Magnetic Source Separation in Earth's Outer Core

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The dipole component of the geomagnetic field is anomalously strong at both Earth's surface and the core-mantle boundary (CMB). Because dipole terms are of the lowest degree, they are the most capable of reaching the CMB from sources deep within the outer core (*1*). Nondipole (higher-degree) terms need originate from sources residing closer to the CMB if they are to emerge. Yet, the power associated with the equatorial dipole terms is compatible with the nondipole power spectrum [e.g., (*2*)], leaving the axial dipole to stand alone given its unique strength. The question then is whether the source of the axial dipole is physically distinct from sources responsible for the rest of the field, the so-called nonaxial dipole (NAD) field.

Analyses of the NAD field at Earth's surface indicate that its present structure is similar to that when time-averaged over the past 400 years (*3*); the most intense patches of vertical flux (Fig. 1, right) appear almost motionless, indicative of long-term control over shallow core fluid by the lowermost mantle. Hence, the time-averaged NAD field may be used as a proxy for the modern-day NAD field and vice versa.

Twentieth-century observatory data suggest further that these standing features strengthen at independent rates (*4*). The effect about the globe of this NAD field secular variation is displayed in Fig. 1 (left): Localities close to (and hence dominated by) a single flux feature, versus those more equally proximate to multiple features, experienced lesser and greater vector field changes, respectively.

We focus on two widely separated sites—West Eifel, Germany, and Tahiti, French Polynesia—from which we have available paleomagnetic transitional field data obtained from lavas that erupted since the Matuyama-Brunhes polarity reversal. The $^{40}Ar/^{39}Ar$ age determinations of West Eifel lavas indicate the recording of five excursions spanning some 200,000 years, including the Big Lost Event (table S1). The transitional lavas from Tahiti also record the Big Lost Event (*3*) and the Matuyama-Brunhes reversal (*5*). Virtual poles recorded in transitionally magnetized lavas from West Eifel are spread across Eurasia, whereas the two events recorded on Tahiti are associated with the same tightly clustered virtual geomagnetic pole (VGP) location west of Australia, where the most intense NAD field flux feature exists at Earth's surface (Fig. 1, right).

Modern-day NAD field structure and behavior tend to explain the paleomagnetic findings: The site of West Eifel lies within the sphere of influence of three concentrations of NAD field flux within the area of greatest directional secular change. In contrast, Tahiti is considerably closer to one, the Australasian feature, and is within the area of least secular change. Thus, both the wide east-west spread in West Eifel Brunhes–aged transitional VGPs and the nearly identical Tahitian VGP clusters are compatible with recent and historic geomagnetic findings.

Also plotted in Fig. 1 (right) are south VGPs associated with the NAD field at both sites throughout the 20th century (*6*). These recent-field virtual poles, associated with complete removal of the axial dipole term, show behavior similar to the paleomagnetic data, both in angular change and location, for both sites. From these correlations, we conclude that polarity transitions first involve the demise of the source generating the axial dipole, which leaves the field generated only in the shallow core with a pattern strongly controlled by the physical variability of the lower mantle. Hence, we suggest that there are two significantly independent field sources: one generated deep within the outer core; the other generated in the shallow core, which we designate the SCOR field.

The SCOR field is essentially the NAD field; however, its complex pattern most assuredly contains a small contribution to the axial dipole. The deeper-core field then provides nearly all of the observed axial dipole, yet it must also contain a (small) contribution to lower-degree harmonics in the observed NAD field (*7*). Such a field source dichotomy may be the key to solving the problem of the reversing geodynamo.

References and Notes

1. Having the longest spatial wavelengths, dipole components are least likely to be screened out by overlying electrically conductive fluid.
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6. The dynamo is blind to the field sign, so either case is equally valid.
7. Some field asymmetry is required by Cowling's theorem to maintain dynamo action.
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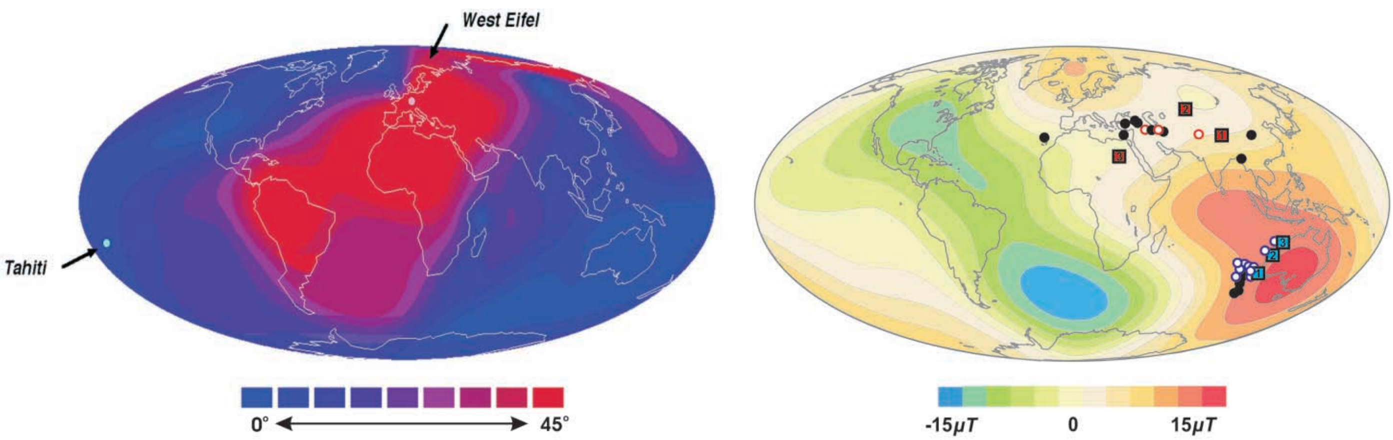

Fig. 1. (**Left**) Contoured angular change from 1900 to 2000 of NAD field VGPs about the globe. (**Right**) (i) Transitional north VGPs recorded in lavas on Tahiti (clustered near west Australia) and West Eifel (spanning much of Eurasia), each case spanning ~200,000 years (Big Lost Event VGPs, which were recorded at both sites, have open symbols), and (ii) concurrent south VGPs for the years 1900, 1950, and 2000 (indicated on the map by 1, 2, and 3, respectively) NAD field at Tahiti (blue squares) and West Eifel (red squares) plotted on the 1590–1990 time-averaged surface NAD field.