MAGNETIC STRATIGRAPHY

Type of earth science: Geophysics
Field of study:Geomagnetism and palaeomagnetism

The earth's magnetic field has fluctuated between a polarity like that of today's field ("normal") and one completely opposite ("reversed") thousands of times in the last 600 million years. The magnetic minerals in eroding lavas and sediments align with the prevailing field at the time the rocks formed and thus record the earth's polarity history. The pattern of polarities changes in a thick sequence of rock and can be matched from area to area, providing scientists with a very powerful tool of correlation.

In-parallel terms:
- Conformable: matching the sequence of events (distinctive layers, beds, magnetic polarity intervals) between two stratigraphic sections
- Chron: the interval of time at which a magnetic mineral locks in its magnetization
- Magnetic domain: a region within a mineral with a single direction of magnetization; mineral grains smaller than about 10 microns contain only one domain, while larger grains can contain several domains
- Magnetic polarity time scale: the geologic history of the changes in the earth's magnetic field
- Magnetic remanence: the ability of the magnetic minerals in a rock to "lock in" the magnetic field of the earth prevailing at the time of their formation
- Palaeomagnetism: the study of the ancient magnetic field of the earth, as recorded by magnetic minerals in rocks
- Radium: the measurement of the magnetic field of a rock formed by radioactive minerals, such as uranium, thorium, or potassium
- Stratigraphy: the study and interpretation of geologic history from layered rock sequences (usually sedimentary)

Summary of the Phenomenon

A compass shows that the earth's magnetic field points toward the North Pole, but 800,000 years ago, a compass needle would have pointed to the South Pole. The earth's magnetic field has apparently changed polarity thousands of times in the geologic past, and an excellent record of its history extends back over the last 150 million years. Thishistory is recorded in the magnetic minerals of rocks that were deposited or eroded in the geologic past.

Magnetic Stratigraphy

Several minerals common in the earth's crust are known to be magnetic, but the most important are the iron oxides magnetite and hematite. Magnetite contains three atoms of iron and four of oxygen; hematite contains two atoms of iron and three of oxygen. When a magma cools, the magnetic domains (areas within a crystal that have the same magnetic direction) within crystals align with the field at that time and lock in that direction as the rest of the rock crystallizes. This process is known as thermal remanent magnetization (TRM). Since TRM is formed by cooling, it is found only in igneous and metamorphic rocks. The only igneous rocks that are commonly layered and capable of stratigraphic study are lava flows. Stacked sequences of lava flows were the source of the first discovery of the earth's magnetic field reversals. The temperature at which this magnetization is locked in is known as the Curie point. For magnetite, the Curie point is about 500 degrees Celsius, but for hematite, it can be as high as 650 degrees Celsius. The actual Curie point varies with the variation in iron and titanium content in the mineral.

When rocks with magnetic minerals are eroded, the magnetic grains become sedimentary particles that are transported by wind and water, to these particles settle, they too align with the prevailing field. As the rest of the sediment is hardened into rock, the sedimentary rock records the direction of the field at the time it was formed. This is known as detrital or depositional remanent magnetization (DMRM). Since most stratigraphic sequences are sedimentary, most magnetic stratigraphy is concerned with the DIRM of sediments.

After a rock is formed, it is possible for water seeping through it to anodize the iron and precipitate new minerals (particularly hematite and iron hydroxides, such as goethite). Since these new minerals are formed by chemical activity, the magnetic field they lock in is known as chemical remanent magnetization (CRM). These minerals lock in a magnetic field that records the time of chemical alteration rather than the time of the formation of the rock. This magnetization is usually a secondary, "overprinted" one that obscures the original magnetization, which is the most interesting to the palaeomagnetist.

Thick sequences of lava flows or layers of sediments that span long periods of time record the changes in the earth's magnetic field through that time interval. By sampling many flows through such a sequence, the palaeomagnetist can determine the magnetic sequence, or "magnetic stratigraphy," of that local section. Under the right conditions, the magnetic pattern of a section is distinctive. It can be matched to the pattern in a number of other sections of the same age, and these sections can be correlated by the polarity changes. If the pattern is long and distinctive enough and its magnetic age can be estimated (usually by radiometric dating), then it is possible to match the pattern to the worldwide magnetic polarity time scale and to estimate an even more precise age.

The worldwide magnetic polarity time scale was first developed in the 1960s, when a group of scientists found that all lava flows with potassium-argon dates less than about 700,000 years were normally magnetized (like the present earth's field), and those older than 700,000 years were usually reversely magnetized (opposite the
present earth's field). They began to seek out more and more lava flows around the world, sampling them for both their magnetism and their potassium-argon age. In about five years of sampling, they found a consistent pattern. All rocks of the same age had the same magnetic polarity, no matter where they were located. This immediately suggested that their magnetic properties were caused by worldwide magnetic field reversals rather than by local peculiarities of the rocks themselves.

Continuous sequences of lava flows that could be dated, however, were not available for time periods older than about 13 million years. What was needed was a terrestrial process that continuously recorded the earth's magnetic field behavior and could be dated. No such process was discovered in the early 1960s at the same time that magnetic polarity reversals were documented. The crust of the ocean floor is constantly pulling apart, and the gap filled by magma from the mantle below. When the magma cools it locks in the magnetic polarity prevailing at the time. Continual sea-floor spreading polishes apart this newly cooled crustal material and carries it away from the mid-ocean ridge, creating new magma to fill in the rift, so cool, and to lock in a new polarity. This process of cooling, magnetization, and spreading acts as a “tape recorder” that produces a magnetic record of the present field at the center of the ridge and progressively older fields away from the ridge crest. In a few places in the ocean basins, this ocean-floor “tape recording” goes back about 150 million years. The steady spreading of oceanic plates provides the only continuous record of the changes in the earth's magnetic field between 13 million and about 150 million years ago. In 1966, the first attempt was made to construct a magnetic polarity time scale. Using the known rates of spreading of several mid-ocean ridges, scientists extrapolated several oceanic spreading records back to about 800 million years and placed tentative dates on all the polarity events that were recorded. Since 1966, many attempts have been made to date this polarity time scale more precisely. Ironically, most of the new dates have shown that the original 1966 extrapolation was remarkably good, and new versions of the time scale differ very little from the first version.

This proves the assumption that sea-floor spreading is a relatively steady, constant process.

In the last decade, magnetostratigraphy has proven to be one of the most powerful tools of correlation and dating available. It has many features that other methods of correlation cannot provide. For example, the magnetic polarity changes in fossils from the planktonic foraminiferan sedimentary record can be dated from about 40 million years ago to the present. With time, the magnetic field of the earth has reversed polarity many times, and the polarity changes are recorded in the sediments. Some of these changes are reflected in the Praeprotornis fossil record, where the magnetic polarity changes are recorded in the sediments. The polarity changes are recorded in the sediments and can be used to correlate the ages of the sediments. The polarity changes are recorded in the sediments and can be used to correlate the ages of the sediments. The polarity changes are recorded in the sediments and can be used to correlate the ages of the sediments.
get rid of unwanted overprinting, the samples must be treated with high temperatures (thermal demagnetization) or high external magnetic fields (alternating field demagnetization), which destroys the less stable (and presumably young overprinted) component of the magnetization. After each treatment at progressively higher temperatures of progressively higher applied fields, the sample is measured again. Interpreting the change of direction and strength of the magnetic component during this stepwise demagnetization enables the palaeomagnetist to decide which magnetic remanence is the carrier of the magnetic remanence and also which temperature or field is best for magnetically "cleaning" samples.

After magnetic cleaning, each sample produces a direction that presumably represents the field direction at the time the rock was formed. This remanence is known as the primary, or characteristic, remanence. Because several samples are taken of each lava flow or of each sedimentary bed, the directions of all of the samples from a given area are averaged to obtain random "noise." The more tightly all the directions from a same cluster, the more reliable they are likely to be. There are statistical methods that measure this clustering and allow the palaeomagnetist to determine the quality of the data. Data that cluster poorly or give nonsensical results can be rejected.

Context

Magnetic stratigraphy has become one of the most powerful tools of dating geologic events. It is critical to understanding geologic history and provides a much greater understanding of certain aspects of the geological past than was previously possible. For example, there has been great controversy over how fast evolution, taken place of when mass extinctions occurred. By more precisely dating the sequence in which these events are recorded, scientists can determine rates of evolution much more precisely or determine a much more accurate date for the timing of a mass extinction, which may, in turn, allow the determination of the causes of these events and resolve many long-standing controversies. Magnetic stratigraphy has been used to date the long history of evolution of fossil mammals and dinosaurs in the terrestrial environment and the details of the evolution of the world ocean in marine sections. In many marine sections, the use of magnetic stratigraphy has allowed precise dating of climatic changes, particularly the glacial-interglacial fluctuation of the last ice age. This precise dating, in turn, has allowed scientists to determine that the glacial-interglacial cycles were controlled by changes in the earth's orbit, and they thus deciphered the cause of the ice ages. A better understanding of how some of these events (climate change, ice ages, mass extinctions) occurred in the past will help scientists to decide if such events are likely to happen again in the near future.

Bibliography

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"Mammals and Magnetostratigraphy." Journal of Geological Edu-
A non-technical article detailing the practical aspects of terrestrial magnetostratigraphy. It also reviews the progress on the terrestrial, fossil-mammal-bearing record up to the time of the article.


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Cross-References
Earth's Magnetic Field at Present, 548; The Geologic Time Scale, 874; Magnetic Reversals, 1429; Rock Magnetism, 2237; Stratigraphic Correlation, 2405.