g4 Remanent magnetization polarity reversals

< Curie point, reversals, epochs, events >

> And here we must at the outset reject that common opinion of recent writers concerning magnetick mountains, or any magnetick rock, or any phantasmal pole distant from the pole of the earth, by which the motion of the compass or versorium is controlled. This opinion … is entirely at variance with experience. —William Gilbert, 1600.[1]

> French investigators in the 1920s had measured the remanent magnetization of ancient earthenware pots found by archaeologists. ... It had been shown experimentally that if an earthenware pot were fired in a kiln to a temperature above the Curie point for hematite (675°C) and subsequentially cooled to room temperature, it always acquired a remanent magnetization in a direction parallel to the earth's field. As pots are always placed vertically on their bottoms when being fired, it means that it is possible by measuring the direction of the remanent vector, to calculate the magnetic orientation [*sic*: inclination] of the earth's field. —Lawrence Morley, 2002.[2]

Initially igneous rocks are too hot to be magnetic but as they cool, iron oxide minerals in them spontaneously develop domains of magnetic dipoles with random orientation (ferromagnetism) and, at lower temperature (called the *Curie point* or *Tc* to honor Pierre Curie who in 1895 described the phenomenon)[3], those that are paramagnetic undergo an abrupt phase change to have domains of magnetic dipoles aligned to a pervading magnetic field such as the geomagnetic field. The orientation of these (their *remanent magnetization*) stays unchanged at all lower temperatures even if the once alignment-inducing magnetic field changes. For example, a paramagnetic accessory mineral in basalt (and in most igneous rocks) is magnetite. Basalt becomes a rock at below 1100°C. Initially its magnetite minerals have no fixed magnetism. The Tc for magnetite is ~578°C. A typical lava flow takes a year to cool throughout, so daily geomagnetic field fluctuations and magnetic storms add little to its remanent-magnetization record of Earth's local magnetic field strength and polarity.

Beginning in 1953, Jan Hospers found that lava flows of Iceland have recorded the geomagnetic field either as it is today or in a completely reversed direction.[4] A curious observation (and unrelated, it turns out) of "self reversal" of the recorded geomagnetic field had been made in 1906 by the physicist Bernard Brunhes for some dacites from elsewhere, which volcanic rock samples he had heated and cooled back through the Curie point, but he had made no great issue of it. At the time though, with this in mind, Hospers was not able to assert that the reversed magnetic polarity in his undisturbed volcanic strata was not the result of self-reversal. However, in 1956, Stanley Keith Runcorn (1922-1995) made the important point that geomagnetic field reversal theory predicts that contemporaneous rocks will be magnetized in the same direction all over the world.[5] Improvement in accuracy in the radioactive dating of lavas from many locations has since provided this test and geomagnetic field reversals *are* real.[6]

Paleogeomagnetic poles are knowable from the primary magnetization in rocks acquired at the time they originated. Local field measurements find the paleogeomagnetic field was a simple dipole except, perhaps, during reversals. Paleomagnetization with its pole within 40° of Earth's rotation axis is deemed "normal" if its polarity is as present (***Figure g4.1***) and, if opposite, is "reversed." In 1967, Allan and Cox published the history of geomagnetic reversals (***Figure g4.2***) of potassium-

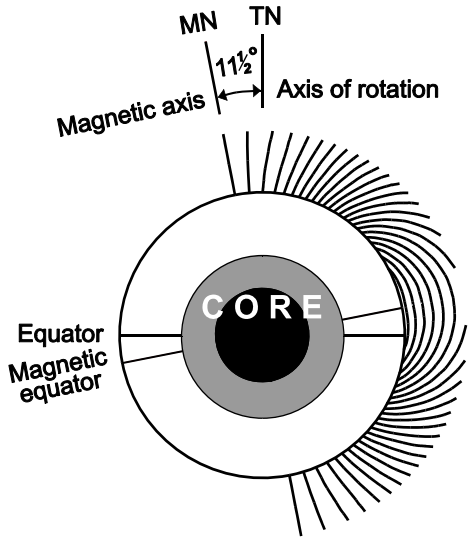
(*Figure g3.1* cont.) Then as a creature firmly in his Age and Place, Gilbert writes:

> "We ... consider that the whole universe is animated and that all the globes, all the stars, and also the noble earth have been governed since the beginning by their own appointed souls and have the motives of self-conservation. Nor are there wanting, either implanted in their homoqenic nature or scattered through their homogenic substance, organs suitable for organick activity, although these are not composed of flesh and blood as animals ... Miserable were the condition of the stars, abject the lot of the earth, if that wonderful dignity of life be denied to them, which is conceded to worms, ants, moths, plants, and toadstools ..."

argon dated lava flows, from the present back to 3.5 Ma (million years ago).[7] The geomagnetic reversals time scale is now well determined by Steven Cande and Dennis Kent back to 83 Ma.[8]

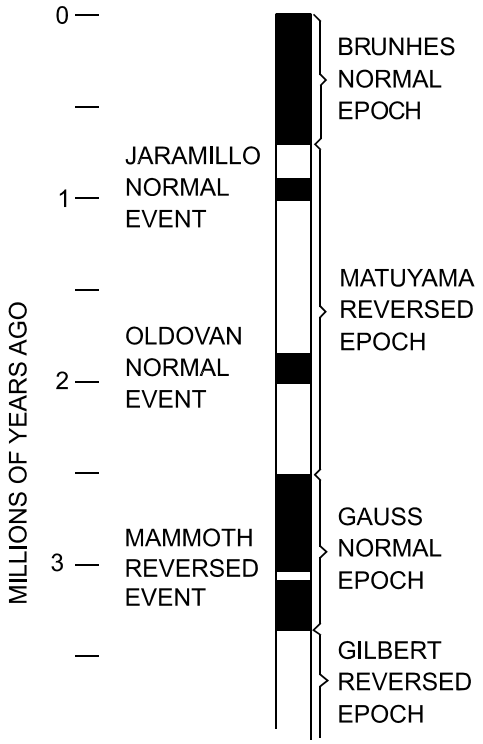
Some 9 to 13 tetrawatts of heat (about 1/4 of the heat from within Earth that is radiated to space) comes from the core.[9] Top down cooling energizes thermal convections in the liquid iron outer core. These turnings and electrical currents make a dynamo that generates Earth's main magnetic field. This field in turn shields surface life from solar wind by deflecting its otherwise incoming, lethally speeding, ionized particles. What loss of shielding occurs during a "reversal" is not certain but indications are that the field at Earth's surface decreases to about a quarter of its usual strength and the reversal, which involves a rapid and wide wandering of the pole, is over after some thousand years.[10] The best documented (from its record in marine sediments) and most recent reversal about 780,000 years ago, the Brunhes/Matuyama transitioned during 2,000 years at the equator and 10,000 years at mid-latitudes. ❑

Figure g4.1 High-resolution images of the geomagnetic field taken in 2000 by the Oersted satellite, combined with similar images taken in 1980 by the Magsat satellite ... have identified patches of reversed magnetic flux concentrated ... beneath the southern tip of Africa ... [and] in the north polar region. Growth and poleward migration of the reversed-flux patches can account for almost all of the decrease in the dipole field in the past 150 years. ... [T]he geological record shows that the magnetic field intensity has oscillated in the past without actually reversing its polarity. But the rapidly evolving reversed-flux patches suggest that an attempt at reversal may be underway ... [and] can explain why [dipole] polarity reversals, once initiated, can happen over only a few thousand years. —Peter Olson, 2002.[11]



Earth's present magnetic field is modeled as being due to a magnetic dipole with its axis tilted 11½° with respect to Earth's rotation axis.

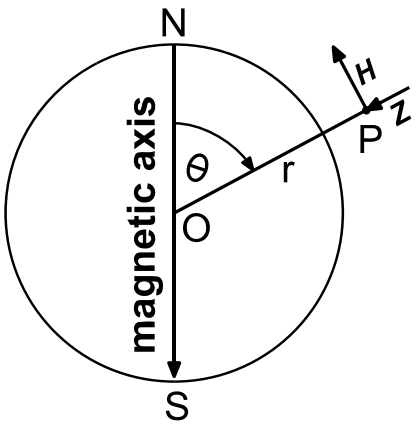
Figure g4.2 The four (consensus) normal (black) and reversed (white) "epochs" discerned by Allan Cox, G. Brent Dalrymple and Richard R. Doell were named to honor people who made significant contributions to our knowledge of Earth's magnetic field.[12] Order-of-magnitude shorter magnetic polarity-reversal "events" were named for the localities where each was first recognized. The proofs of these events are exacting and their existence does bring home an appreciation of the truly irregular nature of reversals of Earth's field. The first polarity event to be discovered was the "Olduvai normal" (Oldovan normal event), which is recorded in a flow in Olduvai Gorge, Tanzania, and was investigated by Grommé and Hay in 1963.[13] Initially, it was not recognized as an anomaly as the Olduvai flow was thought to date within the Gauss normal epoch. When better dating of the epochs placed the date of the Olduvai flow within the Matuyama reversed epoch, it appeared to be an unexplained anomaly in an otherwise coherent picture. But the same age fluctuation in polarity in lava flows in the Pribilof Islands showed that it, being worldwide, was an "event."



The north seeking end of a compass needle was long assumed to be attracted to the North Star to which, from England, it pointed. However, Sir Francis Drake, to his consternation, discovered that it does not point so from America. Back home, Her Majesty's physician William Gilbert determined that Earth itself is magnet as free hanging magnetic needles incline to it and do not lie parallel Earth's rotation axis that points to the celestial north pole. Indeed, the variation in direction of magnetic force near the surface of a piece of lodestone (magnetite), which he had cut in the shape of a sphere, is very similar to mariners' observations of the dip (inclination) of compass needles. He concluded that Earth's globe itself is a great magnet (*magnus magnes ipse est globus terrestris*).[14]

Two hundred and fifty years later, Carl Friedrich Gauss could use the Laplace and Poisson Potential Theory to verify that the dipole field of a uniformly magnetized sphere is indeed an excellent first approximation to Earth's magnetic field and that, as so for the regular, the large-scale irregular parts of Earth's magnetic field are too of internal origin.

To anticipate what the inclination of a freely suspended magnetic needle in a dipole field of a uniformly magnetized sphere will be, note: [15]



The magnetic potential V at P at distance r from a point dipole at O with its magnetic axis in the direction ON is

$$V = \frac{M \cos\theta}{r^2}$$

where M is the magnetic moment, and theta θ is the angle NOP (when r is the distance from Earth's center, and theta θ is the colatitude of the point P).

The inward radial component Z of the magnetic potential is

$$Z = \frac{\partial V}{\partial r} = \frac{2M \cos\theta}{r^3} .$$

In the direction of N, the horizontal component H of the magnetic potential is

$$H = \frac{1}{r}\frac{\partial V}{\partial \theta} = \frac{M \sin\theta}{r^3} .$$

So the angle of inclination I at colatitude θ of the magnetic force field and of a freely suspended magnetic needle, using

$$\tan I = \frac{Z}{H} = 2 \cot\theta$$

is $$I = \arctan (2 \cot\theta) .$$

Historical note: Gilbert's experiments into the mysterious powers of lodestones and amber showed that whereas magnetic forces were limited to lodestones and iron, electrostatic forces (he coined the term "electric", from the Greek word for amber) can be produced by, and act on, many different materials. Justly famous (John Dryden memorialized him with the couplet—now dubious in its second part: "Gilbert shall live till lodestones cease to draw / Or British fleets the boundless ocean awe.") for his *De Magnete* in which is a lively put down of untested legends foisted on the gullible as facts, such as broad medical claims for magnets ("Thus do pretenders to science vainly and preposterously seek for remedies, ignorant of the true causes of things.") and magnet-based perpetual motion engines ("May the gods damn all such sham, pilfered, distorted works, which do but muddle the minds of students!"). [16]

Gilbert anticipated a formalization of the scientific method usually attributed to Francis Bacon by his statement that "stronger reasons are obtained from sure experiments and demonstrated arguments than from probable conjectures and the opinions of philosophical speculators."