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EARTH ROTATION AND RIVER EROSION

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INTRODUCTION

THE singular and romantic fact that all moving bodies on the earth are subject to a deviating or deflecting force due to the rotation of the globe is a modern discovery. The chief application of the law, that the deflection is always to the right in the northern hemisphere, regardless of the direction of movement, and to the left in the southern hemisphere, has its very important application to the atmospheric circulation.

Until the middle of the past century the winds were supposed to be lawless. (St. John, iii, 8). And it remained for a school teacher in Nashville, Tennessee, with a flair for mathematics, Mr. William Ferrel, to make the interesting and important discovery that the prevailing currents of the air are an effect of the earth rotation. His analysis of the forces and his description of the winds, published during the years 1856–1889, yet remain authoritative.

The suggestion that the right-hand deflection of moving bodies might produce excessive erosion of the right banks of rivers was made, by American geologists, in 1873 and 1877, and has been accepted without sufficient study.[1] A recent reference in SCIENCE for February 19 (Vol. 75, pp. 215–216) is the immediate occasion for this writing:

1 (1) W. C. Kerr, "Topography as Affected by Rotation of the Earth," *Proc. Amer. Phil. Soc.*, 13: 190–192, 1873; (2) Elias Lewis, Jr., "Certain Features of the Valleys or Water Courses of Southern Long Island," *Amer. Jour. Sci.*, 13: 215–216, 1877; (3) G. K. Gilbert, "The Sufficiency of Terrestrial Rotation for the Deflection of Streams," *Amer. Jour. Sci.*, 27: 427–432, 1884; (4) M. L. Fuller, "The Geology of Long Island," *U. S. Geol. Survey, Prof. Paper* 82, 50–51, 1914; (5) Kirk Bryan and Shirley L. Mason, "Asymmetric Valleys and Climatic Boundaries," SCIENCE, 75: 215–216, 1932.

THEORETIC

The "deflective force" due to rotation of the globe is described in standard treatises in physics and meteorology. As a "force" the principle applies to specific cases or particular conditions. For the present purpose, the application to streams, it is feasible to use only the measure of horizontal deviation. The increase in velocity, while very important in application to the winds, has no valid application to rivers.

The fact of earth rotation, with its consequent change not only in position but also in direction of all lines on the surface of the globe, is interestingly and convincingly proven by the Foucault pendulum, which is easily constructed. At latitude 42°[2] the pendulum deviates from the north-south direction 10.04 degrees in one hour. But the actual change is chiefly of the meridian, the pendulum tending to hold its original direction in space. The "deflective force" is only inertia, which holds the free-moving body to its original direction.

The eastward rotational velocity at the earth's surface decreases from 1,038 miles per hour at the Equator to zero at the poles. At latitude 30° the hourly movement is 902 miles; at 42° it is 774 miles; and is 522 miles at 60°.

But the change in direction of lines, the rotational deflection or deviation, increases toward the poles. It is noted that the deviation of the Foucault pendulum at latitude 42° is 10.04 degrees in one hour. The space subtended by this angle at the distance of one mile is 924 feet. This figure, therefore, measures the amount of deflection, at this latitude, in one hour in one mile. In other words, any point on the meridian near latitude 42° has an eastward movement 924 feet less in one hour than the point one mile south. But the actual eastward velocity is 774 miles per hour.

By rough computation the mile per hour deflection at latitude 30° is 723 feet; and at latitude 60° is 1,249 feet. These differences in velocity are, of course, inherent in the globular shape of the revolving earth.

The problem now relates to the effect of these differential velocities on the flow and erosion of a stream of water held to a definite channel.

THEORETIC APPLICATION TO RIVERS

The first published description, in American science, of streams assumed to be deflected by earth rotation was by W. C. Kerr, state geologist of North Carolina, in 1873.[1] His features, however, were so large and the description indefinite that his paper has been merely noted in the scanty literature. The only example of assumed greater erosion of right-hand banks that has been accepted is that of the weak creeks along the south side of Long Island, described by Lewis in 1877, recognized by Gilbert in 1884 and confirmed by Fuller in 1914. The error in the assumption will be shown at the close of this article.

The only scientific and mathematical analysis of the deflection as applied to rivers, in American literature, is by Gilbert, in paper 3 of the list above. He developed a formula for estimating the deflective force when combined with the centrifugal force in stream impact on the banks of curves or meanders. Using the quantitative factors, velocity, depth, curvature and load, of the Mississippi River at Columbus, Kentucky, as published by Humphreys and Abbot, he calculated that the combined forces, the "selective tendency" was nearly 9 per cent. greater on the right-hand curves than on the left-hand. He clearly states that the force of deflection can apply only to right-hand curvatures in streams of slight fall, and cites the streams on Long Island. He made no further application of the principle, and failed to pursue the study. Probably he realized that the deflective effect on streams was elusive and inconsequential.

Gilbert referred to a French mathematician, Bertrand, who computed that a river in latitude 45°, with the high velocity of three meters per second, exerts a pressure on its right bank of $\frac{1}{63539}$ of its weight; an amount too small for consideration.

ABSORPTION OF THE KINETIC ENERGY

The example of a mass detached from the earth and moving with no interference, except perhaps the weak opposition of the air, does not properly illustrate the complex mechanics involved in the flow of a stream, held to the earth, and confined in a channel. Let us take an intermediate illustration. I walk up Fifth Avenue from Fortieth Street to Fiftieth Street, one half mile. The amount of kinetic energy possessed by my body mass, due to eastward earth rotation, is greater at Fortieth Street than it is when I reach Fiftieth Street. The decrease in energy is not because any amount has been used in eastward deflection, from the fact that I crossed from the east side of the street to the west side. Evidently the absorbed energy has been utilized in some other way, or transformed in some manner. The problem is one in theoretical mechanics. In this case, according to physical theory, the kinetic energy of the eastward motion, strange as it may seem, have been transferred to the globe as an infinitesimal increase in its velocity of rotation.

Could I have leaped the half mile I would have landed east of the north-south line, the amount of

[2] The parallel of 42° is used here because it lies near the south-leading tributaries of the Delaware and Susquehanna Rivers, which have special reference later.

eastward deflection depending on the length of time in the flight. And in the landing the eastward impact would have given an eastward push to the earth, producing a theoretic increase in the rotational velocity of the globe. But when the half mile is covered step by step the same amount of eastward push is slowly transferred to the earth.

Theoretical mechanics finds another factor relating to moving bodies. The transfer of a body from lower to higher latitude places the mass nearer to the axis of the earth's rotation, and under the principle of the "conservation of areas" thereby increases the velocity of rotation. (Hence it appears that pedestrians, and automobiles, going northward in Fifth Avenue or elsewhere, in the northern hemisphere, accelerate the rotation of the globe; and passing southward they retard the rotation.)

Streams flowing poleward tend to accelerate the earth's rotation, while those flowing toward the equator have the opposite effect.

The river illustrates similar mechanical principles. In a northward flowing river, in the northern hemisphere, an assumed unit mass, in cross-section, possesses more energy of eastward motion at any given point then it does at any point in its northward progress. Under the law of conservation the kinetic energy, becoming less with every foot of northward progress, is transferred to the earth.

It has been casually assumed that some, if not all, of the stream's energy is expended in erosion of its right-hand bank in excess of that on the left bank. But greater erosion is produced only by more vigorous flow of the water laving the bank. Erosion by running water is an abrasion and transportation effect, conditioned by velocity and volume. And it would appear that the mechanical factors here involved do not produce any appreciable effect on the marginal flow, except, as calculated by Gilbert, on the outer banks in right-hand curves, or meanders.

A brief analysis of the mechanics indicates that streams in direct courses can have no effective erosion because of rotative deflection. In the conflict of forces and the mutual impact of river and ground there is no accumulation of stress, to be suddenly released. The river in its entire length is instantaneously adjusting the forces. As an extended and moving mass the river, held to its channel, is losing, or absorbing, its kinetic energy of eastward motion constantly, every second, through every foot of its progress. And an important factor has been overlooked, even in Gilbert's analysis. The mutual theoretic impact between the stream and its bank is not merely at the edge of the stream but at the bottom, and as far as the concave bottom declines away from the shore, usually to the middle of the stream. Any theoretic impact and erosion must involve one half of the base of the stream, with the wide surface friction.

The conception that the earth's rotative deflective force is effectively expended in stream erosion has slight basis in theory, even with acceptance of Gilbert's estimate on outer curvatures. However, an advocate of the idea may claim that while the amount of such erosion is minute in theoretic mechanics, and invisible in its operation, yet when exerted persistently through geologic time its cumulative effect might be recognizable. Such suggestion carries the problem over to physiographic geology, as an inductive and observational study.

OBSERVATIONAL, VALLEY FORMS

The western part of New York is a surpassing field for the study of stream work. The most remarkable series of parallel valleys, including the famous Finger Lakes, extends from Lake Erie on the west to the Catskill highlands on the east. These valleys represent many millions of years of stream adjustment to all dynamic factors; and if earth rotation has any influence on stream erosion it should be registered in the walls of the New York valleys.

The most ancient river flow is suggested in Fig. 1.

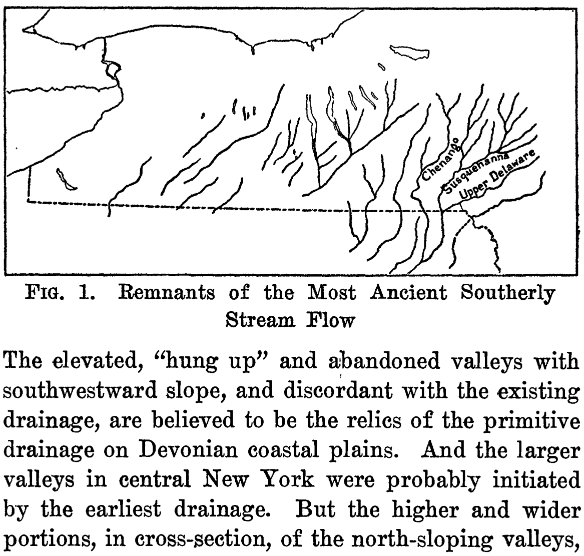

FIG. 1. Remnants of the Most Ancient Southerly Stream Flow

The elevated, "hung up" and abandoned valleys with southwestward slope, and discordant with the existing drainage, are believed to be the relics of the primitive drainage on Devonian coastal plains. And the larger valleys in central New York were probably initiated by the earliest drainage. But the higher and wider portions, in cross-section, of the north-sloping valleys, Fig. 2, and the old abandoned valleys have been subjected to atmospheric destruction since Paleozoic time, and their surfaces reduced.

The north-sloping valleys are certainly old enough to exhibit any differential erosion. They were carved in Tertiary time and represent stream work of at least a few million years. However, the better samples are the upper tributaries of the Susquehanna and Delaware Rivers, shown in both Figs. 1 and 2. These rivers, with southwestward flow, appear to be the

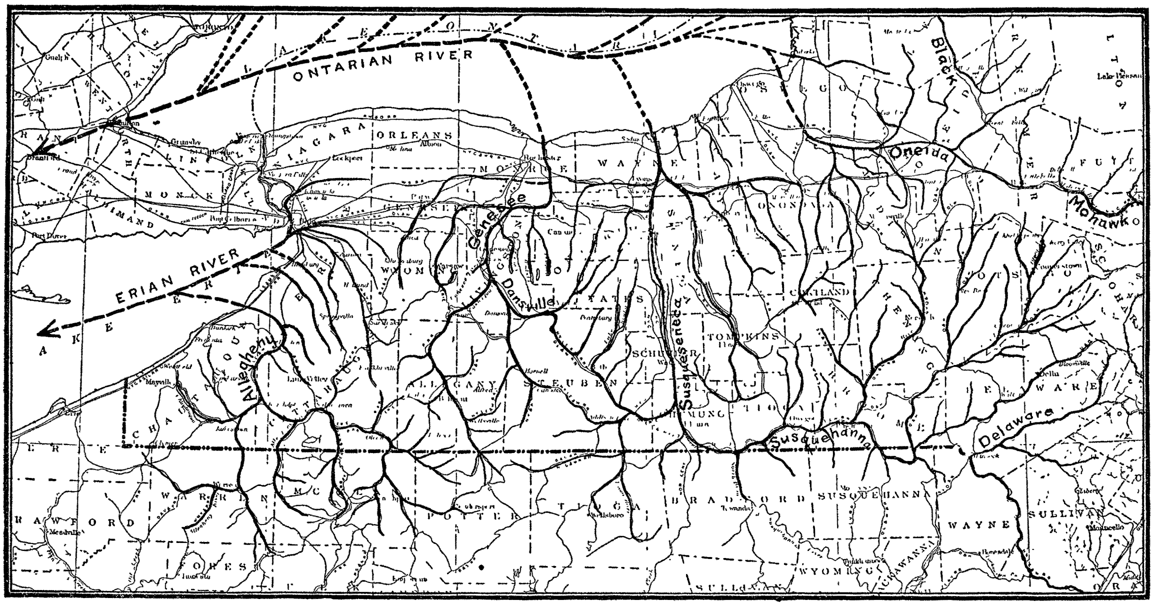

FIG. 2. Preglacial, Late Tertiary, Drainage in New York

lineal descendants of the earliest streams, dating from late Paleozoic time when the region was lifted permanently out of the sea. And their curvatures are inheritances from the primitive meanders on the newly exposed coastal plain. These valleys are carved in relatively hard Devonian sandstone and shale by continuous flow during the enormous stretch of time since the Devonian Period, except the relatively brief episode of burial under the Quebec ice sheet. If the time factor is critical then here are the valleys of record.

Fortunately, all New York is topographically mapped, in 20-foot contours. Examination of the topographic sheets, especially those showing high relief or deep valleys, should be sufficient to reveal any significant difference in the steepness of the valley walls due to undercutting by unequal erosion.

The ice invasion has left morainal fillings at some places in the valleys, obscuring or modifying some short stretches; but the abrasional work of the glacier was little more than a "sandpapering" of the valley walls.

The topographic sheets will fairly show any significant differences between left-hand and right-hand slopes. With these sheets the reader can make his own measurements and form his opinion quite surely from personal study. And he will find the examination exceedingly interesting as an exercise in physiography.

Streams of recent, postglacial origin, as those of Long Island, the Niagara and the Genesee from Portage to Mount Morris, have only some thousands of years for their record, and must be less valuable in this study.

The writer has made extended examination of the topographical sheets, and the recorded data gives only negative results. The large majority of New York valleys are equivocal or indifferent in respect to differences in slope of the walls. Many valleys show steeper slopes on either side for considerable stretches, with no apparent reason. It is found that a majority of the north flowing streams have steeper left-hand walls; while the south-flowing are mostly so listed. It is not advisable to extend this writing by giving lists of the valleys with significant features. The person interested in the matter will be able to make his own study. But the student should be on guard against preference or preconceived opinion, because the psychologic attitude is a factor in physiographic and glacial study.

The deflective effect is quite infinitesimal in comparison with dynamic factors that produce striking irregularities in valley walls. These factors should be recognized in the comparative study.

Differences in the rock strata are not important in western New York, unless there is found considerable slant or "dip" of the beds across the trend of the valley. Some decided curves and undercutting are produced by tributaries, and their deposits, in crowding the receiving stream against the opposite bank.

Exposure to wind is the most dominant factor in deflection.

Intensive study will require precise measure of the comparative steepness of outer walls of right and left meanders. Sheets for this, in the Delaware area, are Deposit, Walton, Andes and Long Eddy.

Handsome display of valley erosion is seen on the Pitcher sheet, and its adjacent Oxford, Greene and

Binghamton sheets. Other instructive sheets are Bath, Wayland and Tully.

THE LONG ISLAND VALLEYS

The only American streams used as evidence of erosion by rotative deflection are the creeks and brooks along the south side of Long Island. And this fact hints at the weakness of the theory.

In a belt about fifty miles long, with direction S.S.W. by E.N.E. some thirty weak streams with southerly flow, in sand and gravel, reach the Atlantic Ocean. The longest is less than ten miles. The valleys are shallow, few being twenty feet deep. The west banks of the shallow valleys are steeper than the east banks, as described by Lewis and by Fuller, and confirmed by Gilbert. The deeper valleys do not present the difference in the walls.

The claim for earth rotation as the cause of the difference in the slope of the valley walls has been made without any reference to other possible and more potent dynamic factors. Yet the most effective agency appears evident. Next to gravity the winds are the greatest force affecting water surfaces.

The Long Island streams have some protection from the west winds in the highlands about New York Bay and the Hudson River; and on the north in the nearby range of morainal hills. But on the south and east the area is exposed to the full force of the winds off the Atlantic. And it is to be noted that the most forceful winds of the district are those of the coastal cyclones and the tropical hurricanes that occasionally sweep the northern coast.

One gale from the southeast or east has more effect on these streams than months of the moderate winds from the west. Moreover, when a stream had developed a steeper west bank that condition aided in protection from the west winds.

It must be admitted that the diminutive streams on Long Island have been more influenced in erosional work by the east than by the west winds. And that excess, however small, is perhaps a thousand times more effective than the force from earth rotation.

The conclusion from this study is that the rotative deflective force, of vast effect on air currents and free-moving bodies, is so small in its effect on stream erosion, especially when masked by forceful agencies, that it is immeasurable and negligible.

For the mathematics of this paper the writer has received help from Professor F. C. Fairbanks, of Rochester, and the keen criticism of Dr. W. D. Lambert, of Washington.

Addendum. Since this paper was submitted another article on the subject appears in SCIENCE, June 3, page 584, by Professor Richard J. Russell; whose paper of November 13, 1931, provoked the present discussion.

Professor Russell's interesting and quite conclusive article is in practical accord with the above writing. He cites further references to the literature, noting especially the early writing by Babinet, in 1849, and the computative paper by von Baer, in 1866; and revives the appellation, "Baer's Law."

The following references to the literature of the subject have been transmitted by Dr. Lambert.

Colin Maclaurin (1698–1746); who also suspected that the winds were affected by the earth's motion.

Collier Cobb, in *Jour. Elisha Mitchell Sci. Soc.*, 1893, page 26.

M. P. Rudski, in "Physik der Erde," 1911, page 495.

K. Wegener, in *Petermanns Mitteilungen*, vol. 71, 1925, page 195.

THE NOBEL PRIZE IN PHYSIOLOGY AND MEDICINE FOR 1932

IT was announced on October 27 that the Nobel Prize in physiology and medicine had been awarded jointly to Sir Charles Scott Sherrington, Waynflete professor of physiology at the University of Oxford, and Edgar Douglas Adrian, Foulerton professor of the Royal Society at Cambridge, for their analysis of the functional activity of the neurone, the ultimate anatomical unit of the nervous system. Few awards could bring greater satisfaction to physiologists and neurologists, especially in this country, where both recipients are well known through their writings and through large numbers of former students. Sherrington's American pupils include Harvey Cushing, R. S. Woodworth, Lewis Weed, Alexander Forbes, Henry Viets, H. C. Bazett, Wilder Penfield, John Fulton, Stanley Cobb, Grayson McCouch and many younger investigators who have had the privilege of working in the Physiological Laboratory at Oxford since the war. Adrian has similarly had numerous students from this side of the Atlantic, including, among others, Alexander Forbes, Hallowell Davis, J. M. D. Olmsted, Detlev Bronk, McKeen Cattell, H. Hoagland and Sarah Tower.

It has been well said that what William Harvey did for the circulation of the blood, Sherrington has done for the nervous system. His earlier work by its careful, progressive and logical advance laid the foundation of our present beliefs concerning the functions of the brain and spinal cord. While a student at Cambridge under Michael Foster, Sherrington became