happened during the magnetic turnovers that have occurred during the last 12 million years. To trace the field's behavior backward in time, they measured the orientation of magnetic minerals within sedimentary rocks. When such grains dropped to the floor of an ancient ocean, they aligned themselves with the direction of the magnetic field existing at the time, eventually becoming locked into place as the sediment layers hardened.

During stable times, such as today, Earth's predominant field has a simple dipolar shape, as if the planet's core held a giant bar magnet. Field lines flow out of a magnetic pole near the coast of Wilkes Land, Antarctica, arc above the planet, and then dive back down into a second magnetic pole in arctic Canada. Geophysicists describe today's field as having normal polarity, while the opposite orientation has a reversed polarity.

In between these two stable states are the relatively short reversals, which can take anywhere from 2,000 to 20,000 years to complete. During a switch, the stable field weakens and then reestablishes itself with the opposite polarity, an act that most recently happened 730,000 years ago.



The mantle connection: In 1991, Laj and his co-workers published this map suggesting a possible link between geomagnetic reversals and the lower mantle. The colored lines represent tracks followed by the geomagnetic pole during four reversals within the last 11 million years. The paths concentrate in two bands: one over the Americas and a less prominent one over Australia and Asia. The locations of the bands match deep-mantle regions with the lowest temperatures (shown in blue shading).

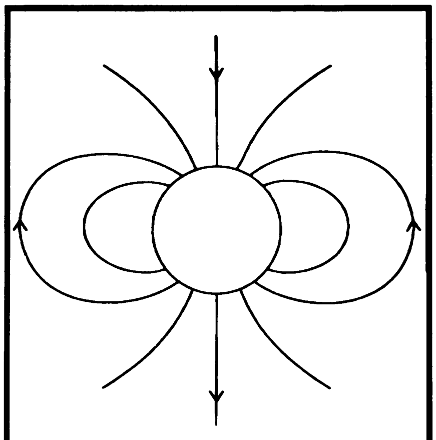
Geophysicists have long sought to understand what goes on during reversals, hoping this might give them some insight into how swirling currents of liquid iron within the core generate Earth's magnetic field.

While studies of reversals progressed rapidly in the 1960s and early 1970s, they hit a lull soon thereafter because accumulating evidence indicated that the magnetic field grew extremely complex during turnovers. This doused many researchers' hopes for deriving fundamental laws about the reversal process.

Unlike the simple field during stable times, the transitional field did not appear to retain a dipolar shape. Rather, it seemed to assume a form with a multitude of magnetic poles, suggesting a dizzying arrangement of field lines that loop in and out of the planet like a Spirograph pattern.

Evidence of such polar complexity appeared when scientists examined rocks at different sites around the world and tried to trace the shifting locations of the south magnetic pole back in time. If rocks at one site showed that the south pole passed through the Atlantic as the field reversed, rocks at another site suggested that the south pole traveled through Asia, and samples from a third site revealed yet another path, through Africa. In other words, the rocks seemed to indicate that a welter of south poles appeared during reversals, following no particular track when the field switched.

But Clement challenged the prevailing view in 1991 when he reported that pole paths from several locations showed a strikingly simple pattern that persisted for different reversals. Laj and his col-



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Schematic diagram of Earth's dipolar magnetic field, with lines and arrows showing orientation of magnetic field lines. The actual field tilts from Earth's spin axis. Because Earth's field is not a pure dipole, the north and south poles do not sit directly opposite each other.

leagues announced finding the same pattern in their own data. Rather than showing a random arrangement of numerous pole paths, both studies revealed that during reversals, the south pole tended to follow only two specific tracks: one through the Americas and another through Asia, on the opposite side of the globe.

Most important, these so-called preferred paths showed up again and again in reversals widely separated in time. To Clement and Laj, it seemed that some enduring factor inside Earth steered the pole along a particular pair of routes time and again over a period of 12 million years.

Looking to explain such persistence, both researchers knew they weren't likely to find an answer in the outer core, the region that generates the magnetic field. The problem is one of timing: The outer core consists of liquid iron, which swirls far too quickly to preserve flow patterns for millions of years.

Just above the fast-moving outer core, however, lies the sluggish mantle, a region of solid rock squeezed and heated so much that it slowly flows, moving at about the speed of a growing fingernail. At that clip, the mantle remains consistent over millions of years, making it a natural spot to look for a pattern that persisted through dozens of reversals.

In an influential map that appeared on the cover of the June 6, 1991 NATURE, Laj fingered one suspect that might have guided the polar path during reversals. The well-traveled tracks through the Americas and in Asia happen to lie above regions in the deep mantle that have unusually low temperatures, Laj pointed out. Such cool spots at the bottom of the mantle could stimulate flow patterns in the liquid core that would recur during most reversals, creating the paths seen in the sedimentary records.

Researchers had long surmised that the base of the mantle influences the magnetic field, but they had lacked any direct evidence to support that idea. Clement and Laj felt they had finally stumbled across a sign that the mantle does indeed play some role in the reversal process.

The connections may not stop there, though; they could extend all the way to the planet's surface. Many earth scientists believe the cool spots in the base of the mantle hold sunken pieces of Earth's outer shell that have been pushed deep into the planet through the process of plate tectonics. That would imply a previously unappreciated link between the planet's skin and its core, 3,000 kilometers underfoot.

During the last year, scientific journals have published a volley of papers alternately attacking and supporting the observations made by Clement and Laj, making the debate appear something like a tag-team tennis match with continuously rotating players.

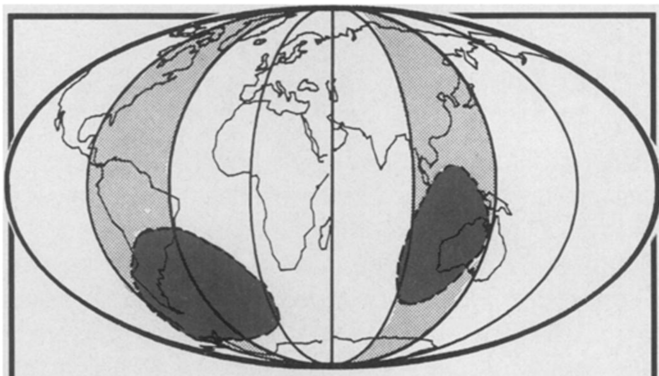
Geophysicists C.G. Langereis, A.A.M. van Hoof, and P. Rochette hit a hard return shot when they argued that the evidence for preferred paths may simply reflect an artifact in the way sedimentary rocks record the geomagnetic field. Langereis and van Hoof hail from the Paleomagnetic Laboratory at Fort Hoofddijk in Utrecht, the Netherlands, while Rochette works at the Faculté des Sciences Saint-Jérôme in Marseille, France.

In their argument, published in the July 16, 1992 NATURE, the three researchers focused on the way sedimentary rocks form. Because it takes thousands of years for sediments to accumulate on the ocean floor and get locked into place, rocks created from such layers do not present a crisp, detailed portrait of how the magnetic field behaves during a reversal. Instead, sedimentary rocks smear together different stages, producing a blurred image of events that occurred over many millennia. Langereis and his co-workers contended that this tendency could present a problem for people trying to study a relatively short event such as a reversal.

The task of finding an accurate reversal record seems all the more difficult because the magnetic field weakens considerably when it switches direction. Langereis' group argued that the sediments deposited during a reversal might therefore bear a blurry overprint of the much stronger, stable field immediately preceding or following the reversal. Examining a sedimentary record from Crete, the team showed that the reversal recording at this site apparently reveals more about the field before and after the reversal than about the field that existed during the event.

A group led by Jean-Pierre Valet of the Institut de Physique du Globe in Paris is also exploring ways in which sedimentary records distort the picture of a reversal. A former student of Laj's, Valet notes that investigators have not collected sediment cores in a uniform pattern around the world. Rather, he says, the sampling sites tend to group into particular bands of longitude that could introduce some bias in the paleomagnetic data, producing the false impression that the magnetic field behaves similarly during different reversals.

On the flip side, several researchers have weighed in with evidence supporting the idea that the mantle exercises control from one reversal to another. Hoffman, for instance, has reviewed data on the magnetic orientations stored within lava, a recording medium that doesn't pose the same problems encountered in sediments. Because lava hardens quickly after an eruption, it provides an instant snapshot of the field's direction.



Adapted from Hoffman/NATURE

Patches and paths: An analysis of volcanic rocks suggests that during many reversals, the magnetic field settles in one of two transitional orientations, with the south pole either in the South Atlantic or near Australia. These recurring pole positions fall within the bands of polar tracks seen in sedimentary records.

Volcanic records do pose a disadvantage, however: They provide information only for times when a volcano erupts. If a mountain blows just once during a particular reversal, a researcher studying that volcano will find a solitary snapshot recording the event.

Examining the lava data, Hoffman found that the magnetic field does behave similarly in several different reversals. In that way, the lava flows support the sedimentary record. But the two records also harbor important differences, he reported in the Oct. 29, 1992 NATURE.

Unlike the sedimentary record, the volcanic data do not show the pole repeatedly following a line of longitude up through the Americas or Asia. Instead, they indicate that the pole tends to return time and again to two discrete places in the southern hemisphere: one off the east coast of southern South America and another off the west coast of Australia. What makes things interesting is that these two clusters fall within or close to the preferred paths discerned in the sedimentary data.

The coincidences don't end there. The clusters detected by Hoffman also correspond with the locations of irregularities in the current magnetic field. These spots represent weak "nondipole" elements of the field – in other words, the part of the magnetic field left over when researchers theoretically subtract the dominating dipole.

Hoffman suggested that such nondipole elements are persistent parts of the magnetic field. To explain the clustering, he proposed that when the dipole weakens at the start of a reversal, it tends to reestablish itself temporarily in a tilted position, oriented in a way that corresponds with the field's nondipole component. That would put the south pole at one of the clustering sites in the South Atlantic or near Australia.

As Hoffman envisions it, the south pole hops to different spots around the globe in a seemingly random way throughout the reversal, but it lingers for the longest spells in one of these special patches. Although each reversal looks different in the lava data, Hoffman found that the pole tended to seek the same two patches in many reversals over the past 10 million years. That evidence pushed him toward the conclusion reached by Clement and Laj two years earlier – that long-lived features inside Earth direct the behavior of the flipping magnetic field.

Other geophysicists, especially in Europe, say the evidence of a mantle influence remains far too flimsy at this point. For every study that suggests some type of recurring reversal pattern, another study appears that bashes the idea.

Pierre Camps and Michel Prévot of the University of Montpellier in France have reviewed the existing lava data for all reversals during the last 16 million years. Using this more complete record, Camps and Prévot could not confirm the clustering that Hoffman found in a limited number of reversals. They reported their findings at a meeting of the European Union of Geosciences, held in Strasbourg in April.

"We don't observe any longitudinal confinement of the magnetic poles," says Prévot. "They are not preferentially located over the Americas. They correspond to a uniform distribution."

While the band of skeptics remains strong, one of their ranks has recently undergone a reversal of his own. In the May 5 GEOPHYSICAL RESEARCH LETTERS, van Hoof presents a detailed study of sedimentary rocks from southern Sicily that apparently supports Hoffman's idea of the magnetic pole lingering in select sites during a reversal.

So the debate will continue, as geophysicists circle the globe looking for new data to test the theory that the mantle helps steer the course of geomagnetic reversals. For his part, Laj grants that the additional sedimentary and volcanic records could well disprove the idea, but he would prefer to see that simple theory win out in the end.

"It gives some sort of unity to the Earth, from the upper part to the deep interior," he says. "I hope it is true, because it is so very elegant." □