Simulations, ancient magnetism suggest mantle plumes may bend deep beneath Earth's crust

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Computer simulations, paleomagnetism and plate motion histories described in today's issue of *Science* reveal how hotspots, centers of erupting magma that sit atop columns of hot mantle that were once thought to remain firmly fixed in place, in fact move beneath Earth's crust.

Scientists believe mantle plumes are responsible for some of the Earth's most dramatic geological features, such as the Hawaiian islands and Yellowstone National Park. Some plumes may have shallow sources, but a few, such as the one beneath Hawaii, appear to be rooted in the deepest mantle, near Earth's core.

Such deep plumes have long been thought to be so immobile that the motions of continental and oceanic plates were measured against them, but University of Rochester geophysicist John Tarduno and his colleagues at Ludwig-Maximilians, Münster, and Stanford universities have combined magnetic evidence from the Pacific sea floor with computer modeling to show how the plume beneath Hawaii likely bent—its root barely moving while its top moved nearly 1,000 miles across the underside of the Pacific Ocean.

"In 2003, we showed that the hotspot—the plume—that created the Hawaiian chain of islands must have moved. We suggested that mantle motion was involved, but the cause of the change in motion remained a mystery," says Tarduno.

Tarduno cites five possible mechanisms in *Science*, but one in particular, he says, stands out as a likely explanation for the way the Hawaiian chain of islands and seamounts formed. "We know from theory and from models, including work by Ulrich Hansen and Norm Sleep, that a plume can move slightly near its base, potentially contributing to motion of the Hawaiian hotspot and hotspots elsewhere," says Tarduno. "But a key observation came from a numerical simulation resulting from Hans-Peter Bunge's models, which show how the upper end of the plume, starting at 1500 depth, can drift like a candle flame drawn toward a draft."

The draft in this case, he says, is an ancient oceanic ridge in the Pacific where the seafloor spreads, allowing magma to bubble up through the ocean crust. The ancient ridge is now lost to subduction, but its past presence is recorded by a few magnetic lineations in oceanic crust south of the Bering Sea. The ridge was active around 80 million years ago but extinguished completely by 47 million years ago. Those dates correspond very closely with the motion history Tarduno detected in the Hawaiian hotspot.

In 2001, Tarduno and an international team spent two months aboard the ocean drilling ship JOIDES Resolution, retrieving samples of rock from the Emperor-Hawaiian seamount chain miles beneath the sea's surface. The team started at the northern end of the chain, near Japan, braving cold, foggy days and dodging the occasional typhoon to pull up several long cores of rock as they worked their way south. Using a highly sensitive magnetic device called a SQUID (Superconducting Quantum Interference Device), Tarduno's team discovered that the magnetism of the cores did not fit with the conventional wisdom of fixed hotspots.

The magnetization of the lavas recovered from the northern end of the Emperor-Hawaiian chain suggested these rocks were formed much farther north than the current hotspot, which is forming Hawaii today. As magma forms, magnetite, a magnetically sensitive mineral, records the Earth's magnetic field just like a compass. As the magma cools and becomes solid rock, the "compass" orientation is locked in place, preserving a precise record of the latitude of origin.

If the Hawaiian hot spot had always been fixed at its current location of 19 degrees north, then all the rocks of the entire chain should have formed and cooled there, preserving the magnetic signature of 19 degrees even as the Pacific plate dragged the new stones north-westward. Tarduno's team, however, found that the more northern their samples, the higher the samples' latitude. The northern-most lavas they recovered were formed at over 30 degrees north about 80 million years ago, nearly a thousand miles from where the hot spot currently lies.

"The only way to account for these findings is if the hotspot itself was moving south," says Tarduno. His magnetic readings leveled off at a latitude of nearly 19 degrees, suggesting that the magma plume ceased moving in the area it resides in today.

In addition to the "draft" created by the upwelling of magma into the paleo-ridge, Tarduno says that theory and computer simulations suggest that the most a plume can bend under such conditions would result in about 1,000 miles of movement across the crust—matching what he sees as the distance between the start and stop points of the Hawaiian hotspot. He points out that the bending of a mantle plume helps reconcile the evidence of mobile hotspots on the Earth's crust with the theories that suggest plumes originate in the deepest mantle where high viscosity limits rapid motion. He points out that the plume-ridge capture mechanism may also help explain seemingly anomalous volcanic features on the seafloor, and help geoscientists to use ancient volcanic tracks to understand the past flow of Earth mantle.

Source: University of Rochester (news : web)

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