Geomagnetism

Synonyms

Earth's magnetic field

Definition

Geomagnetism is a domain of geophysics which studies the origin and nature of the Earth's magnetic field. Geomagnetism involves integrated approaches to decipher ancient and contemporary magnetic fields of the Earth and other planets of the solar system.

Structure and Properties of the Earth's Magnetic Field

The Earth's magnetic field or geomagnetic field surrounds the planet where ~98 % of it the field generated by geodynamo, creating the magnetosphere (Merrill et al. 1996). Geodynamo is the compositional and thermal convection in the outer liquid core of the conductive material (mainly iron). Convective electrical current produces geomagnetic field. The main part of the field is produced in the Earth's core and is described near the Earth's surface as a magnetic field of a dipole (Jones 1977; McFadden and Merrill 1984). The dipole has its magnetic South Pole oriented toward the geographical North Pole (see Fig. 1). The field structure is deformed by the solar wind above the Earth's atmosphere (1-2 % of a total measured field at the Earth surface) (Courtillot and Le Mouel 1988). In reality, there is a deviation between the best-fit dipolar magnetic field on the Earth and the actual field. In the mantle, the shape of the magnetic field is changed to a quadrupole or multipole system. Additional disruption of the field (1-2 %) comes from the magnetized crustal rocks (Merrill 2010).

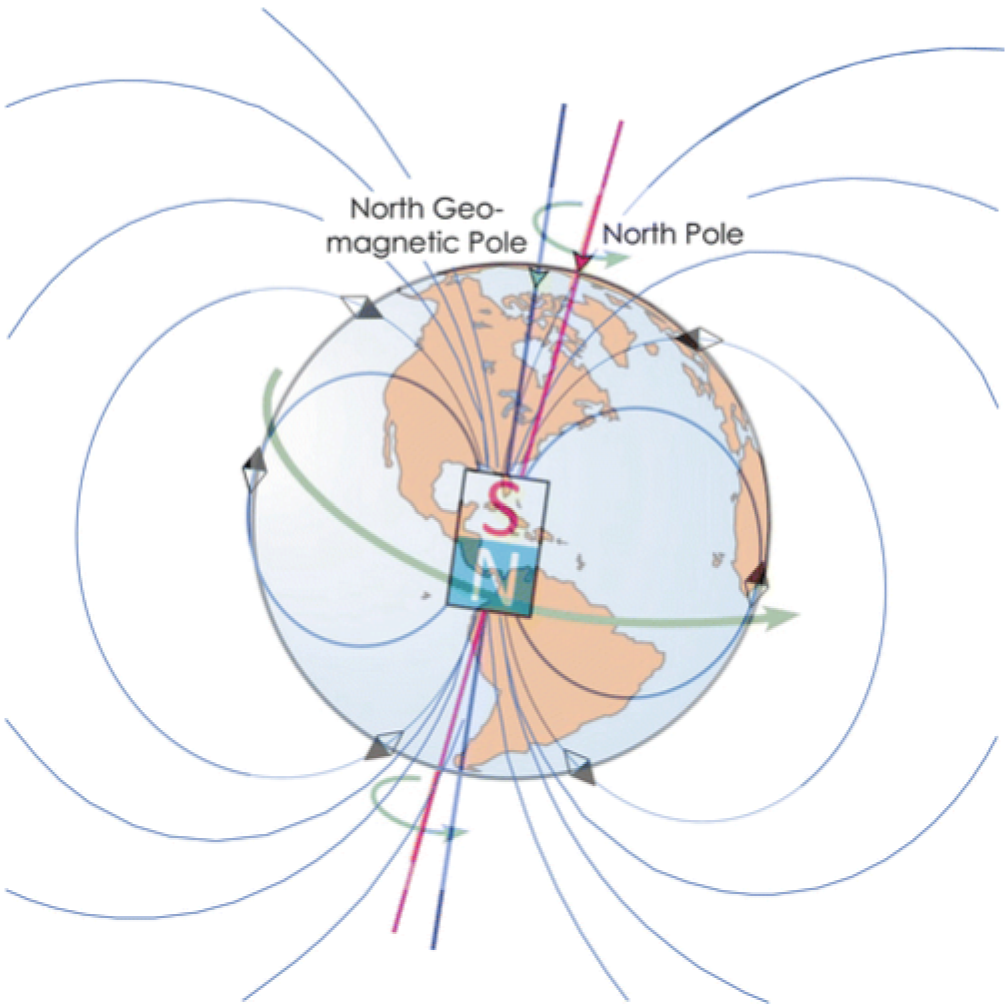

Fig. 1
The geomagnetic dipole position in the center of the Earth with its axis tilted relative to the Earth's axis. Magnetic field lines are shown with horizontal magnetic compass needle pointing along the lines. The needle indicates magnetic inclination, the angle measured from the horizontal surface at the point of observation. Positive values of inclination indicate that the magnetic field of the Earth is pointing downward, into the Earth, and negative values indicate that it is pointing upward

Presently, the horizontal component of the field is directed roughly into the geographic north-south direction. The local deviation from this alignment is called declination (see Fig. 2). In the middle and high latitudes, the magnetic flux lines change from the pointing horizontally vector to a much stronger more vertical vector (see Fig. 1). The inclination angle of the field lines can be measured with a compass needle, whose axis of rotation is mounted horizontally (see Fig. 2). At the magnetic North and South Poles, the inclination is 90°, and at the magnetic equator, it is 0°. Currently, the axis of the geomagnetic dipole field deviates at about 11.5° relative to the Earth's axis of rotation. The present-day dipole moment of the geomagnetic field is $M = 7.746 \times 10^{22}$ Am^2 and can be calculated from the most recent International Geomagnetic Reference Field of 2010 (IGRF-11) (International Association of Geomagnetism and Aeronomy, Working Group V-MOD 2010). It changes constantly with the current annual decrease of -0.006×10^{22} Am^2/year.

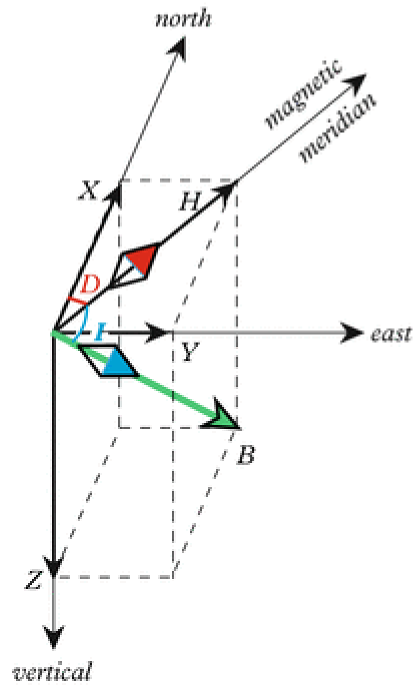

Fig. 2
Illustration of the coordinate systems used for representing the Earth's magnetic field. The geomagnetic field can be described by north (X), east (Y), and vertically downward (Z) Cartesian components and by the angles of declination (D) and inclination (I) together with the total field intensity (B)

Paleomagnetism

Paleomagnetism studies the past geomagnetic field recorded in rocks and sediments. Since the magnetic minerals are abundant in the Earth's crust, paleomagnetic studies can be applied to a wide range of rocks and sediments. When a rock, containing ferromagnetic minerals, is heated to temperatures above the Curie point and then cooled in the ambient geomagnetic field, it is magnetized in the direction of the existing geomagnetic field (McElhinny and McFadden 1999; Tauxe 2010). This applies to volcanic rocks, bricks, pottery, and terracotta. During sediment formation, the magnetic grains align themselves with the local magnetic field until they become locked into place. The acquired magnetization is called a remnant magnetization and can be described by its inclination, declination, and intensity or by the related values of paleolatitude and paleolongitude which define a virtual geomagnetic pole (VGP). When a sequence of VGPs (paleomagnetic poles) has reliable ages, they can be used to produce an apparent polar wander path (APWP). This path is constructed using different poles of known age for a stable continental block and represents the APWP through time for that continent (Tauxe 2010).

Geomagnetic Reversals, Excursions, and Secular Variations

The direction of the ancient magnetic field has been continuously registered in the mid-ocean ridges when the erupted magma cools down. It enables one to study the geomagnetic polarity reversals, i.e., when the Earth dipolar field reverses 180° relatively to the present-day orientation. Such reversals are common throughout Earth's entire geological history. The most recent polarity reversal occurred at ~780,000 years ago (Brunhes-Matuyama reversal) (Langereis et al. 2010). Recent study suggests that an actual pole shift takes around 1,000 years (Valet et al. 2012). Reversals are very well documented until about 160 million years ago from the marine magnetic anomalies (Cande and Kent 1995; Gee and Kent 2007) and are less reliably known for older geological times.

A geomagnetic excursion is a significant change in the prevailing geometry of the geomagnetic field, which lasts on the order of the first thousands of years. The geomagnetic field, however, does not flip to a stable position at 180° during excursion. The most common contemporary conception states that the excursion occurs due to localized disturbances in

the geomagnetic field caused by the convection of electrical currents in the outer core and its interaction with the mantle (Olson et al. 2013).
Geomagnetic secular variations are the changes in the field over periods of a year or more; they reflect shorter-term changes in the Earth's outer core. The variations that predate historical observations and recorded in archaeological and geological materials are called paleomagnetic secular variations or paleosecular variations (PSV).

Paleomagnetic Dating

For paleomagnetic dating, the APWP is used to determine the age of a paleomagnetic pole obtained from rocks or sediments of undefined age by projecting the pole on a sphere to the nearest point on the APWP (Symons and Sangster 1991; Blanco et al. 2013) (see Fig. 3).

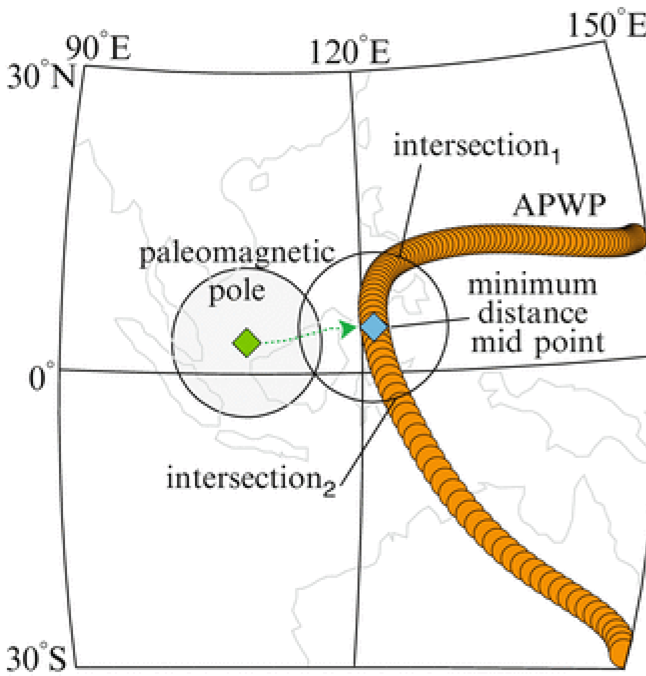

Fig. 3
Illustration of the paleomagnetic age determination (modified from Blanco et al. (2013) with Elsevier permission). The pole and the circle of confidence are projected over the minimum distance point on the APWP. The intersection points 1 and 2 will constrain the error in age

A similar idea arises with PSV. The secular variation reference curves are created to display inclination, declination, and the intensity of the magnetic field for a given region through time. The PSV curves are typically defined for only the last few thousand years, which is useful when dating young material such as archaeological artifacts (Hangstrum and Blinman 2010; Pavon-Carrasco et al. 2011; Tanguy et al. 2003). Recently there have been great strides made in creating well-defined techniques and useful computer software to date archaeological artifacts using inclination, declinations, and intensities (Le Goff et al. 2002; Pavon-Carrasco et al. 2011).

Magnetostratigraphy

Polarity change is a global phenomenon which occurs simultaneously all over the world. Magnetostratigraphy studies polarity change registered in the geological sections, drilling cores, and magnetic anomalies in the ocean. The polarity change pattern can be used for stratigraphic correlation and dating of the geological section separated from meters to thousands of kilometers. Creating a universal reference scale of polarity changes using biostratigraphic and radiometric ages produces the geomagnetic polarity time scale (GPTS). This scale provides valuable stratigraphic markers for short- and long-range correlations of geological sections (Langereis et al. 2010). Oceanic and marine magnetic anomalies are very important for determining the spreading velocities between two plates on either side of a mid-ocean ridge.

Paleointensity

The value of ancient intensity of the geomagnetic field is called geomagnetic paleointensity. Independent records of paleointensity from sediment cores in different areas of the world are stacked together and represent the reference curve of the variations of the geomagnetic dipole moment (Valet et al. 2005; Channell et al. 2009). This provides information regarding the processes governing the geodynamo. So far, this procedure has been limited to the last two million years. The reference curve from the sedimentary records is calibrated with the absolute dipole moments derived from volcanic lavas. Intervals of low intensity often correspond to the geomagnetic excursions and reversals. Comparison of the continued paleointensity records for sediments with unknown age to the reference paleointensity curve results in a possibility to date sediments when other means of dating are not reliable (e.g., Lake Baikal sedimentary cores, Kravchinsky et al. 2007).

Archeomagnetism

Archeomagnetism is based on the variation of the intensity and direction of the geomagnetic field, and on the property of baked clay to record the situation during firing, as it remains fixed in the arrangement of the particles of iron oxides in it, immobilized by heating temperatures of about 650-700°.

The direction of the Earth's magnetic field does not vary in a consistent manner over time or space, and the changes have been recorded by scientists from only the sixteenth century. It is therefore necessary for each region to determine what were the geomagnetic changes through the examination of samples which remained in the same position from the time of heating. In the field of archaeology, once the reference curves are established, this can be used for dating other artifacts (Tarling 1975). The accuracy of dating can vary depending on the rapidity of changes in the Earth's magnetic field at different times, and in general, it is possible to obtain ages with accuracy of decades or quarter century. While other forms of dating are based at the decay of radioactive elements, such as carbon dating, magnetic dating allows archaeologists to figure out the age of more varied and older artifacts.

Summary

The main geomagnetic field is formed in the outer core of the Earth and can be measured on the surface or in space. In the first approximation, the geomagnetic field of the Earth can be represented by the field of a dipolar magnet placed in the center of the planet. Geomagnetic poles migrate at the Earth's surface continuously, and reversals of the geomagnetic field direction occurred many times in the Earth's geological history. Short-term and long-term changes of the geomagnetic field are constantly monitored and studied by geophysicists because they carry important information about the current state of the geomagnetic field and past magnetic events.

The magnetic field has an effect on a variety of phenomena on Earth, in the atmosphere, and closest space. Magnetic measurements are commonly used for chronology and are important in geophysical exploration, for navigation, aerospace, and geodesy.

Cross-References

Archeomagnetic Dating
Geochronology
Geological Time Scale
Magnetic Anomalies
Magnetic Chronology
Magnetism, Rock and Mineral
Magnetostratigraphic Dating
Paleomagnetism, Marine Sediments
Paleomagnetism, Terrestrial Sediments
Potassium Argon, Volcanic Rocks

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