Earth’s magnetic field and its changes through time

Earth is surrounded by an invisible yet powerful shield: its magnetic field. This is what causes the aurora to dance in the skies around the North and South Pole, and protects life on Earth from the intense stream of solar particles racing across the solar system from our Sun. But how can we understand something we cannot even see?

Humans have been using the Earth’s magnetic field to navigate for hundreds of years using compasses, and this remains the easiest way for us to see Earth’s magnetic field in action. Scientists can also measure its intensity at points around the Earth’s surface, as well as its orientation, and satellites play a vital role in its continued monitoring.

The stability of today’s magnetic field is not only important for protecting life on Earth, it is vital for our technology. Mobile phones depend upon it to correctly identify their location. Increases in the solar wind (geomagnetic storms) can disrupt power grids, communications, satellites and navigation systems, and without a stable magnetic field to protect Earth we would be incredibly vulnerable to solar storm events.

Understanding how the magnetic field has changed through time will hopefully give us clues as to how it might fluctuate in the future. Earth’s rocks hold clues about its magnetic field in the past (the palaeomagnetic record), which geophysicists like Dr Daniel Franco at the National Observatory of Brazil, can bring together to understand how the palaeomagnetic field might have behaved.

Generating a Magnetic Field

To understand why Earth’s magnetic field changes through time, we first must understand how it is formed. A magnetic field can be created by a magnet, a piece of permanently magnetised metal that can attract or repel other materials. A magnet creates an invisible magnetic field, which describes the area of influence around a magnet. Magnets have two poles, generally termed a north and south pole, and the magnetic field flows from the north pole, around the outside of the magnet to the south pole. Earth’s magnetic field is well known to have a north pole and a south pole (we call this type of magnetic field an axial dipole), and when you stand on the Earth’s surface with a compass, the needle will align itself to the field pointing towards the north pole. However, it is something much more complex than a metal magnet generating Earth’s magnetic field.

A magnetic field can also be generated by a dynamo. This is when a flowing electrical current creates a magnetic field. Deep inside the Earth, fluid with the capacity to conduct electrical currents is constantly moving. Earth’s inner core is extremely hot, over 5000 °C, and this heat drives convection currents in the Earth’s fluid, metallic outer core. As the planet rotates, these convection currents are forced into columns along which move electrical currents, generating a huge magnetic field that extends out into the space around the Earth.

The Earth’s magnetic field has a structure similar to a simple magnet, with a north pole and a south pole. Scientists measuring the Earth’s magnetic field have noticed that the location of the poles are not completely fixed. For example, the north pole has been “wandering” for around the last hundred years, heading slowly towards Siberia. However, the geological record of Earth’s magnetic field indicates this is not the only type of magnetic fluctuation that occurs.

Palaeomagnetism

The study of rocks that record the Earth’s magnetic field and its fluctuations over millions of years is known as palaeomagnetism. The record of Earth’s magnetic field is recorded in specific minerals, which are found in specific types of rock, especially igneous rocks extruded during volcanic activity. These minerals are rich in iron, and whilst the lava is still fluid, they align themselves with the Earth’s magnetic field just like a compass needle. Once the lava has cooled to form rock, those minerals are a direct record of the strength and orientation of the Earth’s magnetic field at that time.

Geologists have collated this record of Earth’s palaeomagnetism, stretching back further than a billion years. In as early as the 1920s, geologists who were studying this record noticed something strange. Some of the magnetic minerals were aligned in the opposite direction to today’s magnetic field, suggesting that at points during Earth’s history, the north and south pole of Earth’s dipole have swapped. The Earth’s magnetic field has therefore been undergoing both large and small changes throughout its history; these changes over time are known as palaeosecular variation.

Complex numerical models help geologists understand more about the changes in Earth’s palaeomagnetic field and why they might occur.

Dr Franco uses complex numerical models to better understand Earth’s magnetic field structure, the dynamo that drives geomagnetism and palaeosecular variation.
The movement of magnetic poles and its polarity reversal rate through time is controlled by how much the Earth's magnetic field is structured as an axial dipole.

Structure (one north pole and one south pole), however there are additional, complex processes that sometimes cause small variations in the magnetic field that mean less of the overall structure is like a dipole, and there may even be multiple poles. The team noted that these periods of geological time had a higher rate of geomagnetic reversals occurring when the axial dipole structure of Earth's magnetic field was weaker – which also coincides with higher thermal flux at the core-mantle boundary – with more of these variations in its overall structure.

WHAT CAUSES GEOMAGNETIC REVERSALS?

The aim of Dr Franco and his team was to reach a better understanding about how geomagnetic reversals and palaeomagnetic variation evolve as a function of thermal gradient. This has long been a topic of debate amongst geologists studying palaeomagnetic field reversals. It is uncertain as how palaeomagnetic variation occurs due to changes within the Earth's core itself, as well as its connections with the heat extraction from the core and moves across the boundary between Earth's core and mantle.

The team used their numerical model to study the relationship between core-mantle boundary heat flux (how much heat is moved from the outer core into the lower mantle) and how similar the Earth's magnetic field is to a dipole structure.

The researchers discovered that when there is less heat transfer from the core to the mantle, the Earth's magnetic field behaves more like an axial dipole (with opposite north and south poles) and so the magnetic field reverses less frequently when there is lower heat flux. Conversely, when core-mantle boundary heat flux is elevated, there is a higher rate of reversals in the Earth's magnetic field as its structure becomes less like a dipole. This suggests that during geological time periods where there is a high rate of geomagnetic reversals, such as the Illawarra Hyperzone of Mixed Polarity, there is greater movement of heat from the Earth's core into its mantle.

IMPORTANCE OF PALEOMAGNETISM TODAY

Complex numerical models, such as the one used by Dr Franco and his team, that are used to better understand Earth's magnetic field structure, the dynamo that drives geomagnetism and palaeomagnetic variation, are a relatively recent scientific breakthrough. These are incredibly complex systems that have a major impact on life on Earth. The idea of 'the past is the key to the present' is an important concept for geologists, where information from Earth's geological history is examined in the hope of understanding what happens on present day Earth and what we could expect in the future.

Fluctuations in Earth's magnetic field affect all of us, and so if we can begin to understand how features such as the currently wandering magnetic north pole might mean for the overall structure of Earth's magnetic field and what might be causing these changes, we can be better prepared for future fluctuations in Earth's invisible shield.

References