Paper 9: Palaeomagnetics

"The many geophysical and geological paradoxes that have accumulated during the past two or three decades are apparently the consequences of forcing observational data into an inadequate tectonic model." Storetvedt, 1992

Palaeomagnetics is the study of remnant magnetism preserved in rocks and is credited with leading to the revival of the theory of Continental Drift as well as to its subsequent transformation into Plate Tectonics during the mid-1960s. The primary role of palaeomagnetic studies carried out on samples of magnetised rock is to provide measurements to determine the ancient latitude of a sample site and to measure a direction and distance to the ancient magnetic pole. Similarly, measurements taken from widely separated sample sites are also used in conventional Plate Tectonic studies to determine apparent-polar-wander-paths—a Plate Tectonic concept referring to the apparent movement of an ancient magnetic pole location—for ancient continental fragments.

Apparent-Polar-Wander

Understanding apparent-polar-wander is crucial in understanding the difference between conventional palaeomagnetics on a constant radius Earth and palaeomagnetics on an increasing radius Earth model. The fundamental difference being that apparent-polar-wander is only applicable to a constant radius Earth model and does not apply to an increasing radius Earth. Apparent-polar-wander on a conventional Plate Tectonic Earth model is simply a means of using the ancient magnetic pole locations from a number of continents to assist in reassembling the ancient continents. On an increasing radius Earth the ancient magnetic poles cluster as diametrically opposed pole locations—as they should—and do not form apparent-polar-wander paths.

Conventional palaeomagnetic studies use measured palaeomagnetic data to plot the locations of the ancient poles for a range of ages for each country. In Figure 1 the red and blue apparent-polar-wander-paths for North America and Eurasia are shown in conjunction with the ancient magnetic declination lines—red and blue dotted lines. Declination is measured at the sample site and is projected from the sample site towards the ancient magnetic pole location. The dotted declination lines shown simply join each of the sample sites to their respective calculated pole locations for each continent.

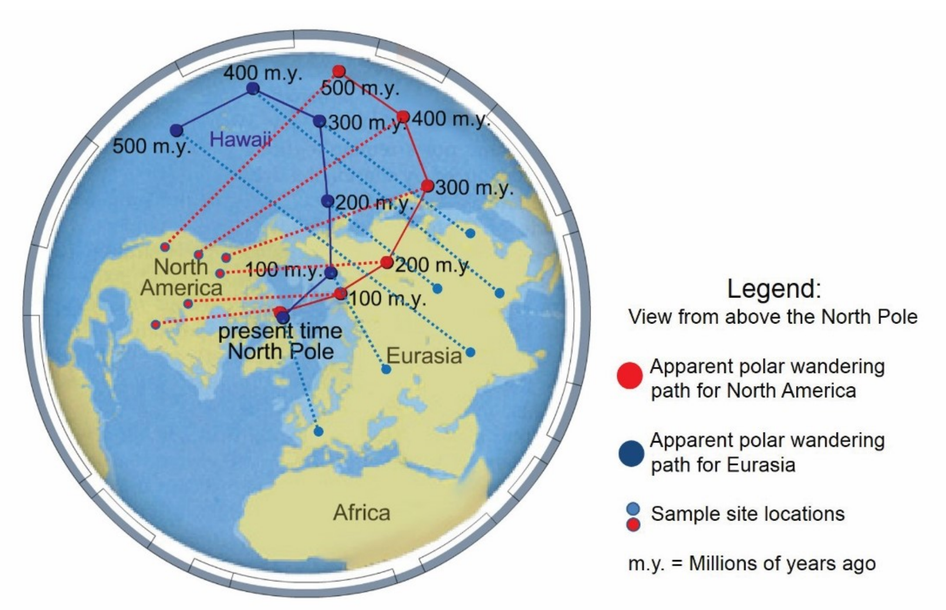

Figure 1 Conventional Apparent-Polar-Wander-Paths for North America and Eurasia showing hypothetical sample sites and declination lines to apparent-polar-wander poles.

In Figure 1 the blue European apparent-polar-wander path for the various ages is shown in relation to the red North American apparent-polar-wander path. By rotating the North American continent with respect to Europe, for instance, until its red apparent-polar-wander-path coincides with the blue European path, the past locations of each of the ancient poles will then coincide. While apparent-polar-wander on a global scale is far more complex than shown here, this fundamental technique has since become the primary means of assembling and constraining past locations of continental plates on a conventional Plate Tectonic Earth.

In order to fully understand the limitations of what apparent-polar-wander represents, Figure 2 is a schematic cross-section of an ancient and present-day Earth crust extending vertically through the geographic and magnetic rotation axis. It is important to appreciate that conventional palaeomagnetic studies have concluded that Earth radius is constant, hence there is no consideration of, or provision for palaeomagnetics on an increasing radius Earth model.

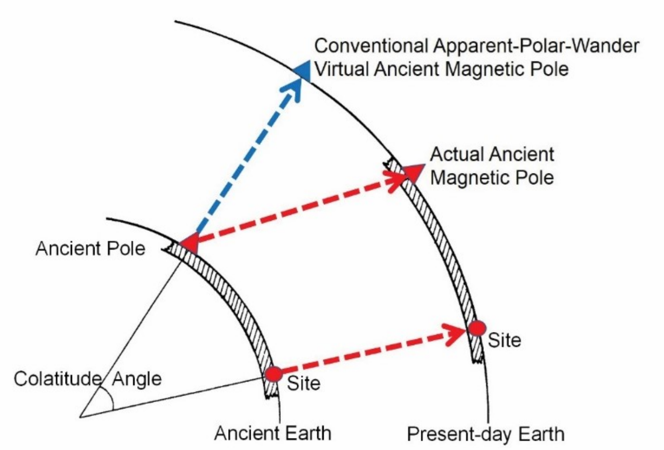

Figure 2 Schematic cross-section of an ancient and present-day Earth showing an ancient sample site plus its actual and virtual magnetic pole locations on the present-day Earth.

Figure 2 shows an ancient sample site located on the surface of an ancient Earth—shown as a red dot. By taking palaeomagnetic declination and inclination measurements from this sample site, the geographic location of the ancient magnetic pole can then be determined—shown as a red triangle on the ancient Earth. This red triangle represents the actual physical location of the magnetic pole on the ancient Earth, as determined from the ancient site sample colatitude and declination measurements. If the Earth were to increase in radius from the ancient Earth to the present-day Earth radius, the ancient sample site and magnetic pole locations are shown by the dashed red lines projected onto the present-day Earth—again shown as a red dot and red triangle. These symbols represent the actual ancient magnetic pole and sample site located on the present-day Earth.

In order to determine an apparent-polar-wander pole location from this sample site located on the present-day Earth, conventional palaeomagnetic formulae adopt the premise that Earth radius has remained constant throughout time. In other words, conventional palaeomagnetics does not consider that there has been an intermediate smaller radius Earth stage so Figure 2 has no relevance to conventional apparent-polar-wander studies. Instead, by adopting a constant radius Earth premise the colatitude calculated from the ancient sample site measurements located on the present-day Earth use the present-day geographic coordinate system to determine the location of the ancient pole.

Using conventional palaeomagnetic formulae the calculated colatitude angle is identical to that determined for the ancient site and will locate the ancient magnetic pole at the blue triangle in Figure 2. In this example the colatitude angle is simply projected radially onto the present-day Earth surface. If there were two or more different ancient sites of the same age located on the ancient Earth crust, their ancient magnetic poles would then plot as a scatter of locations on the present-day Earth. By joining each of these pole locations together they would then generate a separate apparent-polar-wander-path for each continent. This is equivalent to the blue and red apparent-polar-wander paths in Figure 1 for North America and Eurasia.

In contrast, on an increasing radius Earth the ancient magnetic poles from two or more different sample sites of the same age located on the ancient Earth plot and coincide at the same Ancient Pole site—red triangle in Figure 2. This coincident pole location will, in turn, transfer to the same Actual Ancient Pole site—red triangle—as shown on the present-day Earth. In the example above, the conventional blue triangle pole locations are virtual pole locations and these can only be regarded as actual pole locations if they represent present-day sample sites on a present-day Earth. This discrepancy in actual pole and virtual pole locations is the fundamental reason why there is no need to consider apparent-polar-wander on an increasing radius Earth. It is also why conventional palaeomagnetic formulae cannot be used in their current format to locate ancient magnetic poles or to constrain crustal assemblages on increasing radius small Earth models.

In the example shown in Figure 2, the actual colatitude distance—the actual physical distance measured from the ancient sample site to the ancient magnetic pole—is what is used in small Earth studies to locate the ancient magnetic pole position on a present-day Earth model. Only by using the actual pole locations can all poles from each sample site cluster as a single magnetic pole location on an ancient smaller radius Earth model.

Ancient Palaeomagnetic Poles

The locations of ancient north and south magnetic poles established for each of the small Earth models are shown in Figures 3 and 4 respectively (pole data from the International Palaeomagnetic Database, McElhinny & Lock, 1996). These models extend from the Archaean to the present-day, plus one model extended to 5 million years into the future. The small Earth models shown in each of these figures are centred on the North and South Poles respectively. These images show the crustal development of each of the continents as they migrate, relative to the ancient magnetic poles, during crustal extension, breakup, and opening of the modern oceans to the present-day.

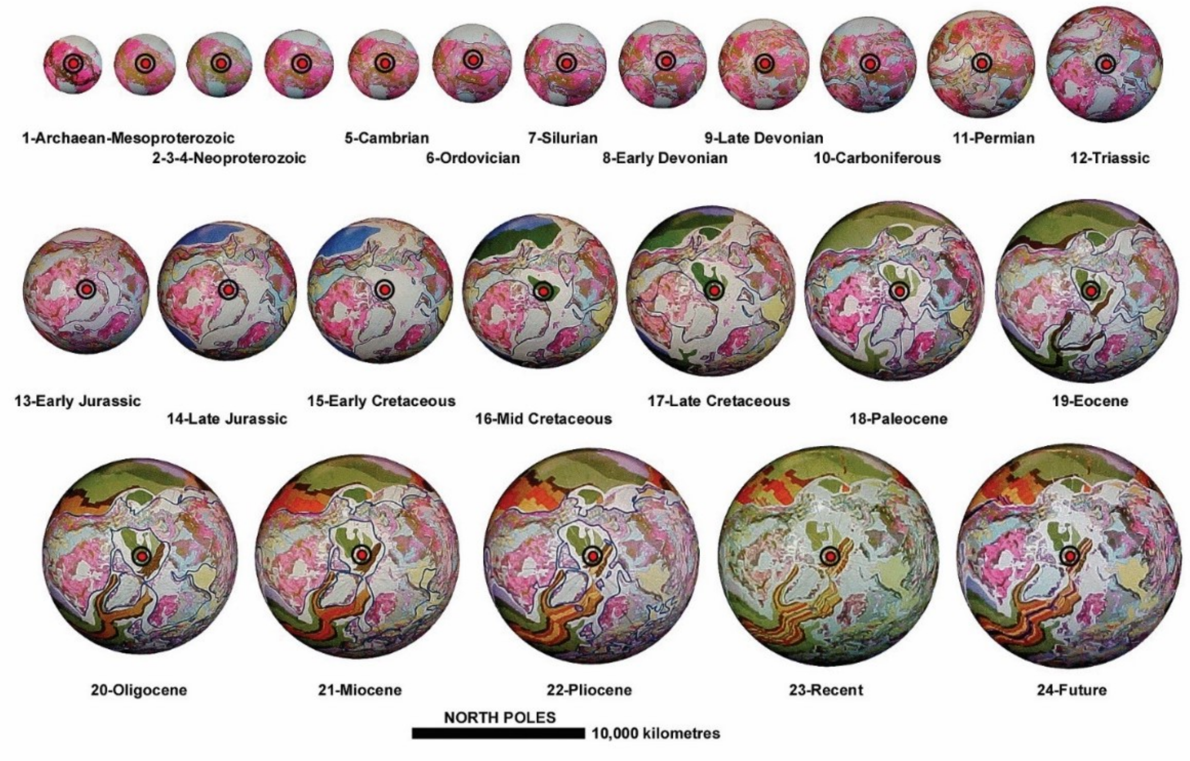

Figure 3 Small Earth Archaean to Future magnetic North Poles (red dots). During the Precambrian and Palaeozoic the North Pole was located within eastern Mongolia, prior to continental breakup and dispersal during the Mesozoic to present-day times. Data after the International Palaeomagnetic Database (McElhinny & Lock, 1996).

In Figure 3, the Precambrian through to the Palaeozoic magnetic North Pole is shown located in eastern Mongolia. As the Pangaea supercontinent ruptured during the late-Permian, and the various modern continents slowly migrated south, the distribution of pole locations shows there was an apparent northward migration of the magnetic pole through Siberia to its present location within the present Arctic Ocean.

Similarly, in Figure 4, the Precambrian and Palaeozoic magnetic South Pole is shown located in west central Africa. As the Pangaea supercontinent ruptured and the various modern continents slowly migrated north, the distribution of pole locations shows there was an apparent southward migration of the pole along the South American and West African coastlines to its present location in Antarctica.

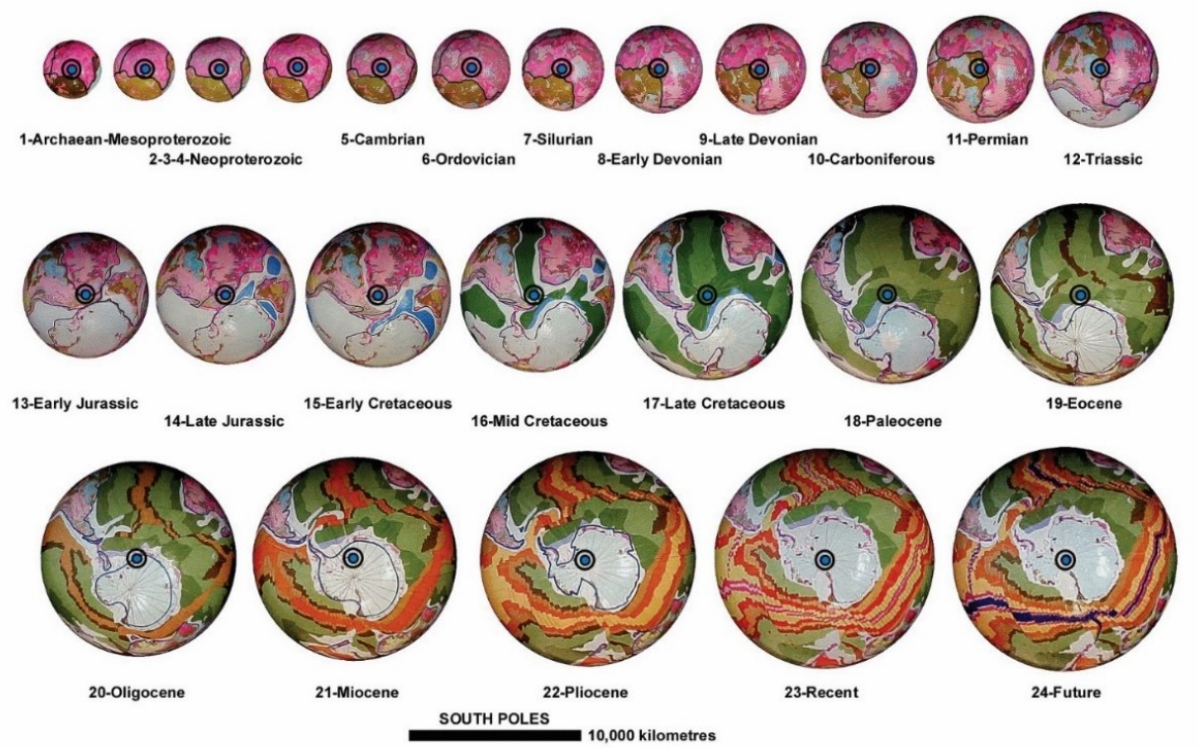

Figure 4 Small Earth Archaean to Future magnetic South Poles (blue dots). During the Precambrian and Palaeozoic the South Pole was located within west central Africa, prior to continental breakup and dispersal during the Mesozoic to Recent. Data after the International Palaeomagnetic Database (McElhinny & Lock, 1996).

The significance of both Figures 3 and 4 is that the distribution of North and South Poles, plotted independently on each small Earth model, confirms that each pole remains stationary throughout Earth history and, more significantly, each pole plots as diametrically opposed North and South Poles. In addition, the distribution of poles confirms an evolutionary history of development of the supercontinents followed by subsequent breakup and dispersal of the continents throughout history. Conventional palaeomagnetic studies using apparent-polar-wander cannot do this.

Ancient Palaeolatitude

In addition to plotting palaeomagnetic pole data, ancient palaeolatitude can also be plotted from each measured sample site. This data is unique in that calculated palaeolatitude represents the actual latitude of the ancient sample site and, unlike palaeopole data, does not require mathematical projection beyond the sample site. Structurally corrected and magnetically screened paleomagnetic data from the International Global Palaeomagnetic Database (Pisarevsky, 2004) was used to calculate palaeolatitude using conventional palaeomagnetic formulae.

Palaeolatitude data are shown plotted on each small Earth model in Figure 5, extending from the early-Archaean to the present-day. In this figure the calculated palaeolatitude data are colour coded to represent data located within the north and south equatorial climate zones—red dots, the north and south temperate zones—green dots, and the north and south polar regions—blue dots. The climate zone boundaries—shown as heavy dashed yellow lines—are based on zonal distributions on the present-day

Earth. Fine dashed yellow lines either side of the climate zone boundaries represent an arbitrary plus and minus five degrees latitude data error.

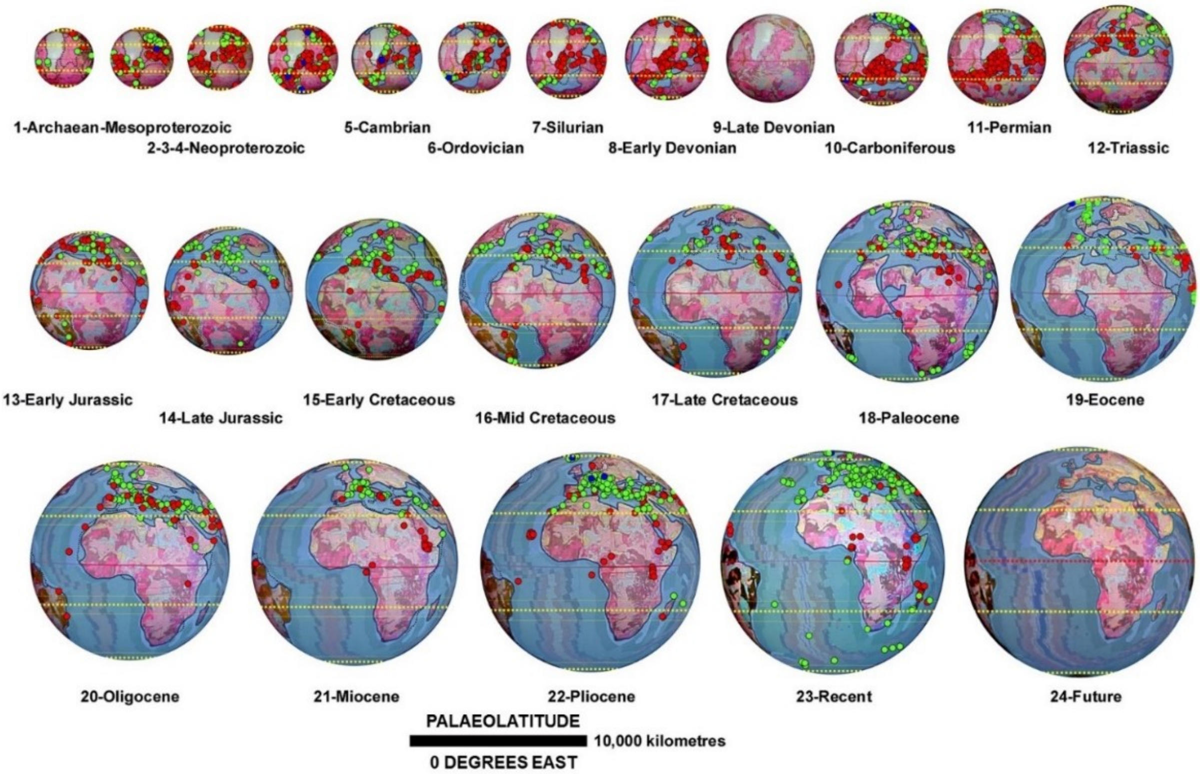

Figure 5 Archaean to present-day palaeolatitude sample site data centred on zero degrees east longitude. Red dots represent calculated data located in the equatorial climate zones, green dots represent data located in the north and south temperate zones, and blue dots represent data located in the north and south Polar Regions. Heavy dashed yellow lines represent climate zone boundaries and fine dashed yellow lines represent an arbitrary plus and minus 5 degrees data error. Note: no data are shown for the late-Devonian model.

Palaeolatitude site data plotted on an increasing radius Earth represent actual latitudes which must accord with actual climate zones. Considering the increasing uncertainty in structural correction and magnetic screening of sample site data when moving back in time, the palaeolatitude data for each small Earth model in Figure 5 shows a good correlation with each of the climate zones—in particular for the Cenozoic and Mesozoic Eras. An increased spread of equatorial zone red dots on each of the Palaeozoic and Precambrian small Earth models may suggest that the ancient magnetic dipole response may have been different, possibly weaker, than what it is now. This data distribution compliments the ancient palaeomagnetic pole data and together they more than adequately quantify the use of palaeomagnetics on an increasing radius Earth model.