Adaptive evolution of shell shape in the Carboniferous bivalve *Carbonicola* can be directly related to changes in sedimentary conditions (R. Eagar, Manchester Museum). Transformations in Mesozoic brachiopods were in most, though not all, cases associated with environmental changes such as sea deepening (Ager).

The important question of whether rapid evolutionary change occurs by genuine saltation or by 'fast gradualism' is in most cases beyond the resolution of the fossil record, as is the question of the pattern of genetic change underlying observed morphological transitions in general. Information of genetic significance may nonetheless be present in some palaeontological data sets. For instance, in both Johnson's scallop *Radulopecten* and Phelps's ammonite *Oistoceras,* variants resembling the descendent form are present in the latest ancestral samples before the punctuation event. In other examples the nature of the developmental switch can be inferred; thus in some ammonite lineages, failure of growth of the outer whorls left the inner (youngest) whorls to form the adult morphology of the descendent (Kennedy and Wright). The potential for unusually finely stratified fossil sequences capable of resolving evolutionary modes may be greatest in the Pleistocene, the most recent geological period. Thus at one locality, the vole, *Microtus oeconomus*, has been sampled across six levels within the 10–15,000 years of a single interglacial, and stepwise size change documented (Stuart and Joysey).

The complexity of the evolutionary process and the problems associated with fossil evidence make it all the more pressing that palaeontologists collect their samples extensively and with precision, and keep the various possible explanations for a given set of data and ways of deciding between them clearly in mind. The potential rewards remain great: fossil sequences which pin down evolutionary modes, while rare, are within our grasp. □

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Earth science

What triggers reversals of the Earth's magnetic field?

from J. A. Jacobs

It has long been tempting to suppose that there is a correlation between changes in the Earth's magnetic field, whose origin lies in the Earth's core, and events at the Earth's surface, but there has been little convincing evidence of such a correlation (see refs 1 and 2 for a sceptical view). Although changes in the magnetic field do sometimes coincide with changes in global ice volume, short-period rapid glaciations and climatic cooling, there is no proof that the relationship is one of effect and cause; indeed magnetic excursions have also occurred at times when the oxygen-isotope curves from deep-sea cores do not record major changes in ice volume or rapid cooling[3]. So is it possible to relate reversals of the Earth's magnetic field to other events, given the problem of establishing any correlation for lack of an accurate chronology?

Olson[4] has recently investigated the behaviour of the Earth's main magnetic field during a polarity transition using the α^2 dynamo model in a turbulent core. He shows that reversals of the dipole field occur with changes in sign of the helicity (a measure of the correlation between turbulent velocity and vorticity). Interestingly, long-term fluctuations in the helicity lead to a reversal of the dipole field, but not the toroidal field, whereas both poloidal and toroidal fields can reverse following short-term fluctuations. Olson explains the reversals in terms of fluctuations in the level of turbulence in the Earth's core caused by two competing energy sources — heat loss at the mantle–core boundary and progressive growth of the inner core. These produce helicity of opposite sign, the α-effect generated by growth of the inner core tending to oppose and destabilize the α-effect generated by heat loss at the mantle–core boundary. One possible shortcoming of Olson's analysis is his neglect of the Earth's non-dipole field, which plays a key part in many other theories.

The presence of two energy sources generating opposite helicity at the two boundaries of the outer core provides an attractive explanation for the triggering of reversals in polarity. The equations of motion governing conditions in the outer core permit a magnetic field of either sign; changing boundary conditions seem to be the most likely cause of a change in polarity. Prior to Olson, Schloessin and Jacobs[5] had suggested such a model in which changing conditions at the mantle–core boundary are caused by the addition of lighter material from the outer core which rises as heavier material precipitates out to form the inner core[5]. In their model, the relative magnitude of the growth rates at the mantle–core boundary and at the inner core boundary determines the polarity of the field. Stevenson[6] has also suggested the existence of two energy sources in the Earth's outer core — but not as a mechanism for causing reversals. He suggested the geodynamo was powered by thermal convection during the early history of the Earth but that this power source died about 10^9 years ago to be replaced by the energy released by the growth of the inner core.

Gubbins has recently considered the possibility that reversals are initiated by such external phenomena as tectonic events, ice ages and the fall of tektites[7]. Investigating the change that such events would have on the pressure in the core — which would in turn affect the rate of freezing of the liquid outer core and modify the power supplied to the dynamo — he estimates that a pressure change of only 1 bar over 10,000 years could supply the power requirements of the dynamo. Even so, none of the external effects that he considered seems likely to be able to cause even so small a change in pressure although such an explanation cannot be ruled out because of uncertainties in the values of the parameters, the time scale for transmission of a pressure change through the mantle and the magnitude of the increment in the power supply necessary to cause reversal.

More recently, Force[8] has suggested a relationship between geomagnetic reversals, seafloor spreading rate, palaeoclimates and black shales. Clearly he is really only presenting a broad correlation; when it comes to individual reversals Force has to admit that "many of the linkages proposed are matters of dispute or incomplete work". His only suggestion of any connection with the Earth's magnetic field is a reference to Sheridan *et al.*[9] who end their paper with the observation that fast rates of seafloor spreading occurred during both the Jurassic and the Cretaceous quiet (magnetic) zones, "suggesting that plume eruptions from the lowermost mantle might connect these two processes and explain the pulses of fast spreading as well as the decrease in reversals of the magnetic field". It is difficult to visualize the physics of such a process; erupting plumes would be more likely to cause increased magnetic disturbances (more frequent reversals) than create magnetic quiet conditions.

It is clear that until we have a better understanding of the mechanism of generation of the geomagnetic field and of the morphology of the transition field, any correlation of reversals with surface phenomena must remain highly speculative. Whether a common source (as suggested by Sheridan *et al.*[9]) can initiate major changes in both the magnetic field and surface phenomena, or whether changing conditions in the core can influence surface phenomena, or vice versa, remains to be seen. □

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