Plate Tectonics . . . on Mars

Magnetic map reveals ancient activity on the Red Planet

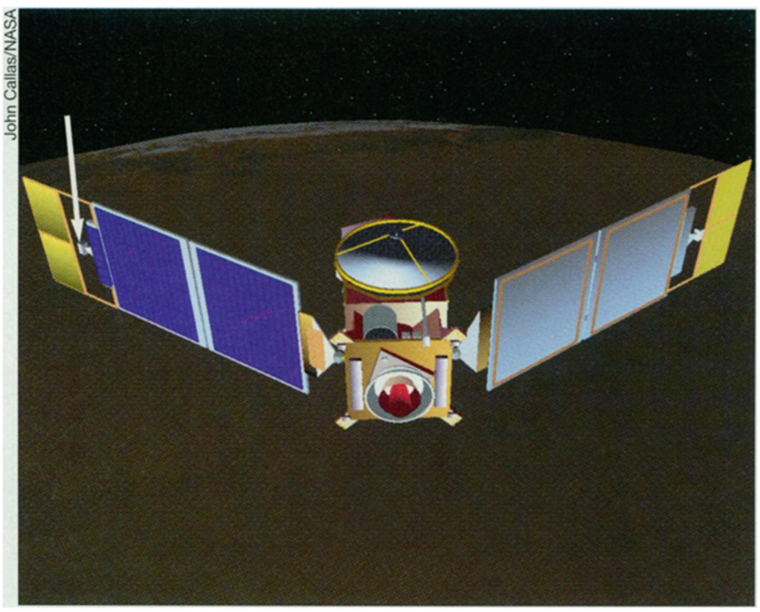
By RON COWEN

Slipping, sliding, sinking, rising: Earth's surface is in constant motion. Fragmented into giant sheets of solid rock that glide atop a layer of hotter, more pliable material, the globe's appearance is forever changing. Where two sheets meet, violent activity ensues. When they crash head-on, mountains arise; where one sheet dives under another, earthquakes may erupt.

Scientists first proposed this movement, now known as plate tectonics, in 1912, but confirmation didn't come until the 1960s. Since then, this model has revolutionized understanding of the forces that shape our planet.

Now astronomers have found evidence that another planet may have undergone a similar series of facelifts. New measurements of Mars' magnetic field suggest that plate tectonics reigned supreme on the Red Planet—for at least the first half billion years or so of its 4.5-billion-year existence.

The movement of sheets of crust could have been every bit as important on the Mars of long ago as it is on Earth today, says Jack E.P. Connerney of NASA's Goddard Space Flight Center in Greenbelt, Md. In the April 30 SCIENCE, Connerney, Mario H. Acuna of Goddard, and their colleagues describe magnetic activity on Mars observed by the Mars Global Surveyor spacecraft.


John Callas/NASA

Drawing shows magnetometer (arrow) mounted on the solar panel of the Mars Global Surveyor spacecraft.

Planetary scientists have contended for more than 25 years that water was once abundant on Mars. Early images had revealed dried-up channels scarring the planet's surface.

"If one believes early Mars was wet, then it makes plate tectonics more reasonable," says Gerald Schubert of the University of California, Los Angeles. "Alternatively, one could turn this around . . . accept plate tectonics, and use this as independent support for a lot of water on early Mars."

On Earth, water serves as a natural lubricant that helps keep the sheets of crust in motion. Connerney suggests that water may have played the same role on ancient Mars.

As the movement of plates dredged up rock from the depths of Mars and brought it back down again, it could have transported both water and carbon dioxide. The recycled carbon dioxide may have generated, or at least helped sustain, a dense, carbon-rich atmosphere early in the history of Mars. This blanket of greenhouse gas could have warmed the planet. Plate tectonics thus would add support to the view that the Red Planet was once a warmer, wetter place with a climate hospitable for life.

An end of plate tectonics on the Red Planet several billion years ago could explain an enduring mystery: If the surface of Mars once had an abundant supply of water, where did it all go?

Geologist Norman H. Sleep of Stanford University argues that water continually transported to and from the surface as a result of plate tectonics would have been trapped in the planet's crust after tectonic activity ceased. Little water would have been left on the surface once plate tectonics stopped, he says.

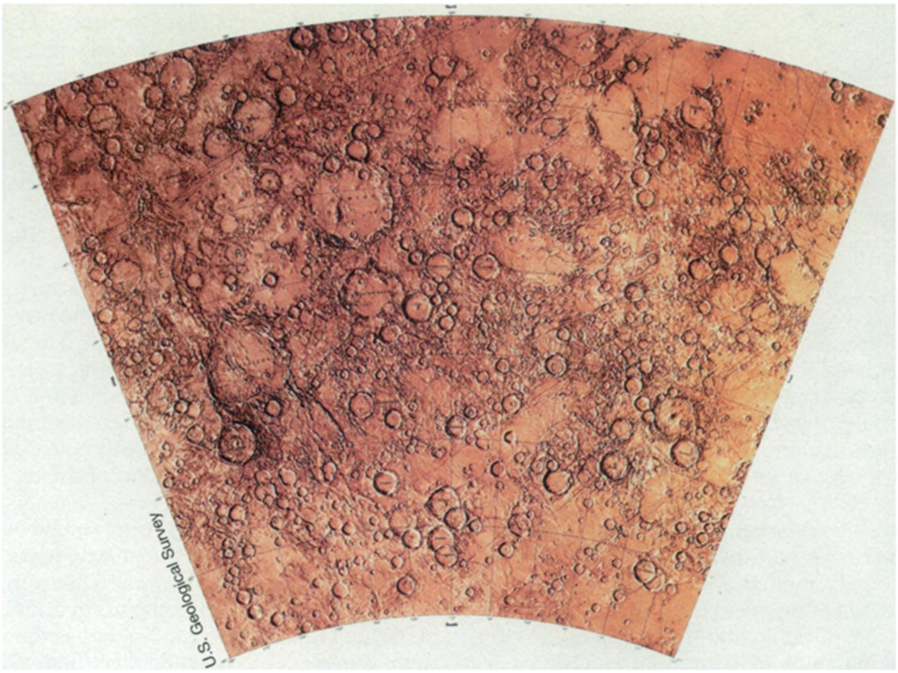
Five years ago, Sleep proposed that plate tectonics could have created the vast lowlands on the northern half of Mars, just as it has formed ocean basins on Earth.

If plate tectonics proves correct, it "explains and unifies the entire geological history [of the Red Planet]. It also will provide a second example to help understand the physics of plate tectonics on Earth," Sleep says.

Adds Maria T. Zuber of the Massachusetts Institute of Technology, "It's going to tell us much more about how the core of the planet dumped its heat." That's vital, she says, because heat loss from the planet's interior might explain why the ancient planet was warm enough and its atmosphere thick enough for water to exist on the surface.

"The thermal state of the interior of the planet is something that you really need to understand to get to the early climate history of Mars. It's a very critical piece of the puzzle," Zuber says.

The new findings stem from measurements made by a magnetometer aboard Mars Global Surveyor, which has orbited the planet since the fall of 1997. Unlike visible-light cameras and X-ray and gamma-ray detectors, which probe at or just beneath the surface, a magnetometer senses activity several kilometers below. Shortly after it arrived in Mars' vicinity, the spacecraft swooped low enough to search



Map of Terra Sirenum, an ancient, heavily cratered area in the Martian southern highlands. Magnetic measurements suggest that plate tectonics played a role in forming the region.

for magnetic activity along a narrow band of the planet near the north pole.

Surveyor detected several magnetized patches of terrain, some with fields as strong as 400 nanoteslas, or 1.3 percent of Earth's field (SN: 10/18/97, p. 246). The most likely explanation for the magnetic features, Connerney noted then, is that they are relics of a global magnetic field active on Mars long ago.

This past January, as part of a maneuver to trim the craft's elliptical orbit into the circular one designed for mapping the planet, Surveyor dipped down into Mars' dense upper atmosphere. It got low enough—101 to 110 kilometers above the surface—for the magnetometer to map a vast region called Terra Sirenum. This highland terrain takes up about one-third of the southern hemisphere.

With those observations, "we won the lottery," says Acuna, leader of the international team of scientists that coordinates magnetic studies on Surveyor. While passing over several strips of land in Terra Sirenum, Surveyor detected buried magnetic fields four times stronger than those it had recorded in the northern region.

The craft, however, found no sign of a magnetic field in the vicinity of several huge, ancient craters. These include the 8-km-deep, 4,200-km-wide hole in the ground known as Hellas, Acuna and his colleagues note in this week's SCIENCE.

Astronomers believe that these craters formed when chunks of debris pelted the inner solar system some 3.8 billion years ago. As old as these craters are, the global magnetic field that once existed on Mars must have vanished before they formed, Acuna asserts.

Any large impact, he notes, heats rock to temperatures well above 600°C—high enough to erase any magnetic field that metallic particles within the rock might have acquired. If the Martian field was still strong at the time the craters formed, it would have immediately realigned and remagnetized the particles as they cooled.

The observations over Terra Sirenum thus suggest that the magnetic field—as well as the turbulent conditions required to generate one—lasted on Mars for only a few hundred million years.

"The planet started off very hot and cooled very fast, which you would expect for a small object," says Acuna. Mars has half the diameter of Earth.

Scientists believe that the Martian field arose the same way that Earth's still-active field did, through the action of a dynamo generated by the rise and fall of molten material deep within a rotating planet.

Knowledge of the duration and strength of the dynamo may ultimately reveal the composition of the Martian core, in particular the relative amounts of iron and sulfur it contains. Too little sulfur, and the fluid might congeal too rapidly to generate a magnetic field lasting for even a few hundred million years. Too much sulfur, and the molten material generating the dynamo would maintain the magnetic field even to the present.

"The dynamo tells us what was going on inside of Mars," Acuna notes.

The measurements also date the Martian crust. Areas in which Surveyor detected magnetic fields must be essentially untouched from the earliest days of the planet, 4 billion years ago, when the magnetic field was active. In the southern highlands, "what we're looking at is the oldest surviving unmodified crust of Mars," Acuna says.

Dating the age of ancient crust and determining how long the magnetic field lasted on the Red Planet are but two of the feats accomplished by the magnetometer. During its passage over Terra Sirenum, the detector recorded an intriguing pattern that could change forever the way planetary scientists view the history of Mars, Connerney says.

As Surveyor flew over Terra Sirenum, the magnetometer acted like a compass needle alternately pointing north and south. The instrument indicated that Terra Sirenum is divided into several stripes, each about 200 km wide, whose residual magnetic fields point in opposite directions. That same pattern, known as magnetic striping, led geologists in the 1960s to conclude that plate tectonics continually reshapes Earth's surface.

Connerney's interpretation of the striping hinges upon the observation that a dynamo periodically flips the direction of its magnetic field. Earth's magnetic field, for example, averages several reversals every million years.

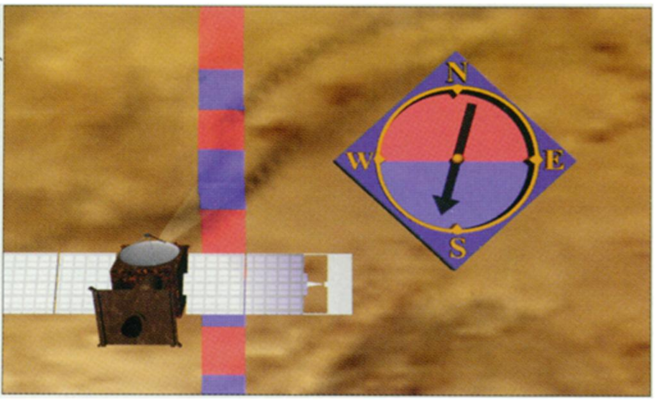
The stripes of iron-rich rock on Mars have different magnetic orientations, he argues, because they solidified at different times. Each stripe represents a snapshot of the Martian magnetic field from a different epoch.

So far, so good. But why should the surface exhibit the striping pattern rather than consisting of a jumble of patches with randomly oriented magnetic fields?

To explain the pattern discovered by Surveyor, Connerney introduces the idea of plate tectonics. He suggests that striping arose at ancient Martian sites where neighboring plates of rock slowly pulled apart, allowing molten material from below to rise to the surface and form new crust. If the planet's magnetic field had flipped its polarity between the times that the old and the new crust solidified, the freshly generated crust would carry a magnetic imprint exactly opposite to that of the plates on either side of it.

"This magnetic imprint that we see is similar to the imprint that we see on Earth where plate tectonics is making new crust in the ocean," says Connerney. "So we think this is certainly a possible explanation for what we see on Mars."

If anything, the magnetic data collected by Surveyor is more clear-cut than comparable measurements made on Earth, Connerney adds. "In all the centuries that we've been making magnetic measurements on Earth, we've never



Chris Meaney/NASA

Red and blue colors represent reversals in magnetic field direction found in adjacent strips of the Martian crust in a region known as Terra Sirenum. The Mars Global Surveyor spacecraft passed over Terra Sirenum in January, as part of a maneuver to trim the craft's elliptical orbit into a circular one.

produced a map quite like this," he says.

Any magnetic map of Earth's crust, Connerney notes, must contend with our planet's still-active global magnetic field. That makes it difficult to determine whether a magnetic signal from the crust represents a permanent field—akin to a bar magnet embedded in the rock—or a field induced by Earth's still-active global magnetic field.

On Mars today, "there is no global magnetic field," he says. Consequently, measurements truly reflect a remnant field rather than an induced one. "Clearly, you can do things on Mars that a geophysicist can only dream of doing on Earth."

The younger, northern lowlands of Mars show no evidence of striping, and much less of the crust appears to be magnetized, Connerney says. These observations suggest that both the Martian magnetic field and plate tectonics had died away before volcanic activity melted and resurfaced this vast region of the planet.

It's possible that the fading of the global magnetic field and plate tectonics are intimately linked, Connerney speculates. When the interior lost so much heat that it could no longer power the dynamo, it may also have had too little energy to drive plate tectonics.

Schubert says he's skeptical about interpreting the magnetic field measurements as evidence of plate tectonics. He says that Connerney and his colleagues need to consider other models before concluding that Terra Sirenum is composed of elongated sheets of rock that have opposite polarity.

Moreover, Acuna argues that a process completely independent of plate tectonics could explain magnetic striping. He proposes that stresses or fractures in the crust may account for the pattern. Breaks in the crust could jumble the original magnetic signature and create a new, oppositely directed field. The process, he says, is similar to what happens when a bar magnet is cut in two. The cut ends generate a north pole and south pole opposite in direction to the field of the uncut magnet.

"These hypotheses are going to take a lot of testing," comments Zuber, who plans to look for signs of plate tectonic activity in gravity maps compiled from Surveyor data. "What I think is going to hold up is that there is evidence of a dynamo action really, really early in Mars' history, and then it appeared to shut off rapidly," she says.

If ancient Mars truly did undergo a period of plate tectonic activity, says Zuber "then it's a real home run." □

Astronomy

Black holes go middle class

Astronomers generally accept the existence of two kinds of objects that wield enormous gravitational pull: baby black holes just a few times more massive than the sun and giant black holes weighing as much as a billion suns.

Two groups of researchers now claim to have found a new, intermediate class of these bizarre beasts—black holes 100 to 10,000 times as massive as the sun.

"This is a new mass range that doesn't have a clear explanation," says study collaborator Edward J.M. Colbert of NASA's Goddard Space Flight Center in Greenbelt, Md.

One theory suggests that the midsize black holes arise from the merger of many smaller black holes. In another proposal, middleweights formed outright early in the universe and will ultimately pack on enough mass to become supermassive black holes, like the one believed to lurk at the core of our own galaxy.

The two teams studied X-ray emissions from galaxies suspected of harboring dense concentrations of matter near their cores. Both groups reported their results in mid-April at a meeting of the American Astronomical Society in Charleston, S.C.

As dust and gas disappear into a black hole, they emit a swan song of X rays. Studying the X-ray spectra with the Japanese satellite ASCA, Colbert and Richard Mushotzky of Goddard found that 10 of 17 nearby spiral galaxies emit a pattern of radiation expected from middleweight black holes. Colbert says that half of all spirals may contain midsize black holes. The team's survey of elliptical galaxies proved inconclusive.

Andrew Ptak and Richard Griffiths of Carnegie Mellon University in Pittsburgh found the same X-ray signature in the starburst galaxy M82. Starburst galaxies contain many massive stars, which provide the raw material for black holes.

Ramesh Narayan of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., says that the findings are intriguing. However, he cautions that determining the mass of a black hole by studying its X rays is not nearly as accurate as inferring its weight from its tug on neighboring objects. —*R.C.*

Life on Mars: Take two

They're at it again. The same team that 3 years ago made the controversial suggestion that a 4.5-billion-year-old Martian meteorite contains fossils of tiny bacteria has now announced finding similar fossils in two much younger rocks from Mars.

Using electron microscopy, researchers from NASA's Johnson Space Center in Houston and their colleagues identified minute spherical and rod-shaped features suggestive of fossils in the Martian meteorites Nakhla, about 1.3 billion years old, and Shergotty, about 180 million years old.

"Because we are finding evidence for fossilized organisms in meteorites with such young ages, it is conceivable that there could still be life somewhere on Mars at the present time," says study collaborator Kathie Thomas-Keptra of Lockheed Martin Corp. in Houston. Her team announced the findings in March at the annual Lunar and Planetary Science Conference in Houston.

Thomas-Keptra says the possible fossils have much in common with mineralized bacteria found in terrestrial rock known as Columbia River basalt. The spherical and rod-shaped features in the Martian samples are rare but occur in patches, a pattern "highly suggestive of biological activity," she notes. "Inorganic chemical precipitation, for example, would not likely occur in sporadic, random, colonylike patches."

John P. Bradley of MVA in Norcross, Ga., and the Georgia Institute of Technology in Atlanta says it's best to keep an open mind. However, he says that there's no compelling evidence that these features must be fossils. "The absolutely key prerequisite is to look inside these objects to see if you can see cellular structure," he says. "In the absence of that, [the scientists are] going to spin their wheels." —*R.C.*