ART. XX.—*The Influence of the Earth's Rotation on the Course of the Rivers on the Canterbury Plains.*

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Plate X.

WILLIAM FERREL, in 1859, published a paper in the *Mathematical Monthly* announcing the law now known as "Ferrel's law": "If a body move in any direction on the earth's surface, there is a deflecting force arising from the earth's rotation which deflects it to the right in the Northern Hemisphere and to the left in the Southern." The application of this law to the explanation of the course of the trade-winds is familiar to everybody, and it must also apply to streams. There are, of course, many other factors which come into play to decide the course of the stream, and the question is one that has aroused considerable discussion.

G. K. Gilbert, writing on "The Sufficiency of Terrestrial Rotation for the Deflection of Streams," in the "American Journal of Science," vol. xxvii (1884), says he started by considering the rotation of the earth quite unnoticeable, owing to greater differences due to hardness of rocks, slope, &c., but nevertheless, on giving the matter full consideration, is now compelled to write supporting the contention that the terrestrial rotation is sufficient to cause deflection. In a discussion in the French Academy of Science, Bertrand demonstrated that a river flowing in S. lat. 45°, with a velocity 3 metres per second, would exert on its left bank $\frac{1}{63529}$ of its weight, and he regarded this as too small for consideration. Henry Buff pointed out that the influence of rotation combined with that of gravity would be to heap the waters up on the left side, make them a little deeper there, and so increase the velocity slightly, so that the terrestrial rotation increases the transporting, and therefore corrading, power on the left bank. It is true, however, that he regarded this as of less effect than the wind-waves on the same surface. It has been held by others that the influence of the rotation merely amounts to a slight change in the direction of gravitation—that a river flowing down an incline to the sea will flow not straight down, but slightly to the left, and that that is all. The river will take up this course, adjust itself to it, and then nothing further will happen. Gilbert himself held this opinion for some time, but saw fit to abandon it.

A stream flowing straight has a symmetrical cross-section, the swiftest current in the centre. Admit a curve and centrifugal force comes into play; and since this force varies as the square of the velocity, it throws the swifter strands of the stream towards the outer bank; corrasion results there, a deposit is formed on the inner bank, and the eccentricity, so far from correcting itself, goes on increasing until quite other forces come into play.

Now, Ferrel proves that the deflective force of the earth's rotation (be its apparent effect large or small) varies as the velocity of the stream; and this is the main point of the argument. If it varies as the velocities, it must exert a selective action on the various strands of water moving at different velocities. It moves over to the left bank* the strands of water moving most quickly. Now, in water moving round a curve, with the outside to the left, the centrifugal force moves the water to the left as the square of the velocities, and the rotational force moves the water to the left as the velocities, and these two forces act in concert, and their effects are summed. If the curvature has its outside to the right, the centrifugal force tends to move the thread of greatest velocity to the right, but the rotational force tends to move it to the left, and the two forces are opposed. Gilbert expresses this by means of the following equation:—

v = Velocity of stream;
r = Radius of curvature of stream-course;
n = Angular velocity of earth's rotation;
l = Latitude of locality:

$$\frac{\text{Total displacement of velocity to left}}{\text{Total displacement of velocity to right}} = \frac{v + r\sin l}{v - r\sin l}$$

Giving the values derived from the study of the Mississippi,

n = 0·000072924 rad. per second,
v = 8·4 ft. per second,
r = 8,000 ft.,
l = 37°,

we have, were it in Southern Hemisphere,

$$\frac{L}{R} = 1{\cdot}087$$

—that is, the selective movement of velocities to left bank is nearly 9 per cent. greater than to right bank.

Let me refer now to the law that the transporting-power of a stream varies as the sixth power of its velocity. It is a matter

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* All streams are supposed to be in the Southern Hemisphere.

of experiment. A stream running 1 ft. a second is, we suppose, able to move a stone 2 lb. in weight. Increase the velocity to 2 ft. a second: instead of now being able to lift a stone 2 lb. in weight, it can lift one of actually 64 lb. weight, 64 being 2^6.

Now, consider these accumulated facts: The effects of the terrestrial rotation are unceasing and cumulative. It is allowed to cause an extra pressure on the left bank; it is allowed to increase depth of water and so increase the velocity on left bank; it is allowed, in a river of the rate of flow and S. latitude (altogether neglecting the size) of the Mississippi, to cause a selective motion of velocities towards left bank of curves of 9 per cent., and then the transporting-power of stream varies as sixth power of velocities, so that even if the velocity on the left bank be very slightly greater the difference in corroding-power will be very appreciable. Consider these accumulated facts, and we may believe that the rotation of the earth may well have some slight effect on the course of a river—slight, of course, is agreed, but not so slight as to be unappreciable in favourable circumstances.

Gilbert, in the paper mentioned above, describes an actual case where he believed that the terrestrial rotation had most evidently determined the course of several streams. On the south side of Long Island, New York, a number of streams flow down a plain of gentle slope and essentially homogeneous formation. Each of these valleys is bordered on the right side by a bluff from 10 ft. to 20 ft. high, while its gentle slope of the left side merges imperceptibly with the general plain. The stream in each case follows closely by the bluff at the right, and there seems no reasonable doubt that these peculiar features result from the influence of terrestrial rotation.

Thus much I read at a time when I had seen the Canterbury rivers only while crossing them on the main line of railway. But thinking over them, I remembered that the Rangitata and Waitaki had steep and high banks on their left sides, and very sloping or unnoticeable banks on their right. I also thought then that the Canterbury Plains were homogeneous in structure, and had several streams running across them, so that if the rotation of the earth did have a deflecting influence on the courses of rivers, we should on these plains see it as well as anywhere. To be able to detect the influences of the earth's rotation we need an even slope through a homogeneous structure. Where rocks of different hardness occur, or where the slope is not regular, we can expect the influence of the earth's rotation to be partially or wholly obscured. I started a year ago to take measurements of the height of the banks of the rivers, and the distance of these banks from the right and left side of the stream. In the course of the measurements I have visited, I think, all the chief streams of Canterbury, with the exception of the Selwyn and Hinds. When I say "visited them," I mean I have travelled up and down both their right and left banks from the mountains to the sea, taking a section of the river under observation about every four miles. The rivers and streams thus examined were the Ashley, Waimakariri, Rakaia, north and south branches of the Ashburton, the Rangitata, Orari, Opihi, Otaio, Makikihi, Waihao, and Waitaki. My outfit consisted of a bicycle, to get from place to place, with a tested cyclometer to determine the distances I had travelled up or down the river when taking each section; a pedometer, tested to record one mile for each 2,000 paces I walked, and which was very useful for determining the width of terraces; a chain tape measure and ball of string, to determine the height of the most important terraces; and, finally, a couple of levels to find out when, standing on one bank, I was at the same elevation as the top of the opposite bank of the stream. One of these levels was a small dumpy, and the other a small builder's level screwing into a stick, for the rougher observations. My method of work was to choose a road as near the banks of the river as possible, and every four miles or so make expeditions on foot to the river-bank; then, having found the first terrace, to walk to the stream, recording the heights of the escarpments and the breadths of the terraces as I went. This observation was supplemented at a later date by a corresponding observation on the other side of the river, at a point as nearly as possible opposite the first. Early in the course of the investigation I found that the conditions obtaining on the plains were not as favourable as I had imagined. The Rakaia and Rangitata do not flow down a perfectly even slope, but my observations on these rivers are included with the others. On the other hand, it will be noticed that no section of the Waimakariri is given, as it was evident that the two disturbing factors mentioned—namely, want of uniformity of texture of the plains and want of uniformity of slope—are particularly obtrusive in this case. For the first nine or ten miles of its course the river is continually held or deflected by the fan of the Kowhai and Rock Ford; by the abutments of Eagle Hill, which run down into the river; by the Gorge Hills, and by Brown's Rock. After a few more miles the river, which used to run through Prebbleton and down to the sandhills at Halswell, is entirely thrown out of its course by its own fan striking against the Port Hills, and its present bank is about nine miles from its old southernmost one. Owing to the magnitude of the disturbing factors, then, the Waimakariri was unsuitable for the purposes of the investigation.

The results of the investigation in the case of the other rivers will be best seen by examining the generalised section of each river shown on Plate X, *figs.* 1–6. These sections have been prepared in the following manner: The heights of all the escarpments on the left bank were added, and divided by the number of sections across the river: this gives the height of the left bank. The same thing was done with those on the right. Then the width of all the terraces from the first escarpment on the left bank to the river-bed were added, and divided by the number of sections taken, and this gives the breadth of the left bank, and a similar calculation that of the right bank. The average width of the bed was also taken, and the black spot in the bed shows the average position of the main body of water in the stream. It will be seen that the general result shows to a very marked degree that the left bank is much more abrupt than the right—that is, that the rivers have corroded that bank to which the influence of the earth's rotation tends to deflect them.

It may be pointed out that if the Waimakariri had been used in the investigation, it would have given very exaggerated results of the same nature as those shown by the other rivers, as in its lower course its first terrace on the right bank is about nine miles from the present bed of the stream.

The Rakaia is the only river observed that has higher banks on its right bank than on its left. Von Haast concludes—and is, I believe, generally supported by other geologists—that the Ashburton was at one time much the biggest of the three rivers now known as the Rangitata, Ashburton, and Rakaia—or, indeed, that these rivers were one, and emptied themselves in the position now occupied by the present Ashburton. This joint river deposited upon the plains a huge fan, whose front edge stretched southwards past the present Rangitata and northwards past the present Rakaia. This fan is still fairly evident, especially in the cliffs along the Ninety-mile Beach, which cliffs rise from 10 ft. at the mouth of the Rakaia to 60 ft. at the Ashburton, and fall away to 20 ft. or less at the Rangitata.

Standing on the right bank of the Rakaia with my level, it was only by looking backwards up the plain that I could find a point on the left bank as high as that on which I stood, for I was standing on the fan of the old Ashburton; and the same was true while standing on the left bank of the Rangitata. On the opposite side of the river, and in a direction at right angles to its flow, there was no land as high as that on which I stood, for here, too, I was on the old Ashburton fan, but on its southern edge. Now, the presence of the fan will easily account for the height of the right bank of the Rakaia, if we can find any reason why the river should have corroded this higher bank rather than run down beside this bank.

The Rakaia when it first became independent was running through its present gorge in a direction that would carry it well into Lake Ellesmere, along the line where the Ashburton fan overlay the general seaward slope of the plains. This would give the river a course from gorge to sea of about forty-five miles, while its present course from gorge to sea is thirty-eight miles, and the shortest possible course is thirty-five. Now, the shorter the course is, the greater is the fall per mile, the greater the velocity, and the greater—by the sixth power—the corrasion. Suppose the river formed a delta at its mouth: one arm would flow southward into the sea, and the other north; but the one flowing south would have a shorter distance to go for the same fall, would corrade more rapidly, and would become the master stream. Thus the continual tendency of the stream's mouth would be to move southward so as to reach the position in which it would have the least distance to go to pass through the fixed amount of fall from the gorge to the sea. I believe this conclusion is valid, and my belief is strengthened by Von Haast's reference to an apparently well-known law—namely, "that rivers that unite tend to do so by the shortest line." If this statement is a true one it should also apply to rivers that reach the sea: they endeavour to do so by the shortest line. At the same time, I must confess that in my working models of this system of fans and rivers the stream that represented the Rakaia corraded the fan and shifted its mouth southwards in a less marked degree than I had anticipated.

This consideration, if accurate, then, explains the only exception to the general truth—that the rivers flowing through the plains have eaten into their left bank more than their right bank. The Rangitata was in the same position as the Rakaia in regard to the Ashburton fan—namely, it ran down the side of it; so that we may neglect the presence of this fan altogether, for its influence on one bank of one river is counterbalanced by its influence on the other bank of the second. I have therefore prepared an average section of the larger rivers of Canterbury, including all but the Waimakariri (fig. 8). If it is considered that the fan of the Ashburton has too great an effect to be negligible on the courses of the Rangitata and Rakaia, we will reject those rivers, and take an average section of those remaining—viz., the Ashley, Opihi, Ashburton, and Waitaki (fig. 7). I have omitted the Waihao, Makikihi, and Otaio owing to their small size; but these streams show the same peculiarities in a very marked degree. In either case, it will be seen that the average left bank is steeper than the average right, and that the average position of the main stream is nearer the left bank. This renders it probable that the rotation of the earth has had a deflecting influence upon the courses of the rivers running through the Canterbury Plains.

Note 1.—Gilbert says he would not expect to see the influence of the terrestrial rotation marked in rivers that are flowing rapidly and corrading their beds vertically; but even in this case there must be certain curves in the course of the stream with differential corrasion on the opposite banks.

Note 2.—Some of the Canterbury rivers, notably the Ashley, flow almost due east, and in such cases the influences of the rotation must be much less marked. But again, the curves in the course of the river must occur, and even if the general course of the river is due east, in its curves it will flow more or less north or south, and so again present favourable conditions for the effect of the terrestrial rotation to make itself apparent.

EXPLANATION OF PLATE X.

In all cases the east side of the river appears on the right-hand side of the section, following the convention in map-drawing. The arrangement has the disadvantage, in southwards-flowing rivers, that the left bank is on the right-hand side of the observer. He should imagine himself looking up the stream.

Each ordinate represents 4 ft., the abscissæ 200 yds. The black dot in the bed of the stream represents the position of the main body of water.

Each ordinate in figs. 7 and 8 represents 10 ft., the abscissæ 200 yds.

Art. XXI.—*Notes on Protective Resemblance in New Zealand Moths.*

By Alfred Philpott.

[*Read before the Philosophical Institute of Canterbury, 1st November,* 1905.]

These notes have been put together with a view of forming a base for future work. There is, I am afraid, but little that is new in them, but I have preferred to risk repetition in order to give them some measure of completeness.

By far the greater number of our native moths are protectively coloured; one can easily gauge from this fact the severity of their struggle for existence. Many of our birds live entirely or in part on insect food. The fantails (*Rhipidura*) and