The Long-term Nature of the Geodynamo Based on Coupled Analyses of Paleointensity and Paleosecular Variation

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To gain a complete picture of the long-term nature of the geodynamo we must characterize the morphology, secular variation and intensity of the field versus reversal frequency. Fortunately, magnetic polarity stratigraphy, as pioneered by Neil Opdyke in the 1960's, has led to a robust geomagnetic polarity timescale from which we can select study intervals during which reversals were relatively more or less common.

Arguably the most reliable way to determine the past strength of the magnetic field is the Thellier technique whereby igneous rocks are subjected to a stepwise progression of paired heating steps. Unfortunately, many whole rock samples are unsuitable for Thellier analysis. One complicating factor is the growth of new magnetic minerals associated with the thermal alteration of clays (which are ubiquitous in pre-Quaternary whole rock samples) during Thellier experiments. Hence, this geologic (and associated experimental) alteration often prohibits the simultaneous definition of past field directions and intensities.

We have developed an approach for the determination of paleointensity that uses single plagioclase crystals separated from mafic igneous rocks. These crystals contain magnetic inclusions which are less affected by experimental alteration and thus may allow us to overcome the obstacles described above. Transmission electron microscopy and a host of rock magnetic methods reveal that these crystals contain small single to pseudo-single domain, equant to slightly elongated magnetic inclusions (50 to 250 nm). In a test of the method, Thellier analyses of plagioclase crystals from a modern lava flow yielded an intensity that agreed with that recorded by magnetic observatories. Here we discuss applications of the method to the nature of the geomagnetic field during superchrons and that of the early Earth.

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If relationships exist between the frequency of geomagnetic reversals and the other basic characteristics of the field, they should be well expressed during superchrons, intervals tens of millions of years long lacking reversals. We have been studying secular variation (recorded by whole rock samples) and paleointensity (recorded by single plagioclase crystals) from Arctic lavas of the Cretaceous Normal Polarity Superchron that formed on the North American craton near the tangent cylinder (that imaginary cylinder about the rotation axis that is tangent to the solid inner core). These data suggest a time-averaged field that is remarkably strong and stable.

The Arctic directional data, when combined with data from lower latitude North American sites, provides an opportunity to examine the geometry of the field (thus touching on another major contribution of Neil Opdyke). These North American data define a time-averaged field that is overwhelmingly dominated by the axial dipole (octupole components are insignificant). This conclusion is also supported by a consideration of global high-resolution paleosecular variation studies. These observations suggest that the basic features of the geomagnetic field are intrinsically related. Superchrons may reflect times when the nature of core-mantle heat flux allows the geodynamo to operate at peak efficiency, as suggested in some numerical models.

On even longer time scales, paleointensity data from Proterozoic-Archean rocks are of interest as this interval brackets the time suggested in some models for the initiation of inner core growth. We have been investigating this interval through Thellier analyses of plagioclase separated from mafic dikes. Although our results to date are unlikely to adequately represent the time-averaged field, the mean and range of values is similar to that of the present-day field. These values suggest that the inner core, which may stabilize the geodynamo, had started to grow by Early Proterozoic times (~2.45 Ga).