A Rotating Solar Magnetic "Dipole" Observed from 1926 to 1968

Abstract. *A recurring pattern with a period of 26⅞ days observed in the polar geomagnetic field during the interval from 1926 to 1941 appears to persist in the interplanetary magnetic field polarity observed with spacecraft during the interval from 1963 to 1968. This observation suggests the existence of a rotating solar magnetic "dipole" with a period of 26⅞ ± 0.003 days.*

Olsen (*1*) has discovered a recurrent pattern with a period of 26⅞ days in the horizontal component of the geomagnetic field observed at Godhavn, Greenland (corrected geomagnetic latitude, 77.5°N), during the years from 1926 to 1941. A relation between this component of geomagnetic activity and the polarity (toward or away from the sun) of the interplanetary magnetic field has been discovered by Svalgaard (*2*) and by Mansurov (*3*) and confirmed by Friis-Christensen *et al.* (*4*), who used a prediction technique. We have therefore taken an integral number of 26⅞-day periods from the starting date of 1 July 1926 used by Olsen and have made a superposed epoch analysis of the average polarity of the interplanetary magnetic field observed by spacecraft in the interval from 1963 to 1968. The resulting pattern of the interplanetary magnetic field polarity is just as would be expected on the basis of the considerations presented above, and the phase has been preserved over approximately 550 occurrences to within a day or two. This result indicates that Olsen's period of 26⅞ days is accurate to within ± 0.003 day. Since the interplanetary magnetic field has been shown to have its source in the photospheric magnetic field (*5*), these results further suggest that a layer or the core of the sun rotates with a period of 26⅞ days and has a magnetic pattern such that during approximately the first half of the period the field is predominantly directed into the sun and during approximately the second half of the period the field is directed predominantly out of the sun.

Olsen (*1*) made a superposed epoch analysis of the daily means of the horizontal component at Godhavn. His results are shown in Fig. 1. In order to see if the phenomenon was accidental, Olsen divided the results obtained from 1 July 1926 to 19 March 1941 into four equal parts, with the results shown in curves b–e of Fig. 1. In each case there is a clear tendency for the horizontal component to be less than average during approximately the first half of the recurrence interval and greater than everage during approximately the second half of the interval.

The relation between this horizontal component of the geomagnetic field and the polarity of the interplanetary magnetic field is such that on a day when the interplanetary polarity field is away from the sun the daily mean of the horizontal component is larger than average, and on a day when the

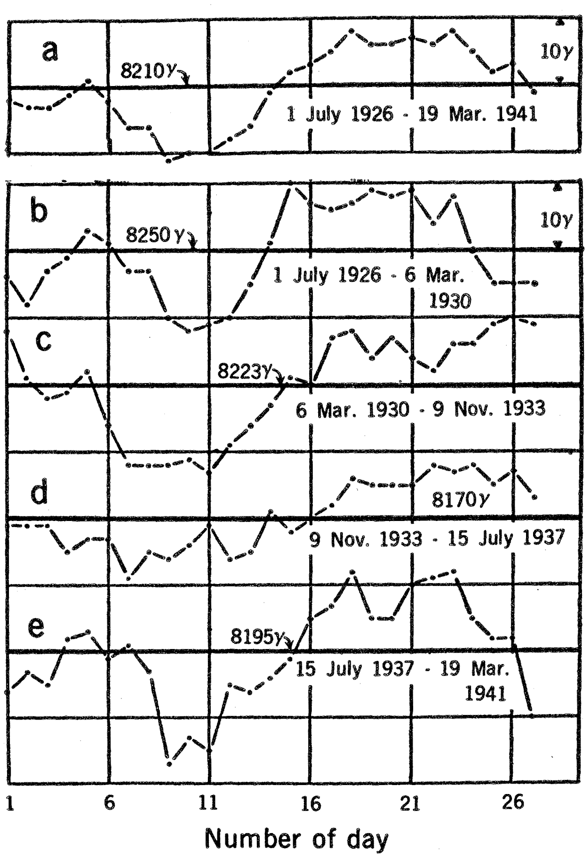

Fig. 1. Superposed epoch analysis (that is, average shape) of the daily means of the horizontal component of the polar geomagnetic field observed at Godhavn, Greenland. The abscissa is the number of the day in the recurrence interval of 26⅞ days. The ordinate is the average value of the horizontal component. Curve a shows the results obtained from 1 July 1926 to 19 March 1941. Curves b–e show the results obtained by dividing this interval into four equal parts [from Olsen (*1*)]. [Courtesy of the American Geophysical Union, Washington, D.C.]

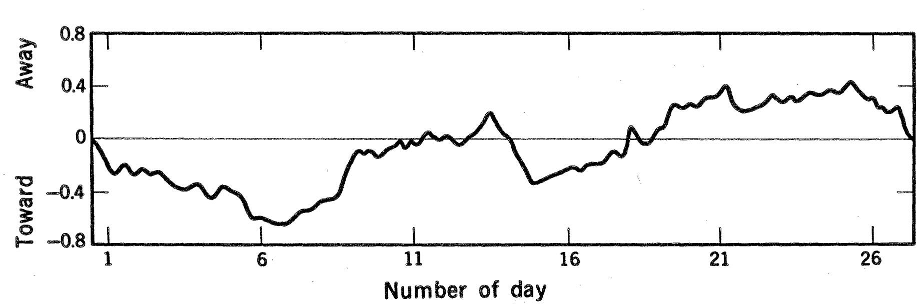

Fig. 2. Superposed epoch analysis of observed interplanetary magnetic field polarity from 1963 to 1968 The period (26⅞ days) and phase are taken from Olsen's analysis of the horizontal component of the geomagnetic field at Godhavn from 1926 to 1941. The ordinate is $(N_A - N_T)/(N_A + N_T)$, where N_A is the number of polarity sectors away from the sun and N_T is the number of polarity sectors toward the sun at each 3-hour interval within the 26⅞-day period.

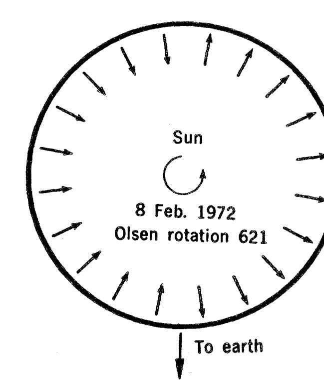

Fig. 3. Schematic of the rotating solar magnetic "dipole." The figure is a cross section through the solar equator.

interplanetary magnetic field polarity is toward the sun the daily mean of the horizontal component is less than average. The physical cause for this relationship has not yet been determined, but it may be related to an increased drag on the tail of the geomagnetic field from the northern polar cap during an interplanetary field polarity away from the sun as compared with a polarity toward the sun, or perhaps to plasma flows in the polar cusp regions of the magnetosphere (*6*).

These considerations suggest that we might expect to find in the observed interplanetary field polarity a 26⅞-day recurrence pattern with the field polarity predominantly toward the sun (negative) during approximately the first half of the period and predominantly away from the sun (positive) during approximately the second half of the period. To investigate this possibility we have taken an integral number of 26⅞-day periods from the starting date of 1 July 1926 used by Olsen. Thus period number 505 began on 1 August 1963. The result of such a superposed epoch analysis of the polarity of the observed interplanetary magnetic field from November 1963 through December 1968 is shown in Fig. 2. The polarity pattern expected from the above considerations is clearly evident, and it is very nearly in phase with Olsen's recurrence system. If we assign a 2-day uncertainty in the phase for Fig. 2, then the period as determined over the approximately 550 rotations since 1926 is 26⅞ ± 0.003 days. A schematic drawing of the rotating solar magnetic "dipole" inferred from these considerations is shown in Fig. 3.

In addition to the two basic polarity intervals per period shown in Fig. 2, there is evidence in the range from 9 days to 19 days for a modulation that may be related to a structure of four polarity changes per period, such as has been observed in the form of four interplanetary magnetic sectors per solar rotation during a portion of the interval from 1963 to 1968 observed with spacecraft (*7*). It thus appears that the basic pattern in the rotating solar layer is two polarity regions per rotation, but that effects perhaps related to solar activity and to the Babcock (*8*) model of solar magnetism cause the observed photospheric (and interplanetary) magnetic fields to display considerable variation about this basic pattern. A relatively unchanging rotating magnetic dipole may be lurking within (figuratively or literally) the highly variable sun that we see in day-by-day observations.

Note added in proof: Yearbooks for most of the years from 1926 to 1964 (*9*) containing observations on the horizontal component at Godhavn have recently become available to us. The recurrence pattern of Olsen shown in Fig. 1 is present in each individual sunspot cycle during this interval, except during the cycle from 1944 to 1954, which appears to be anomalous (*10*).

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Evolving Subduction Zones in the Western United States, as Interpreted from Igneous Rocks

Abstract. *Variations in the ratio of K_2O to SiO_2 in andesitic rocks suggest early and middle Cenozoic subduction beneath the western United States along two subparallel imbricate zones dipping about 20 degrees eastward. The western zone emerged at the continental margin, but the eastern zone was entirely beneath the continental plate. Mesozoic subduction apparently occurred along a single steeper zone.*

Sea floor magnetic anomalies (*1, 2*) and andesitic continental margin volcanism (*3, 4*) indicate that until middle Cenozoic time a spreading rise system was continuous west of North America, and a subduction zone was continuous along the western continental margin. We here attempt to interpret the late Mesozoic and Cenozoic evolution of this subduction system from variations in the composition and distribution of igneous rocks in the western United States.

Modification of the subduction system in late Cenozoic time has produced plate boundaries in the western United States (Fig. 1) that consist of an oblique transform system separating two remaining segments of the spreading ocean rise (*1, 2, 5*). Initiation of extensional faulting through a wide region inland from this transform boundary (Fig. 1) followed termination of the subduction system (*1, 6*). Miocene and younger igneous rocks associated with the extensional faulting are fundamentally basaltic; they include basalt fields, differentiated alkalic basaltic sequences, and bimodal basalt-rhyolite suites (*6*). This late Cenozoic basaltic association is not discussed further.

Lower and middle Cenozoic continental lavas (Fig. 2) are predominantly calc-alkalic intermediate compositional types (andesite-rhyodacite), commonly with associated, more silicic ash-flow sheets. Compositional zonations in some individual ash-flow sheets, from rhyolite upward into quartz latite, record magmatic differentiation in underlying batholithic source chambers (*7*). The intermediate lavas probably are samples of the bulk of these batholiths, with the ash-flow tuffs representing their differentiated tops (*3*). Similar igneous rocks continued to form in later Cenozoic time but were restricted to a shrinking zone opposite the continental margin trench (*6*). By Quaternary time predominantly intermediate-composition igneous activity was restricted to the Cascade Range and to central Mexico (Fig. 1).

These calc-alkalic intermediate igneous suites, although compositionally varied, are within the range observed in active volcanic arcs that are associated with plate convergence (*3, 4*), where chains of andesitic volcanoes are aligned