Geomagnetic reversal paths

SIR — New palaeomagnetic records of the transitional fields during geomagnetic reversals are bringing about a radical revision of ideas on the morphology of these fields. Recently, we and others have reported many new reversal records, a remarkable preponderance of which show the position of the virtual geomagnetic pole (VGP) moving along the longitude of the Americas or its antipode^{1,2} as the reversal proceeds (a in the figure). The VGP is by convention the south magnetic pole of the dipole field that would give the observed declination and inclination at a site; hence, comparison of VGP paths from different sites yields information on the morphology of the field. The records include reversals ranging from 100,000 yr to at least 10 Myr in age; the persistence of the observed pattern may therefore reflect inherent characteristics of the geodynamo.

Here we point out that the same bands of longitude picked out by the transitional VGP paths prove to be important in other geophysical observations. For example, they have

particular significance in models of the present magnetic field at the core/mantle boundary, as they mark the boundaries of the dominant non-dipole feature at low latitudes, between 90° E and 90° W³. In the frozen flux approximation, this feature reflects the pattern of fluid motion in the outer core — specifically, a strong westward toroidal flow from 90° E to 90° W at low latitudes (part b of figure). The source of the flow appears to be partly influx of fluid from higher latitudes and partly upwelling from depth; there is a similar but weaker flow eastward from 90° E to 90° W. The longitude bands preferred by the VGP paths are thus those along which north–south flow is seen in the core models.

The preferred longitudes also represent regions of fast seismic-wave propagation (and therefore low temperature) in the lower mantle, possibly related to subducted lithospheric plates (part c of figure)⁴. The VGP paths therefore link the morphology of the transitional fields not only to features of the

present-day field and core flow patterns, but also to temperature anomalies in the mantle.

Although we do not yet understand the nature of these links, we can suggest some possibilities. As the poles of the dipole field are the foci of radial flux lines entering and emerging from the core, the VGP paths during reversals should tell us something about the behaviour of the flux bundles. The flux bundles are reduced in strength compared with times when the field is not reversing, but the VGP paths suggest that some vestige remains throughout the reversal. Given the core flow pattern, it seems likely that flux bundles will, at least initially, move towards the Equator at those longitudes where there is flow towards the Equator. Similarly, during the recovery phase, flux bundles should be transported poleward at longitudes where there is poleward flow. The longitudes of north–south flow are at 90° W and 90° E, which are indeed the preferred longitudes of the VGP paths.

The degree to which the field is dipolar during the reversal, or displays some more complicated geometry, with paths dependent on the observation site, will depend on the details of the radial flux bundles. It is not at all clear how intact the flux bundles will remain, nor how important diffusion will

be. For example, does some of the radial flux get swept into the toroidal flow? Do the flux bundles remain antipodal during the reversal? We think that it is not simply a coincidence that the longitudes of north–south core flow are those preferred by the VGP paths.

The link between reversal paths, the present magnetic field, flow in the core and temperature in the mantle, if confirmed by further work, will have profound implications. Because the time constants of mantle convection are orders of magnitude longer than those of the core, the persistence of the VGP bands over tens of millions of years suggests that fluid flow in the core is controlled, or at least modulated, by the temperature at the core/mantle boundary, which is determined by the pattern of mantle convection⁵. Thus, the engine of the planet appears to manifest itself in related internal motions from the core to the lithosphere, and geomagnetic phenomena in the core are ultimately related to plate tectonics.

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Triple helix stabilization?

SIR — There is an error in the interpretation of the data in the recent paper by Reaban and Griffin¹. They demonstrate that when a plasmid containing a 2.3-kb segment of IgA switch tandem repeats is transcribed *in vitro* in the same direction as it is *in vivo*, the synthesized RNA forms a heteroduplex with the plasmid DNA, which results in a reduction of the supercoiling of the plasmid. This does not occur when the same sequences are transcribed in the antisense direction.

The authors interpret this to suggest that the switch sequence forms a triple-stranded DNA structure, which is stabilized by the RNA. But the RNA transcribed in this direction from the plasmid and also *in vivo* would be purine-rich, and not pyrimidine-rich, as they suggest, and therefore would probably

a, VGP trajectories for the Blake event (115,000–120,000 yr before present), the Upper Olduvai reversal, (~1.8 Myr) and two reversals at ~6.5 and ~11 Myr. b, Fluid motion at the top of the core (from ref. 3). c, Seismic P-wave velocity of the lower mantle, at a depth of 2,300 km (adapted from ref. 6). Velocities given as deviations from the mean. (See cover for colour version.)

not stabilize a triple-stranded DNA structure, as this plasmid has been shown to form a triple-stranded structure consisting of one purine strand and two pyrimidine strands, with the free single-strand being the purine strand².

This error does not diminish the value of the observation¹, as the finding of a heteroduplex and altered conformation of the DNA in the transcribed plasmid suggests a hypothesis for how transcripts from unrearranged heavy-chain constant-region genes could direct switch recombination.

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REABAN AND GRIFFIN REPLY — Further DNA sequence analysis of the plasmid pBS- α S2.3 confirms Stavnezer's observation that transcription by T7 RNA polymerase would produce a transcript containing the polypurine sequence (AGGAG)₂₈, rather than the polypyrimidine transcript reported in our manuscript¹. We regret this error in our data.

But the fact that the T7 transcript is purine-rich would not exclude it from stabilizing an intramolecular DNA triplex. Under our transcription conditions (8 mM MgCl₂ and pH 8.0) a purine-purine-pyrimidine intramolecular DNA triplex is likely to form. This triplex would be stabilized by base-pairing with the purine-rich T7 transcript via its excluded pyrimidine strand. A poly(dG)-poly(dC) sequence has been shown to form either a poly(dG)-poly(dG)-poly(dC) or a poly(dC)-poly(dG)-poly(dC) triple helix in a supercoiled plasmid, depending on the presence or absence of Mg²⁺, respectively³. The +Mg²⁺ triplex forms stably in neutral or slightly basic buffers, whereas formation of the -Mg²⁺ triplex is enhanced by low pH. The formation of dG-dG-dC (ref. 4), A-A-U (ref. 5) and 5'-TGGGGA-GGGGTGGGAGGGGTGGGGAA-GG-3' purine-purine-pyrimidine (ref. 6) colinear triplexes under similar buffer conditions have also been reported. The base triplets predicted to occur with these triplexes have been observed in yeast transfer RNA⁷. Therefore our error does not alter our interpretation that the T7 transcript stabilizes an intramolecular DNA triplex.

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Whales and the military

SIR — Several live mass strandings of Goose-beaked whales (*Ziphius cavirostris*) have recently been reported¹ on the coasts of Fuerteventura, Canary Islands. In February 1985, 12 were stranded in the southern coast accompanied by a Gervais' beaked whale (*Mesoplodon europaeus*); in June 1986, four more were stranded alive on the northern coast, again with a single *M. europaeus*; in November 1988, three *Ziphius* and a single northern bottle-nosed whale (*Hyperoodon ampullatus*) were stranded on the southeast side (on the same date two pygmy sperm whales (*Kogia breviceps*) were stranded on the neighbouring island of Lanzarote). Military manoeuvres were observed at sea close to the stranding sites in February 1985 and November 1988 (ref. 1).

A further hitherto unreported mixed-species live mass stranding occurred on Fuerteventura in October 1989; three *M. europaeus* came ashore with two *M. densirostris* (de Blainville's dense-beaked whale) and many *Ziphius*. In total, about 24 animals are estimated to have stranded by M. Pizarro, R. Vonk and V. Martin. Again, the stranding occurred when naval vessels were clearly visible out to sea. Local people have only been aware of such military manoeuvres three times since 1985; on each occasion mass live strandings have occurred. No pathological examinations were conducted on any of the stranded animals but there were no apparent abnormalities or wounds. All the stranded animals soon died.

Strandings of *M. europaeus* on the east side of the Atlantic are very rare. Before the strandings in the Canaries only two others had been reported². There are also only a few reports of multiple deaths of *Ziphius* outside the Canaries¹; first, off Venezuela, when four decomposed bodies washed ashore on an island (the recorder considered that an underwater explosion, related to naval manoeuvres, might be responsible; second, when the bodies of three *Ziphius* and a striped dolphin (*Stenella coeruleoalba*) came ashore on the coast of Corsica with bul-

let holes in them; and third, a mass stranding, about which no further details are known, that occurred on the east coast of the United States. Two further small strandings are also known from the Galapagos and Puerto Rico.

Details of the general pattern of strandings in the Canaries from 1981 to 1987 have been noted by Vonk and Martin, and are presented with the mass strandings of 1988 and 1989 in the figure. The island of Fuerteventura is the closest of the Canary Islands to the African mainland. It is also the main island from which local people fish (off the east side) for squid. The sea between Africa and the island may, therefore, be an important feeding ground for toothed whales. (*Mesoplodon* stomachs have been found to contain hundreds of squid beaks.)

Reports of military interactions with cetaceans are rare, although sperm whales in the southeast Caribbean became atypically

Cetacean strandings in the Canaries, 1982-89. (The data were obtained by Vonk and Martin.) Shaded bars, *Ziphius*; open bars, other species; asterisks, live strandings; black arrowheads, military activity.

silent and then scattered when exposed to intense underwater, local, military sonar signalling, apparently from submarines³.

Naval manoeuvres off Fuerteventura may have stimulated an invasion of the island by ships coming towards the east coast through the whales' feeding grounds. This could have driven the whales shorewards and caused them to strand. Very little is known about the biology of *Ziphius*, so the reason for the unusual strandings can only be the subject of speculation.

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