

VARIATIONS OF THE EARTH'S MAGNETIC FIELD AND RAPID CLIMATIC COOLING: A POSSIBLE LINK THROUGH CHANGES IN GLOBAL ICE VOLUME

Michael R. Rampino, *Goddard Institute for Space Studies, New York, New York 10025*

ABSTRACT

A possible relationship between large-scale changes in global ice volume, variations in the earth's magnetic field, and short-term climatic cooling is investigated through a study of the geomagnetic and climatic records of the past 300,000 years. The calculations suggest that redistribution of the earth's water mass can cause rotational instabilities which lead to geomagnetic excursions; these magnetic variations in turn may lead to short-term coolings through upper-atmosphere effects. Such double coincidences of magnetic excursions and sudden coolings at times of ice-volume changes have occurred at 13,500, 30,000, 110,000, and 185,000 YBP.

Introduction. A relationship between variations in the earth's magnetic field and changes in climate has been suggested by many authors (e.g., Harrison and Prospero, 1974; Wollin et al., 1971). The low field strengths at the times of magnetic reversals or excursions should lead to an increase in the cosmic-ray flux in the upper atmosphere. It has been proposed that this might cause increased upper-atmosphere ionization and cloud formation or perhaps a catastrophic depletion of the ozone layer. These are conditions that could ultimately result in increased high altitude cloudiness and increased precipitation and cooling in the mid-latitudes (Harrison and Prospero, 1974; Reid et al., 1976).

It has also been suggested that long-term climatic changes which cause major fluctuations in global ice volume, and hence in the redistribution of water mass on the earth's surface, could lead to rotational instabilities and therefore result in changes in the magnetic field through core-mantle effects (Doake, 1977; Mörner, 1977). A glacio-eustatic sea level change of about 100 meters would cause a change in rotational energy of 1.9×10^{24} J. In this case, the fractional change in angular velocity, length of day and moment of inertia would be 10^{-5} (Doake, 1977). In the model of Doake, the changes in core energy involved are of the same order of magnitude (a rate of energy dissipation of 10^{12} W) as the energy required to drive the geodynamo. Doake (1978) has noted a statistical correlation between magnetic reversals and climatic change.

There is thus an indication in the geologic record of a correlation between long-term, large-scale changes in ice volume (and therefore sea level) and excursions of the earth's magnetic field. The magnetic excursions, which occupy a relatively short time span, may produce rapid climatic coolings. It is therefore worthwhile to search for a further co-

incidence; magnetic excursions which occur during a time of large-scale melting or growth of ice sheets may be accompanied by a significant cooling and short-term growth of ice sheets (Fig. 1).

Study of climatic and geomagnetic records. A first step in this problem is to examine the climatic and geomagnetic records of the past several hundred thousand years in search of evidence for such double coincidences of major ice/water redistributions, magnetic excursions, and rapid coolings. One such double coincidence at the time of the Gothenburg Magnetic Excursion $\sim 13,500$ YBP, has been documented by Fairbridge (1977). This event came at about the midpoint of the melting of the latest Pleistocene northern hemisphere ice sheets. Furthermore, the magnetic excursion appears to correlate with a time of short-term rapid climate cooling and ice buildup. Sea level dropped more than 10 meters between 13,000 and 14,000 YBP and glaciers on North America readvanced over an area of some 500,000 square kilometers.

Several other magnetic excursions are reported to have occurred during the past 300,000 years. The two excursions considered to rest on the best supporting evidence are the Lake Mungo Excursion at $\sim 30,000$ YBP and the Blake Event at $\sim 110,000$ YBP (Verosub and Banerjee, 1978). Furthermore, study of a core from Lake Biwa, Japan has indicated the presence of the Blake Event (dated at $\sim 110,000$ YBP) as well as two other magnetic excursions, estimated to date from $\sim 185,000$ YBP (the Biwa I Event) and $\sim 295,000$ YBP (the Biwa II Event) (Fig. 2). These excursions are coincident with pronounced lows in organic carbon in the Lake Biwa sediments (Fig. 3). The decrease in organic carbon is believed to be related to climatically controlled changes in the productivity of the lake (Kawai et al., 1975).

The Blake Event has previously been correlated with a time of quite sudden climatic cooling and ice buildup, following the large-scale melting of the ice sheets which marked a change from full-glacial to full-interglacial conditions (Mörner, 1977). A cooling at about 110,000 YBP might be expected from considerations of earth orbital variations (the Milankovitch mechanism) (Kukla, 1975). However, the actual cooling and glacier buildup was extremely rapid. Studies of changes in sea level (Matthews, 1972) and of changes in the oxygen-isotope ratios in deep-sea cores (Shackleton, 1976) indicate that sea level fell rapidly, 60-70 meters in a few thousand years. These rapid rates of change in global climate and ice volume might be explained as being a result of the alterations of atmospheric circulation and precipitation that have been suggested to accompany magnetic-field fluctuations (Fairbridge, 1977).

The Lake Mungo Excursion at $\sim 30,000$ YBP was also associated with a time of apparent rapid cooling and glacier advance. This cooling came soon after the global warming and large-scale melting of ice associated with an interstadial interval. Evidence from Long Island, New York in the form of radiocarbon-dated marine deposits points to the possibility that the sea at $\sim 30,000$ YBP rose to within 20 meters of modern sea level (MSL) and then dropped to more than -100 meters MSL by about 20,000 YBP (Rampino and Sanders, 1976). Pollen analyses from the same deposits indicate a very rapid cooling just after 28,000 YBP. Temperate-forest vegetation on Long Island was replaced by boreal type forests within a few hundred years. Ice sheets readvanced to the Long Island area by 23,000 YBP (Sirkin, 1977).

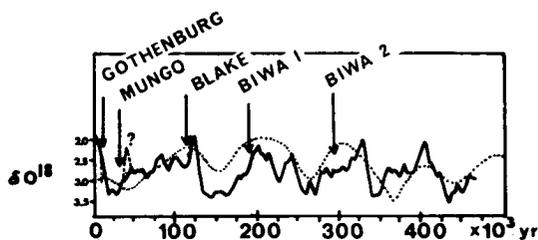
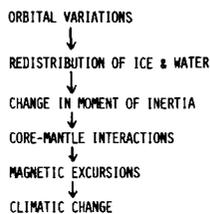


Fig. 1 (left). Diagram of possible relationships between the redistribution of global water mass, magnetic excursions, and short-term climatic cooling.

Fig. 2 (right). Record of global ice volume for the last 400,000 years as inferred from oxygen-isotope records in sub-Antarctic deep-sea cores (Hays et al., 1976). Low values of δO^{18} indicate small ice volumes; high δO^{18} values indicate large ice volumes. The dotted line is a plot of the eccentricity of the earth's orbit. The times of five reasonably well-established magnetic excursions are shown by arrows.

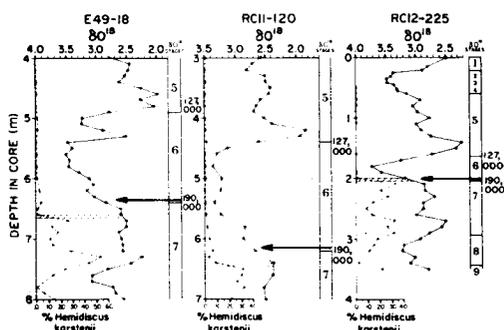
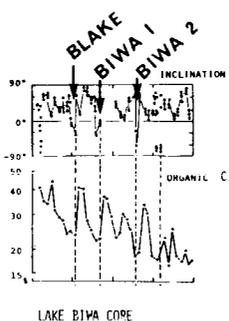


Fig. 3 (left). Magnetic inclination and percent organic carbon in the Lake Biwa sediment core. The positions of the Blake, Biwa I and Biwa II magnetic events are shown by arrows (Kawai et al., 1975).

Fig. 4 (right). Oxygen-isotope record (solid line) and percent abundance of the diatom *Hemidiscus karstenii* in sections of sub-Antarctic deep-sea cores. The last appearance of *H. karstenii* is shown by the diagonal hatched areas (Burckle et al., 1978). The date of the Biwa I magnetic event, as inferred from the Lake Biwa core, is shown by arrows.

The sequence of events at $\sim 30,000$ YBP could be an example of a climatic warming induced by changes in seasonal insolation (the Milankovitch mechanism) which was cut short by magnetically induced cooling. The original warming and melting of ice sheets led to changes in the earth's rotation and therefore to magnetic instabilities; the magnetic influences on climate in turn caused a pronounced short-term cooling.

The magnetic excursion estimated to have occurred at $\sim 185,000$ YBP (the Biwa I Event) also appears to be correlated with a time of rapid growth of ice as indicated by oxygen-isotope records in deep-sea cores (Fig. 2). It is estimated that at about 190,000 YBP summer sea-surface temperatures in the sub-Antarctic declined approximately 2°C (from 9°C to 7°C). This time also marked the last appearance of the diatom *Hemidiscus karstenii* in sub-Antarctic deep-sea cores (Burckle et al., 1978) (Fig. 4). This probable extinction might be related to the environmental stress generated by the climatic cooling, magnetic excursion, or some combination of the two.

The Biwa II Event at $\sim 295,000$ YBP was apparently not accompanied by rapid changes in ice-volume as indicated by oxygen-isotope curves (Fig. 2), although the Lake Biwa Core shows a marked decrease in productivity, interpreted as a cooling of the climate at that time (Fig. 3). However, a very short period of rapid ice-sheet growth might be beyond the resolving power of the isotope record in most deep-sea cores.

Discussion. An association of events such as changes in global ice volume, magnetic excursions and short-term rapid cooling and glaciation of course does not prove that any cause and effect relationship exists. Several magnetic excursions that have been reported in the literature (including the Biwa II event mentioned here) are apparently not associated with times of ice-volume changes or rapid cooling as recorded in oxygen-isotope curves (for a review of reported excursions see Verosub and Banerjee, 1977). This argues against a one-to-one cause and effect relationship. However, some of these reported excursions are very likely spurious or poorly dated (Verosub and Banerjee, 1977). Furthermore, the climatic record in many deep-sea cores may have poor resolution of events shorter than a few thousand years, as a result of slow deposition, bioturbation and/or dissolution of calcium carbonate.

A more definitive answer to the question of possible relationships between magnetic excursions and climate change will depend upon further study of the response of the core and mantle to changes in the earth's rotation, and upon a better understanding of the possible effects that geomagnetic variations might have on climate through upper-atmospheric mechanisms. Further empirical tests of the validity of the relationship between magnetic excursions and short-term climate cooling can be obtained from analyses of sedimentary sequences with high rates of deposition, and from closely spaced paleomagnetic determinations in suitable materials.

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