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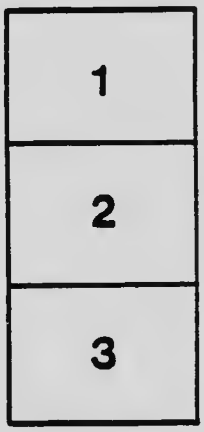
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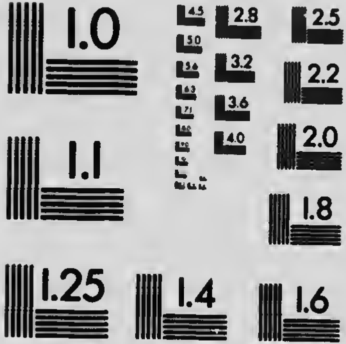

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THE TIDES OF HUDSON BAY

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THE TIDES OF HUDSON BAY*

By W. Bell Dawson

THE chief interest attaching to the tides in this region is the successful outcome of the endeavor to discover tides of similar types in older harbors for which tide tables are calculated. This correlation has enabled immediate results to be obtained; instead of adopting the lengthy and expensive plan of establishing tidal stations in these remote regions, to obtain a tidal record during a year or more as a basis for calculation. The proceedure adopted thus affords an example of the successful application of the method advocated by the writer, of classifying tides according to their various types, for purposes of reduction and calculation. (See this Journal, July-August, 1907.)

The tides in this region are chiefly important because the great range in Hudson strait gives rise to strong tidal streams; and the shallow water around the shores of Hudson bay make the rise of the tide of consequence in entering the harbors.

OBSERVATIONS AVAILABLE

The earliest observations obtained were during the Gordon expeditions in 1884 to 1886. Observers were landed on the desolate shores of Hudson strait with instructions to observe the tides, the drift of the ice, and the weather. Those stationed along the strait during the first year were H. M. Burwell, W. A. Ashe, R. F. Stupart, C. V. DeBoucherville and A. N. Laperrière. The coasts were so unknown that their names were given to the localities; as Port Burwell, Ashe inlet, Stupart bay, etc. These pioneers are thus commemorated. They were relieved in the following year by G. R. Shaw, J. W. Tyrrell, F. F. Payne, J.

*Delivered as a lecture to the Ottawa Centre of the Royal Astronomical Society of Canada, 27 November, 1913.

M. Mackenzie and P. Woodworth, who occupied the same series of localities throughout the length of the strait.

The work was strenuous, mostly done in the dark, with lanterns to read the tide scales. With few exceptions, the observations were taken during twelve hours in the twenty-four; sometimes in the day and sometimes in the night hours. They are thus broken and difficult to reduce. When the whole series was plotted out as tide curves, it was found that Ashe inlet at the centre of the strait, was the most complete and satisfactory station; and it is also at the best situation in the strait, for tidal purposes, that could be chosen.

In Hudson strait the range sometimes exceeds 30 feet; but on entering the bay the tide spreads out and the range is much less. Observations have been obtained in recent years at Churchill, Nelson, and Moose Factory in James' bay. They were taken by readings on tide scales in the summer seasons of 1910 to 1913; as there are no wharves yet, except at two points in James' bay, where registering tide gauges have now been used in the summer.

When the whole of this material was looked into, it was found that the earlier observations, though taken with so much pains and expense, had never been adequately worked up. It was evident, that with so much material, good results might be obtained and data for the calculation of tide tables secured, if any other harbors could be found where the tide is similar in type to these. It might thus be possible to calculate tide tables for these new localities by means of a difference in time from such harbors, wherever they might be situated. Before describing the lines on which this research was carried out, we must first explain clearly the meaning of the *type* of the tide, as well as the special characteristics of the tide in these regions. For, in correlating tides, it is not those that happen to have the same range that can best be compared; as the type of the tide counts for much more than this.

REDUCTION OF TIDAL OBSERVATIONS

The modern method of dealing with the tide is known as the

Harmonic Analysis, due chiefly to Lord Kelvin and Sir George Darwin. The name "harmonic" shows that it is in a general way similar to music; and to follow out this comparison may be the most intelligible way to understand the matter. We know that musical notes are represented by very fine waved lines; and any given tone is a perfectly regular series of similar undulations. If we examine a phonograph record, or even a gramophone, we will see that the piece of music is represented by a very complicated wavy line, yet the special point to note at present is that after all it is a single continuous line. A whole orchestra is thus reduced to a zig-zag line which is made up of the individual tones of all the instruments; the simple undulations from the vibrations of each being all combined into one exceedingly complicated result. The larger variations on this resulting line correspond with the rhythm or beat of the music.

Now, when we turn to the tide, we have the reverse problem to solve. We have the final or resulting line before us, and the problem is to find out all the individual instruments that have contributed in making it up. This resulting line, as a tide curve shows, has a much wider and more uniform sweep than a phonograph record; but none the less, it has proved in just the same way to be made up of a whole series of individual tones which produce the result. Its majestic curve is more like some old Gregorian chant; but the time is slow in this music, and our ears are dull of hearing, and we do not catch the grand cadences.

In this great orchestra, it is the sun and the moon that take all the parts. We may say that the sun takes the bass and tenor, and moon the soprano and alto. The total number of instruments or primary tones in the orchestra amounts to twenty-eight. Some of these individual tones produce undulations as rapid as 6 or 8 to the day; others are so slow as to have a period of half a month, a whole month, or even a year in length.

It is thus no flight of fancy to compare these tide curves to music; very slow music if you will, but really the same in character. For every movement of the moon and the sun, is exactly reflected in the tide ; every variation in their distance or position has its effect. The tides in their physical way, are thus the most heavenly thing on the earth. So, Nature holds up to us the standard of perfection ; for if our thoughts and actions reflected heavenly influences with the perfect accuracy of the tides, the will of God would be done on earth as it is done in heaven.

We cannot take space here to follow out t... ideas into greater detail ; but instead of attempting to de... the individual instruments, we must be content for our purpose at present to make a broad distinction between the various types of the tide ; just as we may distinguish the opera and the national anthem, the oratorio and dance music.

TYPES OF THE TIDE

There are then three leading types of tide, in correspondence with the influence of the three movements of the moon which have the greatest effect. These may be thus summarized, with less avoidance of technical language than used in the lecture. (1) The synodic month of the moon's phases, which is the most generally recognized. (2) The anomalistic month of the moon's distance, from perigee to p...ee. (3) The month of the change in declination of the moon, ...rth and south of the equator ; its average length being the same as the tropical month. In the case of the sun, the change in its meridian altitude, due to declination, from s...mer to winter, is very evident ; but it is not so ge...rally recognized that the moon does exactly the same thing in the course of each declination-month. When the moon is in high north or south declination, its attraction is oblique to the plane of the earth's equator ; and this gives rise to diurnal inequality in the tide. Each of the "months" above mentioned, has its own special period ; so that they necessarily over-run each other. It is thus possible for perigee to fall at the springs, and a few months later, at the neaps ; or for the springs to be most affected by diurnal inequality at one date, and the neaps at another.

The most important fact to note is that these various movements of the moon have a very different effect upon the tide in different regions. As a rule, in any particular region some one of these movements has so preponderating an effect that the influence of the others is obscured. Or, it may be that two of them have a nearly equal effect and the influence of the third is difficult to detect.

In the North Atlantic and notably on the coasts of Europe, the most marked feature of the tide is the variation from springs to neaps in the synodic month. This probably accounts for the explantion of this feature exclusively, in the physical atlas and the school geography. But to assume that this is the leading characteristic of the tide everywhere in the world and that all other influences may practically be ignored, is a mistake which has probably placed the chief obstacle in the way of a correct understanding of the tides generally.

An example of the dominance of the anomalistic month is given by the Bay of Fundy ; where the variation in the range of the tide from perigee to apogee is distinctly greater than the variation from springs to neaps, with the moon's phases.

The large development of diurnal inequality during the course of the declination-month is illustrated by Northumberland strait, where the difference in range between the two tides of the day is at times half as much again as the true difference between springs and neaps. The tide on the Pacific coast of Canada, and notably in the Strait of Georgia, is also of the declination type. The diurnal inequality is there so developed that it obscures every other feature in the tide ; and the springs and neaps can only be detected by a careful analysis.

In regions where declination is thus the dominant element, the change in the declination of the sun during the year may have a greater effect than any other of the moon's own motions. There is consequently a marked annual variation ; and the extreme tides of the year, due to inequality, necessarily occur at the moon's maximum declination which is nearest to the date of the solstice, in summer and in winter.

A fourth type of the tide, due to local influence and not astronomical, is the estuary type; which has a rapid rise and a slow fall. This may become so accentuated as to break and form a Bore.

The enquiry why it should be that in different regions the tide is thus more influenced by one element in the moon's motion than another, is a question to which we can give no satisfactory reply. But the classification of the tides of the world into their various types on the lines here indicated, would probably offer the best hope of a correct understanding of the matter; whereas any stereotyped method of springs and neaps exclusively, will tend to let it remain in obscurity. Meanwhile, the fact itself is a warning not to theorize too far, regarding the features that the tide ought to present in any new locality; but rather to investigate its actual characteristics, for purposes of correlation.

TIDES OF HUDSON BAY

In Hudson bay the tide is of two distinct types, one being an open-water type, as found at Churchill where the duration of the rise is longer than the fall, an unusual feature; and the other an estuary tide of an extreme kind, as exemplified at Nelson. This contrast in characteristics is quite similar in James' bay; and the tides at Churchill and Nelson are thus probably typical of the whole region. Their leading features are as follows:—

Churchill — Range at springs 13¼, at neaps 7¾ feet.
Duration of Rise $6^h\ 25^m$; Fall $6^h\ 00^m$.

Nelson — Range at springs 14½, at neaps 11 feet.
Duration of Rise $4^h\ 20^m$; Fall $8^h\ 05^m$.

When the endeavor was made to find tidal stations which would serve as ports of reference for these harbors, it appeared possible that the tides of Hudson bay would prove similar to those of the North sea. The main tide, running up the Atlantic, branches to the east and west in entering these two water areas, where the land configuration is not unlike. If this conjecture were correct, the tide at Nelson should be similar to the extreme angle of the North sea, between Germany and Denmark. The endeavor was therefore made to find an estuary tide there of the same type. Bremerhaven in the mouth of the Weser was selected as very similar, and although numerous comparisons were made with other places in the North sea, this original choice proved to be a correct one. The difference of time between Bremerhaven and Nelson is remarkably constant, more especially for high water ; as the variation in the difference is actually less than between two estuaries in the Gulf of St. Lawrence, or from one end of Northumberland strait to the other.

By following this clue with regard to the similarity of Hudson bay and the North sea, an investigation on similar lines showed that Harwich is the best port of reference for Churchill. Most of the harbors on the eastern coast of Britain are in estuaries ; but Harwich affords a suitable open-water type, and it shows the same unusual feature as at Churchill, in that the rise is slower than the fall. The result in this case is equally satisfactory ; as the difference in time between Harwich and Churchill, for both high water and low water, is remarkably constant.

The success of this method is valuable in avoiding the necessity for the establishment of permanent tidal stations at these harbors. To obtain definite data for the calculation of tide tables for Nelson, the time of the tide as observed at Bremerhaven was obtained from Germany, to make a simultaneous comparison. A value was thus obtained by which high water is calculated by means of a direct difference ; but as for most European ports the time of low water is not published, it was found best to compute this from the duration of the fall of the tide. This duration varies throughout the course of the synodic month, but the law of variation was ascertained. The calculation of the height of the tide was a matter of much greater difficulty ; because the observations available were for short periods, which happened to be of the same type from an astronomical standpoint, as the effect of the moon's distance was always superposed similarly on the springs and neaps. By a method of successive approximations however, a satisfactory solution was reached, by which the height of high water can be calculated in terms of two series of variables. One of these is in the period of the synodic month, and the other affords a plus and minus correction in the period of the anomalistic month. The problem of tide tables for Nelson which will be reasonably accurate, may thus be considered as solved; although further observations are desirable to improve the accuracy of the values used in the calculations. Tables giving the time of the tide have already been published for the season of 1914.

TIDES OF HUDSON STRAIT

In this strait the tide has an unusually large range, the average at Ashe inlet, in the central part of the strait, being 30½ feet at the springs and 15¼ feet at the neaps. The duration of the rise and fall is almost equal, and there is very little diurnal inequality; but the semi-monthly variation with the moon's distance, is extremely large. The spring range is twice the neap range, as above indicated; and the variation in the anomalistic month from perigee to apogee may occasion a difference of almost *seven feet* in the range of successive spring tides.

With these variations and tide curves for only half the day, their completion by interpolation was too uncertain to be attempted, as a basis for harmonic analysis. But for comparison with any reference station, the broken character of the record was relatively unimportant.

Among the ports selected for comparison, as most similar in their characteristics and nearest in range, those found to be best were Liverpool, Port Talbot in the Bristol Channel, and St. John, N.B., in the Bay of Fundy. The outstanding variation in the difference of time between Ashe inlet and these harbors, was chiefly in the period of the anomalistic month. St. John was chosen as the most suitable of these three; as the range is nine-tenths as much as Ashe inlet, and the anomalistic variation is the same, absolutely, which makes it slightly greater in proportion. The comparative features at the two places are shown in the following table:—

Description		St. John, N.B. Bay of Fundy		Ashe Inlet, Hudson Strait	
		Range in feet.	Difference.	Range in feet.	Difference.
At Perigee.	Range at Spring tides......	27·10	6·75	33·90	6·85
At Apogee.	Range at Spring tides......	20·35		27·05	
SPRING RANGE.	Mean of the above....	23·72	6·29	30·48	15·18
NEAP RANGE.	At Moon's mean distance.	17·43		15·30	

To obtain the best comparison possible, tide tables for St. John were re-calculated for the back years 1884, 1885 and 1886. Such calculation for the past can be made as readily as for a future year, by means of the tidal constants deduced from the harmonic analysis. For St. John, these constants are now derived from 15 complete years of observation, which gives a high accuracy to the tide tables so calculated. The differences of time between Ashe inlet and St. John which result, are very constant and thus afford satisfactory values for computing the tide in Hudson strait. In this case, it is the time which is of chief importance, in order to bring the turn of the tidal streams into relation with the tide; as it is not likely that harbors will develop in this strait for which the height of the tide will be required.

The progress of the tide throughout the length of Hudson strait, from Port Burwell to Laperrière, can be determined by a comparison of the successive localities in the strait. The observations are not always simultaneous, but the final reduction will afford a series of tidal differences with Ashe inlet as the port of reference for the strait.

We may note in conclusion that tidal work in Canada has now reached an advanced position. The best port of reference on the Atlantic coast of the United States is Sandy Hook, at the entrance to New York, where eight years of tidal observations have been secured. At five of our harbors in Eastern Canada we have a basis of nine to fifteen years of observation. This may be taken as representing the relative accuracy of the tide tables for the two countries. Much the same may be said of the Pacific coast, where three of our harbors are now superior to

San Francisco, which is the best on that coast of the United States for which tide tables are published. With the exception of Great Britain and Europe, the only country which has a better basis for tide tables is India. A beginning is being made in Australia and New Zealand, where much the same lines are being followed as those which we adopted in Canada twenty years ago. In the investigation of the currents, which is the other branch of the work of the Tidal Survey, very full information is now available on the routes of all the leading steamship lines in Eastern Canada, as well as for the navigable passes on the Pacific coast.

TIDAL SURVEY, OTTAWA,
March 25, 1914.