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THE VARIATION OF LATITUDE

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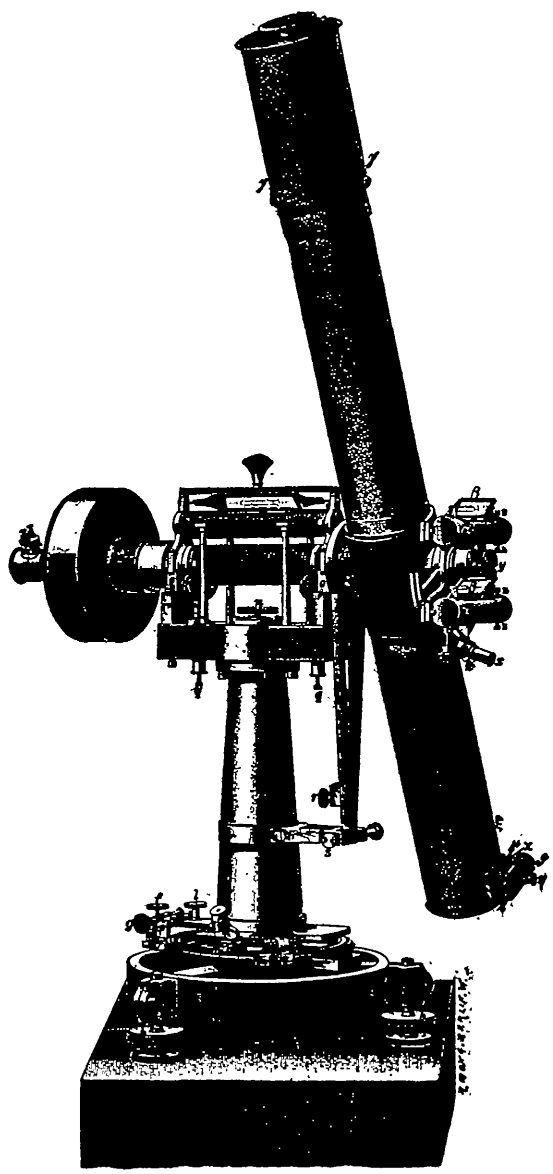

The Zenith-Telescope.

THE late Professor Young of Princeton used to say, "Astronomy, like charity, begins at home." A knowledge of the earth as an astronomical body is necessary before we can solve certain problems of the other celestial bodies. This is especially true regarding the motions of the earth, since all our astronomical observations are made from it. The principal motions are its daily rotation; its annual revolution about the sun; its top-like precessional motion in a period about 26,000 years; its monthly revolution with the moon about the center of mass of the two bodies; its journey through space with the sun and other members of the solar system at the rate of twelve miles a second.

There are two lesser motions that are not so well known by the nonprofessional astronomer. A slight nodding, to and fro, of the axis of rotation, in a period of nineteen years, called nutation, and a wobbling of the figure axis. This latter motion of the entire earth causes the axis of rotation to occupy different positions within the earth and consequently *pierces the surface at different points*. Since the terrestrial equator is an imaginary circle ninety degrees from the poles, it, too, is displaced on the earth's surface. This displacement of the equator causes a variation in the latitude of all places. It was discovered by Dr. Küstner at Berlin in 1888. Following his announcement several observatories made simultaneous observations for latitude and all agreed to a small but systematic variation.

In 1891 Dr. Chandler of Cambridge began a study of the observations in order to determine the actual path of the pole. His study led to the following conclusions. The period of latitude variation is about fourteen months. The figure axis of the earth revolves about the axis of rotation, during that period, in an approximate circle of thirty feet radius. Later observations showed that the amplitude of variation was not constant and the wandering of the pole was mainly due to two separate motions. One of these is an annual revolution in an ellipse which varies in form and position. The second, an approximate circle with a period of about 430 days. The resultant of these two motions is an irregular complicated path as shown in Figures 1 and 2. The squares represent an area at the pole slightly smaller than a baseball diamond. Figure 1 shows that the path described by the pole was at its maximum in amplitude in 1922-1923 and moved to its minimum in 1927. Figure 2 shows the reverse motion from minimum through the next maximum. These clearly indicate the variation in amplitude. When the annual component has the same phase as the fourteen-month period they combine to give the maximum and when they are out of step the amplitude reaches its minimum.

In the latter part of the last century it became evident that systematic observations for latitude must be made, over a long period of time, in order to solve the complexity of the problem. In 1896 the International Geodetic Association decided to establish a number of observatories in widely different longitudes around the earth. The following station sites were selected:

Mizusawa, Japan, 141° East longitude.
Carloforte, Italy, 9° East longitude.
Gaithersburg, Maryland, 77° West longitude.
Ukiah, California, 123° West longitude.

The four stations are, within a few seconds of arc, on the same parallel of latitude, 39° 8′ North. This parallel passes through the grounds of the University of Cincinnati. The university observatory volunteered to cooperate in the program of observations. The Russian government offered to equip and support a sixth station at Tschardjui, Asia Minor. The same type of instrument, the Zenith

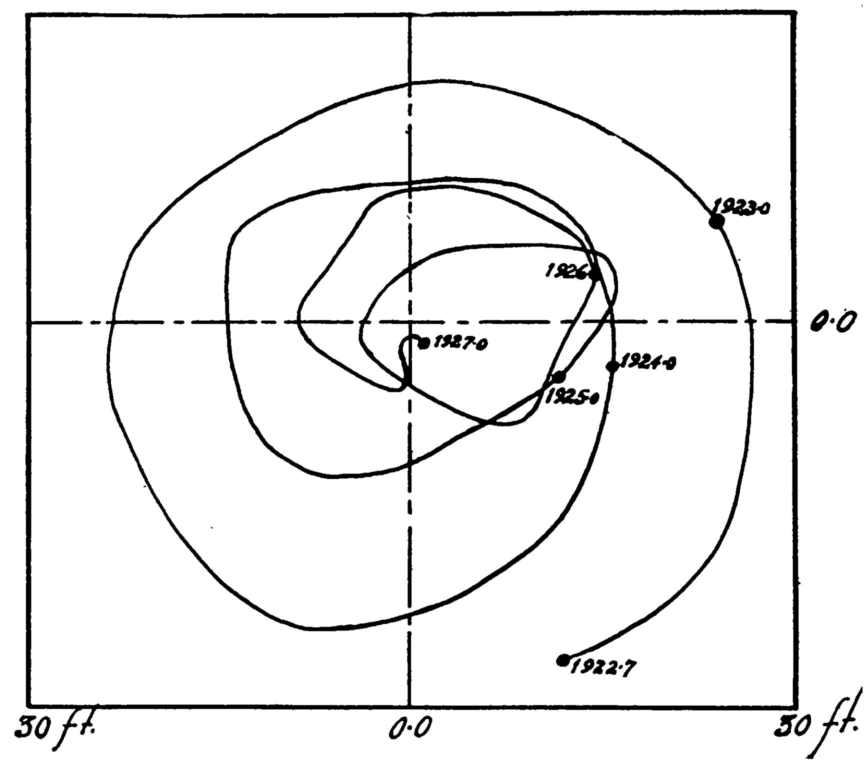

Figure 1. Path of the earth's pole from 1922.7 to 1927.0.

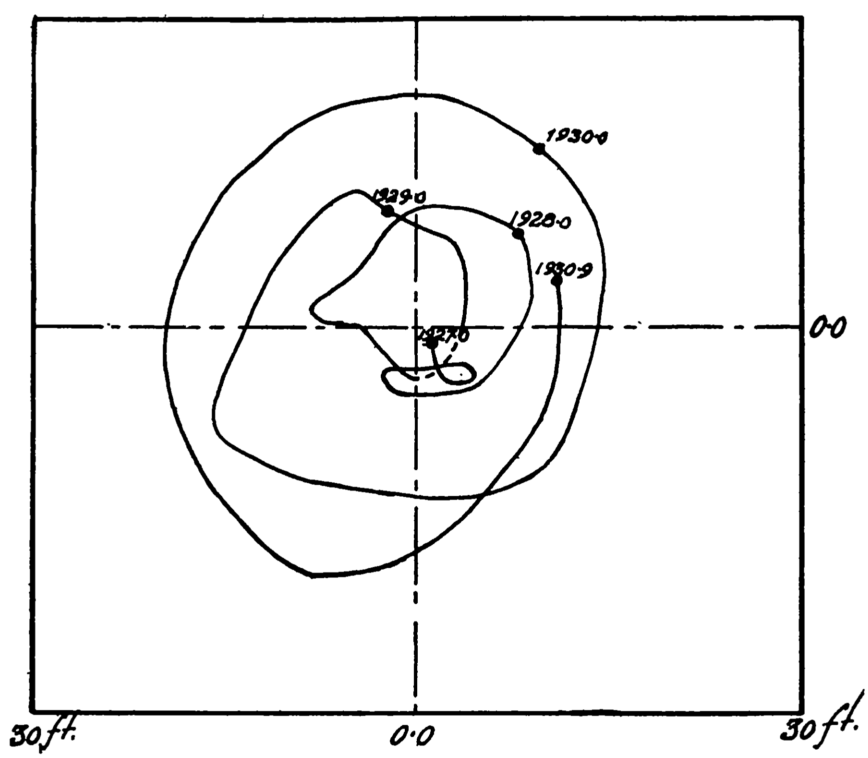

Figure 2. Path of the pole from 1927.0 to 1930.9.

telescope, was to be used at each observatory and the method for latitude determination Talcott's method. By this method the latitude is determined by observing with a micrometer the difference between the nearly equal zenith distances of two stars which pass the meridian within a few minutes of each other, one *north* and the other *south* of the zenith. The Zenith telescope is set to the proper zenith distance for the first star with the bubbles of the delicate level, which is attached to the telescope, adjusted and read. After the star has been observed, the telescope is reversed on its vertical axis without altering the position of the level. The telescope can now be adjusted to point to the same zenith distance as used for the first star. Since the stations have nearly the same latitude, the same stars can be used at each, thus assuring homogeneous results. Observations were begun about 1900 and continued without interruption to 1914, when the World War disrupted the International Geodetic Association. During and after the war the observations were continued at the three stations Mizusawa, Carloforte and Ukiah, the work being supported by the governments of the countries in which these are located. The results of the extended observations have substantiated the earlier conclusions. It is now known that the path of the pole can be observed more accurately than it is possible to predict it. Beginning in 1932, observations are again being made at Gaithersburg and a new northern station established at Kitab, U.S.S.R. In addition to the present five northern observatories, three have been established in the southern hemisphere.

The practical value of these observations lies in their application to the determination of international boundaries, since these are determined on the basis of latitude values. The variation of latitude must be taken into account in determining the declination of fundamental star positions. These are determined from observations made with the meridian circle. The observed zenith distance of the star, combined with the latitude of the observer, gives the declination of the star. It should also be stated that the wandering of the pole causes a very slight variation in the *longitude* of a place.

The problem is to account for the variation of latitude and the motions of the earth that produce it. In the Eighteenth Century the great mathematician Euler developed the law of rotation for rigid bodies. He showed that a body, like the earth, if it were perfectly rigid, and if its axis of rotation did not originally coincide exactly with the figure axis, the latter would revolve about the former in a period of about ten months. There was a time when it was believed the earth consists of a crust, about one hundred miles in thickness, with a liquid core. More recent evidences indicate the earth is as rigid as steel and contains no large liquid masses within its interior. With seismological stations in many different parts of the earth it is possible to determine the speed of earthquake waves that are transmitted along the surface and through the interior. The speed depends upon the density and the rigidity of the earth. The observed results indicate the rigidity is considerable. The rigidity and elasticity of the earth can be determined from the effects of exterior forces acting upon it. We are all familiar with the tide-raising forces of the moon and sun. If the earth were perfectly rigid the height of the water tide would be greater than if it were largely liquid. In the latter case the entire surface of the earth would yield to the tide-raising forces and the water tides would be less. From experiments made by Michelson and Gale it was found the tide in a pipe was approximately 70 per cent of the value to be expected if the earth were perfectly rigid. This leads to the conclusion that the earth has a rigidity somewhat greater than a sphere of steel of the same size. Newcomb and others have pointed out that the observed period, 433 days, of the variation of latitude, instead of 305 days as predicted by Euler, is due to the fact that the earth is not perfectly rigid. Further study showed that the observed period is to be expected if it has the rigidity of steel, thus agreeing with results from the speed of earthquake waves and tidal experiments.

It has been suggested by some authorities that the annual component of the pole's motion is due to seasonal changes. These effects have been analyzed by Jeffreys in his book, *The Earth*. He points out there are several annual changes in the distribution of mass over the surface that could affect the products of inertia which produce the polar motion. The principal methods for redistribution in the course of a year are the variation of atmospheric pressure (highs and lows) observed at the surface; precipitation of snow and formation of ice, and the periodic changes in vegetation. The calculated effects indicate that such seasonal changes may have some part in producing the annual period, but the observed values for different years differ among themselves. These cannot be explained as being due to errors of observation and they are too great to be attributed to variations in meteorological conditions from year to year. At present no final conclusions can be drawn regarding the cause of the annual component.

There have been great changes in the climate of the earth during geological ages. It has been suggested that these were due to large displacements of the poles, but there are no observational data to support this suggestion and there are no reasons for believing that the poles have ever been displaced beyond the present small values observed in the variation of latitude.