APPARENT PALEOMAGNETIC POLAR WANDERING

In this controversy [fixity of continents vs. continental drift] between physicists and geologists, the physicists, it would seem, have come out second best! They gave decisive reasons why polar wandering could not be true when it was weakly supported by paleoclimatic evidence, and now that rather convincing paleomagnetic (i.e., physical) evidence has been discovered, they find equally decisive reasons why it could not have been otherwise.

—Walter Heinrich Munk, 1956.[1]

j3 The paleomagnetic pole < remanent magnetism >

...in the center of Amalfi, a town situated by a small harbor. Above an archway, I saw a bronze plaque with an inscription in Italian. Translated, it read: *All of Italy, and Amaifi, must give credit to the great invention of the magnetic compass, without which America and other unexplored places would not have been opened to civilization. Amalfi commemorates this pure Italian glory with special honors to its immortal son, Flavio Gioia, the fortunate inventor of the magnetic compass.—1302-1902.* ... [But in] a pamphlet quoting the words of the Italian historian Padre Timoteo Bertelli. I began to read: *Flavio Gioia never existed. He represents only a kind of myth, created late after his presumed lifetime, and hence suspect. He is a fantasy produced by the fertile southern imagination of the people of Amalfi and elsewhere.*

—Amir Aczel, *The Riddle of the Compass*, 2001.[2]

A freely suspended compass needle will align itself parallel to geomagnetic field lines with its north seeking end pointing to magnetic north and with an inclination related to latitude. In 2001, the geomagnetic north pole was in the Arctic ocean headed northwest towards Siberia having traveled 700 miles on a line (Roald Amundsen in 1904 first found it had moved) from where James Clark Ross in 1831 first found it in Boothia Peninsula, Canada, just north of the Arctic Circle.

The angular difference between the direction of magnetic north and true north is called the *magnetic declination* and the angular difference between the horizontal and the slope of a freely suspended magnetic compass needle (north-seeking end: + Down, – Up) is called the *magnetic inclination* (***Footnote j3.1***). These (magnetic declination and inclination) vary from place to place systematically in the likeness of a magnetic field due to a strong dipole magnet at Earth's center and askew 11½° currently to Earth's rotation axis. Modeled so, and matching observation, the inclination is 0º (horizontal) at the magnetic equator, +90º (straight down) at the magnetic north pole, –90º (straight up) at the magnetic south pole and at some intermediate angle between. Observation has also shown that the magnetic declination and inclination at any place changes in time fast enough that this cannot be ignored when a compass is to be used for surveying or for navigation. The magnetic inclination is treated by a surveyor as a practical annoyance that can be compensated for on the fly by moving a sliding counter balance on the compass needle to level it during a survey. The declination must be known to be adjusted for. The magnetic declination and its rate of change is included on maps, such as a USGS topographic map, at the time of printing. For maps that are several decades old, this information will no longer be reliable and updated information for the map area, or a more recent map, should be obtained.[3]

When, as today, magnetic and geographic poles are not coincident, a simple model predicts a systematic change of magnetic declination along any parallel. So its measurement at a place should give the longitude. This was Edmund Halley's hope in 1701 when he published a map of the Atlantic (***Figure j3.1***) that showed this. After his two year sailing voyage to the South Seas in the pink (not a pun) *Paramore* (which would have given a chuckle had it been *paramour*), he failed the method for large departures from his model-predictions. These "anomalies" are due to crustal-rock magnetizations and because the geomagnetic main-field is not constant.[4]

The behavior of freely suspended magnetic needles have been recorded for two hundred years at Greenwich Observatory, England, and in Paris, France (***Figure j3.2***). Although, the magnetic poles and the geographic poles do not coincide today, two hundred years of observation hints that in the long term, the magnetic poles are statistically identical with the geographic ones. And this is a principle of paleomagnetic studies. At a place and a time, the geomagnetic declination will have been statistically zero, the inclination statistically a constant I. The latitude of that place at the time can be calculated using $\tan I = 2 \cot \theta$, where θ is the colatitude.

Between times of geomagnetic field reversals, variance is not great. To know the latitude and orientation of a place at a time in the past, apply Fisher's statistics [5] to measurements on oriented close-in-age samples from a succession of volcanic lava flows, or from an intrusive igneous rock body at different distances from its chilled margin, or from a succession of sedimentary beds.

For the study of past continental positions, paleoinclination gives a measure by hypothesis of the distance to the geographic north-pole, and paleodeclination gives the paleoorientation with respect to geographic north of an area. For example: in 1955, J. A. Clegg and E. R. Deutsch could report from paleoinclination measurements of oriented samples from the Eocene Deccan traps of India that some 70 to 100 million years ago the subcontinent had been far enough south of the equator to make unsurprising evidence of its then continental glaciation; and earlier, in 1954, Clegg from paleodeclination measurements of oriented samples from the New Red Sandstone of Britain, had found that this desert erg (sand sea) formation of Triassic age has since rotated 34° clockwise.[6]

Each paleomagnetic determination of a paleoinclination and paleodeclination data-pair can be recorded as the point on an Earth globe where the north pole *appears* to have been at the time. These are obviously easier to plot, than to draw a succession of outlines of a moving continent, and, moreover, the spread of positions of apparent paleopoles can be analyzed statistically for their mean-positions in past intervals of time.

Paleomagnetic measurements in Europe and North America by S. K. Runcorn, beginning in 1956, provided the first unequivocal proof of continental drift. Discovered was that the apparent positions of the paleopoles for North America before the Late Triassic were consistently 20° to the west of those for Europe (***Figure j3.3***). The inescapable conclusion is that since the Late Triassic these two continents have drifted some 2200 kilometers apart (at the latitude of the samples) whereas before they had long drifted as one.[7]

Reprise Apparent polar wandering geophysical evidence of continental drift is not needed to reconstruct Pangea. For that reconstruction, geomagnetic reversal-history in seafloor rock is far more definite (*recall* Topic *g23*). That is so for the last 180 million years. But to reconstruct the world before Pangea, apparent polar wandering paths are the *only* paleomagnetic evidence. However, as apparent polar wandering path evidence for ancient positions of continental areas occurs in undeformed parts of continents of all ages, we do have this surviving information that continental drift goes back as far as does the age of such continental rock itself. Which is for billions of years! ❑

Footnote j3.1 Robert Norman familiar with the compass after 20 twenty years at sea, set up shop as a mere "unlearned Mechanician" to make and sell astronomical and navigating instruments. Each compass needle of iron or steel he would first hone to balance perfectly on its pivot. Then he stroked it from middle to tip with a loadstone to magnetized it. "Stroken [stricken] with choler [expletive not deleted]" the needle's north end dipped down (to an astonishing +71° 50' when pivoted to do so freely in an experiment suggested by William Borough). His solution, and still the way, was to added a small piece of wire at the needle's south end (he was in the northern hemisphere) as a counterbalance. All is described in Norman's *Newe Attractive*, 1581, dedicated to William Borough and in a binding that included Borough's small volume: *A Discourse of the Variation*.[8]

Figure j3.1 [9] A sketch of the map (isogonic projection of latitude and longitude grid) Edmund Halley (of comet fame) prepared in 1701 to test the magnetic variation method of longitude determination (numbers are degrees of declination that hold along the “Curve Lines”— the first use ever of contours to generalize the areal variation of a place to place measured quantity in a map).[10] Otherwise, to know longitude, local time and the time at the prime meridian is needed. Land based astronomical observations of eclipses of Jovian moons, then used for determinations of longitude, could not be duplicated at sea. In the mid-1700s, the lunar distance method was employed. For this, the mariner needed to measure Moon’s altitude above the horizon, the altitude of a night star (or Sun) above the horizon, and the distance between Moon and the night star (or Sun). These three angles and 1/2 - 3 hours of calculations with the aid of tables compiled (by 1742) for a reference point (the observatory at Greenwich, England) and Moon’s 18 year saronic cycle, allowed longitude to be known. Little wonder mariner’s delight when in 1761-2 the first chronometer (John Harrison’s fourth sea clock, the H4 watch completed in 1759)[11] weathered a rough passage on its sea test of 147 days, round trip from Portsmouth to Jamaica aboard the sailing ship Deptford, and lost only 1 minute 54.5 seconds.

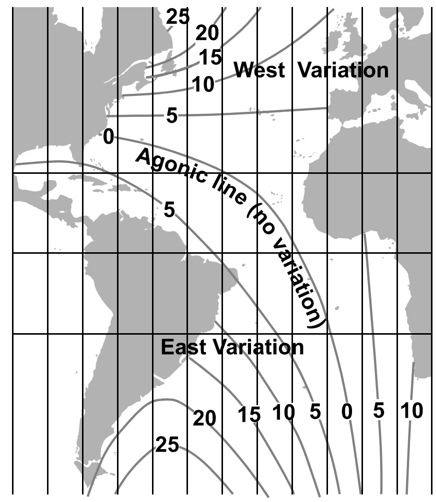
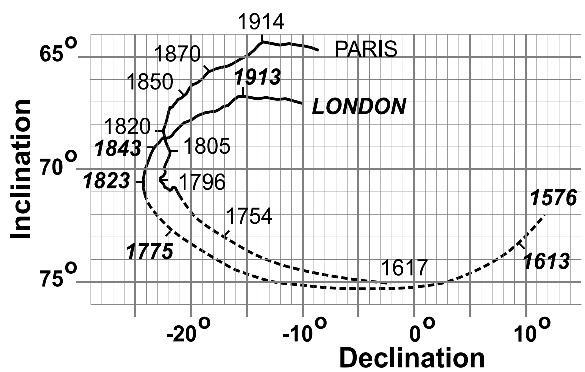


Figure j3.2 [12] Secular variation of the geomagnetic field direction in London and Paris. *Note*: The curves suggest a cyclical variation but variations at other stations are not in keeping and at any place the motion sampled over a long time is that the mean position indicated for the magnetic north pole is coincident statistically with the true north pole. Alexander Neckam (1157-1217) in *De Naturis Rerum*, 1187, provided the first known reference (in the West) to the compass, a clue to its making, its mysterious (at the time) behavior, and its use:



> The sailors, moreover, as they sail over the sea, when in cloudy weather they can no longer profit by the light of the sun, or when the world is wrapped up in the darkness of the shades of night, and they are ignorant to what point of the compass their ship’s course is directed, they touch the magnet with a needle. This [magnetized needle inserted in straw, and floated on water in a wood or brass bowl] then whirls round in a circle [a magician’s obfuscation was to move the loadstone rapidly around the bowl’s rim] until, when its motion ceases, its point looks direct to the north.[8]

The bearing Neckam reports could be true, but this datum is valueless as he does not record where and when he, or another, witnessed it.

Figure j3.3 Plot of apparent geomagnetic paleopole positions joined by lines for North America and Europe to indicate the apparent polar wandering paths for each continent.

Keeping Europe fixed, the apparent polar wandering path for North America is moved and rotated (arrow) to find a best fit. The good fit which is found for the Jurassic (J) back to the Carboniferous (C) indicates that then the Atlantic had not opened and during that time the two continents moved north as one.

Data from: M. W. McElhinny, 1973.[13] *Historical footnote*: The first data were found and interpreted by P. M. Dubois in 1957.[14]