Mike Follows

Going into reverse?

How Earth's magnetic field is changing

The Earth's magnetic field helps us navigate over its surface. It also protects us from the solar wind – a stream of high energy particles pouring out from the Sun. Now scientists have shown that the strength of the Earth's field is decreasing. So are we heading for one of the periodic reversals of the field which we know have happened in the past? And what might this mean for life on Earth?

Key words
magnetic field
dynamo
electric current
plate tectonics

What generates the geomagnet?

Figure 1a shows the structure of the Earth. Both the solid inner core and the liquid outer core are made of metal, mainly iron with some nickel. Diagrams in textbooks often suggest that the Earth's magnetic field behaves as if the Earth is skewered by a giant bar magnet, aligned about 11° from its spin axis – see **Figure 1b.**

The real explanation is more complicated. As the molten outer core freezes to become part of the solid inner core, latent heat is released. This heat drives convection currents in the outer core. Because the core is metallic it contains de-localised electrons. The convection currents and the spin of the Earth cause these electrons to move and so to form electrical currents. This generates a magnetic field whose direction is given by the right-hand grip rule.

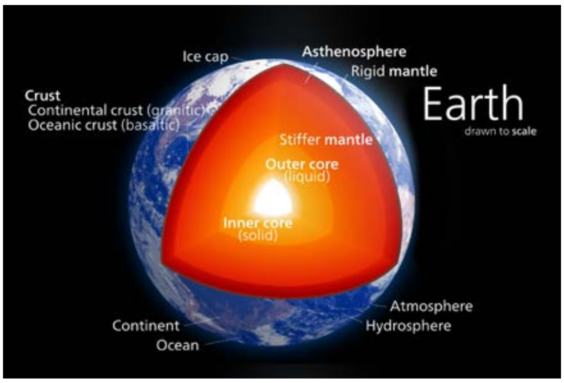


Figure 1 *The structure of the Earth – the magnetic field is thought to arise from electric currents in the metallic outer core.*

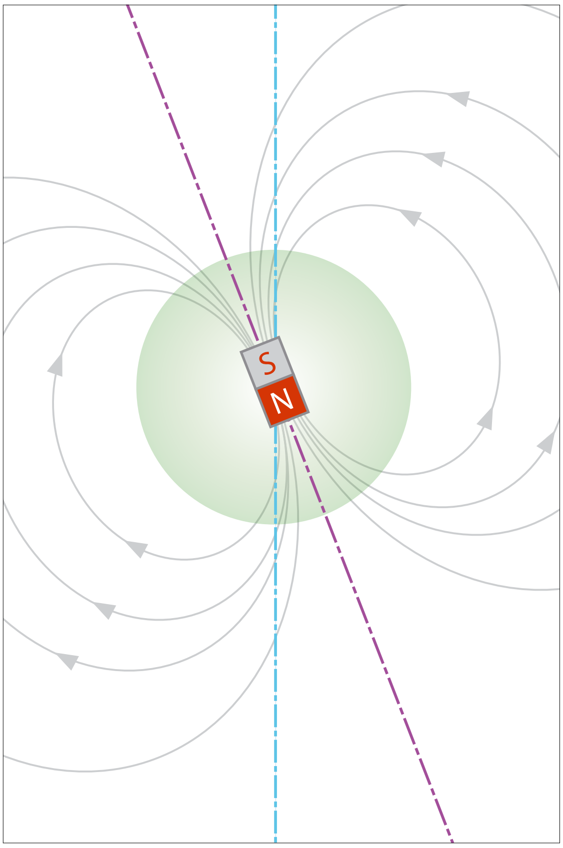


Figure 2 *The axis of the Earth's magnetic field (blue) is tilted relative to its axis of rotation (purple).*

Bar codes and how we discovered flipping fields

In the late 1950s, the USA and USSR had developed military submarines to help them wage the Cold War. This motivated the US Navy to secretly map the ocean floor as a potential battlefield, leading to the discovery of mid-ocean ridges in the Pacific. When molten rocks intrude between the diverging plates at mid-ocean ridges, grains of magnetite act like little compasses. At high temperatures they are free to change direction because thermal vibrations prevent any alignment. However, as the rock cools below its Curie temperature, the preferred direction of the magnetite becomes fixed – and aligned with the direction of the Earth's magnetic field prevailing at that moment.

By towing a magnetometer behind a ship, scientists can measure variations in the magnetic field on the seabed. Where the rocks beneath the magnetometer have reversed polarity the total magnetic signal is relatively weak, coloured white in **Figure 3**. In contrast, when the magnetic field of the rocks is in the same direction as the Earth's field, a stronger magnetic signal is detected (coloured black).

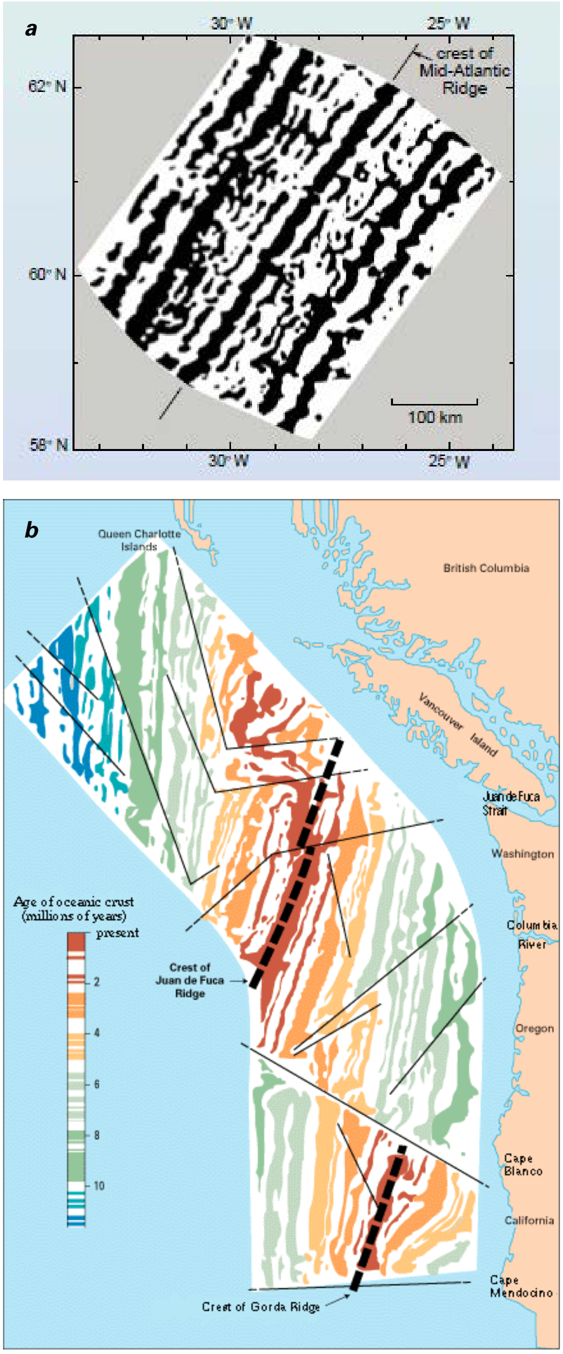


Figure 3 a *Stripes of opposite magnetisation on either side of the mid-ocean ridge in the North Atlantic, near Iceland. The symmetry of the pattern shows that the seabed formed from material gradually pushing outwards from the ridge in both directions.* ***b*** *In this more recent data from the north-east Pacific, white stripes represent reversed magnetisation. Colouring shows the age of the crustal rocks. The pattern of alternating stripes is clear, but it is broken up by fault lines caused by the movement of tectonic plates.*

Scientists had unwittingly discovered the mechanism for plate tectonics, and provided support for the continental drift hypothesis championed by Alfred Wegener, which he used to explain the near-perfect jigsaw fit of Latin America with Africa. Driven by convection currents in the mantle, ocean-floors move tens of millimetres per year, the same speed as fingernails grow.

It quickly became clear from the marine magnetic anomalies that the Earth's field has collapsed and reversed more than 60 times in the last 20 million years, about once every 300 000 years on average. Because reversals are random, the date of the next one cannot be predicted but we know that the last reversal took place 778 000 years ago so perhaps the next one is overdue – and evidence is mounting that our magnetic field is getting weaker.

Using ships logs

Until recently, scientists were only able to trace the magnetic field's behaviour back to 1832, when Carl Friedrich Gauss invented the magnetometer, the first device to measure both the strength and direction of the field directly. But ships' logs have now been studied allowing scientists to look further back in time.

We can navigate by the Sun and stars but a compass has the advantage that it can be used even when clouds obscure the heavens. Early ocean-going explorers like Captain Cook measured the declination and sometimes the inclination of the Earth's field (see **Figure 4**). Professor David Gubbins and his team of researchers at Leeds University believe that these measurements were very accurate given that 'their lives depended on it'. Using the locations of the ships at the time measurements were taken by Captain Cook and other explorers has allowed the Gubbins team to construct a map of the relative strength of Earth's magnetic field since 1590.

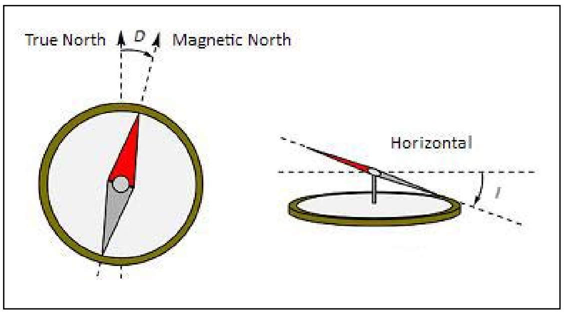


Figure 4 *Two important angles:* ***declination****, the angle D between geographic and magnetic North, and* ***inclination****, the angle I that a freely suspended magnet makes with the horizontal.*

They have discovered that the Earth's magnetic field has been weakening at a rate of 5% per century since 1860 and we might be heading for a reversal. However, Gubbins says that the decline is almost entirely due to the South Atlantic Anomaly (SAA), an area where the Earth's field strength has fallen dramatically (**Figure 5**).

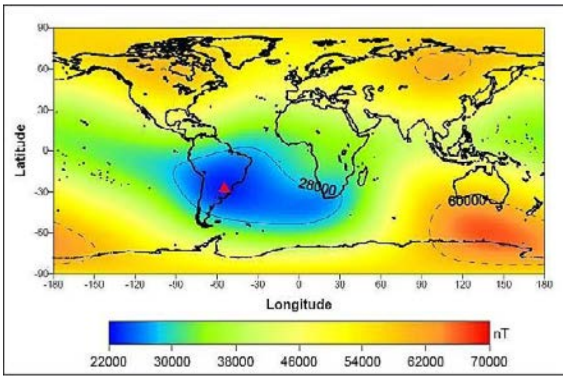


Figure 5 *The Earth's magnetic field is weakest at the South Atlantic Anomaly, an area which shows up clearly on this map. Field strength is shown in units of nanoteslas (nT).*

Different approaches

The appearance of the SAA might be further evidence of a reversal because computer modelling suggests that reversals get complicated. As **Figure 6** shows, several new poles may appear in odd places before the geomagnet returns to the familiar dipole pattern (i.e. a north and south pole) but with the poles swapped over.

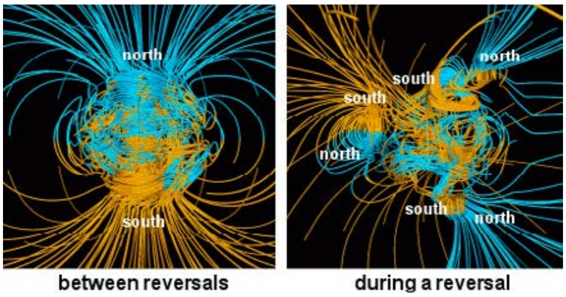


Figure 6 *Computer modelling shows how the familiar pattern of the Earth's magnetic field (left) can become entangled in the course of a magnetic reversal.*

Gauss started a network of observatories based on the magnetometer he developed in 1832 but, because this network was patchy, NASA launched the MAGSAT satellite in November 1979, which collected data for about six months. This has led to a greater understanding of the Earth's magnetic field. To enhance our understanding still further, at the end of 2013 the European Space Agency launched three identical Swarm satellites to monitor the Earth's field from different orbits.

Getting experimental

In a further bid to understand what is going on, Daniel Lathrop and his colleagues at the University of Maryland have set up a spinning sphere of molten sodium to act as a model of the Earth's core (**Figure 7**). They are hoping to show that the spinning sphere acts as a dynamo, generating its own magnetic field. Sodium is the best liquid metal conductor available and melts at the relatively low temperature of 100°C. The downside is that sodium is highly reactive and, if the spinning sphere were to rupture, it would probably explode.

Figure 7 *This 3 m diameter sphere contains molten sodium, a metal. When set spinning, electric currents may be produced, resulting in a magnetic field. But will it be similar to the Earth's?*

The 3-metre dynamo experiment continues a tradition started by William Gilbert, who published *De Magnete* in 1600. In it he describes many experiments with his *terrella*, the model Earth he had constructed out of lodestone (**Figure 8**). He correctly concluded that the Earth is magnetic and dispelled the myth that the North Star (Polaris) or a large magnetic island at the North Pole was attracting compass needles. Given that nothing surpassed his work on magnetism for more than two centuries, it is surprising that his contribution is largely forgotten, particularly as a pioneer of experimental science, whose approach greatly influenced Galileo and those who followed.

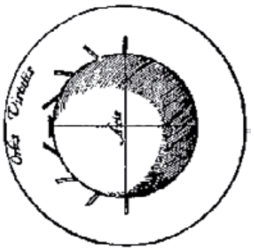
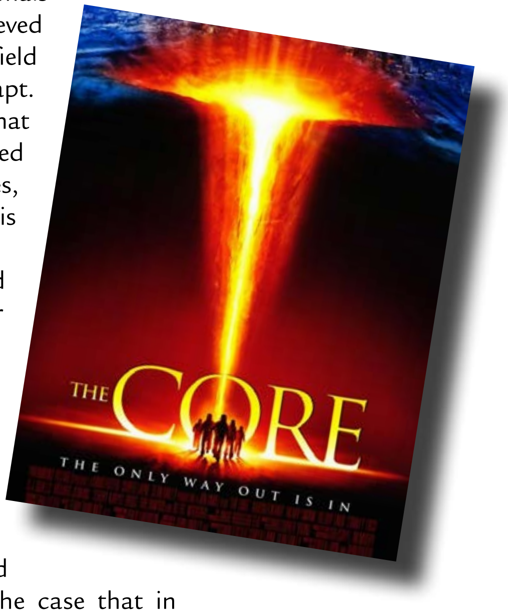


Figure 8 *William Gilbert invented this 'terrella' to explain the Earth's magnetic field. It is made of magnetic lodestone and shows how compass needles align at different points on the Earth's surface.*

Assessing the future

Unlike dramatic portrayals of geomagnetic phenomena in Hollywood films such as The Core, it would probably take thousands of years for the Earth's north and south poles to actually swap. This might allow migratory animals such as birds, which are believed to rely on the geomagnetic field for navigation, time to adapt. A few scientists believe that past reversals have caused mass extinctions of species, though the evidence for this is weak.

However, the solar wind would penetrate further into our atmosphere so there may be an increase in the amount of ionising radiation reaching the ground. Evolution might proceed at a slightly faster pace with the increase in background radiation. It is certainly the case that in the last 10 million years humans have survived 30 reversals and will undoubtedly survive the next.



The Earth's core has stopped spinning – scientists rush to set it in motion once more.

Mike Follows teaches Physics. In a future article, he will describe how a declining magnetic field might prove hazardous for many of our everyday technologies.