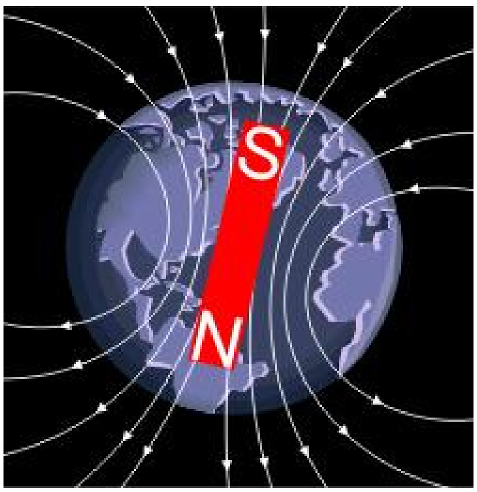
Reversals of Earth's Magnetic Field Explained by Small Core Fluctuations

April 23 2009, By Lisa Zyga



According to a new model, small fluctuations in convective flow in Earth's core can explain how the Earth's magnetic field reverses. Image credit: Wikimedia Commons.

(PhysOrg.com) -- Based on studies of old volcanic basalt, scientists know that the Earth's magnetic field reverses at irregular intervals, ranging from tens of thousands to millions of years. Volcanic basalt rock contains magnetite, and when the rock cools, its magnetic properties are frozen, recording the Earth's magnetic field of the time. With this data, scientists estimate that the last magnetic field reversal occurred about 780,000 years ago.

Although volcanic basalt reveals when reversals occurred, it's much more difficult to find evidence for why or how the Earth's magnetic field reverses. In a recent study, scientists from the Ecole Normale Supérieure and the Institut de Physique du Globe de Paris, both in Paris, have proposed a general mechanism that provides a simple explanation for field reversals. In their model, small fluctuations in convective flow in Earth's core can push the planet's sensitive magnetic system away from one pole toward an intermediate state, where the system becomes attracted to the opposite pole.

"We have found a mechanism that gives simple explanations of many features of the reversals of Earth's magnetic field," François Pétrélis of Ecole Normale Supérieure told *PhysOrg.com*. "In particular, it explains the existence and the shape (slow phase followed by fast phase) of reversals, the existence and the shape of aborted reversals ('excursions'), the statistical properties of reversals, and the possibility for very long durations without reversals ('superchrons')."

At present times, the Earth's magnetic field can be described as a magnetic dipole, with the magnetic south pole currently located near the Earth's geographic north pole, and the magnetic north pole near the geographic south pole (both magnetic poles are misaligned along the Earth's rotational axis by about 11.3 degrees). The existence of such a long-lived magnetic field can be explained by dynamo theory, which describes how a convective, electrically conducting fluid that rotates can maintain a magnetic field.

As the scientists suggest, the reversal mechanism relies on the existence of a second magnetic mode, in addition to the dipolar field. The presence of a second mode, such as a quadrupolar field, can have significant effects on how the magnetic system reacts to changes in equatorial symmetry. As the researchers explain, the equator can be thought of as a plane of symmetry, and the convective flow in the Earth's outer core is usually north-south symmetric. Previous studies on paleomagnetic data have proposed that reversals involve an interaction between the dipolar and quadrupolar modes, which would correlate with changes in equatorial symmetry. In support of this idea, some recent numerical simulations have shown that reversals do not occur when the convective flow remains equatorially symmetric.

"The quadrupolar field (it is likely to be a quadrupole but another structure could be possible) is also generated by the flow of the liquid core of the Earth, exactly like the dipolar field," explained the researchers. "Most of the time, we observe a dipolar field because it is more easily generated by the flow, but in other conditions a quadrupolar field could be maintained, and this occurs in a temporary manner during a reversal."

To further explain the dipole-quadrupole interaction, the scientists invoked a model that was recently used to describe the dynamics of a magnetic field generated in a very different system: a lab experiment involving a von Karman swirling flow of liquid sodium (which, like the Earth's magnetic field, is generated by the dynamo effect). The scientists suggest that a general mechanism could explain both magnetic fields, independent of the different symmetries and velocities of the two systems.

"We have shown that if the dipolar field of Earth is coupled to another magnetic mode (a quadrupolar field, for instance), this coupling provides a path to flip the dipole to its opposite," the scientists said. "If this coupling is strong enough, the magnetic field will spontaneously oscillate between the two modes and their opposite polarities. We will then observe periodic reversals of the magnetic field (this is the case of the solar magnetic field, for which the period is 22 years). In the case of Earth, the coupling is not strong enough, and oscillations are not observed. Velocity fluctuations in the liquid core are then needed to trigger a reversal."

In the model, small fluctuations in convective flow can push the system away from one pole toward the intermediate quadrupolar state, where it becomes attracted to the opposite pole. A reversal occurs in two phases: a slow phase where the fluctuations are the motor of the evolution, and a fast phase during which the dynamics does not rely on the fluctuations. The first phase, during which the dipole amplitude decreases slowly, seems to last around 50 kiloyears (30,000-70,000 years). The second phase, which starts when the dipolar mode vanishes, is quite faster: 10,000 years are required for the dipole to recover with the opposite polarity. Sometimes, at the end of the first phase, the system may simply return to the initial pole, which is called an "excursion" when it occurs on Earth. However, if the system does reverse, the behavior happens relatively abruptly. In addition, the system usually overshoots immediately after reaching the opposite pole.

The scientists noted that the amplitude of the fluctuations does not need to be large: "Fluctuations of the flow do not switch off the magnetic field and then regenerate it with the opposite polarity," they said. "In contrast, the dipolar field continuously changes shape during a reversal because the amplitude of the other mode (the quadrupole, for instance) continuously increases, whereas the dipole decreases. When the dipolar component vanishes, it can increase again with the opposite polarity whereas the amplitude of the other mode decreases."

The model shows that the duration of the magnetic field in one state depends on the intensity of the convection fluctuations and also on the efficiency of the coupling between the two modes. Even a moderate change in convection can greatly affect the magnetic field polarity duration, which could account for "superchrons" - very long periods without geomagnetic reversals. Although little is known about the actual flow inside the Earth's core, recent observations have shown that the ends of superchrons are often followed by major flood basalt eruptions, which are likely to produce equatorial symmetry breaking of convection at the core-mantle boundary, in support of the scientists' model.

More information: Pétrélis, François; Fauve, Stéphan; Dormy, Emmanuel; and Valet, Jean-Pierre. "Simple Mechanism for Reversals of Earth's Magnetic Field." *Physical Review Letters*, 102, 144503 (2009).