PALAEOMAGNETISM

Core message

Archaean and early Proterozoic rocks reveal that the Earth's magnetic field two billion years ago behaved differently than over most of the past 200 million years. Do these changes relate to the growth of the inner core?

Gauthier Hulot
is at the Institut de Physique du Globe de Paris, Université Paris Diderot, INSU/CNRS, 4 Place Jussieu, 75252, Paris cedex 05, France.
e-mail: gh@ipgp.jussieu.fr

COR LANGERIES

Figure 1 An outcrop reveals late Archaean age rocks in the Pilbara region, Australia.

Reconstructing the Earth's very ancient magnetic field is no easy task. But understanding the evolution of the geomagnetic field can provide invaluable information about the way the geodynamo that generates it within the Earth's liquid core may have evolved as the Earth slowly cooled and grew a solid inner core. Smart strategies can be designed to unravel the subtle magnetic messages that have quietly survived in some of the oldest rocks on Earth. On page 395 of this issue, Biggin and colleagues[1] analyse a carefully selected series of 2.82 to 2.45 billion-year-old magnetized igneous rocks (Fig. 1), which provides exciting evidence for a very long-term trend in geomagnetic behaviour. The authors argue that this could be the signature of a more stable geodynamo associated with a much smaller ancient inner core.

Remarkably, igneous rocks, which are formed from magma, are magnetized permanently as they cool, at a level that is proportional to the ambient magnetic field at the time. Provided that no later significant thermal, chemical or other event affects this magnetization (which relevant tests can assess), such rocks provide natural spot readings of the past geomagnetic field. The direction from those readings can be used to infer a so-called virtual geomagnetic pole, which marks the position of the pole of the geomagnetic field that would have led to the observed magnetization. If one avoids rock units affected by local tectonics, virtual geomagnetic poles from all rocks of a common geographical site with similar ages can be used to produce an average location for the virtual geomagnetic pole, and an estimate of the dispersion about that average.

This inferred average location then allows the recovery of the palaeolatitude of the corresponding geographical site, and the dispersion can be used to reconstruct the way in which secular variations of the geomagnetic field affected field directions at that palaeolatitude. Both the reconstructed palaeolatitude and the inferred dispersion are insensitive to whatever global tectonic movement might have subsequently occurred. They can therefore be used to produce curves of the dispersion of virtual geomagnetic poles (VGP) as a function of palaeolatitude throughout the Earth's history. However, such curves implicitly rely on a number of important assumptions, primarily that the Earth's magnetic field has always been dominated by the axial dipole component. Thus, resulting curves must be interpreted with care[2], but they do provide a unique opportunity for investigating the extent to which the Earth's magnetic field behaved differently in the past.

Biggin and colleagues[1] compare their reconstruction of the ancient magnetic signal with one covering the more recent, and better documented, past 200 million years. They find that the VGP dispersion curve for the period from the Archean to early Proterozoic eons, 2.45 to 2.82 Gyr ago, exhibits low equatorial values similar to that of the Cretaceous Normal Superchron from 80 to 110 Myr ago, when the field did not experience any reversals. This behaviour contrasts with that of the VGP dispersion curves for all other periods over the past 200 million years, which display much higher equatorial values. These are periods when the field often reversed, on average two to three times per million years, as it has in the recent geological past.

Plotting a single VGP dispersion curve for the nearly 400 million years stretching between 2.45 to 2.82 Gyr ago is a bold move. Indeed, close inspection of the past 200 million years shows that VGP dispersions can strongly vary on timescales of a few tens of millions of years[3]. But Biggin and colleagues make a reasonable case that their curve provides evidence that during Archean and early Proterozoic times, the field more often behaved the way it did during the Cretaceous Normal Superchron. These findings suggest that the geomagnetic field should have experienced far fewer reversals then, in agreement with the limited number of direct observations of reversals during that time[4].

Such a stable early geomagnetic field has important implications for our understanding of the geodynamo, which generates the magnetic field and controls its variations. Numerical simulations suggest that the geometry of the liquid core, the amount and type of energy available for driving the dynamo, and the heterogeneous boundary conditions imposed by the mantle on the core can all influence the behaviour of the magnetic field. Mantle convection, for example, produces changes in the boundary conditions, typically on timescales of 100 million years and this could be the cause for the observed variability in the behaviour of the geomagnetic field over the past 200 million years, in particular the transition to the Cretaceous Normal Superchron[5]. However, this sudden transition could alternatively result from a spontaneous transition from a reversing to a non-reversing state of the dynamo[6].

Could similar mantle control also be responsible for the changes observed by Biggin and colleagues on the much longer timescales they investigate? Perhaps, but this is not the interpretation the authors favour. Rather, they note that on the billion-year timescale, the growth of the inner core may have played a more important role than mantle convection. They point out that the size of the inner core is an important parameter for dynamo action, both from a magnetic[7] and dynamic[8] point of view, and that recent simulations[4] show that a smaller inner core can stabilize the field behaviour.

Biggin and colleagues argue that what they have found could be the magnetic signature of a smaller inner core some two billion years ago. But, perhaps even more important than the size of the inner core is the power available to drive the dynamo. This must have been quite different before and during the initial stages of inner core growth from what it is at present[9]. Recent extensive investigations of numerical geodynamo simulations show that energetic considerations are more important in defining the nature of the field produced than previously thought[10]. Changes in available energy to drive the dynamo therefore may well turn out to be the main explanation for Biggin and colleagues' findings. Only future investigations will tell.

References

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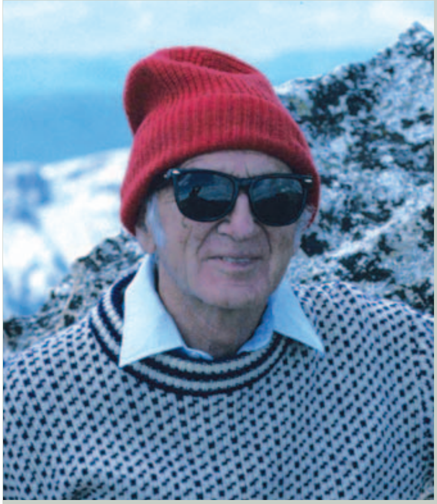
EDWARD LORENZ (1917–2008)

Chaotic beginnings



HOWIE BLUESTEN

Serendipity is a term often misused, but if anyone in modern science could lay claim to it, it was Edward Lorenz. A meteorologist by training, he founded the entire discipline of chaos theory by accident — while attempting to improve a weather forecast.

Lorenz was born on 17 May 1917 in West Hartford, Connecticut, and recalled childhood interests in both mathematics and meteorology that seemed to predestine him for his later career. He first studied mathematics, but became a weather forecaster for the US Army Air Corps during the Second World War. In 1943, he took a masters degree in meteorology at the Massachusetts Institute of Technology, the beginning of a lifelong association with the institution. There, he set about using mathematical tools to break down complex climate phenomena, establishing a series of elegantly simple mathematical models to describe various aspects of atmospheric energetics and transport.

Lorenz was tinkering with one such model in 1961 when, wishing to repeat a simulation over a slightly longer timescale but disinclined to start over again, he began in the middle using values generated from the first run. The print-out with the input parameters rounded the six decimal places of the actual output to just three. Such a small discrepancy would not have been expected to materially affect the end result; but the second simulation produced an entirely different evolution from the first.

At first, Lorenz suspected a computer malfunction, but the irreproducibility of the result proved eminently reproducible. He was quick to grasp the implication that, as far as the atmosphere is concerned, "the prediction of the sufficiently distant future is impossible by any method, unless the present conditions are known exactly" (Lorenz, E. *J. Atmos. Sci.* **20,** 130–141; 1963). In the absence of such knowledge, the question of what the weather will be in a month's time is one we are fated never to answer.

Lorenz first illustrated this with the metaphor that a flap of a seagull's wings was enough to alter the course of the weather forever. It was not until a decade later, in December 1972, at an invited talk at a meeting of the American Association for the Advancement of Science, that he used the description that was to lodge chaos in the public imagination: "Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?" That vividly framed question had a perfect visual accompaniment in tracings of the 'Lorenz attractor', a three-dimensional representation of chaotic flow established by Lorenz when considering atmospheric convection, whose paths resemble nothing more than a pair of butterfly wings.

For establishing the theoretical basis of climate predictability, Lorenz was awarded the Crafoord prize by the Royal Swedish Academy of Sciences in 1983, and the Kyoto prize of the Inamori foundation in 1991. The citation for the latter prize attested Lorenz as having "brought about one of the most dramatic changes in mankind's view of nature since Sir Isaac Newton". Edward Lorenz died on 16 April at his home in Cambridge, Massachusetts, at the age of 90.

Richard Webb