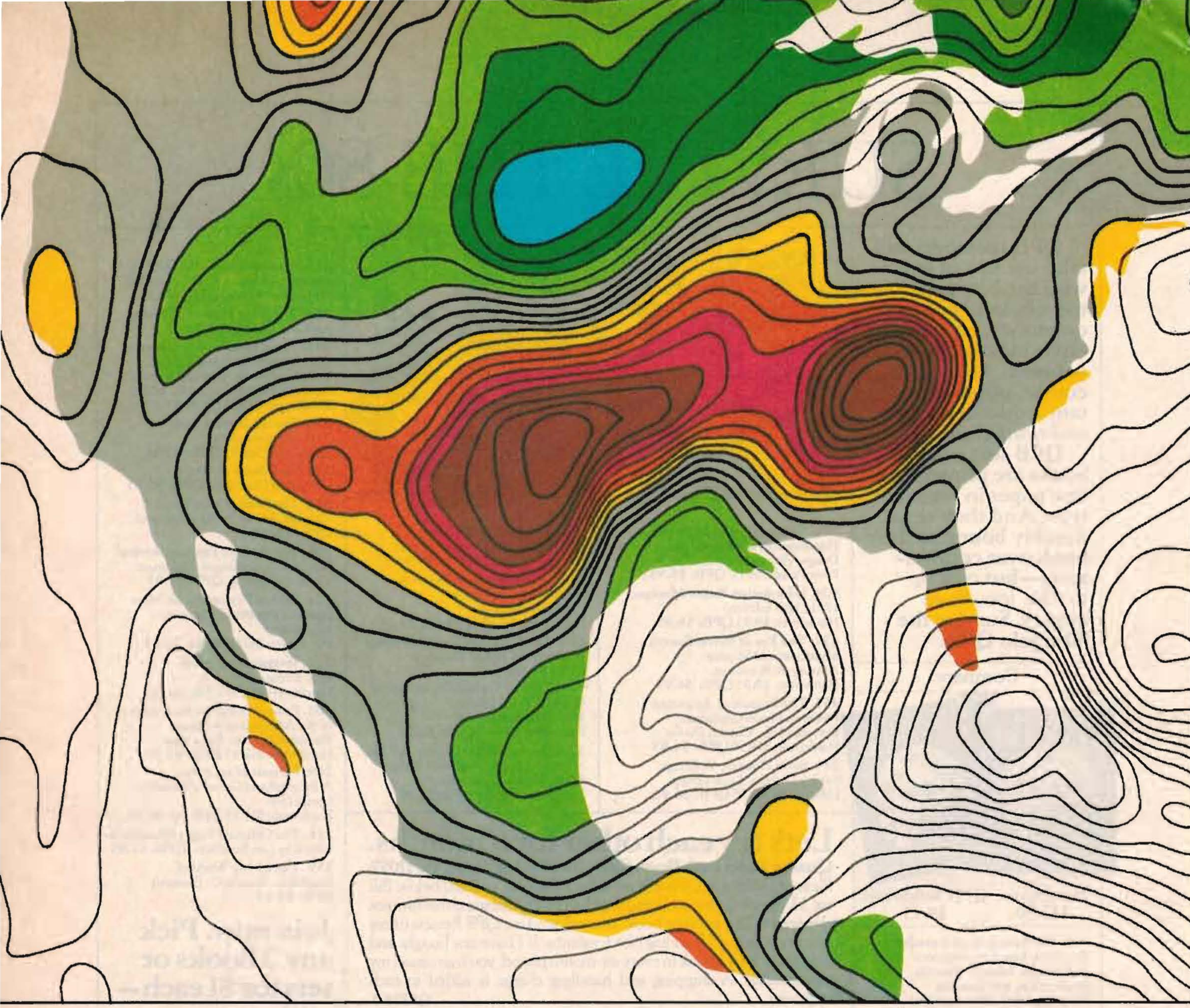


# MAPS OF MAGNETISM

New satellite maps of magnetic features in the earth's crust may reveal geological secrets

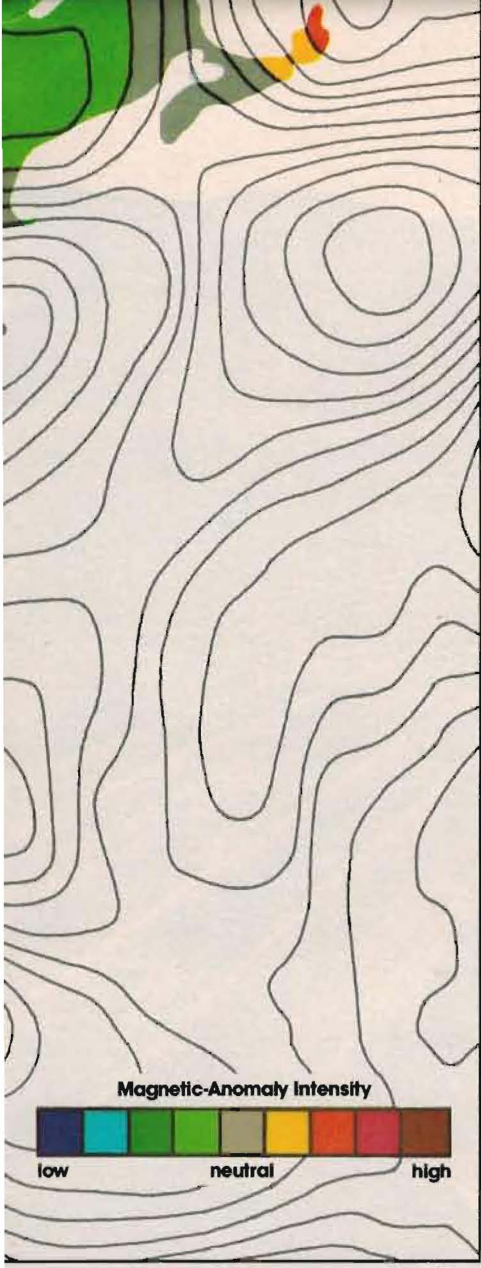
by MARCIA BARTUSIAK

High above the North Atlantic last June, a bright ball of light traced a path across the early morning sky. Like a meteor, Magsat (magnetic field satellite) was plunging back into the atmosphere after nearly eight months in space. Now, months after the satellite's fiery death, its mission has begun to pay off—in the remarkable maps shown above and on page 45.

While in orbit some 250 miles up, the satellite took more than a billion readings of the strength and direction of the earth's magnetic field. Scientists have grappled with only a small fraction of those Magsat data, which are now spewing out of NASA computers. Each of the magnetic measurements includes several components. The largest is contributed by the earth's main field, which scientists believe is generated by the motion of the fluid portion of the plan-



ILLUSTRATIONS OF NASA MAPS BY JOHN HAINES




**Map shows magnetic features in the United States arising from sources deep in the earth's crust. They range in intensity from low (blue) to high (brown)**

et's iron core and which causes compasses to point north. It is much like the field that a giant bar magnet would produce if it were placed at the center of the earth along the axis. A smaller, yet no less important contribution comes from "magnetic anomalies," the very faint fields caused by sources deep within the earth's crust. In the view of many scientists, those anomalies—in effect, magnetic signatures of the rocks beneath the earth—will provide the most interesting portrait of the planet, perhaps solving long-standing geological mysteries.

Magsat's colorful anomaly maps, here published first by DISCOVER, were produced by scientists at NASA's Goddard Space Flight Center in Maryland from the data analyzed so far. In coming months, the global charts will be improved to include even more detail. "It will be some years before these maps are fully understood," says Robert Langel, project scientist for Magsat and a physicist at Goddard. "But they are expected to shed new light on the geology of the deep crust. It is one of the few tools we can use to look at the crust all the way down to the earth's mantle. Drilling can penetrate only a few miles into the crust."

Resembling isobaric weather maps, the preliminary charts show magnetic irregularities ranging from reddish-brown "highs," like the one centered over Kentucky in the map at the left, to blue-green "lows," like those shown in the western states. Each bright color tells the scientists how rocks beneath the surface are being magnetized by the main field—much the way a needle is magnetized by being rubbed on a magnet. The highs pinpoint areas where the crustal fields are adding to the strength of the main field; the lows subtract. The grey areas indicate regions in which the rocks are unaffected, at least on this large scale. The swirls of color promise to provide clues about the composition, temperature, and structure of the crust below. They may also reveal more about the tectonic forces that ever so slowly are moving huge crustal slabs around the face of the globe, causing continental drift, earthquakes, and volcanoes.

Magsat maps may help nations around the world assess their natural resources and decide on long-range strategies in the search for oil and minerals. Says Gilbert Ousley, Magsat's project manager, "Magsat is providing new information on crustal composition over very large areas, including those in which bedrock is poorly exposed. It will be helpful in selecting the most promising areas for mineral exploration." In the American southwest, for example, copper deposits often appear in certain kinds of granite found in regions of block faulting—places where the crust has been cracked into blocks of different elevations. Chromium is usually located in large intrusions of older, iron-rich igneous rock, which is formed by the solidification of molten material. Each formation may have a different magnetic signature that scientists will some day be able to detect on Magsat contour maps.

A major problem in preparing the maps was the wide disparity between the intensity of the earth's main magnetic field and that of the magnetic anomalies. At the surface of the earth, the main field has an intensity of half a gauss,* about the strength of a toy magnet. The anomalies are about ten thousand times as weak. To sort out the anomaly readings that were needed to prepare these maps took months of painstaking screening and hundreds of hours of computer analysis.

Airplanes equipped with magnetometers have been used for years by oil and mining companies to map magnetic fields and locate underground resources. But these low-altitude surveys can discern only local geological structures, like a surface fault or a mountain. Not until the 1970s did scientists realize that they could use satellite data to describe large-scale magnetic features that spanned entire continents. Magsat has provided by far the best resolution to date. "Only ten years ago nobody thought you could do this, because the intensities are so small," says Langel. "Even I laughed at first, but I started believing when the anomalies always showed up during analysis of the satellite data. It's a totally new ball game."

Mapping the global anomalies is one thing; understanding them is another. One scientist who has made some progress in translating them is Michael Mayhew, a geophysicist with Business and Technological Systems, a consulting firm in Maryland. Mayhew believes that some of the anomalies coincide with stretches of thin crust, where heat flows out of the earth's interior relatively quickly. In the western United States, for example, these regions are marked by geysers and hot springs. Below these hot spots, Mayhew believes, the lower boundary of the "magnetic crust"—the point at which the rocks lose all their magnetism—is unusually close to the earth's surface. So, in his view, the broad magnetic low east of California results from a thin magnetic crust, perhaps only ten miles deep. In other places, the magnetic crust can extend all the way down to the mantle, which starts at 20 or more miles below the surface. The magnetic crust can be compared to a blanket with some thin spots in it laid over a source of heat (the mantle); obviously, more heat flows through the thin spots.

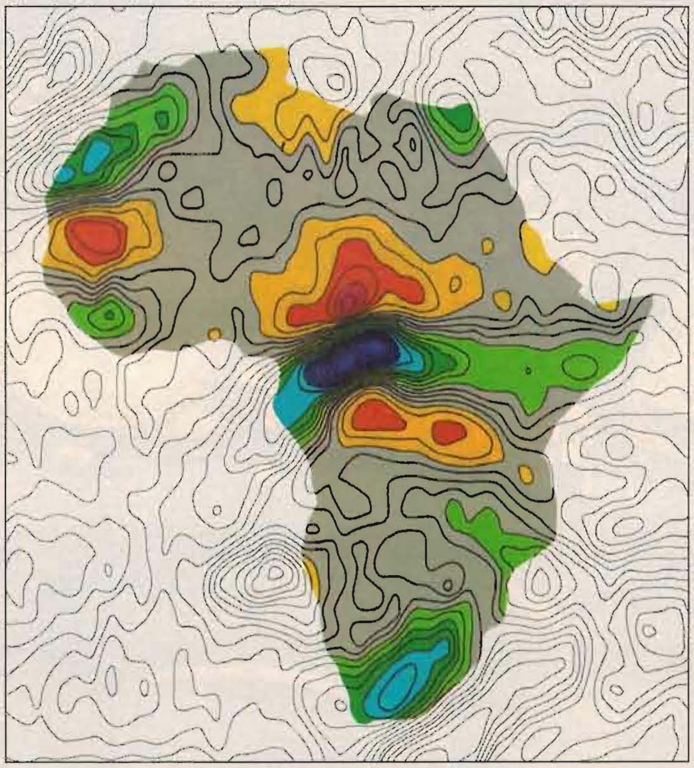
**Unit of magnetic field strength named for the 19th century German mathematician Karl Friedrich Gauss*

This connection between anomalies and heat flow may make it easier for geologists to locate new regions that can be tapped for geothermal energy. According to Mayhew, the Great Plains look promising. "This is not to say we can pinpoint specific sources from the maps," he cautions. "But it does suggest we can find large regions that have good potential."

Other anomalies appear to be caused by huge underground structures with unusual magnetic properties. Says Langel, "It's like a rock buried in a mud puddle." The intense magnetic high in the eastern United States may result from such a source. Says Mayhew, "Geophysical data suggest that there is a large mass of unusually magnetic dense rock centered right beneath Kentucky." That "Kentucky body" is about 125 miles long and 40 miles wide, and lies from 4 to 18 miles below the surface. Similarly, a large magnetic high in the Soviet Union, just north of the Black Sea, sits atop a huge deposit of magnetite, an iron ore that is strongly magnetic. Africa has the Bangui anomaly, one of the first discovered by satellite. This conspicuous magnetic low, in the center of the continent, is thought to be connected to a mass of once molten rock that forced its way to the surface more than a billion years ago.

Stephen Haggerty, a geologist with the University of Massachusetts, is intrigued by the Bangui feature as well as by other lows in western and southern Africa. "All these magnetic lows appear over areas in Africa where kimberlite is located exclusively," says Haggerty. "That mineral is found nowhere else on the continent." This observation is of more than academic interest; kimberlite is the type of rock in which diamonds are found. But that does not mean diamonds would be a sure bet in all magnetic lows; the anomalies are much more complicated than that. Langel stresses that each anomaly is too large for use in pinpointing individual deposits. Also, a magnetic low or high in Africa is not necessarily the same as one in the United States. The nature of an anomaly seems to depend on its latitude (a rock at the poles will not interact with the earth's main magnetic field in the same way as a similar rock at the equator) and on its cause—higher heat flows, massive underground rocks, tectonic movements, or perhaps a combination of factors.

To bring some order out of the growing mass of magnetic data, Herbert Frey, a geophysicist at Goddard, decided to see whether the earth's interesting geological features matched up with any anomalies. He has had some success. "The big magnetic high in western Africa sits right over a craton, an area of very ancient crust about three billion years old," says Frey. "The same is true for magnetic highs in Saudi Arabia, western Australia, and the Szechwan Basin in China, although it's still not known why."



**Magnetic anomalies in Africa**

Frey is also finding clues in rift valleys, where the movement of tectonic plates has pulled apart the earth's crust to form a depression. He points out that in Africa, the extensive high situated just north of the Bangui anomaly seems to follow the contour of the Benue Trough, a rift produced when Africa nearly split apart some 150 million years ago. Frey finds it noteworthy that the rift forming the Mississippi River Valley runs along a sort of pathway between the two United States highs. Why? Frey is not certain. "The earth is a mosaic where pieces of the crust have been pulled apart and put back together over millions of years," he says. "It looks as though many of these anomalies are associated with major blocks of the earth's crust. The bottom line will be explaining why some are highs and others lows."

Many scientists suspect that areas showing the greatest range in magnetic anomalies will turn out to be those that have experienced intense tectonic activity. For example, the subcontinent of India is covered by a large magnetic high that butts against an intense low stretching along the Himalayan mountains to the north. This close association of a high with a low may reflect how the crustal slab on which India rests is being inexorably thrust under the edge of the larger Asian plate, forming the Himalayas in the process. "A geologist can walk along the surface of the earth and see a feature, but he doesn't know how deep it extends," says G. Randy Keller, a geophysicist with the University of Texas at El Paso. "Magsat comes along and can tell us that it is not a simple fault, but rather the result of two continents slamming into each other."

Whatever the cause, some of these anomalies seem to be magnetic features that last over thousands, perhaps even millions of years. To prove that point, Frey and his colleagues used the anomaly maps to reconstruct Pangaea, the supercontinent presumed to have existed some 200 million years ago, when the Americas, Africa, Antarctica, and Australia were a single land mass. They found that certain magnetic highs in Australia and Antarctica "matched up" when those continents were assigned their former positions. Says Frey, "This shows that at least some of the anomalies are of very long standing."

The Magsat scientists have their work cut out for them. They plan to keep matching magnetic anomalies with measurements of seismic activity and rock densities until they have mapped a complete model of the earth's crust and upper mantle. Says Frey, "We have enough data to keep us busy for many years to come." ◼