Earth's magnetic field and its changes through time

Complex convection currents in the Earth's core create a vast magnetic field around the Earth, protecting us from the charged solar particles that emanate from the Sun. However, the Earth's magnetic field has not always been quite the same. Earth's rocks provide a record of geomagnetic reversals and variations through time in the geomagnetic field. Dr Daniel Franco and his team at the National Observatory of Brazil use complex numerical models to better understand the structure of Earth's magnetic field and what might cause these changes over geological timescales.

Dr Franco aims to better understand the structure of Earth's magnetic field and what might cause these changes over geological timescales.

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?

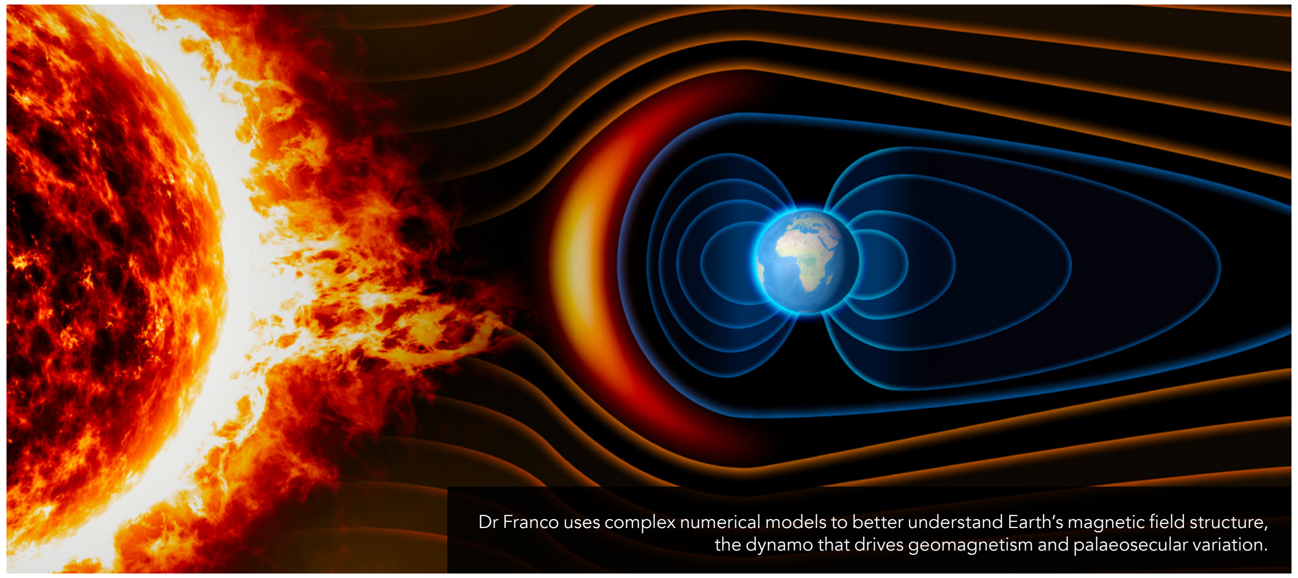
Humans have been using the Earth's magnetic field to navigate for hundreds of years using compasses, and this remains the easiest way for us to see Earth's magnetic field in action. Scientists can also measure its intensity at points around the Earth's surface, as well as its orientation, and satellites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



Dr Franco uses complex numerical models to better understand Earth's magnetic field structure, the dynamo that drives geomagnetism and palaeosecular variation.

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

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.

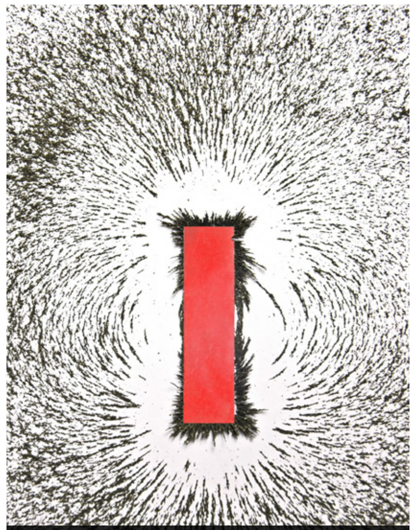
Geologists have collated this record of Earth's palaeomagnetism, stretching back further than a billion years. In as early as the 1920s, geologists who were studying this record noticed something strange. Some of the magnetic minerals were aligned in the opposite direction to today's magnetic field, 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.

The auroras, both surrounding the north magnetic pole (aurora borealis) and south magnetic pole (aurora australis) occur when highly charged electrons from the solar wind interact with elements in the Earth's atmosphere.

STUDYING GEOMAGNETIC REVERSALS

Dr Franco and his team including graduate students Wellington Paulo de Oliveira and Felipe Barbosa Venâncio de Freitas, are using complex numerical models to understand more about the changes in Earth's palaeomagnetic field and why they might occur. They investigated a geological interval where there are an unusually high number of palaeomagnetic reversals (this high rate of reversal is about 6 reversals per million years). The Illwarra Hyperzone of Mixed Polarity occurred between 267 and 229 million years ago, and the team gathered an in-depth dataset of palaeomagnetic information including the magnetic field polarity (the orientation of the north and south poles of Earth's axial dipolar field) and paleosecular variation (the long term temporal variations of the Earth's magnetic field on local, regional, and global scales) throughout that period.

The researchers compared this period of frequent geomagnetic reversals to other times where a similar number of reversals had been noted. They discovered that the movement of magnetic poles through time is possibly controlled by how much the Earth's magnetic field is structured as an axial dipole. The majority of Earth's magnetic field is part of the 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 that recorded a higher rate of geomagnetic reversals were 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.



Earth's magnetic field behaves more like an axial dipole (with opposite north and south poles).

'The past is the key to the present' is an important concept for geologists;. Information from Earth's geological history can help explain present day Earth and what we could expect in the future.

WHAT CAUSES GEOMAGNETIC REVERSALS?

The aim of Dr Franco and his team was to reach a better understanding about how geomagnetic reversals and paleosecular 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 palaeosecular 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 Illwarra Hyperzone of Mixed Polarity, there is greater movement of heat from the Earth's core into its mantle.

> ***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.***

IMPORTANCE OF PALAEOMAGNETISM 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 palaeosecular 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.

Behind the Research

Dr Daniel Franco

E: drfranco@on.br **T:** +55-21-98713-6838 **T:** +55-21-3504-9293
W: http://lattes.cnpq.br/9874436698730620

Research Objectives

Daniel Franco has expertise in rock magnetism, paleomagnetism and magnetostratigraphy, signal processing and analysis of high-resolution sequences of enviromagnetic data.

Detail

Department of Geophysics
Observatório Nacional (ON/MCTI)
Rua Gal. Jose Cristino, 77
20921-400 Rio de Janeiro (RJ), Brazil

Bio

Dr Daniel R. Franco (Observatório Nacional, Brazil) completed his MSc in Solid State Physics (2002) and his PhD in Geophysics (2007) from the University of São Paulo. He undertook post-doctoral training at the Department of Earth and Planetary Sciences, John Hopkins University. He is a researcher and associate professor of the Graduate Program in Geophysics and coordinator of the Laboratory of Paleomagnetism and Magnetic Mineralogy (under construction) of the National Observatory (Brazil). He is Associated Editor of the Geoscience Data Journal (Royal Meteorological Society, UK) and Revista Brasileira de Geofísica (RBGf).

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Collaborators

- Dr Jean-Marie Flexor (National Observatory, Brazil) – *In Memorian*
- Dr Marcia Ernesto and Daniele Brandt (University of São Paulo, Brazil)
- Ricardo Sant'Anna Martins (State University of Rio de Janeiro, Brazil)

References

Franco, D, de Oliveira, W, de Freitas, O, Takahashi, D, da Ponte Neto, C & Peixoto, I. (2019). Paleomagnetic evidence for inverse correspondence between the relative contribution of the axial dipole field and CMB heat flux for the past 270 Myr. *Scientific Reports*, 9, 282. DOI:10.1038/s41598-018-36494-x

Personal Response

Why do you think it is so important to understand how the Earth's magnetic field can change?

" The importance of understanding how the geomagnetic field can change throughout the geological eras can especially shed light on the following three points: (1) how it reverses its polarity; (2) which geodynamic mechanisms could be involved, and its operation timescales; and (3) the Earth's magnetic field provides an important shield for life – the magnetosphere – against high-energy particles which come from Sun and outer space. There is reliable evidence that the intensity of the field may decrease during geomagnetic reversals, which probably also affects the magnetosphere. That is why it is important to recognise the "signs" of a geomagnetic reversal and its associated mechanisms. "

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