

means already arrived at. The process is purely an inductive one. The machine of the future resides potential in the machine of the present. Which is the fittest of present systems to give it birth I leave you to determine. One thing is certain. The machine of the future will have for its share of the work the entire task which admits of machine execution, it will make the least demands upon operative skill, and the expenditure of mechanical means will be in inverse not exact ratio to its functions.

Mining and Metallurgical Section.

Inaugural Meeting, held April 28, 1897.

MR. JOHN BIRKINBINE in the chair.

COMPASS VARIATION AFFECTED BY GEOLOGICAL STRUCTURE IN BUCKS AND MONTGOMERY COUNTIES, PA.

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The purpose of this paper is to call attention to a remarkable correspondence between the strongly bent axis of seemingly very irregular curves of magnetic declination and an independently demonstrated profound fault, dying out into a sharp anticlinal, in the new red region of Bucks and Montgomery Counties. The magnetic curves were mapped some years before the beginning of the recent geological survey, that for the first time fully proved the peculiar structure; but the curves had no influence whatever in the interpretation of the geology, and the correspondence was not perceived until long after the geological map was printed.

The magnetic map was made about the year 1883, by the Water Department of the city of Philadelphia, for use in its excellent topographical survey of the Perkiomen and neighboring valleys under Mr. Rudolph Hering. The map records the results of a number of determinations of the magnetic

declination made by the Water Department itself and by the Coast Survey and by other observers, and curves of equal declination were drawn for every tenth of a degree. The curves are so extremely at variance with the simple, nearly straight, lines of earlier less detailed maps, as either to show extreme confidence in the accuracy of the observations, or perhaps, even to excuse a suspicion of the possible incorrectness of the curves in some way, especially in view of the acknowledged want of precision of some of the observations, and the absence of any obvious topographical or other occasion for such great irregularity. But the curves are in the main beautifully confirmed and thoroughly vindicated by the underground geology.

The striking feature and dominant peculiarity of the curves is a very strong bend convexly northeastward near New Hope and Lambertville, on the Delaware; but gradually changing towards the west, so that the curves near Shwenksville and Boyertown point still more sharply southeastward. The axis of the bend in the curves is, then, itself greatly bent, nearly to a right angle. The geological survey of the two counties, begun at the end of 1887, has proved beyond a question the existence of an enormous fault, of about 14,000 feet, in the rock beds, almost precisely on the line of the Delaware River end of that magnetic axis, and following the same course past Doylestown, gradually dying out, and west of that town turning northwestward, passing north of Shwenksville, disappearing there as a fault, but continuing as a sharp anticlinal to the border of the New Red and of Montgomery County, 5 miles northeast of Boyertown.

The geological structure of the map of 1893, published by the State Geological Survey, was drawn without the least reference to the magnetic curves, and indeed without any knowledge at that time of the slightest correspondence between them and the geology. The geological map gives the direction and amount of the dip at a couple of thousand points, amounting to a complete demonstration of the structure, and to a full proof of the situation and extent of the fault and of the sharp anticlinal into which the fault runs. The topography

also given on the same map shows that there is no one strongly-marked ridge following the course of the axis of the magnetic curves. Indeed there are more decided topographical indications in the way of long, rather high ridges in other directions. Furthermore, the form of the out-cropping rock beds, sedimentary or igneous, does not correspond in any degree with the magnetic curves.

It is perfectly clear, then, that the remarkable magnetic peculiarity of the region must be closely related to the equally remarkable and completely corresponding geological structure; and if either were in need of corroboration, the confirmation given by two such thoroughly independent pieces of work would be of the strongest kind.

Moreover, some light is perhaps thrown upon the obscure subject of terrestrial magnetism. It is true, the nature of the relation between the magnetic and geological phenomena is not so easily determined; but it seems to become certain that the internal structure of the earth's crust has an important influence upon terrestrial magnetism, even if it be not in any degree its first cause. Terrestrial magnetism and its changes have sometimes been considered explainable by solar influences alone, no longer by direct action of the sun as a magnet, but by the sun's heating the atmosphere or the earth's crust. The present phenomena seem, however, to point to more strictly terrestrial processes as the true cause, and to suggest that the solar influence may partly at least be exerted through the attraction of gravitation as well as through heat. The enormous and locally unequal strains produced by the contraction of the earth's crust in cooling would be particularly liable to be affected by the presence of a deep fault or by a sharp anticlinal. Such lines would be places where the crust has yielded and is readier to yield, and consequently where the strain has been to some extent relieved and is less. The recent occurrence of earthquakes along the New Jersey end of this very fault line shows that the resistance there is less, and that the remaining strain must likewise be less. On such a comparatively weak yielding line the rock beds in readjusting themselves, even where there is no violent earthquake, must

occasion a certain amount, not only of strain, but of friction and heat that might give rise to electrical currents. A decided magnetic effect, too, has sometimes been observed to accompany earthquakes, and in some cases to precede them. In like manner, the strains and yielding or readjustment that may be occasioned by the attraction of the sun and moon might apparently cause electrical currents; and, in fact, magnetic disturbances have been found to correspond, like tides, with the place of those heavenly bodies. Again, the broken or arched form of the rock beds may permit at least a temporary local variation in the temperature of the crust, as affected by the earth's hot interior, that could occasion electrical earth currents. Terrestrial magnetism seems then to arise not only from the manifold action of the sun's heat upon the air and the earth's crust, but from the internal movements of the crust and from the tidal effect of the sun and moon upon the air, ocean and solid earth.

PHILADELPHIA, APRIL 26, 1897.

POSTSCRIPT.

The discussion that followed the reading of the paper suggests the need of a few further remarks. The question was raised whether deposits of iron ore, some of them as much as 50 miles away, could not have so affected the compass variation at the points determined as to give the magnetic curves the peculiar form on the map. But the power of iron ore to affect the magnetic needle at a distance is apt to be exaggerated, somewhat after the fashion of the ancient oriental tales of the lodestone that drew men's boot-nails, and of the seaside mountain that pulled the bolts out of ships' sides. Deposits of magnetic iron ore, though differing much in magnetic force, seldom directly affect the most delicate magnetic needle at a distance of more than a few hundred feet. If they sometimes appear to have a more distant effect on the needle, our present experience would strongly indicate that it is because the iron ore happens to be at some line of such great structural import-

ance as to give rise to a diversion of electrical earth currents. Furthermore, it is hardly conceivable that just these peculiar Bucks and Montgomery forms of the magnetic curves could have been produced by any known deposits of iron ore or trap, whether near or distant, whether strongly magnetic or weakly so, or could have been occasioned by anything else than the closely corresponding equally irregular geological structure.

The number of points (18) where the magnetic declination was determined is not very great, yet sufficiently so to make it impossible to draw any essentially different curves that would conform to them. Nevertheless, it is obvious that the magnetic curves, while not made essentially different, might with the greatest ease be so slightly changed as to have their axis conform exactly to the course of the fault and anticlinal; and several such proposed amendments have been dotted in upon the map. The close agreement of the strongly bent axis of the curves with the geological line of fault and anticlinal is therefore a surprising confirmation of the correctness of the magnetic observations, and at the same time thoroughly indicative of some causal connection between the two phenomena.

Some of the magnetic irregularities that were instanced during the discussion may be wholly unexplainable with our present knowledge of terrestrial magnetism; but if they be not connected with mere temporary disturbances—magnetic storms—we can now see that they may be due to hidden geological structure, in some cases, perhaps, submarine as well as subterranean. It is evident that it is highly desirable that the magnetic investigation of every portion of the earth should be thoroughly carried out, in order to ascertain more fully the world-wide magnetic laws. Such work is, in particular, one of the most important parts of Arctic and Antarctic exploration, one that must be of practical value to surveyors and navigators of every other region.