GEOMAGNETISM

Hum from the quiet zone

During the middle of the Cretaceous period, the polarity of Earth's magnetic field remained stable. A magnetic survey of oceanic crust formed during that time, however, suggests that the field intensity was surprisingly variable.

John A. Tarduno

Throughout Earth's history, the north and south poles of the planet's geomagnetic field have reversed aperiodically (Fig. 1). During intervals known as superchrons, the magnetic field undergoes few or no reversals for tens of millions of years. These stable periods contrast with the frequent reversals that have occurred during the past five million years, and, together, demonstrate the end-member conditions of geomagnetic field behaviour. Superchrons are often attributed to a long-term pattern of mantle convection and core/mantle boundary conditions. But the exact conditions governing superchrons are ambiguous: both an increase and a decrease in active convection of liquid iron in the outer core could explain this pattern of magnetic field generation. Writing in *Nature Geoscience*, Granot *et al.*[1] add to this complexity by suggesting that the activity of the dynamo was highly variable during the Cretaceous Normal Superchron.

Earth's magnetic field has alternated between episodes of normal polarity, when the direction of the field is the same as it is today, and reversed polarity, when the poles are switched. Where oceanic lithosphere forms at a mid-ocean ridge, the cooling magma preserves a record of the polarity of Earth's magnetic field at that time. As the sea floor spreads away on either side of the ocean ridge, a distinctive pattern of magnetic stripes, alternating between normal and reversed polarity, form parallel to the ridge. The striped pattern of magnetic anomalies on the sea floor can be measured using magnetometers towed by ships at the sea surface. Independent, typically land-based measures can provide absolute ages for some magnetic reversals, allowing us to estimate the age of virtually the entire oceanic crust.

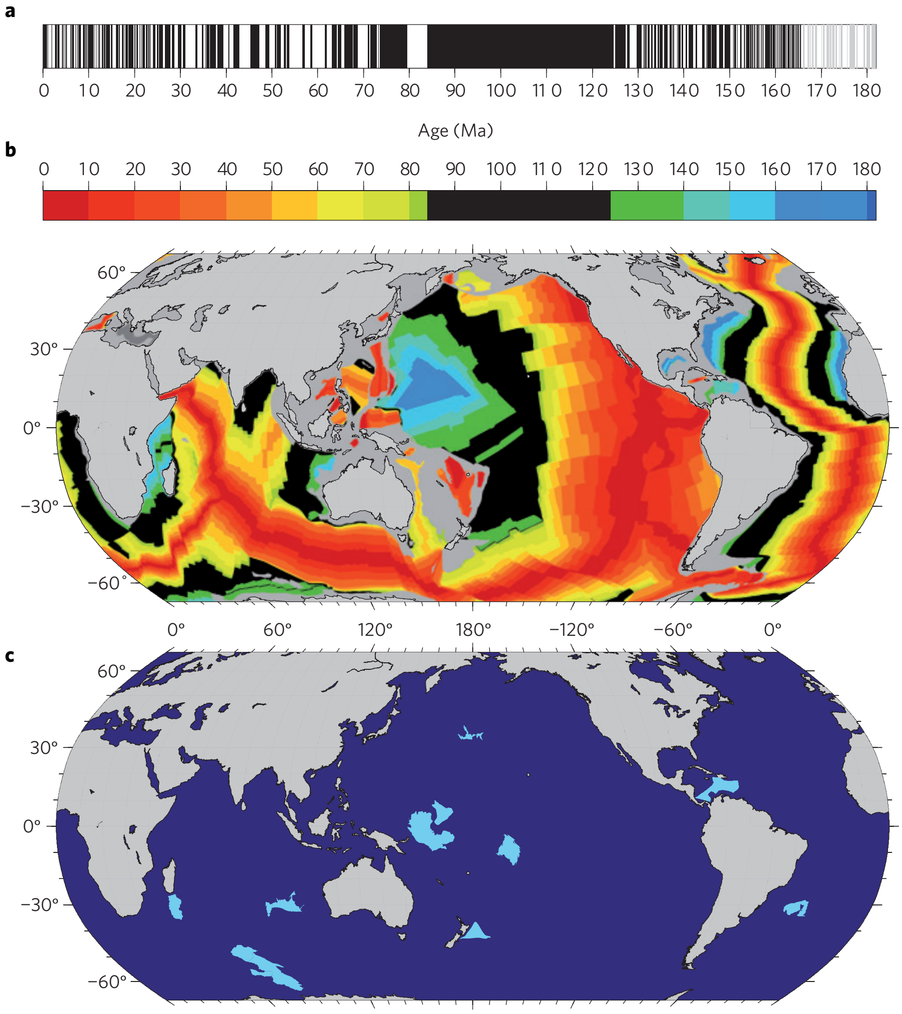

Figure 1 | Reversals through time. **a**, Reversals[8] of Earth's magnetic field during the past 180 million years (black, normal polarity; white, reversed) are reflected in oceanic crust as it forms. Between approximately 121 and 83 million years ago (the Cretaceous Normal Superchron), the field did not reverse. **b**, Oceanic crust formed during the superchron is called the Cretaceous quiet zone (black region) because it lacks the magnetic stripes created by polarity reversals. Granot *et al.*[1] claim that despite the lack of polarity reversals, the geomagnetic field did exhibit intensity variability throughout the superchron. **c**, The duration of sustained polarity coincides with the eruption of numerous oceanic plateaux (light blue) and other large igneous provinces[10], suggesting links between core–mantle heat flow and the geomagnetic field.

However, this becomes difficult in periods without frequent reversals. The Cretaceous Normal Superchron, between about 121 and 83 million years ago, is the most recent ultra-long interval of constant magnetic field polarity. Oceanic lithosphere formed during this time lacks the readily detectable magnetic anomalies that characterize more typical periods (Fig. 1). Plate tectonic reconstructions indicate that significant changes in plate motions may have occurred during the mid-Cretaceous, but without a clear-cut way to estimate the age of oceanic crust forming what is known as the Cretaceous quiet zone, rates of plate spreading are difficult to assess.

Granot *et al.*[1] report that the quiet zone is not so quiet after all. They employed deep-tow magnetometer measurements, taken only about 1,000 m above the sea floor, to obtain a high-resolution magnetic record from the oceanic crust created in the central Atlantic Ocean during the Cretaceous Normal Superchron. Rather than the flat, monotonous signal that might be expected, their magnetometer data recorded variations that might reflect changes in the intensity of the geomagnetic field throughout the superchron.

Ruling out a tectonic or magnetic origin for the signal, Granot *et al.*[1] propose that the behaviour of the geomagnetic field evolved throughout the superchron. In their scenario, the beginning of the superchron was marked by stability in the intensity of the geomagnetic field. Variability increased gradually, reaching a peak in the middle of the superchron, between 110 and 100 million years ago, and returned to stability by the end. The authors also isolated a few prominent intensity variations that may be useful as time markers within the Cretaceous quiet zone, which should aid estimates of seafloor spreading during this time.

The proposed pattern of geomagnetic field behaviour doesn't provide an easy answer to the question of why the Cretaceous Normal Superchron started, and why it ended. The authors' interpretations also challenge results of numerical simulations of the geodynamo, which so far have predicted lower field variation during superchrons[2]. These models also predict a higher geomagnetic field strength during superchrons, and such behaviour is supported by detailed palaeointensity analyses using single silicate minerals[3] and basaltic glass[4], which are more reliable than bulk samples of igneous rocks[5]. But testing field variability of the kind proposed by Granot *et al.* is beyond the current temporal resolution of these specimen-based experimental data sets.

The discrepancy between the interpretations of Granot *et al.*[1] and current simulations could be explained by the models' lack of changes in core/mantle boundary conditions on a timescale of ten million years. However, the discrepancy may be more fundamental: numerical simulations predict that superchrons are associated with low heat flow across the core/mantle boundary. However, geologic evidence suggests the opposite may be the case, at least for the Cretaceous Normal Superchron. As well as the presence of a magnetically quiet zone, mid-Cretaceous times were extraordinary because of the eruption of unusually large volumes of magma on land, in the form of flood basalts, and across the sea floor. The seafloor eruptions led to the emplacement of numerous oceanic plateaux (Fig. 1), most notably the giant Ontong Java Plateau[6]. These extreme volcanic outpourings are often linked to mantle plumes, and it is thought that plumes can be responsible for significant heat transfer across the core/mantle boundary[7].

The time markers and geomagnetic field variability reported by Granot *et al.*[1] should be recognizable in deep-tow records from elsewhere in the Atlantic and other ocean basins. If confirmed, this would force us to revisit the question of what core and mantle conditions lead to superchrons. ❒

John A. Tarduno is in the Department of Earth & Environmental Sciences and the Department of Physics & Astronomy, University of Rochester, Rochester, New York 14627, USA.
e-mail: john@earth.rochester.edu

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OCEANOGRAPHY

Arctic freshwater

The Arctic Ocean has become less saline, perhaps in response to climate change. Satellite and *in situ* observations reveal changes in the regional wind patterns that have re-routed freshwater and prevented it from leaving the Arctic Ocean in the past decades.

Cecilie Mauritzen

The hydrological cycle, which transports freshwater to almost every corner of the world, is an endless loop. It encompasses the atmosphere, mountain tops and glaciers, river valleys and lakes, groundwater and the ocean itself. In the ocean, the freshwater cycle leaves its signature in the distribution of salinity: surface salinity is high in regions where evaporation dominates rainfall, typically in the subtropics. On the other hand, low surface salinity characterizes regions where precipitation exceeds evaporation, such as the tropics and the subpolar and polar regions. In a changing climate, both evaporation and precipitation are projected to intensify. Indeed, over the past decades a decline in salinity has been observed in the — already relatively fresh — western Arctic Ocean. Two studies, published in *Nature*[1] and *Nature Geoscience*[2], explore where the freshwater came from, and how it was captured in the Canadian section of the Arctic Ocean.

As the Earth's climate changes and the atmosphere becomes warmer, the air is also likely to become moister. In fact, for every 1 °C warming the atmosphere can hold another 7% of water vapour. Therefore it is commonly thought that the hydrological cycle will strengthen in a warming climate. So far, the most convincing evidence for this effect is found in the ocean, where the regions that are typically saline have become even more so, and vice versa. This suggests that both evaporation and precipitation have increased. In the absence of direct measurements of these processes over most of the world's ocean, these observations of ocean salinity are our clearest evidence.

The Arctic Ocean, where precipitation dominates evaporation, is expected to