

XXX. *Report of further Observations upon the Tidal Streams of the North Sea and English Channel, with Remarks upon the Laws by which those Streams appear to be governed. By Captain F. W. BEECHEY, R.N., F.R.S. Communicated to Sir FRANCIS BEAUFORT, K.C.B., Hydrographer, and presented to the Royal Society by G. B. AIRY, Esq., F.R.S., and Astronomer Royal, &c.*

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SIR,

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IN pursuance of directions from the Lords Commissioners of the Admiralty that I should make further inquiry into the phenomena of the tidal streams of the Channel, I commenced a systematic investigation of the whole feature of tidal-streams throughout the strait which separates England from the Continent, and I have now the satisfaction to lay before you for their Lordships' information the result of these labours.

In order to prosecute this inquiry with as much advantage and as little delay as possible, I have combined with the information furnished by the vessel appropriated to this service as many observations from various authentic sources as were recommended by the known reputation of their authors.

These consisted of various observations upon the streams of the English Channel and the North Sea by Captain MARTIN WHITE, R.N., Captain WASHINGTON, R.N., Captain HEWITT, R.N., and Captain BULLOCK, R.N. Also by Monsieur MONNIER, M. BEAUTEEMS BEAUPRES, and by the Engineers Hydrographiques, published in the 'Pilote Française.' To these have been added some by Mr. GRÈME SPENCE about the Scilly Islands, and a few by Captain ANDERSON, as given in the Philosophical Transactions; numerous observations along the shore by the Coast Guard, and a series of observations kept on board the light-vessels by order of the Trinity Board, which are particularly valuable as being made simultaneously, and, like those of Captain WASHINGTON, continued throughout several days at each station. Authorities consulted.

The method pursued in making the observations, was to anchor the vessel at each of the stations* for twelve hours and upwards, and to observe the direction of the tide, ebb and flood, every half-hour. The rate of the stream, in addition to the usual method by the common log, was detected by current logs, constructed for the purpose by Mr. MASSEY, and which registered feet; and that it might be ascertained whether the stream was confined to the surface or extended to the depth of a vessel's hull Method pursued in making the observations.

* See Chart of the Stations, Plate XXXII.

in the water, another of these logs was occasionally sunk 12 feet, and registered simultaneously with the one which was 2 feet beneath the surface.

Method of
making the
observations.

The time of slack water, as well as the times of the cessation and commencement of the stream, were noted, as closely as such observations are capable of being made; and to render the times more certain, I have taken the mean interval between the time of the cessation of one stream and the time of the commencement of the next. The times of high water at Dover have been taken from the Admiralty Tide Tables, which were tested by observations made at Dover during some portion of the observations in the Channel, and the agreement being found sufficiently near to render a special register unnecessary, it was discontinued.

All the times of observation being referred to the *meridian of Dover*, and compared with corresponding times of high and low water at that place, tables of differences were obtained which gave *the interval between the time of slack water at each station, and the time of high water on the shore at Dover*, and also the direction and rate of the stream at each hour of the tide before and after the same standard. By this method of comparison observations made at various periods, and even in different years, were brought as nearly as possible to a simultaneous record.

To exhibit these results tables were drawn out, and twelve charts were constructed, showing the position of the stations and the direction of the stream at each hour of the tide at those places respectively, in order that the eye might at once detect the movement of the stream throughout both channels at any instant of time*.

In these charts the direction of the stream is indicated by arrows, which are connected by curved lines empirically drawn through them; these lines are continuous when the water is flowing towards Dover, and broken when running in the reverse direction. Lastly, all those tides which have a rotatory motion are indicated by spirals barbed in the direction in which they revolve.

Results.

All the observations having been subjected to this arrangement, some highly important results were obtained. Instead of these channels having, as has been hitherto supposed, a stream which turns progressively later as the tide advances up the strait, these observations have shown that the progressive changes of stream cease at a certain point near the mouth of the Channel, and that beyond that spot there is a tide peculiar to the Channel, and quite distinct from that of the seas on either side of it; so that there may be said to be two distinct streams on each side of the Strait of Dover,—the stream of the Ocean or outer stream, and the stream of the Channel, or that which is contained between the oceanic stream and the Strait of Dover. These streams are always running in contrary directions, and in the North Sea meet between the Texel and the estuary of Lynn; and in the English Channel between the Start and the Gulf of St. Malo.

Oceanic and
Channel
streams.

Mixed tides.

In the localities where these streams meet, the tide is ever varying its direction according as the strength of one stream prevails over that of the other; giving to the

* Eight of these charts only have been published.

water a rotatory motion, and scarcely admitting of any interval of slack water; whilst in the space between these rotatory tides and the point of meeting of the tides in the Strait of Dover, the stream is free from all rotatory motion, and sets steadily throughout the tide in a direction *towards* Dover, while the water is *rising there* and *away* from it while it is *falling* at that place.

Rotatory
streams.
True Channel
stream.

I have designated the last-mentioned the "*true channel stream*," and its extent is, as nearly as it can be measured, 180 miles in either direction from the point of union of the tides in the Strait of Dover to the region of rotatory tides off Lynn, and off the Start and St. Malo.

Extent of the
Channel
stream.

As the true Channel streams are always running in opposite courses, there is necessarily a point where they meet and separate; and this occurs in the Strait of Dover. But *in this strait*, the stream, although it first obeys one tide and then the other, does not slack with the Channel streams, but is found to be still running at high and low water on the shore, at which times those streams are at rest, so that the Strait of Dover never has slack water throughout its whole extent at any time. I have in consequence called this an *intermediate* tide.

Meet in the
Strait of
Dover.

Intermediate
tide.

The limits of neither of these streams appear to be stationary, but *range to and fro* as the tide rises and falls at Dover, travelling to the *eastward* on *both* tides, and at high and low water suddenly shifting sixty miles to the westward to recommence their easterly courses with the next tide; and although so far apart, they possess the remarkable peculiarity of shifting together; so that the Channel streams preserve, as nearly as possible, the same relative dimensions.

Place of
meeting of
the tides
changes with
advance of
the tide.

In the Strait of Dover this line of meeting and of separation oscillates between Beachy Head and the North Foreland, a distance of about sixty miles. When the water on the shore at Dover begins *to fall*, a *separation* of the Channel streams begins off Beachy Head. As the fall continues, this line creeps *to the eastward*. At two hours after high water it has reached Hastings; at three hours Rye; and thus it travels on until at low water, by the shore, it has arrived nearly at the North Foreland on one side of the strait, and at Dunkirk on the other. At this time the *Channel streams* on both sides slack, but in that portion which I call *the intermediate stream* in the Strait of Dover the water is still running to the westward; and when the new *Channel streams* make as the water rises on the shore, this *intermediate* portion is found to unite with, or to oppose one or the other of these streams, according as it was before the reverse; so that, as before mentioned, the line of meeting at low water appears off Beachy Head to recommence its easterly course. This *intermediate stream* forms a remarkable feature in the tidal system of the Channel; it is well established, as the line of meeting and of separation occupies a very limited space, and it seems to be entirely due to the contracted form of the Channel in this immediate locality, preventing the free escape of the water.

Peculiarity
of the stream
in Dover
Strait.

Captain BULLOCK, in order to test the point of separation, anchored two vessels a mile apart between Beachy Head and Dungeness, and found both vessels at the same

moment to ride with their heads in opposite directions, in obedience to the streams which were then running opposite ways.

Channel stream.

Stream slacks at nearly the same time throughout.

The *Channel stream*, which I have described as running between the intermediate stream and the rotatory or mixed streams at the outer extremities of the Channel, pursues a steady course along the main trunk of the strait, slacking only towards high and low water at Dover, when it is preparing to invert its course; and contrary to the generally received opinion of a *progressive slack water* in a strait having a *progressive establishment*, this stream has the peculiarity of slacking throughout its whole extent at *nearly the same time*, and this time, as was anticipated in my former paper, corresponds nearly with the time of high and low water on the shore at Dover, the site of the combined wave and of the *virtual head of the tide*.

Such is a general description of the phenomena of the streams of the English Channel and the North Sea; and I shall now endeavour to describe more in detail the several peculiarities of these features, and to remove various erroneous impressions which at present exist as to the rotatory motion of our tides, the direction in which the streams turn, and also as to the time of the stream attaining its maximum rate, &c., and then to lay before you such data as it appears to me will help to explain the cause of the tidal streams of these channels differing from those peculiar to ordinary tide-waves.

Simultaneous turn of the stream.

As the simultaneous turn of the stream is a point of considerable interest, I may be permitted to dwell a few minutes upon the data from which it has been derived. But I wish it to be clearly understood, that minute accuracy on such a point is scarcely possible, and could only be obtained by a long series of simultaneous observations at the extremities of the tide-wave; for the period of slack water is almost always spread over an interval of half an hour, and not unfrequently at the neaps, of an hour and upwards; and moreover winds are found to prolong the stream in the Channel according to the direction in which they blow. In estimating the time of slack water therefore from the observations, we must not expect a very close agreement*.

Time of high water at Dover, and the time of the turn of the stream compared.

It will be seen, on a very cursory inspection of the Charts which accompany this paper, that for a period of six hours after high water at Dover, and for five hours before that time, the stream maintains a steady direction from and towards Dover, so that any delay which may exist between the change of the stream and the time of high water is shown by these charts alone to be confined within very narrow limits, but a still closer agreement will be found on referring to the observations themselves*; especially if we take those which were made on board the light-vessels at a distance from the shore, which are particularly valuable from the circumstance of their being spread over intervals of several days at each station.

* The times of observed slack water at the stations marked in the Plans, as compared with the times of corresponding high waters at Dover, as shown by the tide tables, together with all other particulars relating to these observations, will be found entered in a book which accompanies this report, since deposited at the Hydrographic Office of the Admiralty.

Referring then to these observations, and taking them in the order in which the light-vessels are placed with respect to the progress of the tide-wave, we shall have the intervals between the turn of the stream at those places, and the time of high water at Dover (the standard), as follows:—

At the Newarp L.V., the stream is slack twenty-two minutes before Dover.

At the Cockle L.V., the stream is slack at the same time as Dover.

At the Stanford L.V., the stream is slack nine minutes before Dover.

At two stations nearer Dover, the stream is slack twenty-four minutes after.

At the Shipwash L.V., the stream is slack twenty-four minutes after.

At the Galloper L.V., the stream is slack the same time as Dover.

At the Kentish Knock L.V., the stream is slack nine minutes after Dover.

Lastly, off the North Foreland, the stream is slack the same time as Dover.

Between these stations and the meridian of $3^{\circ} 0' E.$ we find the following intervals.

In the parallel of Cromer, twenty-four minutes before Dover; at the next station, southward, twenty-four minutes after; at the next, four minutes after; then, thirty-six minutes after; at the next, nineteen minutes after; at the next, three minutes after; and lastly, off the North Foreland, the same time as Dover.

In the first set of comparisons the differences are not greater than might be attributed to the ordinary irregularity of the tides; in the second we discover a progressive increase, and then the phase of the stream seems to be inverted, until at the end of the series we find the interval vanish, and the stream to turn with the high water on the shore.

To the eastward of 3° of longitude, the times of slack water get considerably later in that part of the Channel which lies between the northern limit of the Thames and the Texel, and the phase of the stream in all this portion of the North Sea appears to be inverted; the intervals also to get *longer* as the Dutch coast is approached. The occurrence of this *inversion of the phase of the stream with the inversion of the phase of the establishments on the coast of Holland, and its position occupying the site of the node of the tide in Professor WHEWELL'S chart of cotidal lines*, is a coincidence which ought not to be overlooked, although I am not able to discover any connection between the phenomenon, which is evidently the cause of the unusual retardation of the stream above-mentioned, and the phenomena of the cotidal chart.

There seems to be very little doubt that the retardation of the stream, and the consequent inversion of phase now noticed in all this part of the Channel, is entirely owing to *the outer stream setting round the Texel*, at a time when the stream is slack in all other parts of the Channel and preparing to go round*.

An inspection of the Plan for one hour after high water will clearly show this to be the case; it will there be seen that the stream of the Channel is making an effort

* See Chart one hour after high water, Plate XXXIII.

to run to the northward, and on the western side of the Channel has succeeded, the North Sea (or outer) stream being in that part favourable to it; but on the *eastern* side of the Channel, the stream coming round the Texel forces its way up the Channel, and creates a temporary disturbance, which is no doubt the cause of the retardation of the turn of the stream in this vicinity.

The two consecutive charts strengthen this supposition, by exhibiting the Texel stream receding as the Channel stream gains strength.

Comparison
of time of
slack water
in the North
Sea with the
time of high
water at
Dover.

If, then, we except such observations as are shown to be due to the disturbance from the Texel tide, we shall find that *in the whole extent of channel from Cromer to the North Foreland, there is not half an hour of retardation in the time of slack water from the time of high water at Dover, while in the establishments there is an increase of at least five hours.* That we may appreciate this very small difference of the time of slack water throughout the Channel and the time of high water at Dover, let us inquire what takes place in parts of the North Sea, which exhibit the ordinary phenomena of tides under the influence of a progressive wave, such for instance, as are comprised in the space between Kinnaird's Head and the estuary of Lynn. There is in this space an increase of tidal establishment of five hours, an amount about equal to that which exists between Lynn and Dover. By the Admiralty Tide Tables, it will be seen that in this space there are nearly five hours' retardation in the time of slack water in the offing, making at least, *hour for hour in the change of the stream with the change of establishment*; whilst in the North Sea, in the same change of establishment, there is scarcely *half an hour difference of time in the change of stream.*

Comparison
of time of
slack water
in the En-
glish Chan-
nel with high
water at
Dover.

If now we take the English Channel, we shall find half-way between the Start and Alderney, that the stream *turns with the high water at Dover.* Off Portland, *nine minutes before*; off St. Albans, *three minutes before*; between the Isle of Wight and Cape Barfleur, *fifteen minutes after*; and so we run on, the differences varying from *eight minutes one way to an extreme of forty-two minutes the other**. In the Baie de la Seine, the turn of the stream is earlier in the western part than towards its eastern extremity, but the formation of the coast about Cape Barfleur will fully account for this.

In the eastern part of the Baie de la Seine a retardation occurs towards the Somme; in that direction the turn of the stream, on the south side of the Channel, *is an hour later than* on the north side opposite; the observations, however, upon that coast are not given in a manner sufficiently clear, and they were made many years ago, and compared with the establishments of ports, which might not at that time have been very accurately determined; therefore I would not dwell much upon them*.

Upon the whole, therefore, judging from the observations which have been collected, there seems to be sufficient evidence to warrant the conclusion, that, with the excep-

* The vessel now about to sail to continue this inquiry, will, it is hoped, get some observations in this quarter.—November 5. Recent observations have shown these intervals to be in excess.

tions arising from extraneous causes, which are now known, and for which an allowance can be made, the streams of the Channel turn sufficiently near to the times of high water on the shore of Dover to be considered as simultaneous, without occasioning any error that can be of the smallest consequence to shipping*.

I shall now pass to the next point of interest,—the supposed rotatory motion of the stream in the English Channel and the North Sea. It will be seen by the Charts, that wherever any circular motion of the water appears, it occurs between the outer extremities of the Channel tide and the stream of the oceanic or parent wave; and is clearly to be accounted for by the streams acting obliquely upon each other.

Captain MARTIN WHITE and Mr. GRÆME SPENCE, who have written upon the tides of the English Channel, were of opinion that this rotatory motion was not only applicable to the whole of the Channel, but common to the tides of all the world. Captain WHITE, in his remarks upon currents, &c., observes, at p. 35, “Tides are governed by a regular periodical reciprocation in most parts of the world, making the round of the compass almost everywhere during the twelve hours. This rotatory motion,” he continues, “is perfectly symmetrical during and after a series of moderate weather, and the curves it assumes resemble the form of *spiral curves*.” It was Mr. GRÆME SPENCE, however, who originated this idea of a revolving tide†. It is a singular circumstance that the observations of these officers should not have extended to parts of the Channel where the stream runs true, but have been confined to the mixed tide. Mr. GRÆME SPENCE obtained his observations in the vicinity of the Scilly Islands, where the streams of the Atlantic and of the English Channel unite; Captain WHITE’s observations extended further up the Channel, but still not far enough to be clear of the effect of the Gulf of St. Malo. M. MONNIER‡, who has often been quoted as the well-known author of a pamphlet on the tides of the English Channel, derived opinions similar to those above-mentioned, from observations made about the Channel Islands also; and was confirmed in his opinions by some observations made about the same time by Captain HEWITT in the North Sea, near the Lemon and Ower sands, which, curiously enough, are on the border of the mixed tide of the

On the rotatory motion of the stream.

Erroneous ideas respecting this motion.

Cause of this erroneous opinion accounted for.

* In my paper upon the tidal phenomena of the Irish Sea, I particularly referred to the nearly simultaneous turn of the stream in that channel which is also under the influence of a combined wave. Since that time observations have been made at the Smalls Lighthouse, at the Kunibeg and at other light-ships; all of which have confirmed in a very satisfactory manner those remarks.

At the Smalls, for instance, situated at the entrance of the Irish Channel, and differing from Liverpool nearly five hours in its establishment, the time of slack water occurs *fourteen minutes* only before high water at Liverpool; at the Kunibeg, *twenty-one minutes before*; then the mean of the intervals in the first page of observations, between Smalls and Bardsey, gives *four minutes after Liverpool*; the mean of the next page of observations thence to Holyhead, *thirteen minutes after*; going northward, the mean of the next page, *twelve minutes after*; off the Isle of Man, *at the same time*; and in the North Channel, *twenty-four minutes after*.

So that throughout the Irish Sea, as in the Channel which separates England from the Continent, the stream slacks throughout at nearly the same time as the combined wave is matured; or as the time of high water at *the virtual head of the tide*, as already stated in my first report.

† See his observations on the tides of the Scilly Islands.

‡ Mémoire sur les Courants de la Manche.

On the rotatory motion of the stream.

North Sea, as those of Mons. MONNIER were on the border of the mixed tide of the other sea. These authors have been followed by other talented men, until a common opinion was gaining ground that streams in general had a rotatory motion.

Had the observers above-mentioned made their observations anywhere between the Start and Beachy Head, or between Cromer and the North Foreland, a different result would have been obtained; for in all this space, occupying nearly 360 miles in extent, the stream runs steadily throughout both tides, scarcely changing its direction for four hours and upwards, and then only preparatory to going round to the new coming tide.

Explanation of Plan 1, Plate XL.

Upon Plan 1, Plate XL. I have given examples of the streams in question. The upper figures represent the revolving tides, exactly in the order in which the observations were made, on a direct line between the Texel and Cromer. The circular arrows show the direction in which the stream revolves, and the figures against the arrows the times before and after high water in which the streams run in those directions. The second line of revolving tides was observed in the mixed tides off the Start, and is similar to those off the Texel. The lower lines are samples of the steadiness of the stream which prevails throughout the ordinary tides of the Channel; the stations are given exactly as they occurred on a parallel of $52^{\circ} 15' N.$, which nearly intersects the position Professor WHEWELL has assigned to the node of the North Sea tide, and as they were observed in the English Channel between Portland and Beachy Head.

It was in the upper or revolving streams that the late Captain HEWITT's observations were made, and in the second row, or similar tides, that M. MONNIER and Captain WHITE made their observations; and there can no longer be any doubt that the rotatory tides are the exceptions to the general courses of the stream, and not the rule.

On the time when the stream attains its maximum rate.

The time at which the stream attains its maximum rate in the Channel is another point of interest and of importance to the seaman. In the 'Pilote Française' we find numerous observations carefully drawn out, and all giving nearly the same result, which is to place the strongest part of the stream at high and low water, and the slack water at half-tide. In 'Mémoire sur les Courants de la Manche,' before referred to, we read at p. 15, "On conclura de ce qui vient d'être dit que l'heure de la haute mer doit coïncider avec celle où le courant de flot acquiert sa plus grande vitesse. . . . On concevra de la même manière que le courant de jusant doit atteindre sa plus grande vitesse au moment de la basse mer. . . .:" and in a work of high authority published in this country, it is stated, doubtless from the authorities before-mentioned, that "in mid channel the motion of the water will be flowing most rapidly up the Channel at the time of high water, and its motion upwards will cease when the water has dropped to its mean height."

This idea of M. MONNIER, viz. of the strongest part of the stream occurring at high water on the shore, is part of the same error which the author before quoted had

fallen into respecting the turn of the stream in the Channel, viz. that of comparing the observations with a false standard. Taking the same observations and comparing them with the high water at Dover, the times in question all give the half-tide as the period at which the stream attains its greatest strength; and by referring to another table, in which our own observations are compared, a precisely similar result is obtained. The question is a very simple one, and rests entirely upon the truth of the observations, a specimen of which I have given in the subjoined Table for the purpose of consultation.

The time at which the stream attains its maximum rate.

Table showing the time at which the stream attains its greatest strength, and also its rate per hour at that time.

English Channel.						North Sea.					
No. of station.	Time from high water, Dover.	Rate of stream.	No. of station.	Time from high water, Dover.	Rate of stream.	No. of station.	Time from high water, Dover.	Rate of stream.	No. of station.	Time from high water, Dover.	Rate of stream.
	h m	Knots.		h m	Knots.		h m	Knots.		h m	Knots.
12	3 15	1 81	G	2 50	5 00	3	4 40	1 18	41	2 30	2 35
13	2 30	2 27	H H	2 34	2 30	4	3 00	2 07	42	2 10	2 35
	3 30						3 00			2 30	
14	2 15	2 05	E E	2 00	2 00	6	2 45	2 53	43	3 00	2 45
	2 00						2 15			2 30	2 70
15	3 15 E.	3 80	D	3 00	2 00	8	3 00 E.	2 84	44	2 30	2 90
16	3 15	3 14		2 40	3 70	10	3 00	2 25		3 15	2 40
	3 00		2 45	4 50	3 60	12	3 30	1 65	45	3 00	2 60
17	2 30	3 30	O	3 50	3 2	13	3 30	1 60	46	3 00	2 21
	3 00	2 75		3 00	3 0		3 30	3 00		1 85	
18	2 15	2 20	48	3 40	3 0	14	4 00	1 37	100	2 00	2 00
	3 00	1 60		3 00	3 15		3 00	2 35		2 60	
19	2 45	2 75	79	3 00	2 90	15	2 45	1 54	101	3 00	2 60
	3 00	2 00		3 00	3 4		3 30	2 45		2 00	
20	2 30	2 25	47	2 15	3 2	17	3 45	2 91	102	2 45	2 00
	3 30	1 80		2 10	3 6		2 45 E.	3 00		1 60	
AA	3 20 E.	1 30	46	3 30	3 3	18	3 30	2 44	102A.	1 45	1 85
A	3 20	1 20		2 10	3 3		3 30	3 00		3 00	
B	2 10	2 00	49	3 30	3 1	19	2 45 E.	2 33	103	2 30	
	3 20	2 50		3 30	3 2		2 30	2 45		1 70	
C	2 20	3 80	58	In the Baie de		39	4 00	2 25	104	2 45	
	3 00	3 80		la Seine.	2 30		3 6	2 30		2 10	1 35
D	2 45	3 86	77	3 00	3 15	45	4 00	3 00	107	3 00	2 60
	3 15	4 33		2 5	3 2		37	2 45		2 40	3 15
E	2 40	2 80	61	3 5	3 0	38	2 40	2 50	107	3 30	1 40
	3 10	2 80		3 00	3 5		38	2 45		2 18	3 20
Ea	2 30	2 80	75	2 30	2 9	39	2 30	2 50	40	2 45	
	3 30	2 80		2 50	3 6		39	2 45		2 35	2 40
			76	3 00	3 20		2 45	1 64			

In the 2nd, 5th, 8th and 11th columns of this Table are given the times before and after high water at Dover at which the stream attains its greatest strength, which is clearly seen to be about the time of *half-tide*, Dover, and not, as supposed, at high and low water on the shore.

Direction in which the stream turns.

The *direction in which the stream turns* will next engage our attention. This is a question more curious than useful to the navigator; it is nevertheless one of interest, and I have given it my attention.

Upon Plate XXXII., I have shown, by curved arrows, the direction in which the streams in all parts of the Channel pass through their various rhombs, and I cannot discover that there is any general rule with respect to *particular sides of the Channel*. On the contrary, the direction appears to be wholly dependent either upon the course of that stream which commences first or continues the longest, or upon that which becomes the most powerful, and which, acting obliquely upon the weaker stream, compels it to partake of its own direction. A good example of this may be seen in the chart of the streams at three hours after high water (Plate XXXV.), where the incoming Ocean stream off the Lemon and Ower is dividing the Channel stream and causing all the tides to the eastward of that spot to turn *with the sun*, and those to the westward of it in a *contrary direction*.

On a supposed tide and half-tide.

I have now only to mention a popular error which still exists with reference to the streams of our channels, viz. a belief in a "*tide and half-tide*;" by which it is understood that the stream runs half a tide longer near the centre of the Channel than it does near the coast. So general an opinion requires substantial proof to invalidate it, and I must refer once more to the diagrams which accompany this report. It will be seen there that in no part of either channel does the change of stream in the centre differ even an hour from the change of stream as near the land as a vessel would be safe in navigating, except in that part of the North Sea which is affected by the tide sweeping round the Texel; and then, at the most, it amounts only to a quarter-tide. It is not difficult to discover that this error has arisen from the confusion of high water on the shore with the time of slack water in the offing.

I have now described the principal features of the tidal streams of this strait, and it is evident from the observations which have been collected that the laws by which the streams of these channels are governed, differ materially from those which regulate the streams of ordinary tides.

It will be interesting to see in what this consists, and to endeavour to account for the cause.

Peculiarity of the wave of the English Channel and North Sea.

Under ordinary circumstances, such as those which attend the passage of a *single tide-wave* up an estuary or deep gulf, or even along an open coast, we find a *progressive turn of the stream to accompany a progressive increase of establishment*. But in the channels under discussion the stream is found to turn *nearly simultaneously throughout the strait*, wholly regardless of the *order of its establishments*, and to reverse *with the time at which a wave peculiar to such channels is matured*.

This wave, which exercises so singular an influence over the streams of these Channels, is occasioned by one portion of the oceanic tide-wave of the Atlantic passing round the north end of the British Islands, while the other finds its way up the English Channel and meets it in the Strait of Dover. In consequence of this meeting or opposition, the character of the wave is changed; its dimensions become

diminished just one half in extent, its rate of travelling is reduced a like quantity, and its streams are almost always in opposition to those of the outer or parent wave.

Plans 3 and 4 exhibit the forms of this wave at full and change, as they appear at the hours respectively marked against them at the side of the Plan. They are constructed principally from the establishments and ranges of tide published in the Philosophical Transactions, 1836, Part II., by drawing a line through the fairway of the Channel, and setting off upon it the times of high water and the ranges of tide as they would exist at the stations selected for this purpose.

Formation of
a combined
wave in the
Strait of
Dover.

In these Plans we can distinctly trace the formation of a combined wave at Dover. In Plan 4, for instance, at V hours, the crests of two waves are seen to be formed a little beyond the Deadman on one side and at the Spurn Point on the other, and the foot of the wave or hollow which they create is resting at Dover. Following the progress of these two crests down the page, we find them gradually approaching each other and wearing out the depression in advance of them, until between VIII. and IX. o'clock the hollow has vanished; at X. o'clock there is a decided convexity of surface, which gradually increases until at XI. o'clock, Plan 3, the crest has attained its zenith: the combined wave is perfected, and it is high water at Dover.

If now we follow the wave down the same page, Plan 3, as the tide falls, we find the crest to become more oblate, and finally, to be obliterated without there being any material progress of the wave in either direction. In fact, the wave on this section appears to descend nearly perpendicularly, and the progress of the derivative waves to be so far destroyed that we can scarcely trace any indication of their advance. On the contrary, we see a new wave on each side preparing to roll up the Channel to renew the wave thus clearly common to both. So far then we perceive, from these data, that the wave in the Strait of Dover is due to the combined action of two waves derived from the parent or Atlantic wave, and which advance from opposite quarters. These waves, it may be seen, are materially different in their dimensions and rate of travelling from those of the oceanic wave from which they are derived. The dotted line drawn through the crests of the wave upon the Plan 3, will sufficiently discover the material change it undergoes on approaching the channel in which the branch wave exists.

The same result, nearly, as regards the formation of the combined wave, is arrived at if we take a mean between the sections of the wave as it would appear from the ranges and establishments along the coasts of England and of France and Belgium. In this mean section, however, we trace the formation of a combined wave at IX. o'clock off Selsebill, and can detect a progressive advance of a small wave thence to the eastward, making high water along the Dutch coast in the inverse order of the high water resulting from the wave upon the opposite side of the channel, and then merging into the wave preparing to renew the order of the tides in the North Sea*.

* This merging of the waves into each other may possibly be the cause of the whole rise of the tide at the Texel occurring in the first half of tide, as stated in "Ariel," Remarks upon the Tides of the Texel, published at Amsterdam.

This wave is not, however, of sufficient magnitude to affect *the streams* which traverse its surface, which seem to be under the entire control of the combined wave. The inverse order of the establishments upon the coast of Belgium and of Holland is a point of considerable interest, and I greatly regret that the season has been so unfavourable that no observations have been made which throw any additional light upon the subject.

If we place the mean water-level of the middle sections of the wave together, we shall form the figures traced in Plan 2, Plate XLI., and shall be struck with the very small limits off Harwich through which the large wave at Dover is transmitted; this contracted portion of the sketch is nearly in the situation in which Professor WHEWELL has drawn the node of the North Sea tides.

Powerful influence of the combined wave over the streams of the Channel.

The influence of the combined wave over the tidal phenomena of the channels on both sides of the Strait of Dover is very remarkable. The streams of both it will be seen reverse together as the wave is matured; they extend to the same distance from the apex of the wave, where they are met by rotatory streams; in short, the whole tidal feature of one-half of the strait bears so close a resemblance to that of the other as to leave no doubt of their being both due to a common impulse. For instance, it may be seen in the Plans which accompany this report, that in the North Sea the streams of the oceanic and Channel wave meet off the estuary of Lynn, as they do off the estuary of St. Malo in the English Channel, at the same hours and at the same distances nearly from the head of the combined wave; that there is an increased rise of the tide at Lynn as in the Gulf of St. Malo, although not to the same extent, owing perhaps to a different conformation of coast, but sufficiently large to establish the similitude, being in both cases nearly double that of the offing rise; that in these localities, on both sides, the streams are all of a rotatory character, and that from the meeting of the streams off Lynn to the meeting of the streams off Dover, there is, as in the English Channel, from the meeting of the streams off St. Malo, to the meeting of the aforesaid streams off Dover, a stream which flows steadily on both sides towards Dover, whilst the water is *rising* at that place and sets *away from it*, whilst the water is *falling* there; each portion having the remarkable peculiarity of reversing its stream throughout nearly simultaneously with the time at which the combined wave is matured.

Streams of the Irish Channel under a similar influence.

I may here observe, that in this respect the Irish Channel is precisely under the same circumstances as the English Channel and North Sea. The tide-wave enters that sea in like manner by opposite routes, and forms one vast wave, having all the peculiarities of a combined wave. On each side of the apex of this wave the streams reverse throughout at nearly the same time; that time corresponding with the time, at which the combined wave is perfected, as occurs with the streams in the English Channel.

In the Irish Channel the streams are even more regular than those of the North Sea and English Channel, and suffer less disturbance from the ocean or offing streams. It is true that in the Irish Sea there is no intermediate stream where the tides meet,

but, on the contrary, a large tract of still water which the streams scarcely ever disturb, but this arises from the different conformation of the inner part of the strait. The Irish Sea, for instance, may be said to be contracted at its entrances, and to expand into a large inland sea in its centre, whereas the other channel has wide entrances and a very contracted centre. They are, however, both canals in which the waves from two tidal seas enter at opposite ends and meet in the centre, where they form a combined wave, and hence they have the property of reversing their streams simultaneously.

Tidal phenomena of the Irish Sea and of the English Channel compared.

There cannot therefore be any doubt that the waves which are formed in the centre of these straits exert a powerful influence over the course of the waters on both sides of them, and in fact that they both govern their movements and regulate the limits of their streams.

It was the consideration of this influence that determined me to refer all the movements of the streams of these Channels to the time when the combined wave was matured. In the Irish Sea I adopted Liverpool as the standard*, and as Dover was situated so near to the apex of the wave in the English Channel, and had tables of its tides already printed and in general circulation, I adopted the time of high water at that place as a standard to which all the observations there should be referred.

I shall now compare the general inclination or slope of the surfaces of the combined wave on both sides with the direction of the streams passing along the Channel at the moment, for the purpose of showing the mechanical action of the water, and of tracing the intimate connection that exists between these slopes and the simultaneous turn of the stream.

Comparison of the inclination of the surface of the wave with the direction of the stream along it.

If we direct our view to the inclination of the surfaces of these waves, Plans 3 and 4, Plates XLII. XLIII., we shall see that the directions in which the streams run do not always correspond with the *existing* slopes of the surfaces, as they might be supposed to do from the known law of gravitation, but that during the last half of the tide they are to be traced to the effect of a *previous* and contrary depression. The maximum rate of the stream may be seen to occur when the surface has its smallest depression†, and that there is no stream at all at the moment of the greatest elevation and depression. It will be seen that the rate of the stream depends upon the amount and continuance of the inclination; and also that a stream, when once produced, will continue its progress for a length of time, although the inclination that produced it may have been reversed by the passage or descent of the crest of the wave. Consequently from the time of the passage of the wave, or the reversal of the inclination of its surface, until the stream finally ceases to flow, the water will be seen to run up an inclined plane, and will continue to do so for nearly as

* See my paper in Philosophical Transactions, Part I. 1848.

† The maximum rate of the stream is shown in the Table at page 711 to occur at half-tide, at which time the wave is seen to have the smallest depression.

long an interval before it be brought to rest as it did to acquire its momentum, the relative inclinations at the beginning and end being about the same.

The reversal of the stream throughout the strait at the same time will not therefore be a matter of surprise, as it will be seen to be only the effect of gravitation due to *the general slope* of the surface. That it is the *general slope* of the surface of the combined wave that occasions the stream throughout these channels, is even more manifest in the North Sea than in the English Channel, from the fact of the stream there pursuing a steady course between two shores, of which the order of their tidal establishments is inverted without reference to either.

Cause of the stream explained.

If it be required to trace the streams of the Channel through their gradations, it may be done on Plan 3, thus: at XI. o'clock, it is high water at Dover, the wave has consequently attained its zenith, and the depressions of the surfaces on either side are at their maximum. There is now no stream, because the momentum acquired during a former depression has only now ceased, notwithstanding the increasing obstruction for two hours which has been presented by the reversed inclination of the wave. The water at Dover now falls, the stream begins, and as the depression of the surface continues, the stream gradually acquires strength until about half-tide, when the depression is at its minimum and the strength of the stream at its maximum: after this the inclination of the surface is unfavourable to a continuation of the stream. From this time, therefore, the rate of the stream begins to diminish, because the reversed inclination is progressively becoming more adverse to its progress, and at low water at Dover, after having run up an elevation for two hours, its effort is exhausted and there is slack water throughout the wave, as at first*.

Conclusion.

In conclusion, I trust it will appear to their Lordships, that the means which they have been pleased to place at my disposal have been advantageously employed; and I venture to express a hope, that whilst science will be benefited by the inquiry, the navigation of our channels will be so far improved that the seaman will in future find his course through these moving waters rendered simple and plain. Hitherto the numerous and perplexing references which he has been compelled to make to establishments of ports, with some of which he was not even furnished, and which, under any circumstances, rendered a calculation necessary, have in too many instances, it is feared, caused the set of the tides to be wholly disregarded, or what is worse, misapplied, the consequences of which, it is now seen, are very likely to have been attended with disastrous results. For instance, the meeting of the streams off the Casquets and the Start in the English Channel, and the direction there given to the water at a particular time of the tide, will fully account for the numerous wrecks about the Channel Islands; whilst near the Strait of Dover an unexpected set of the stream directly down upon the Somme, and in a part of the Channel where from its narrowness a true stream might be expected, is evi-

Beneficial results of this inquiry to the seaman.

* In my report upon the streams of the Irish Sea, Philosophical Transactions, Part I. 1848, at figures A and B the effect is there shown to be precisely the same.

dence of the danger of approaching this part of the Channel if ignorant of the set of the stream; and most singularly this unsuspected evil occurs exactly in the spot where those disastrous wrecks of the *Conqueror* and *Reliance* took place, and where the *Curaçoa*, one of Her Majesty's frigates, so narrowly escaped a similar fate.

Henceforward a simple reference to a Dover tide table will enable the mariner to determine in which direction his vessel is being carried, assured that whilst the water is rising at Dover he will have a fair stream from the Lemon and Ower to the North Foreland in one channel, and from Alderney to Beachy Head in the other, and *vice versa*; whilst the times and places of the meeting of the streams will be apparent upon the Plan, so that it is hoped, when the contents of the present paper are sufficiently known and circulated, they will be the means of diminishing the number of those losses of both life and property with which the annals of LLOYD'S abound, and of advancing our knowledge of the tides by the practical illustration of the phenomena of the tidal streams of straits under the influence of a combined wave.

In closing this report, I particularly wish to observe that my thanks are due to the officers whose names have been mentioned as having contributed to this inquiry, and especially to the Trinity House and Captain BAX, to whose exertions in training the light-vessel keepers the observations made by them owe their value; and to Captains WASHINGTON and BULLOCK and the officers, who have been engaged in both making the observations and drawing the plans.

To you, Sir, I am indebted for the unremitting assistance you have rendered this cause by the exercise of a zeal which is ever forward in promoting whatever tends to the improvement of navigation or to the advancement of science.

I am, Sir, your humble Servant,

F. W. BEECHEY, Captain R.N.

To Rear-Admiral Sir Francis Beaufort, K.C.B.,

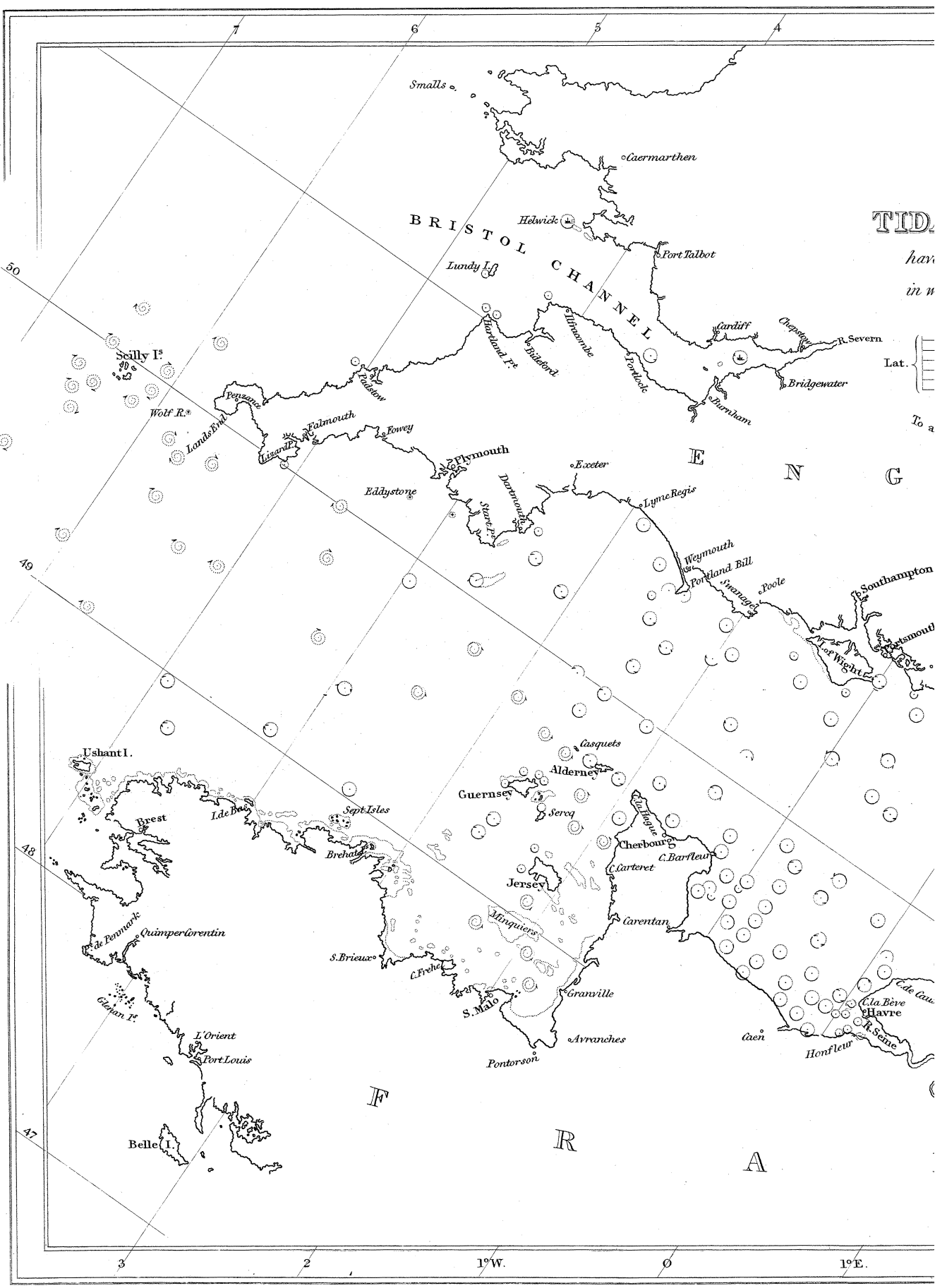
Esq. Esq. Esq.,

Admiralty.

Note.—Since this report was forwarded, observations have been made between the Spurn and Helgoland, and it appears that in all that part of the sea lying between the rotatory streams off the Texel and Helgoland, or rather between 2°30 E. and 7°30 E., the stream *turns nearly simultaneously* with the time of high water at Helgoland and at Dover, the establishments of those places being nearly the same. We may therefore look for a combined wave at the mouth of the Elbe, and for a succession of rotatory streams extending to a considerable distance in a north-easterly direction from Lynn. A few observations have been made in the English Channel also which confirm our former results, and show that such of the observations of the French surveyors referred to in p. 708 as have been tested, were in excess, as had been anticipated.—F. W. B.

EXPLANATION OF THE PLATES.

Chart of the places of observation	Plate XXXII.
Chart of the stream at one hour after H.W.	Plate XXXIII.
Chart of the stream at two hours after H.W.	Plate XXXIV.
Chart of the stream at three hours after H.W.	Plate XXXV.
Chart of the stream at six hours after H.W.	Plate XXXVI.
Chart of the stream at five hours before H.W.	Plate XXXVII.
Chart of the stream at three hours before H.W.	Plate XXXVIII.
Chart of the stream at one hour before H.W.	Plate XXXIX.
Plan 1. Rotatory and true streams compared	Plate XL.
Plan 2. Mean section of Channel wave	Plate XLI.
Plan 3. Hourly section of the rising tide-wave	Plate XLII.
Plan 4. Hourly section of the falling tide-wave.	Plate XLIII.



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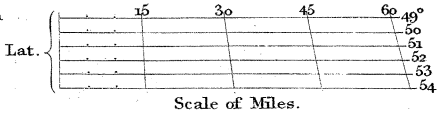
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CHART

*Shewing the situation of
the Places at which*

TIDAL OBSERVATIONS

*have been made; and also the direction
in which the streams (ebb & flood) turn.*

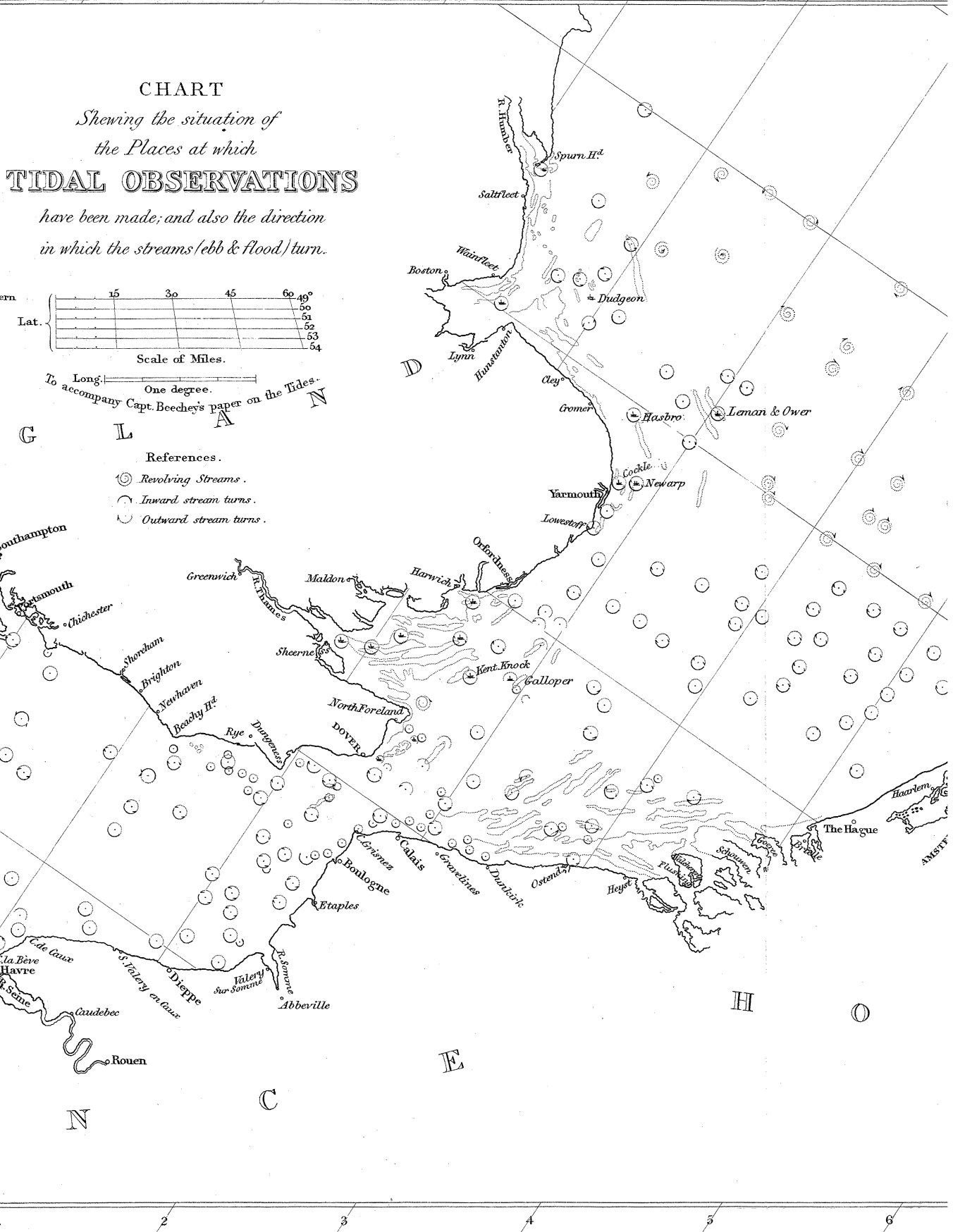


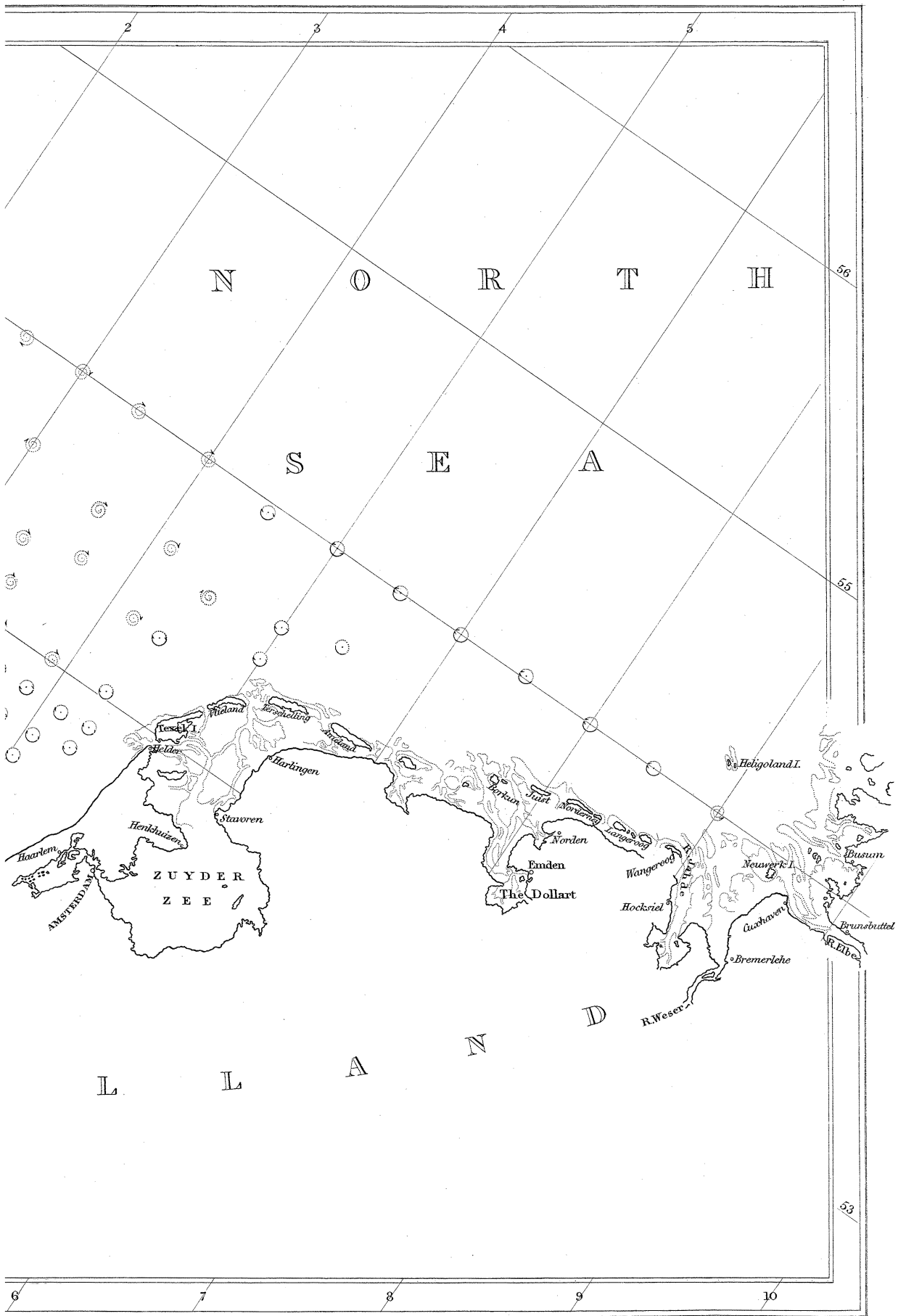
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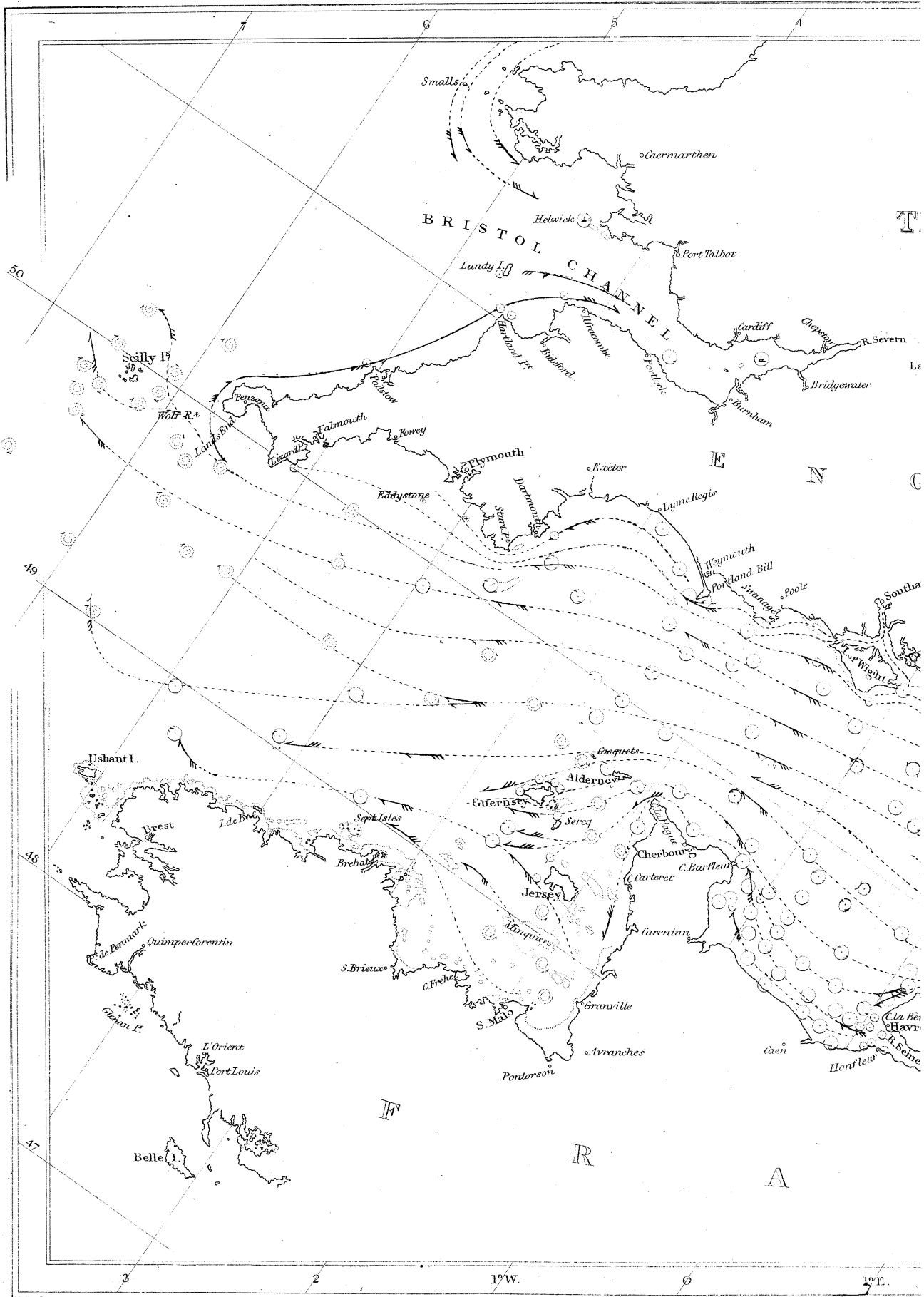
To accompany Capt. Beechey's paper on the Tides.

References.

- ⊙ Revolving Streams.
- ⊙ Inward stream turns.
- ⊙ Outward stream turns.



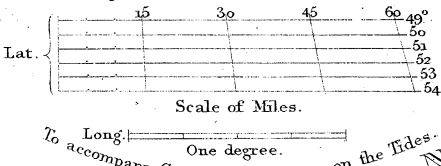




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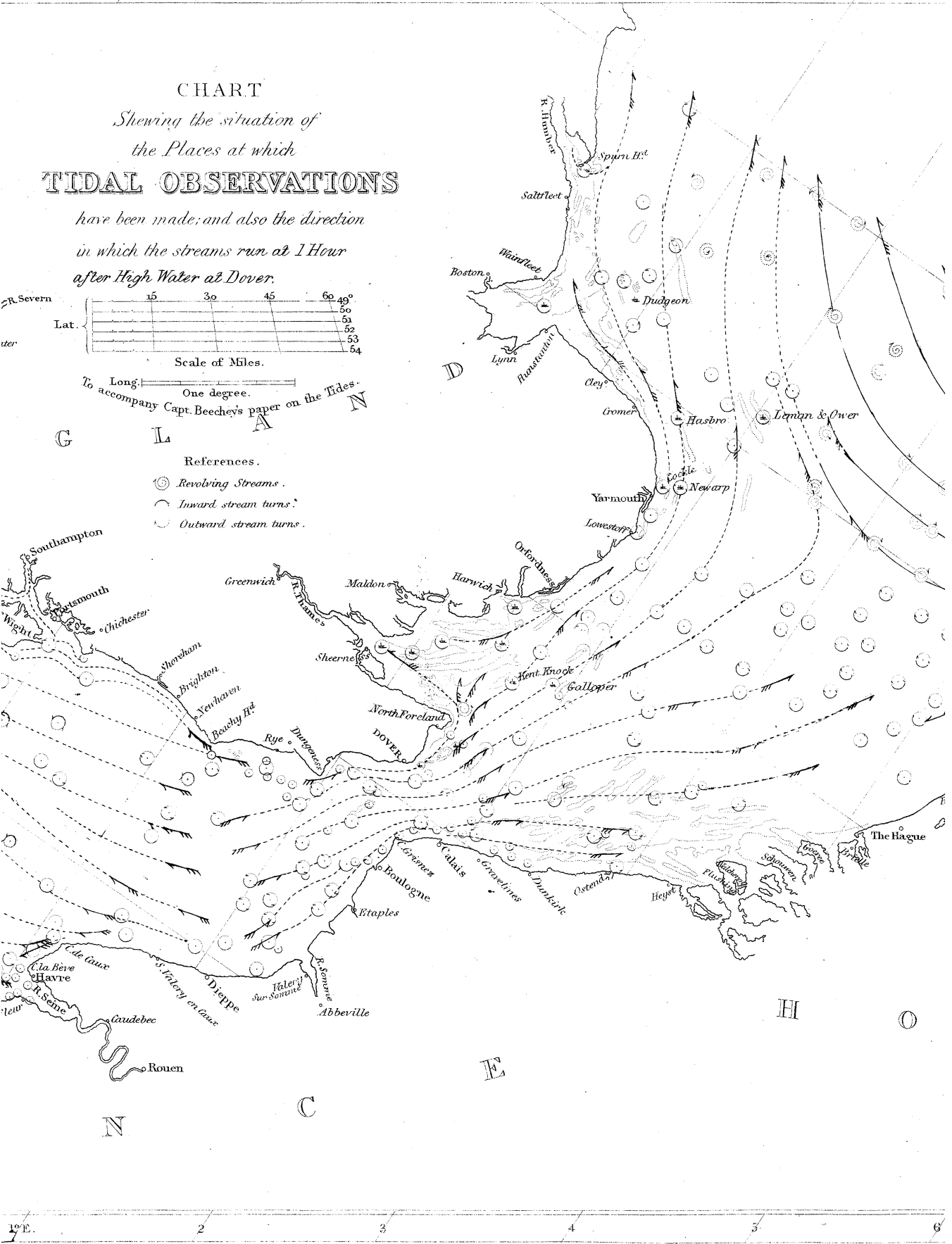
Showing the situation of the Places at which TIDAL OBSERVATIONS

have been made; and also the direction in which the streams run at 1 Hour after High Water at Dover.



References.

- ⊙ Revolving Streams.
- Inward stream turns.
- Outward stream turns.



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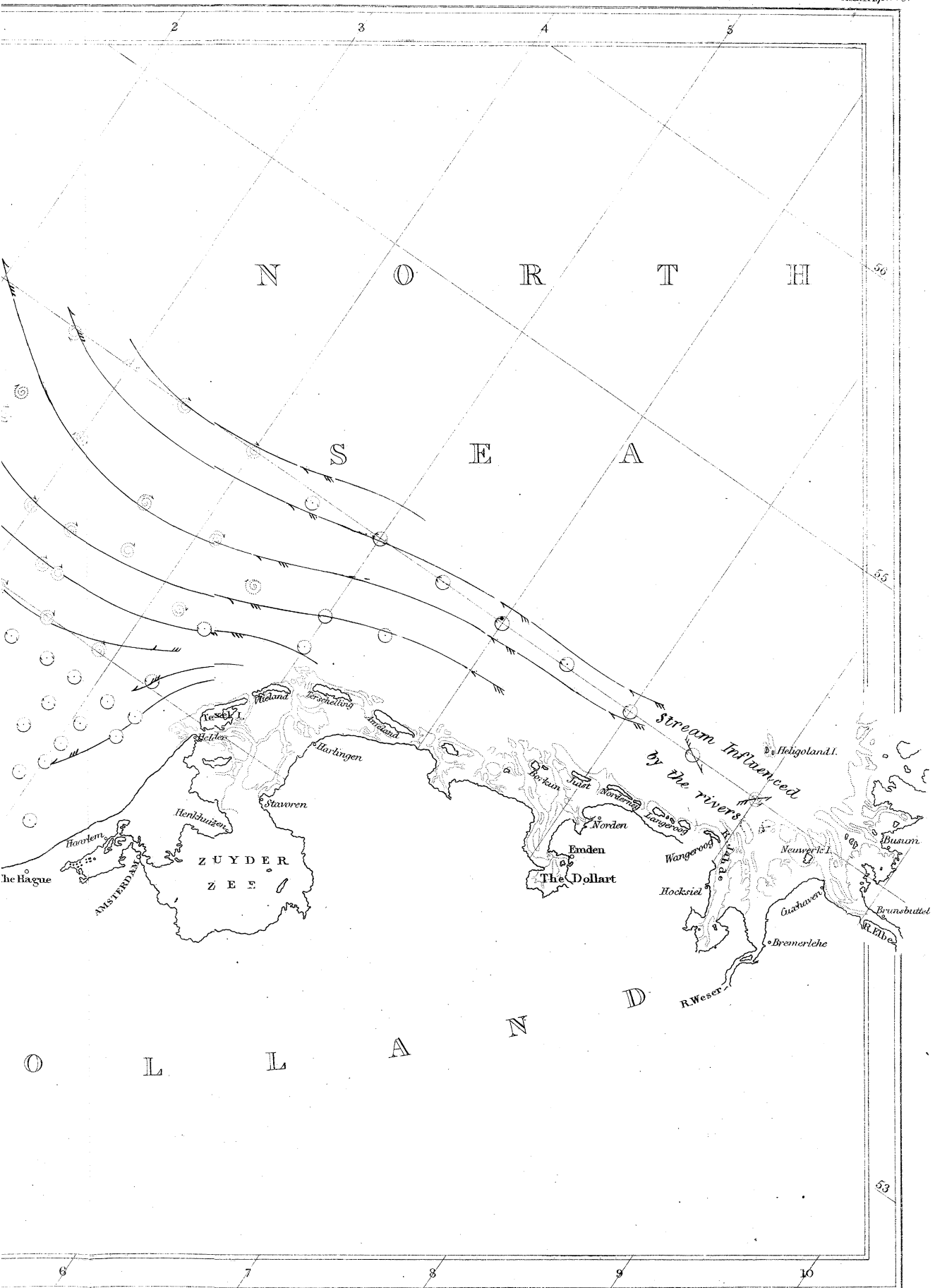
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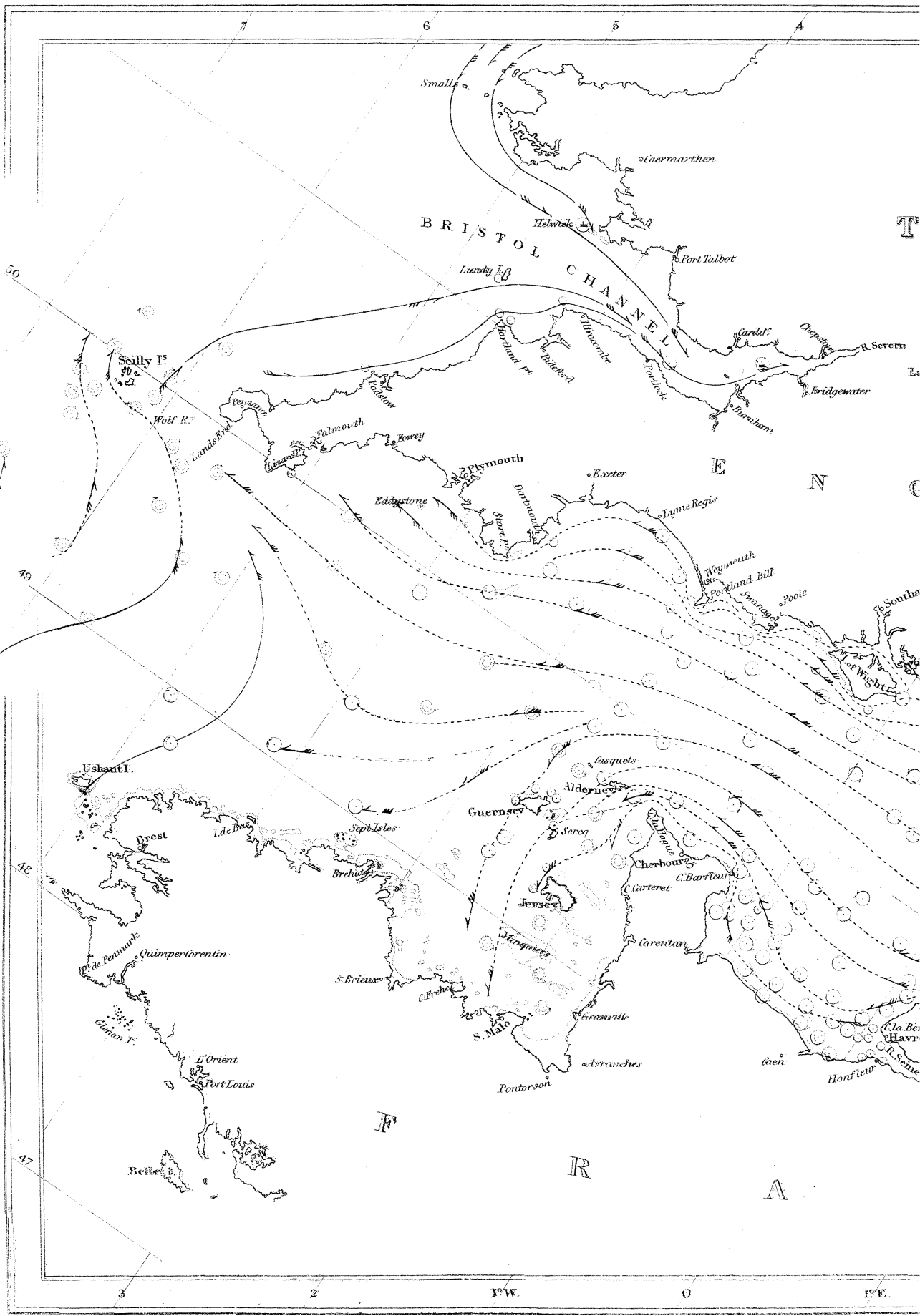
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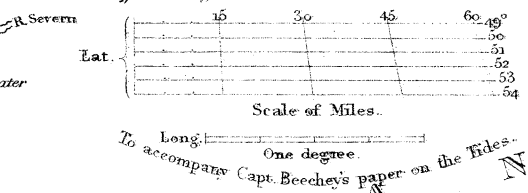


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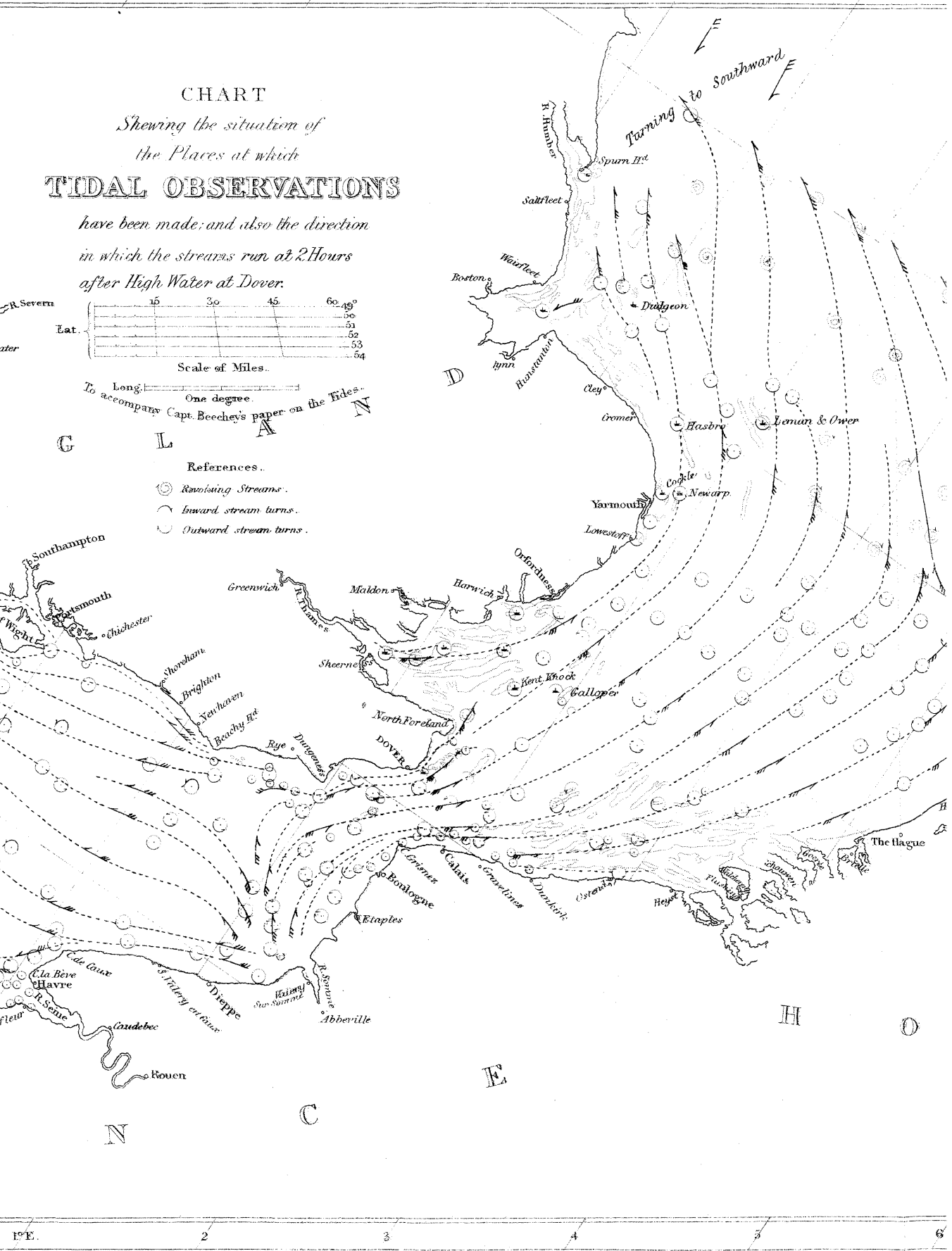
*Shewing the situation of
the Places at which*

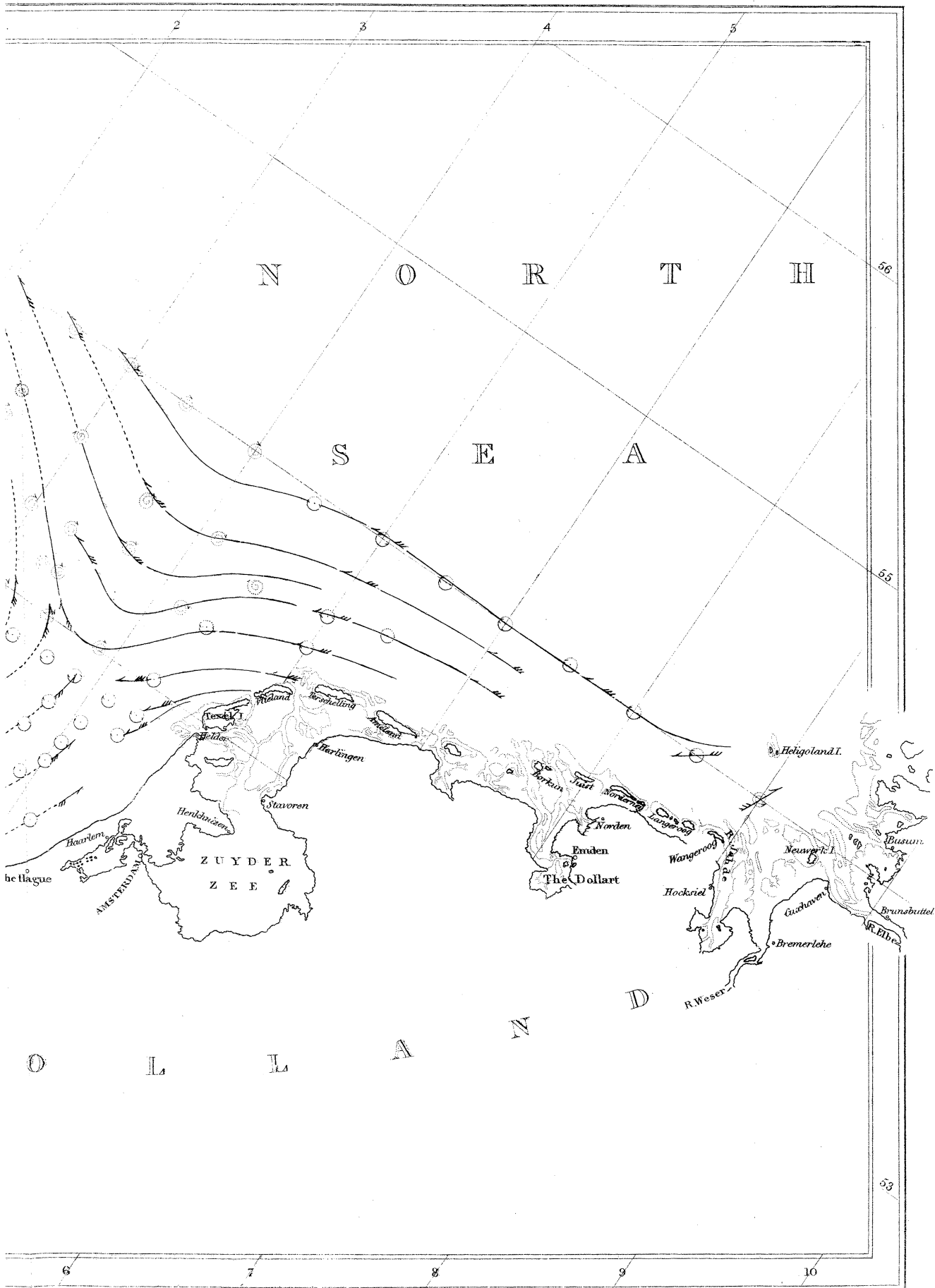
TIDAL OBSERVATIONS

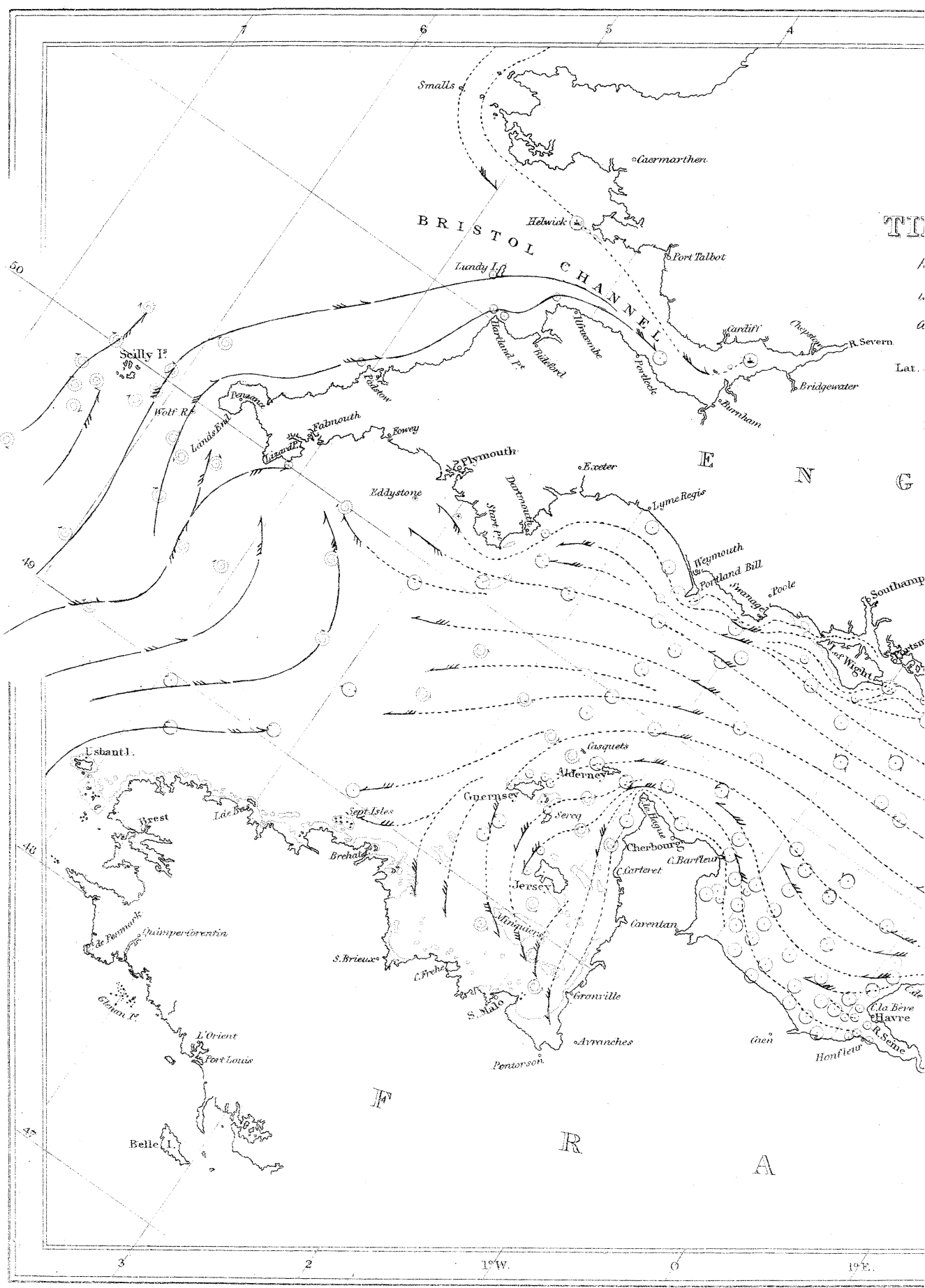
*have been made; and also the direction
in which the streams run at 2 Hours
after High Water at Dover.*



- References.
- ⊙ Revolving Streams.
 - ⊖ Inward stream turns.
 - ⊕ Outward stream turns.







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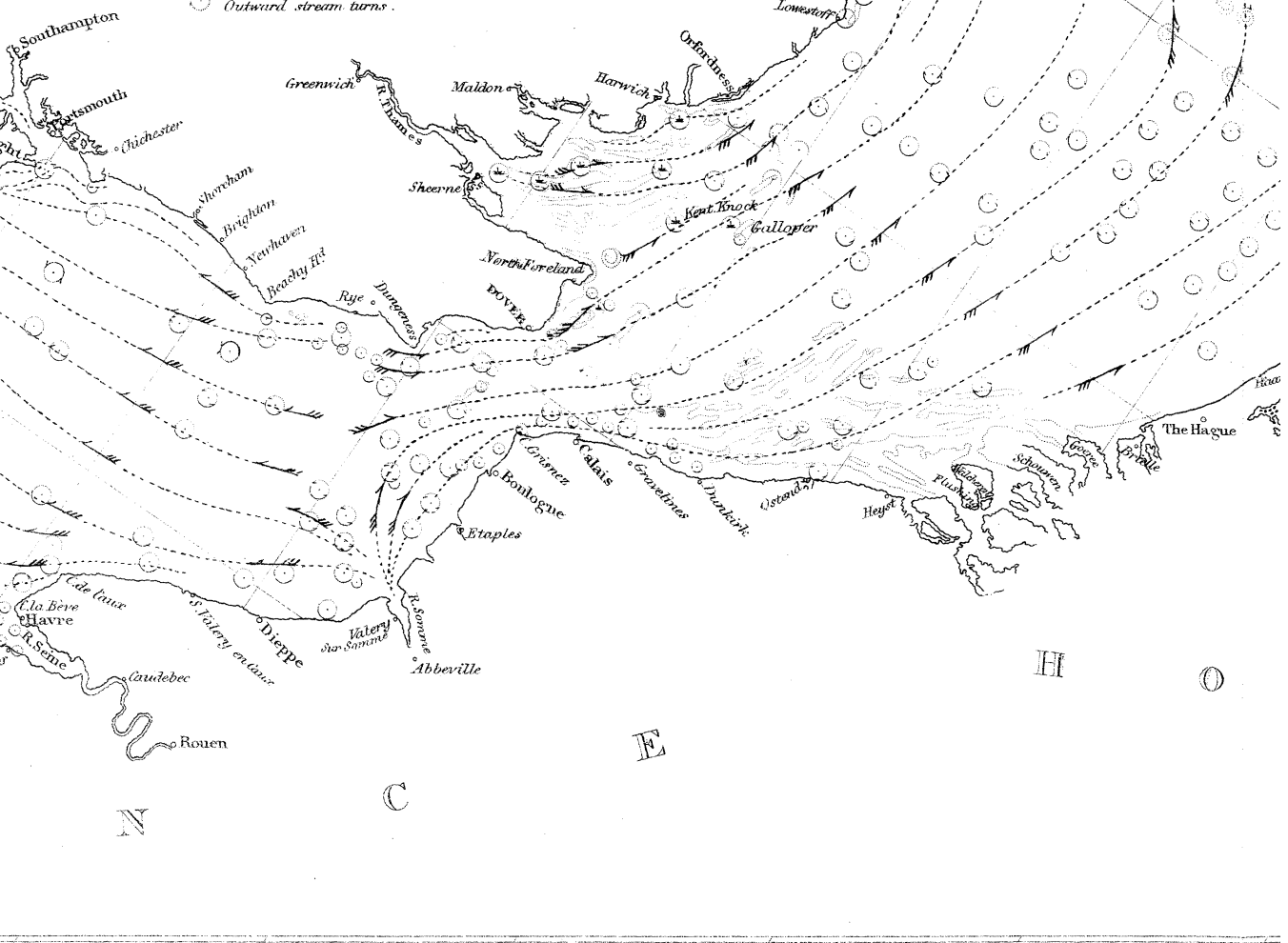
*have been made; and also the direction
in which the streams run at 3 Hours
after High Water at Dover*



Long. One degree.
To accompany Capt. Beecheys paper on the Tides.

References.

- ⊙ Revolving Streams.
- Inward stream turns.
- Outward stream turns.



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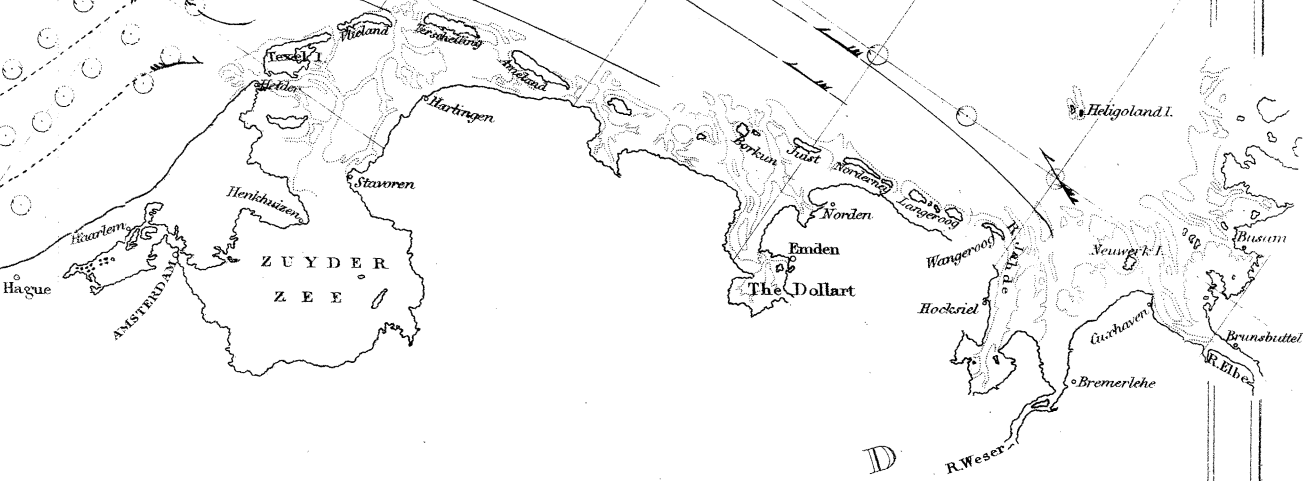
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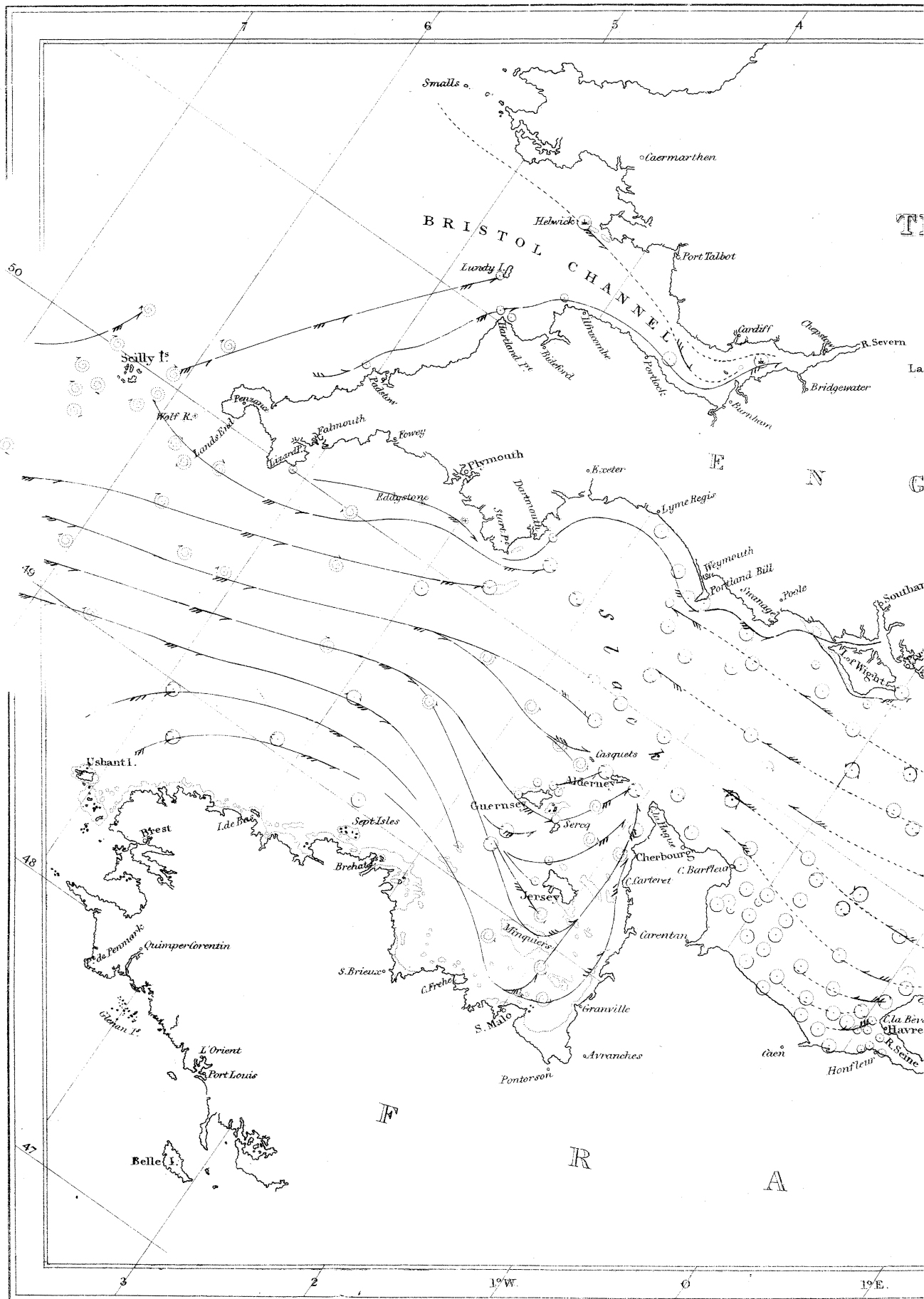


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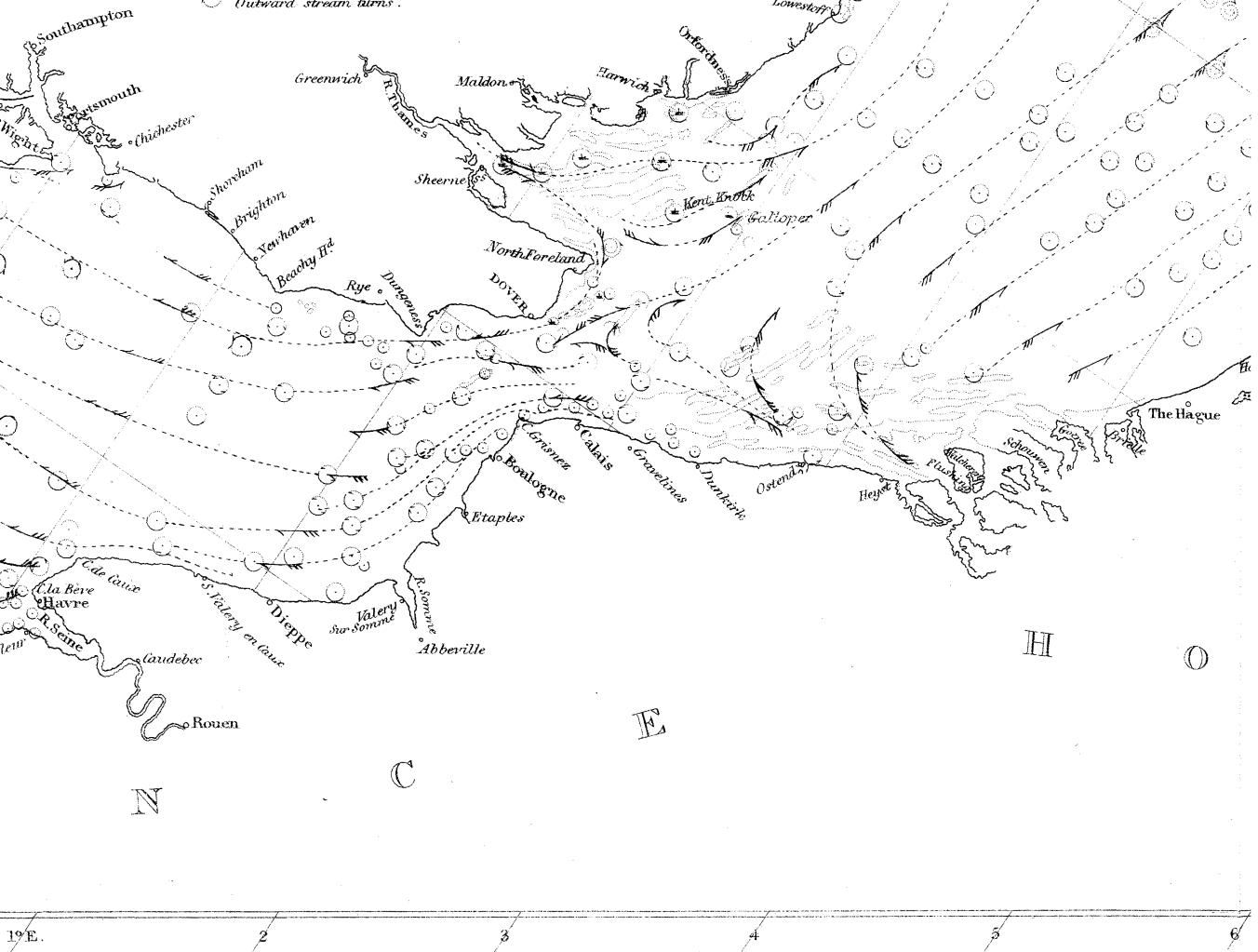
*have been made; and also the direction
 in which the streams run at 6 Hours
 after High Water at Dover*

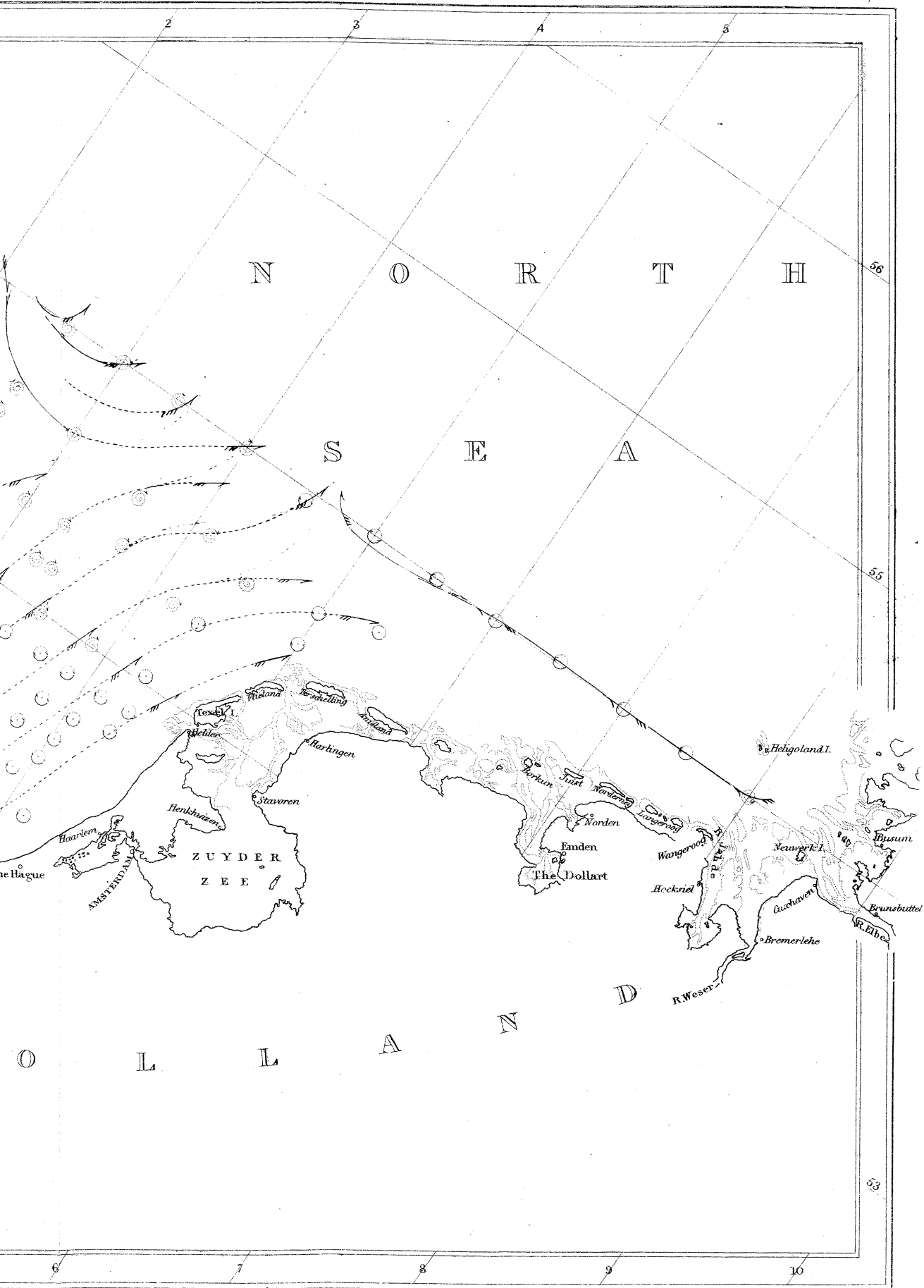


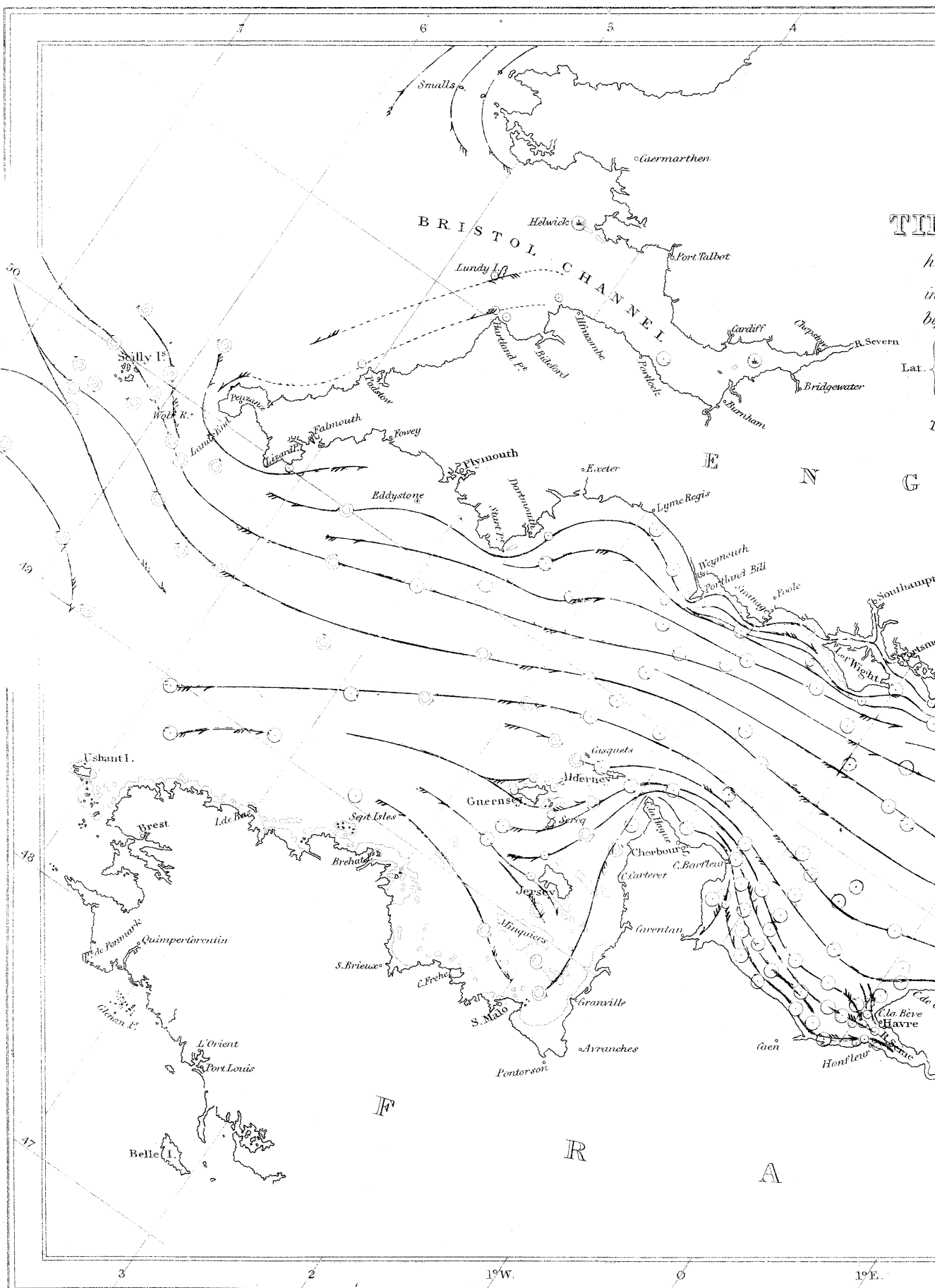
To accompany Capt. Beechey's paper on the Tides.

References.

- ⊙ Revolving Streams.
- Inward stream turns.
- Outward stream turns.







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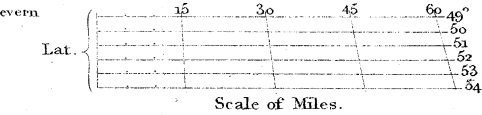
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CHART

*Shewing the situation of
the Places at which*

TIDAL OBSERVATIONS

*have been made; and also the direction
in which the streams run at 5 Hours
before High Water at Dover.*

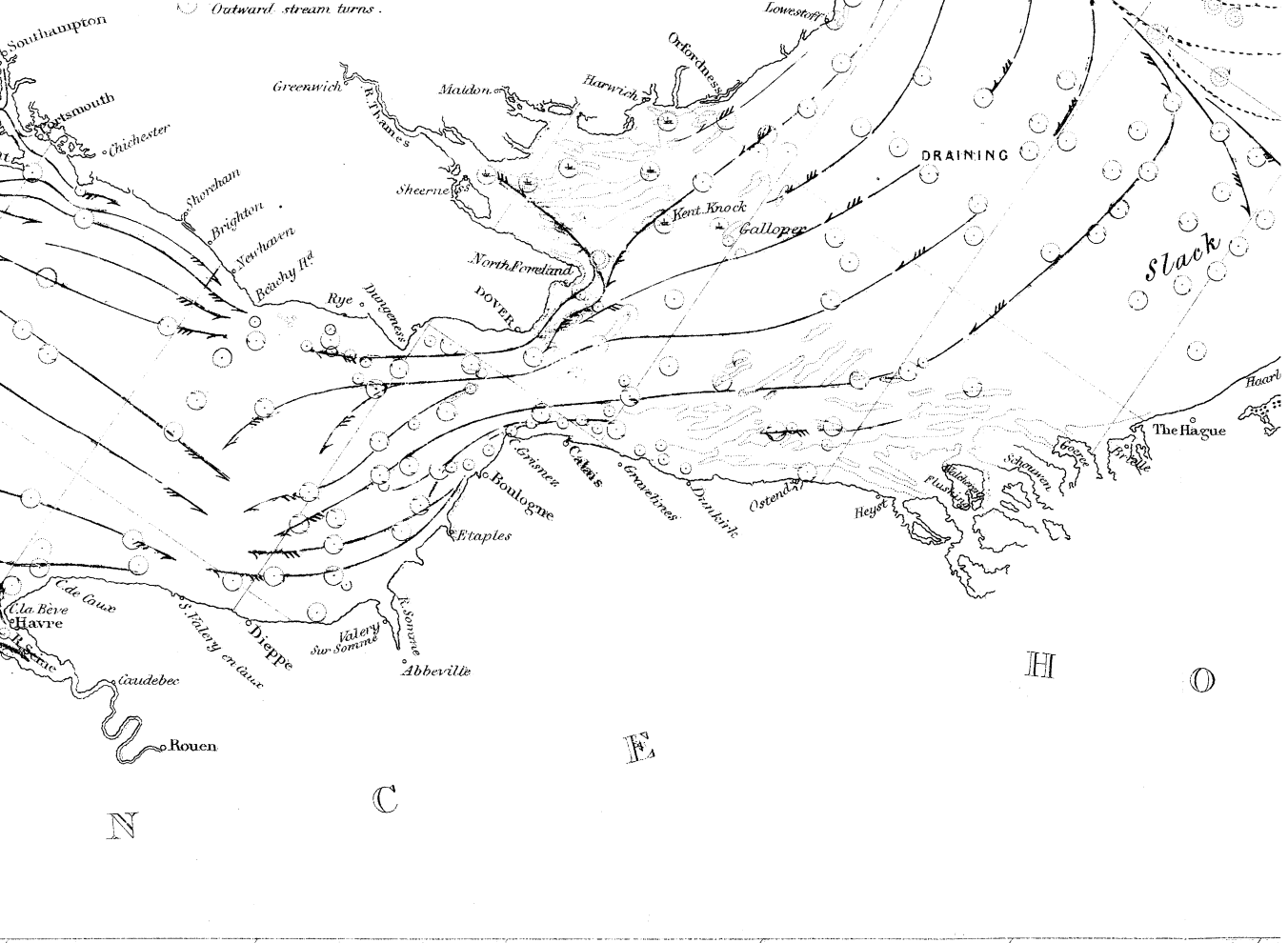


Long: One degree.

To accompany Capt. Beecheys paper on the Tides.

References.

- ⊙ Revolving Streams.
- Inward stream turns.
- Outward stream turns.



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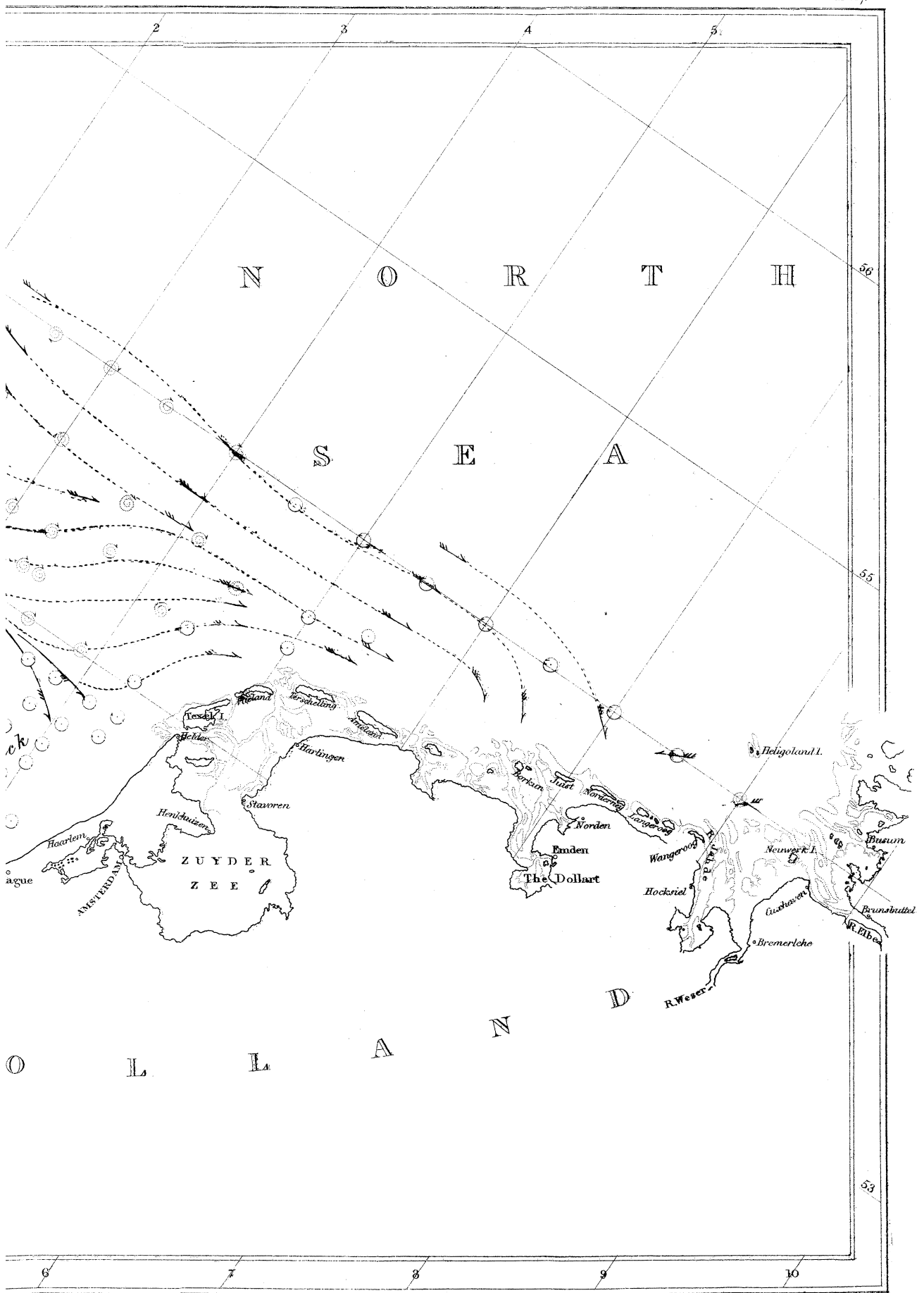
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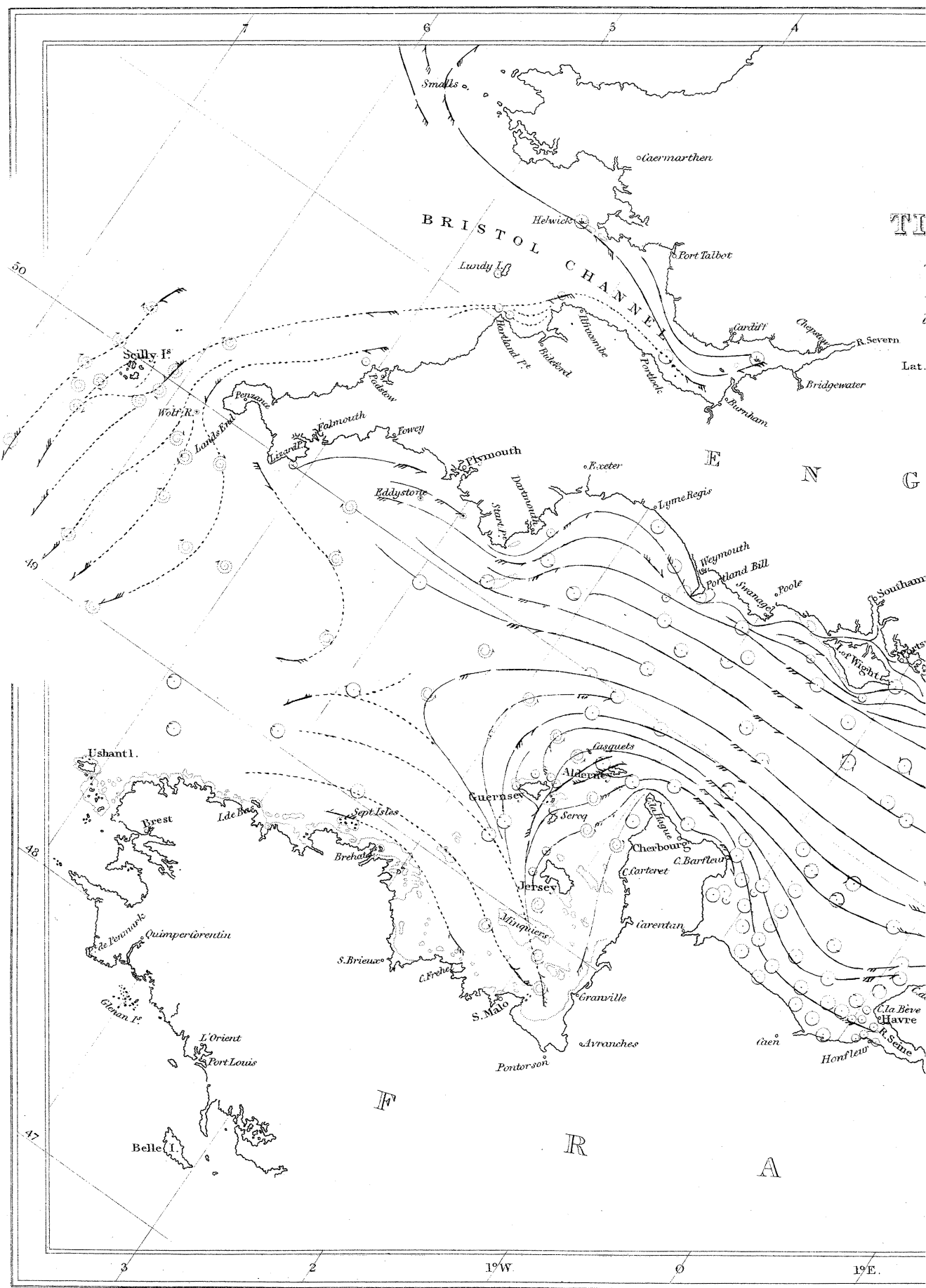
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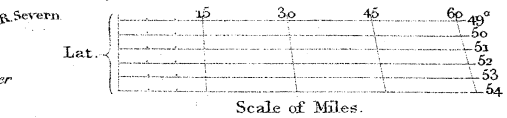


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*Shewing the situation of
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TIDAL OBSERVATIONS

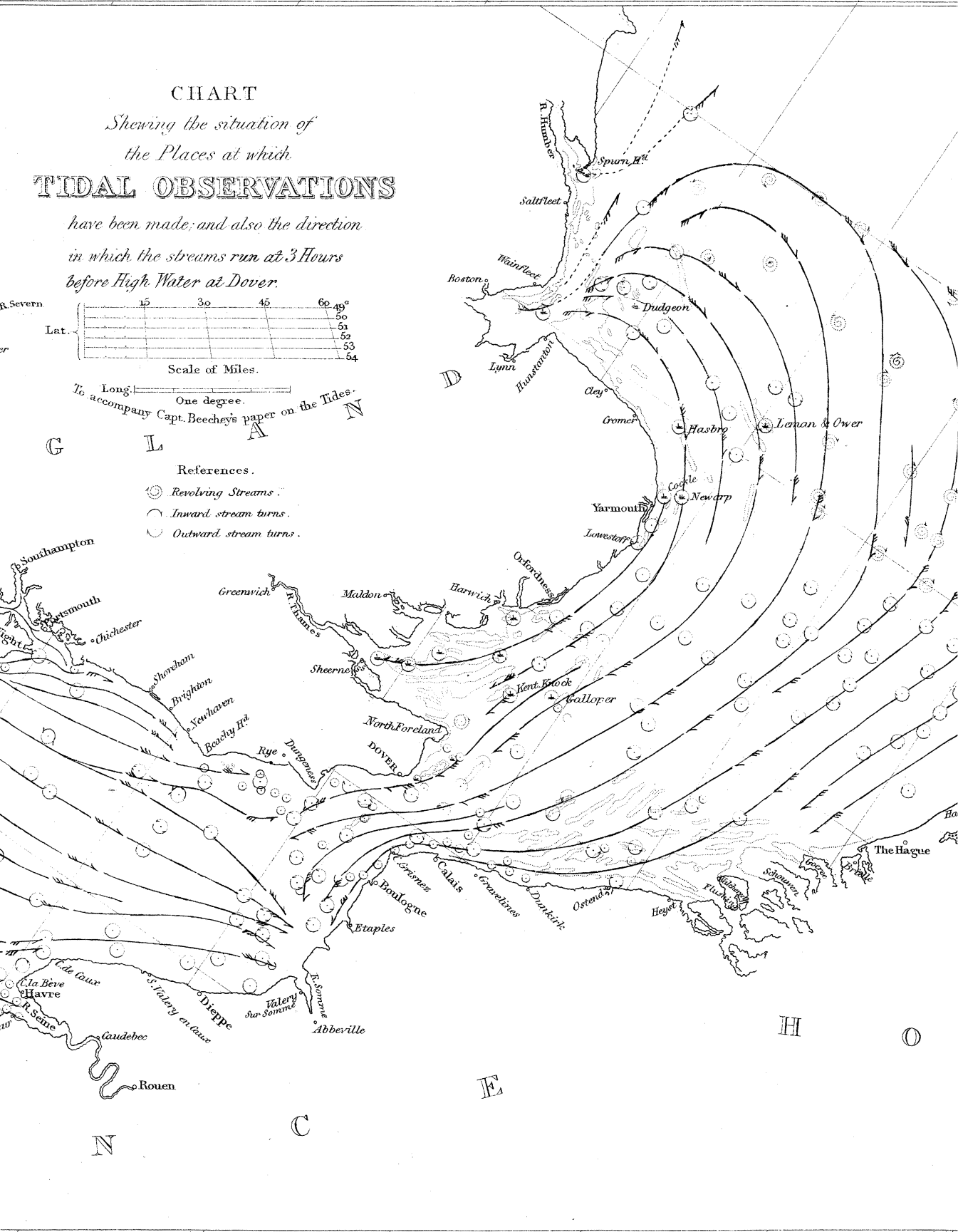
*have been made; and also the direction
in which the streams run at 3 Hours
before High Water at Dover.*

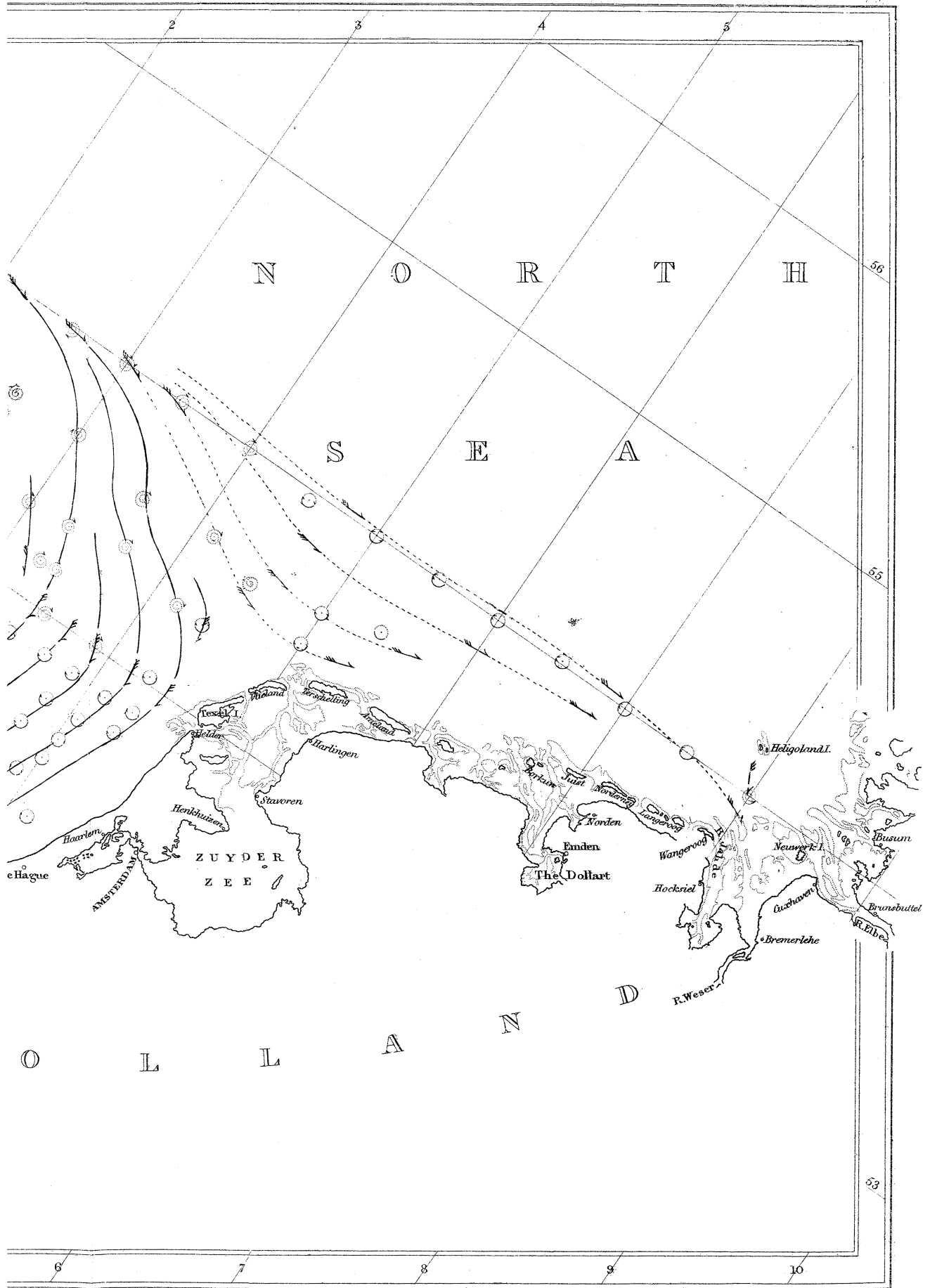


To accompany Capt. Beechey's paper on the Tides.

References.

- ⊙ Revolving Streams.
- Inward stream turns.
- Outward stream turns.





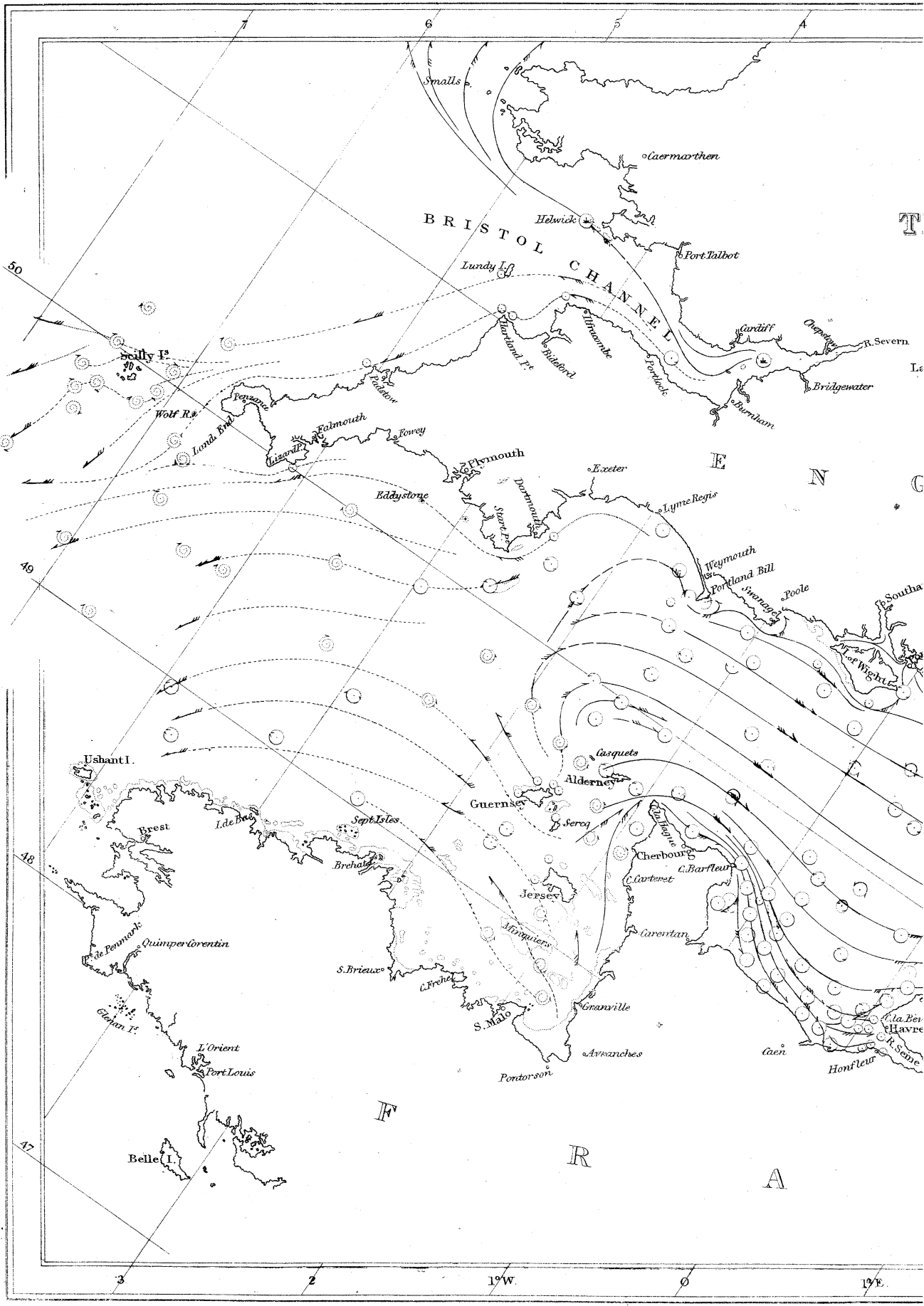


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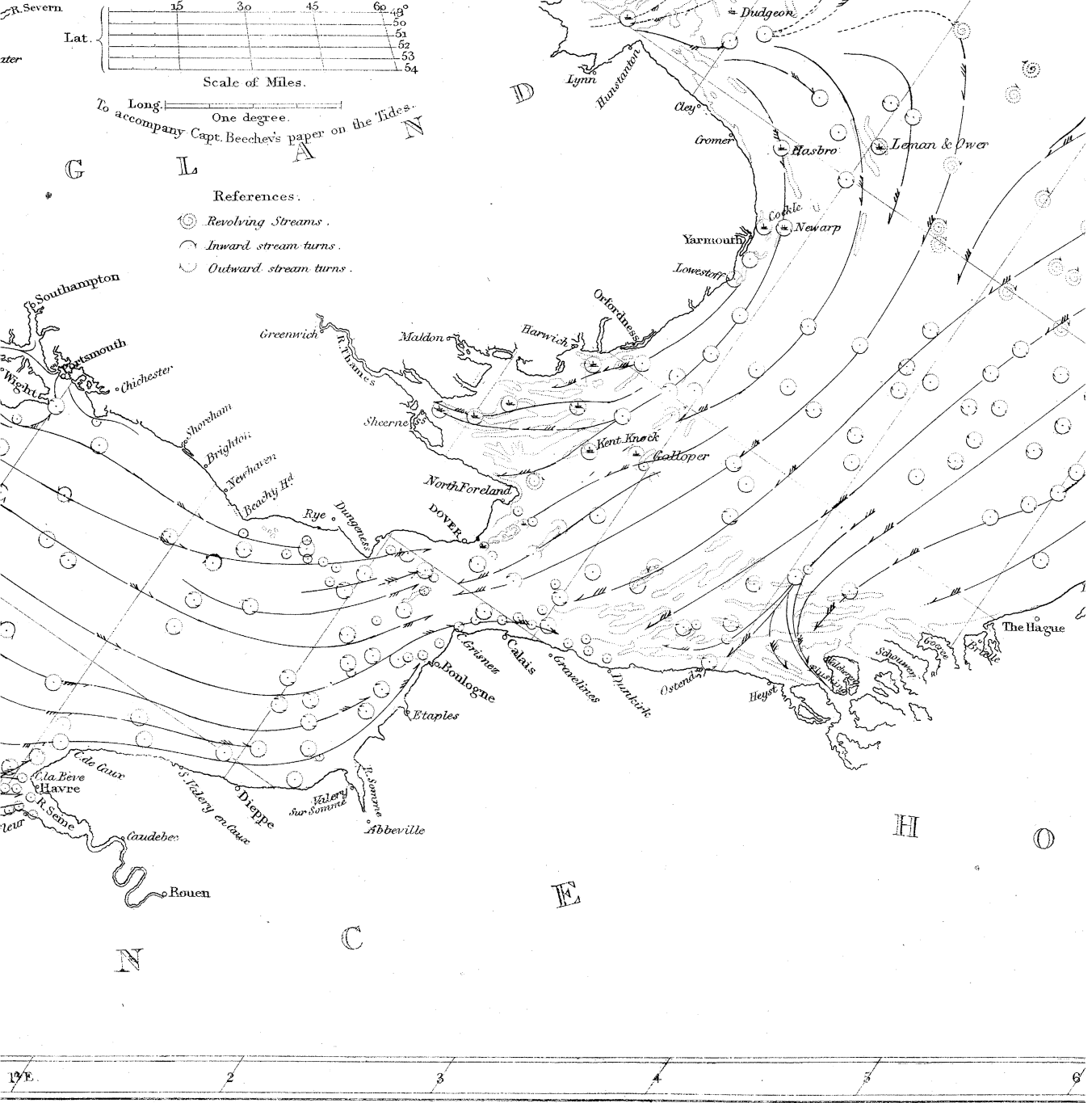
have been made; and also the direction
 in which the streams run at 1 Hour
 before High Water at Dover.

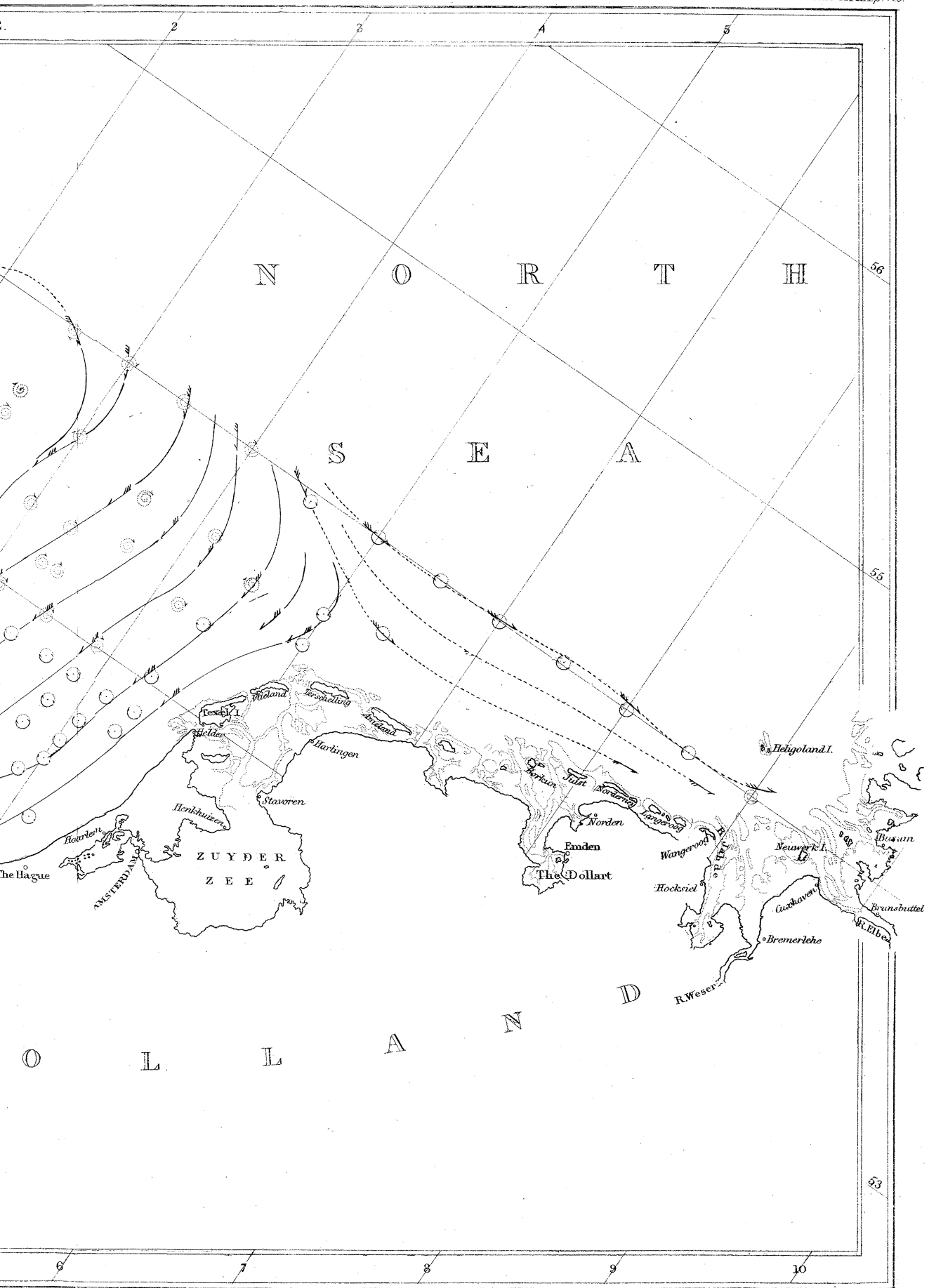


Long. ———— One degree.
 To accompany Capt. Beechev's paper on the Tides.

References.

- ⊙ Revolving Streams.
- Inward stream turns.
- Outward stream turns.

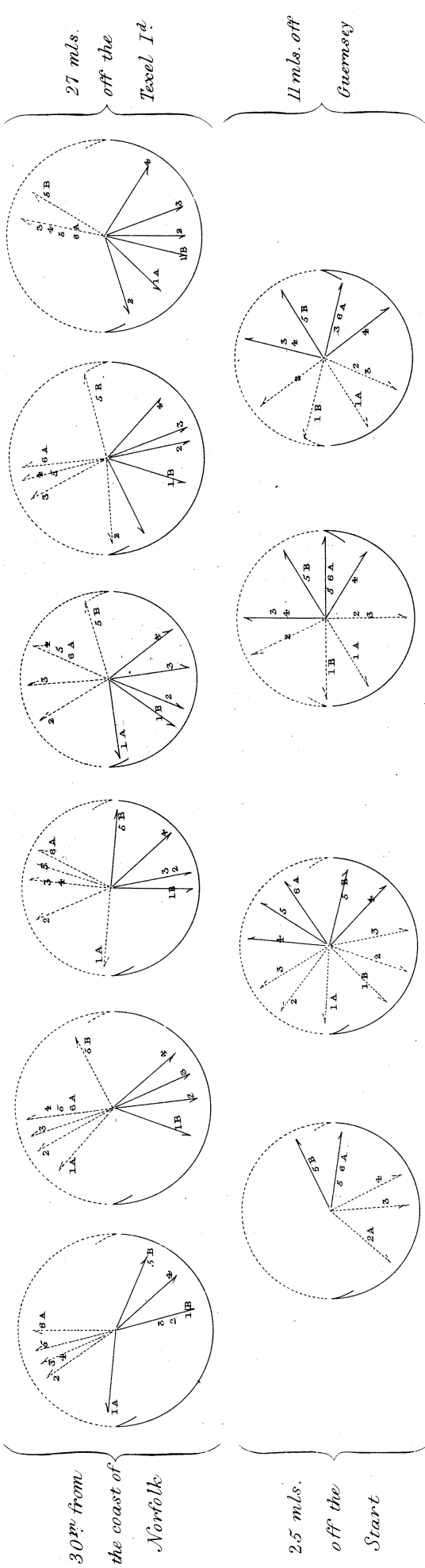




PLAN I.

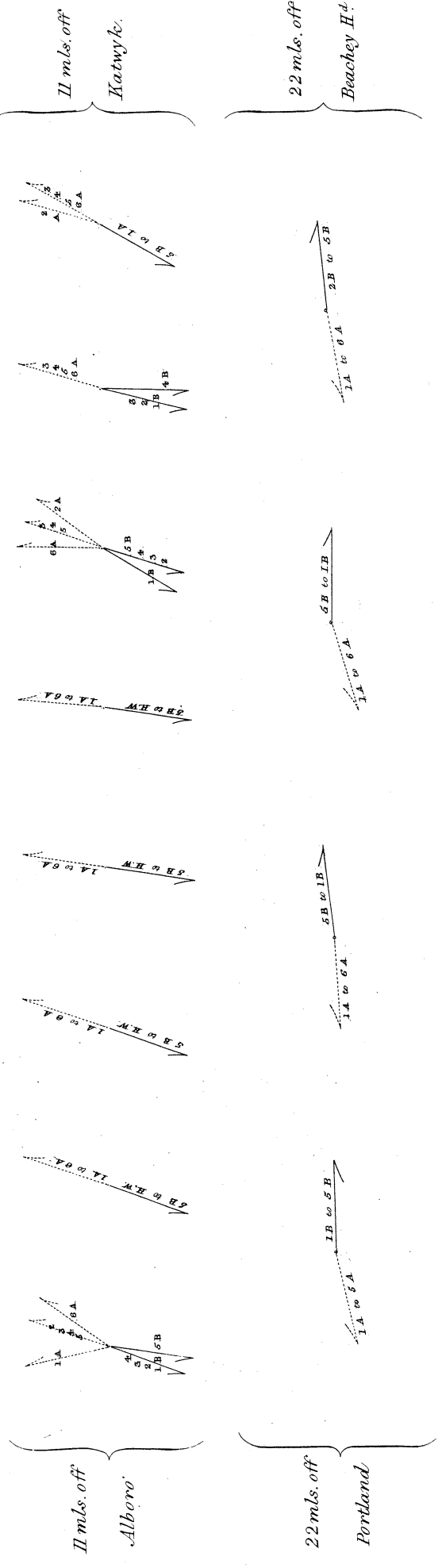
Shewing the course of the stream both in the revolving and in the true Tides of the North Sea and English Channel.

REVOLVING TIDES.

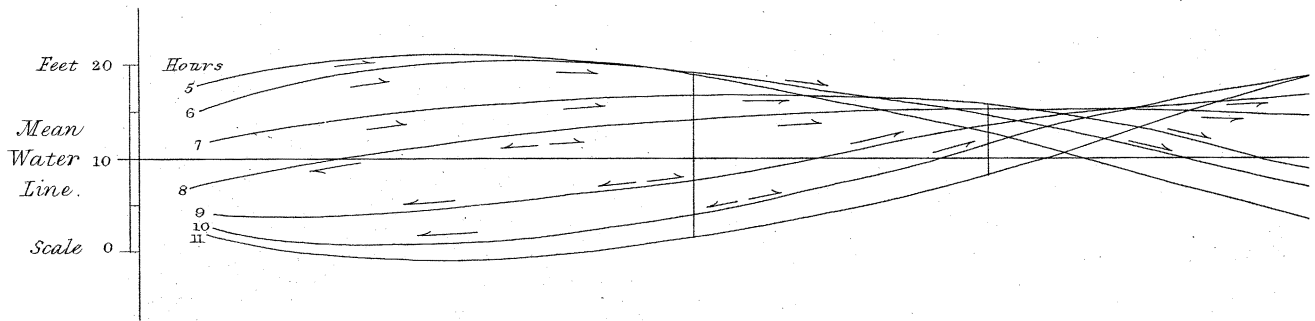
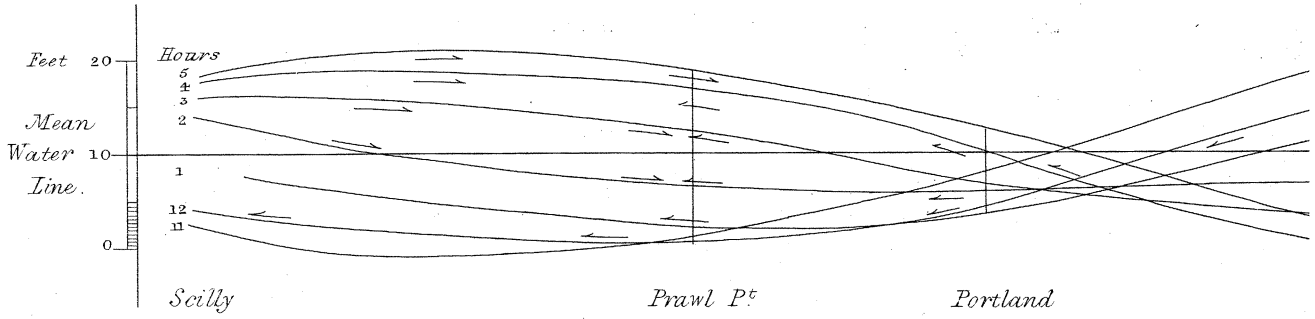


TIDES

observed in the true stream of the Channel.



Shewing the form of the surface of the water

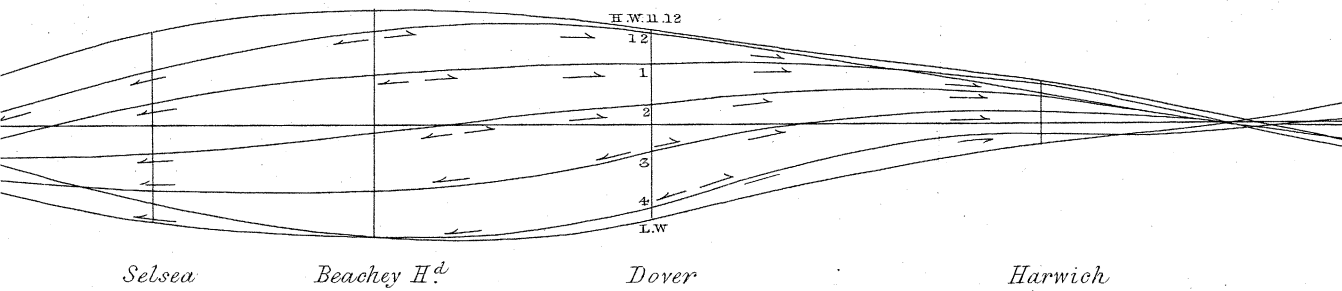


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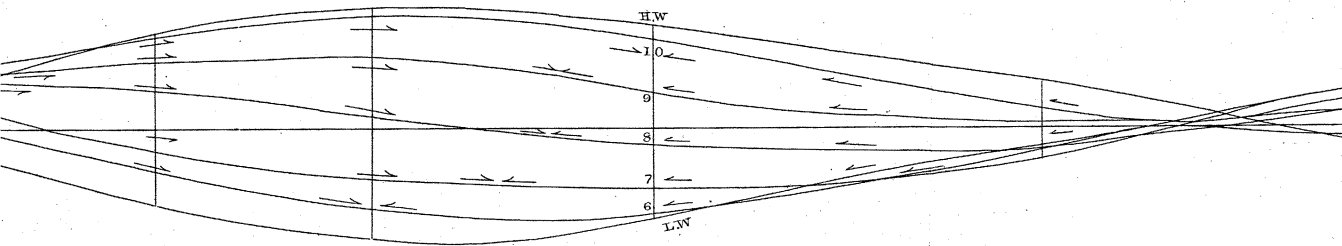
PLAN 2.

*of the water, and the direction of the stream between Scilly and Spurn Pt
at each hour of the Tide.*

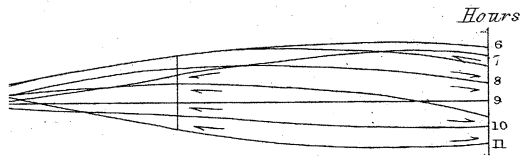
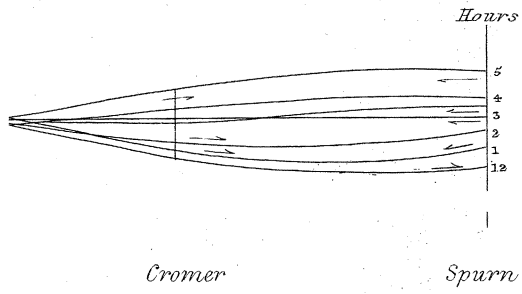
FALLING TIDES AT DOVER.



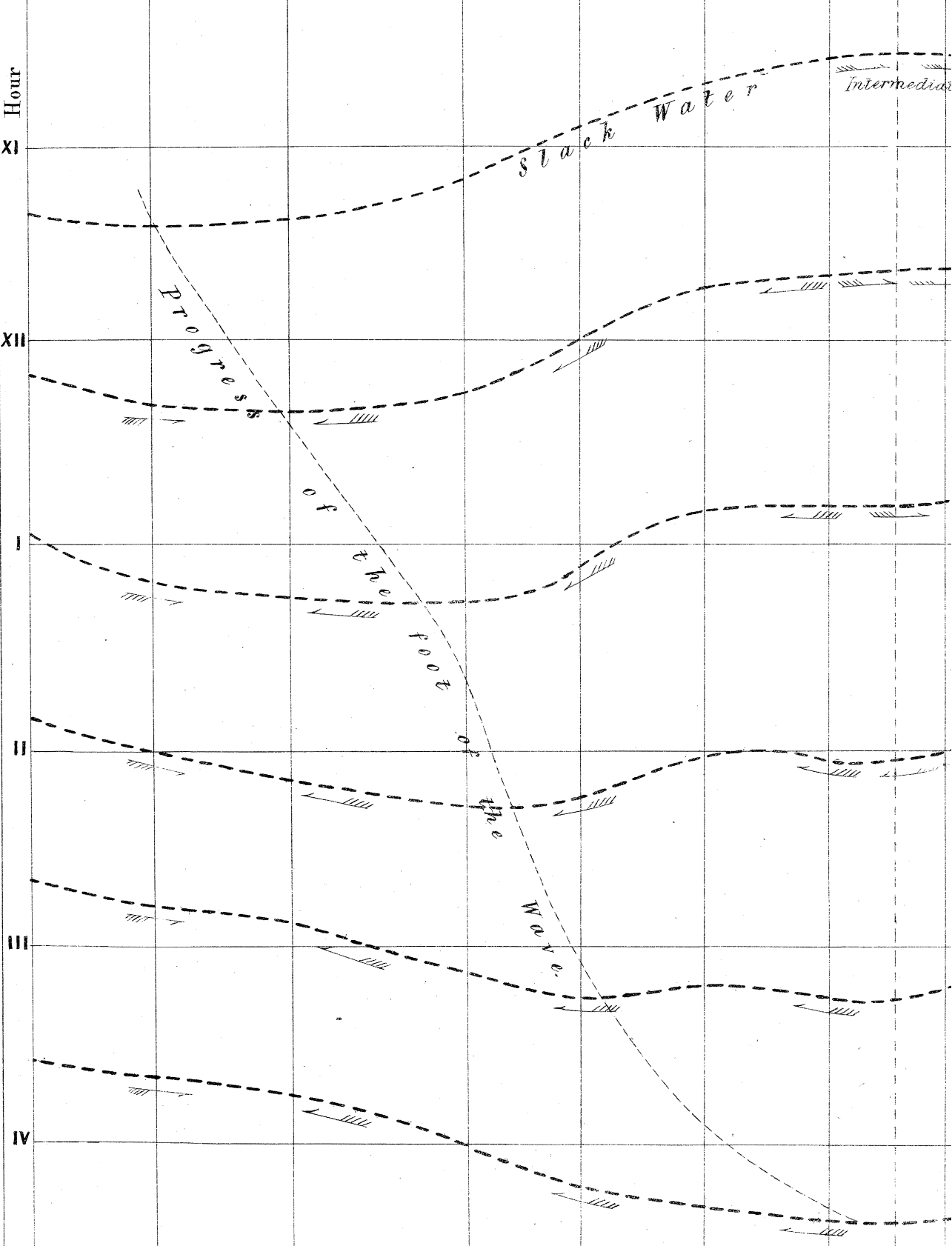
RISING TIDES AT DOVER.



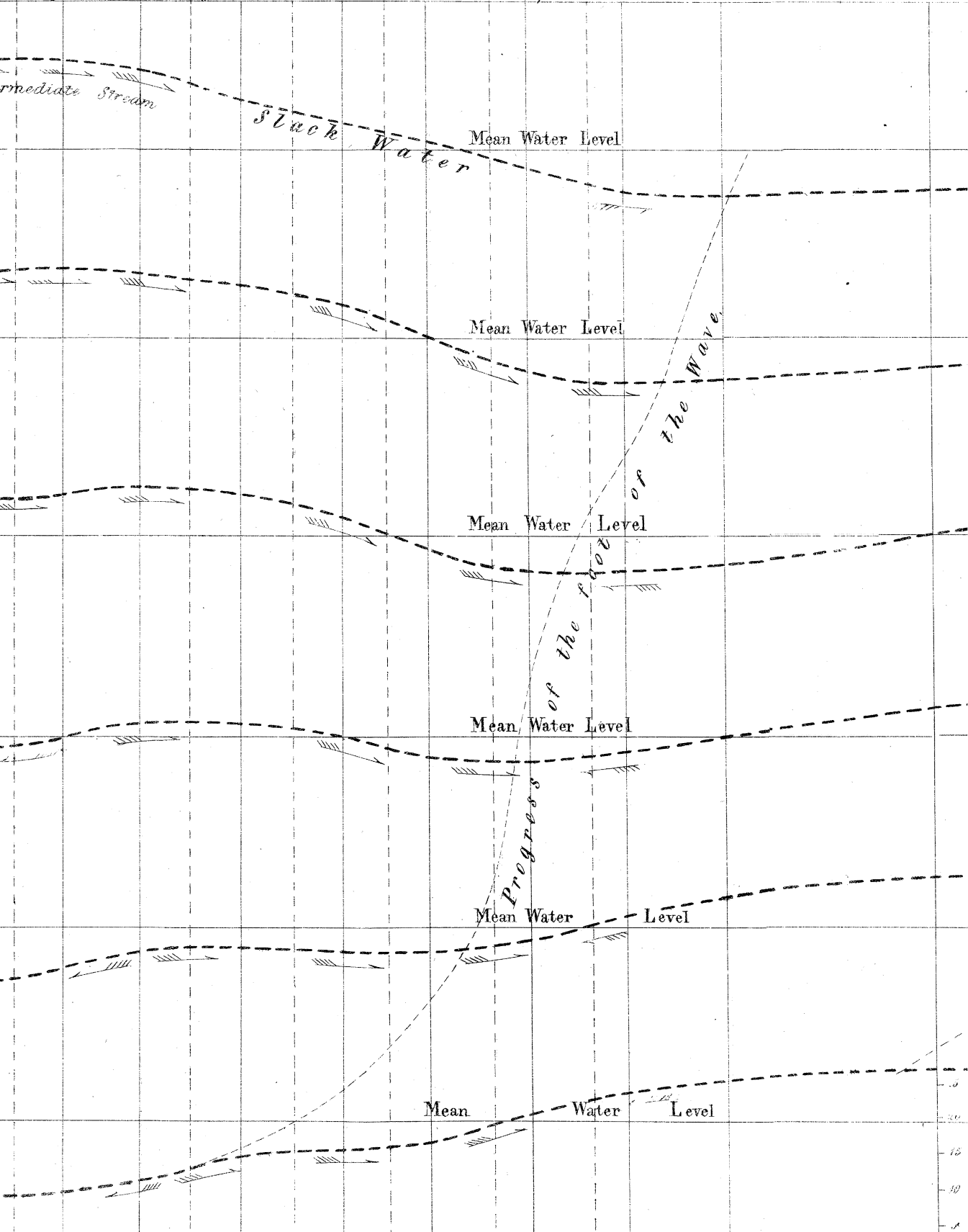
*These sections are THE MEAN of the Wave Lines
they occur upon the English and French Coasts.*



IV.20	V.0	V.32	VII.0	IX.0	XI.0	XI.6	XI.
20 feet	21 feet	20 feet	17 feet	15 feet	18 feet	25 feet	25
Landsend	Deadman Pt	Start	Portland	Poole	Selsea Bill	Beachy Hill	Dungeness



XI.0	XI.14	XI.30	XI.0	IX.0	VI.30	V.30	V.0	Correct	IV.E
25 feet	21 feet	14 feet	9 feet	6 feet	1 feet	12 feet	14 feet		16 feet
Dungeness	Dover	Ramsgate	Harwich	Southwold	Cromer	Spurn Point			



IV Establishment <i>16 feet.</i>	III <i>15 feet.</i> Range	II <i>15 feet.</i>	I <i>15 feet.</i>
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PLAN 3

Exhibiting the Exaggerated form of the surface of the Tide-wave between Cromarty and the Lands End; at every hour of the tide. (Dover Establishment.)

From data in Professor Whewell's paper on the Tides *Phil. Trans* 1836, and in the *Annuaire des Marées des Côtes de France* 1848. etc.

the direction of the stream excepted

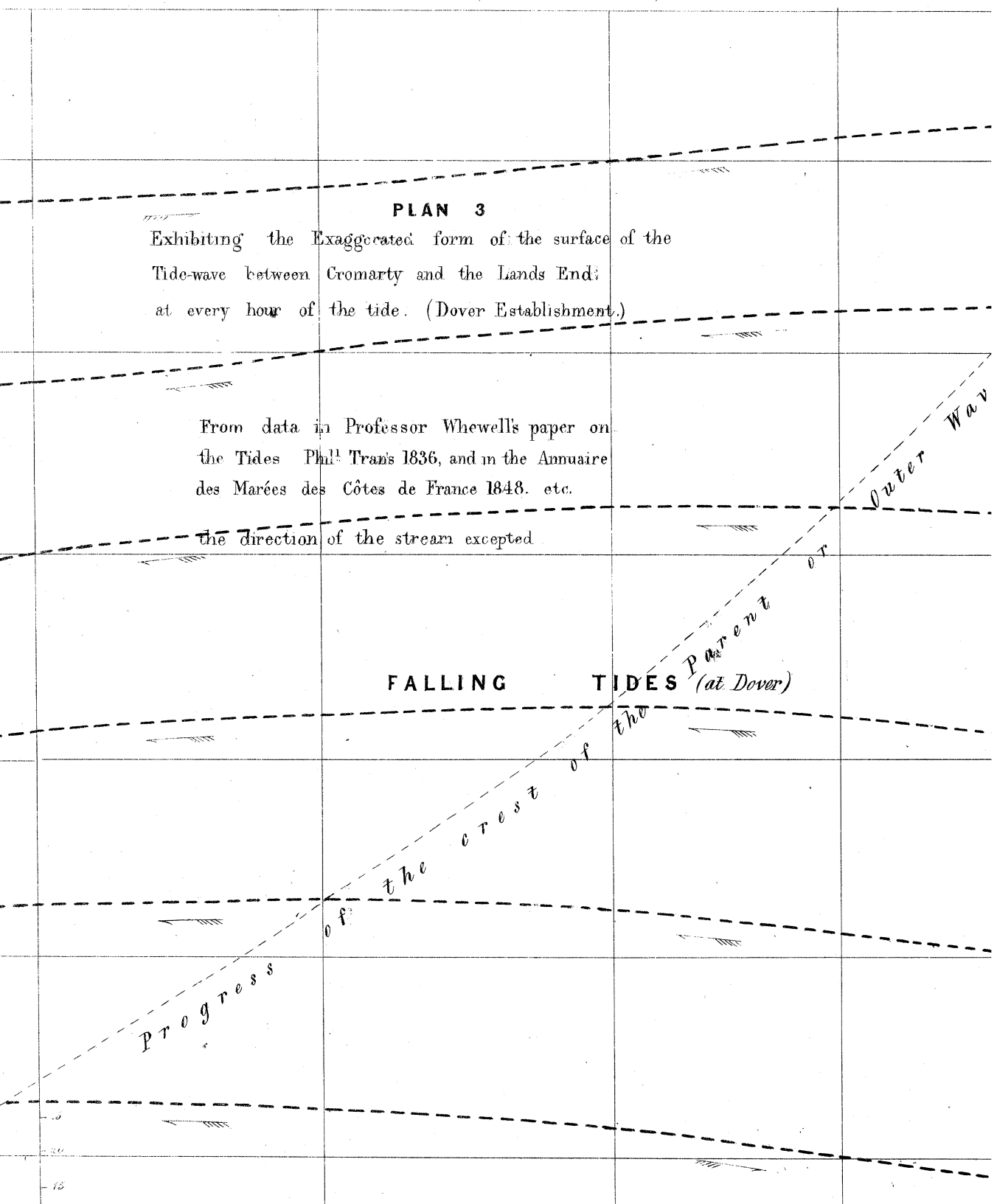
FALLING TIDES *(at Dover)*

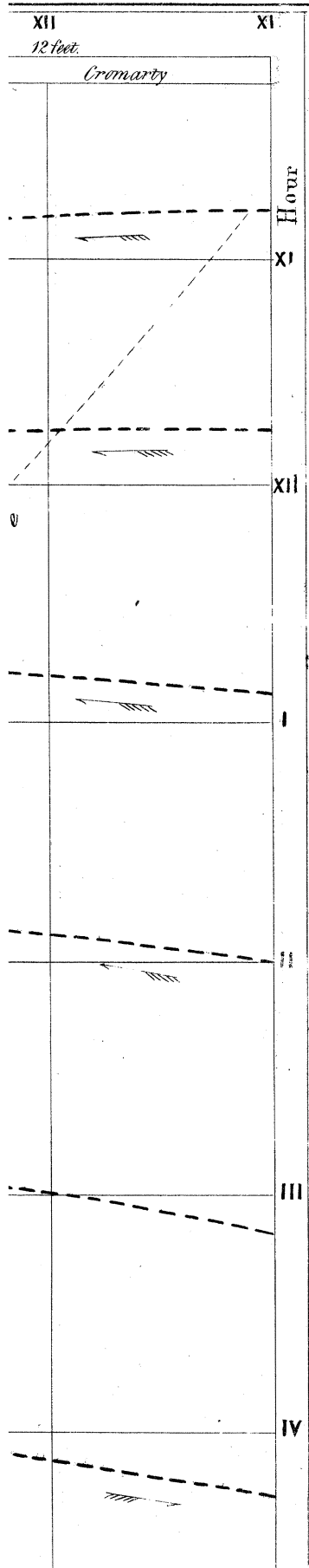
of the crest of the

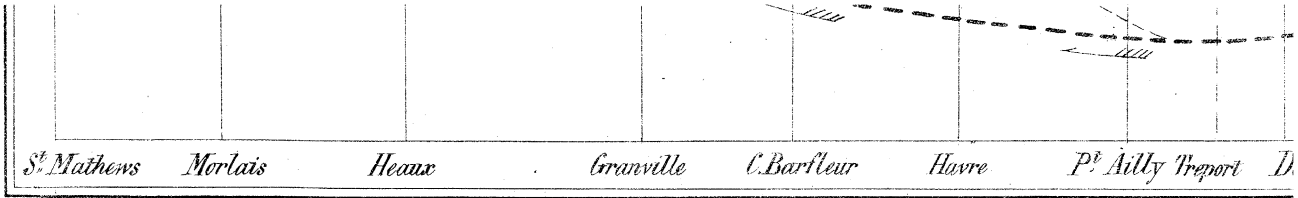
Progress

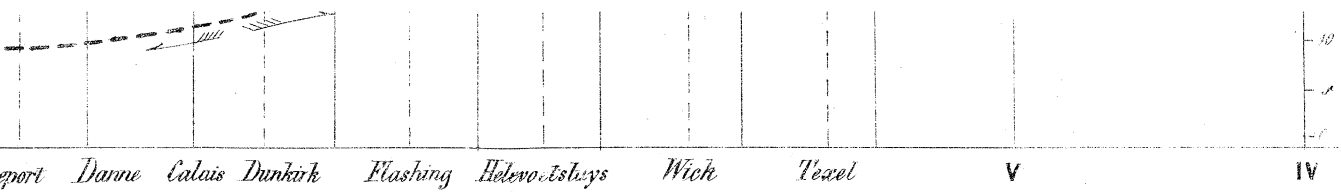
Outer Wave

10 Scale of feet





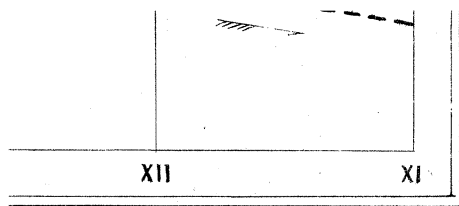




To accompany Cap^t. Beechey's report upon the Tides of the English Channel.

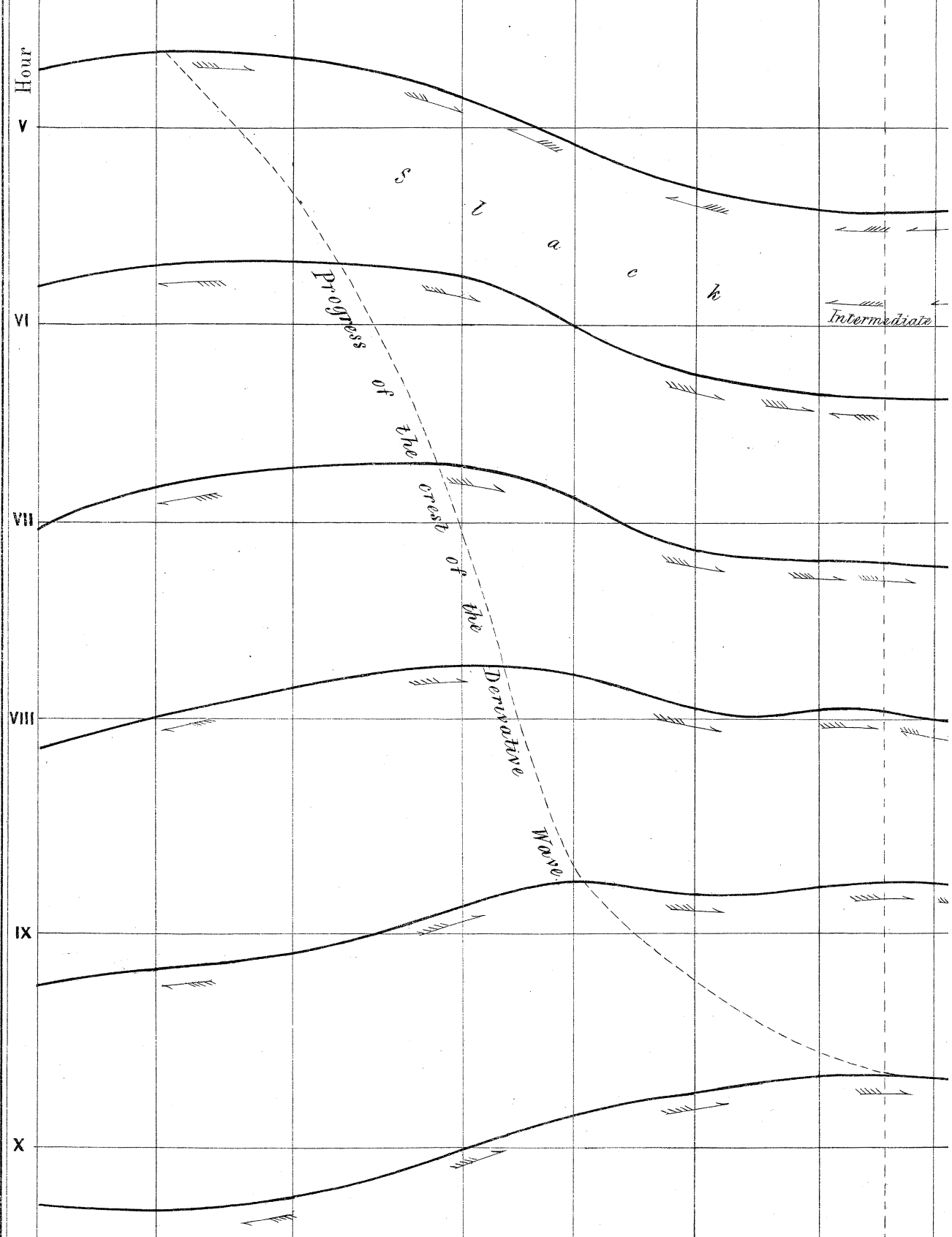
10 Scale of feet
- 10
- 5
- 0
IV III II I

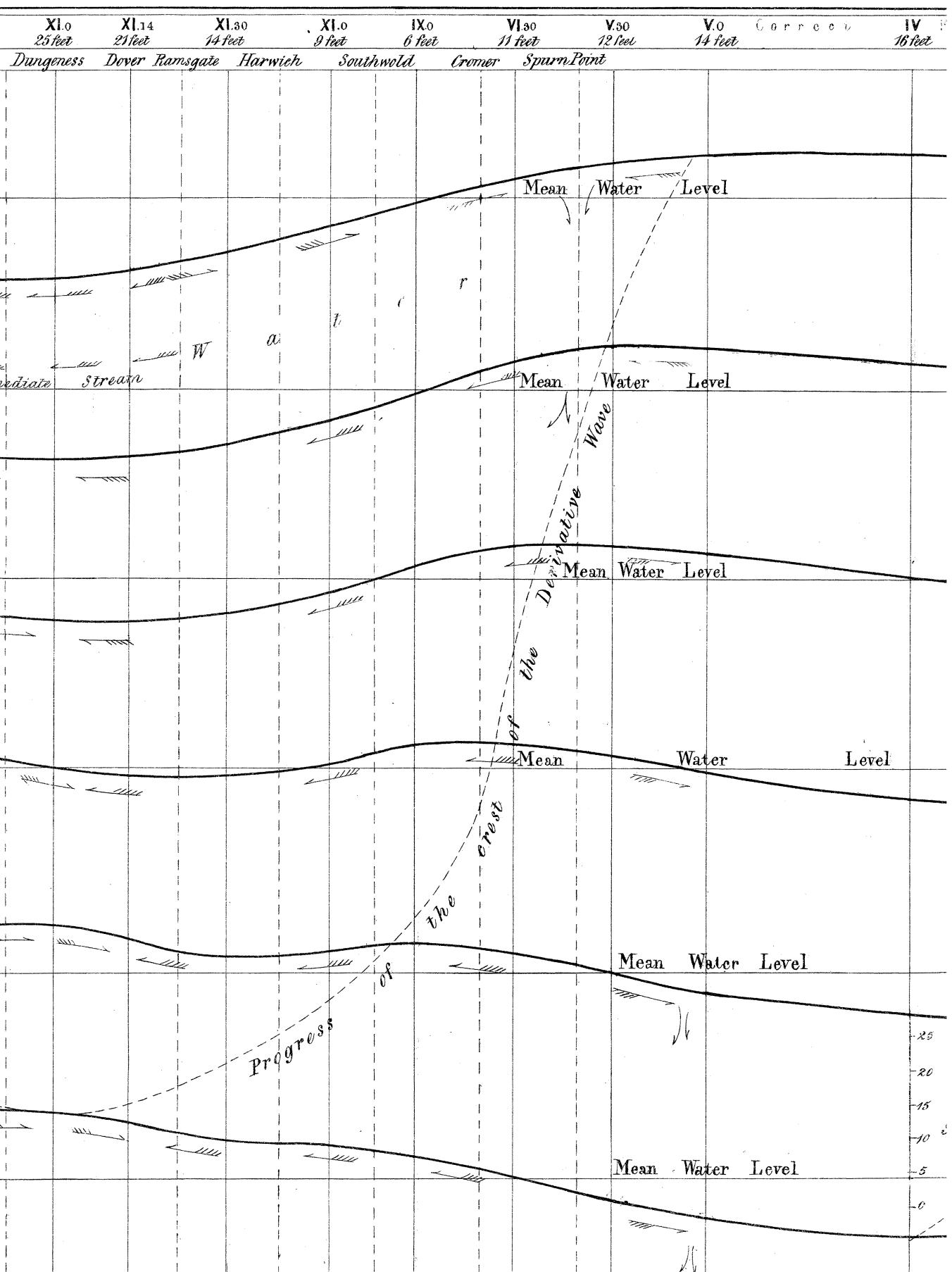
net.



J. Bastre, Litho.

IV ²⁰ 20 feet	V ⁰ 21 feet	V ³² 20 feet	VII ⁰ 17 feet	IX ⁰ 15 feet	XI ⁰ 18 feet	X ⁴⁶ 25 feet	XI ⁰ 25 feet
Landsend	Deadman Pt ^r	Start	Portland	Poole	Selsea Bill	Beachy Head	Dungeness





IV Establishment
16 feet

III
15 feet

Range

II
15 feet

I
13 feet

PLAN 4

Exhibiting the Exaggerated form of the surface of the Tidewave between Cromarty and the Lands End at every hour of the tide. (Dover Establishment.)

Compiled From data in Professor Whewell's paper on the Tides Phil. Trans. 1836. and in the Annuaire des Marées des Côtes de France 1848. etc the direction of the stream excepted

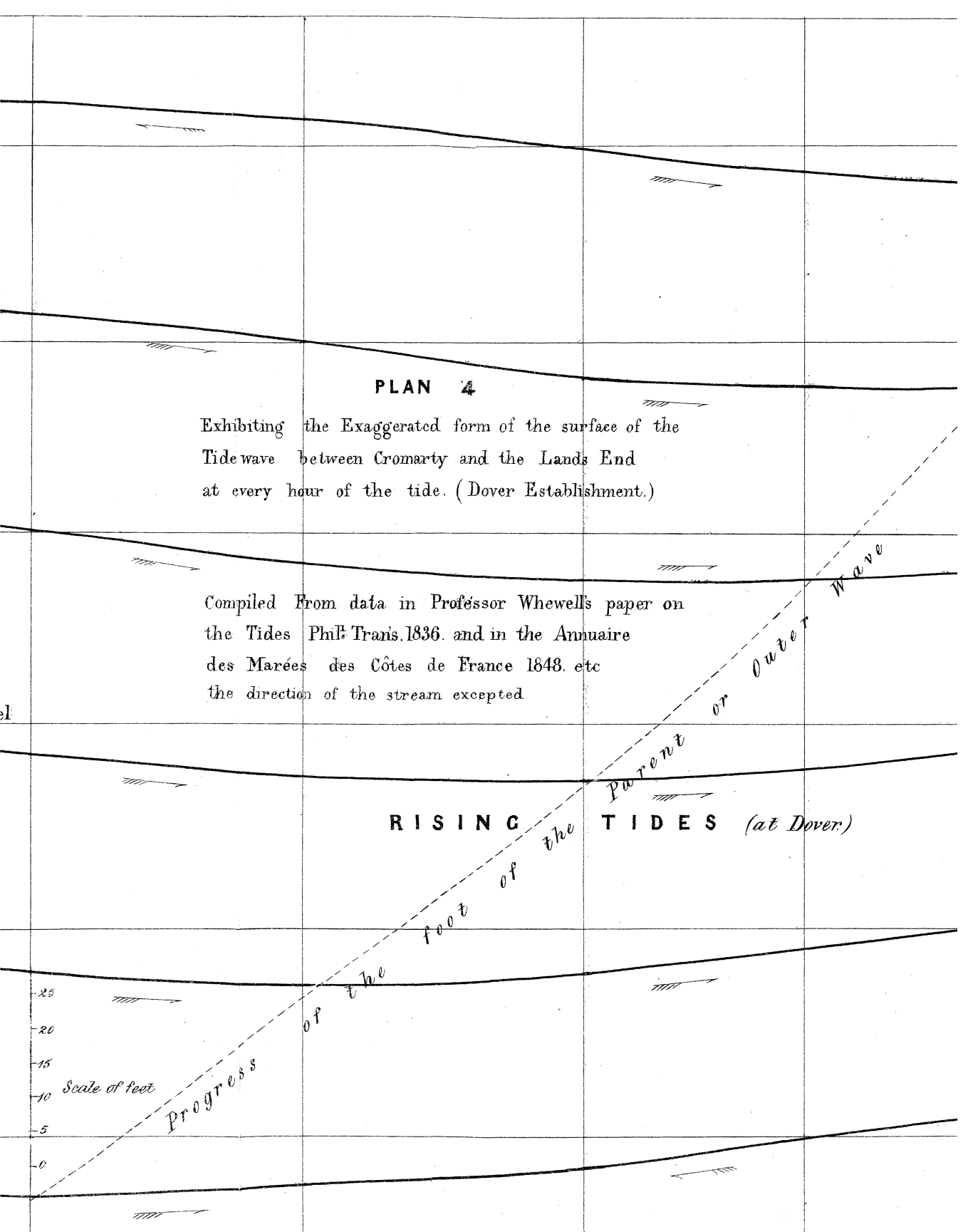
RISING TIDES (at Dover)

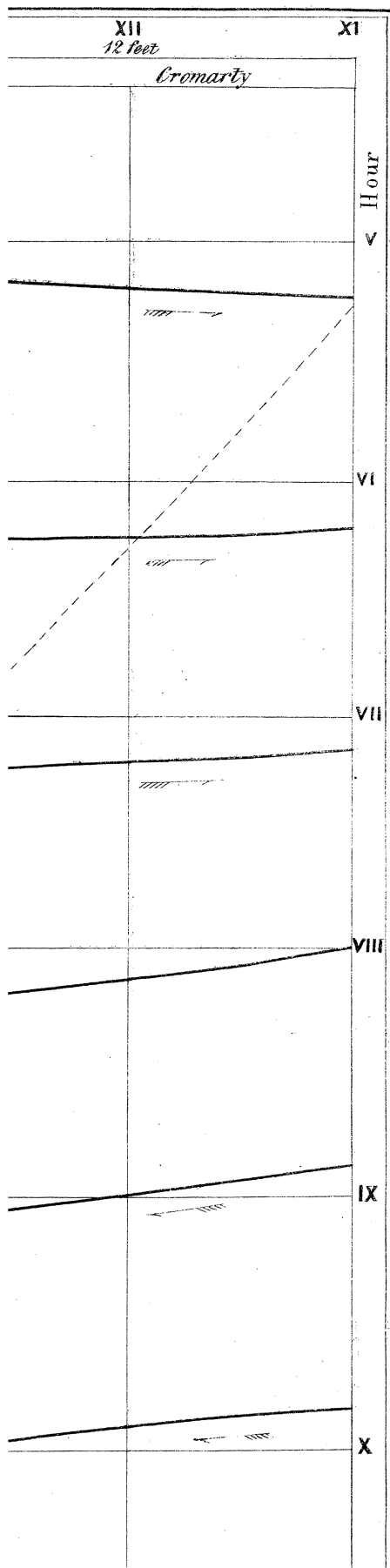
25
20
15
10
5
0
Scale of feet

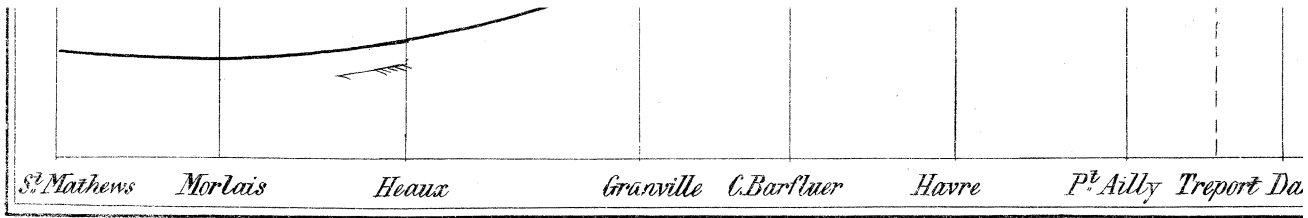
Progress

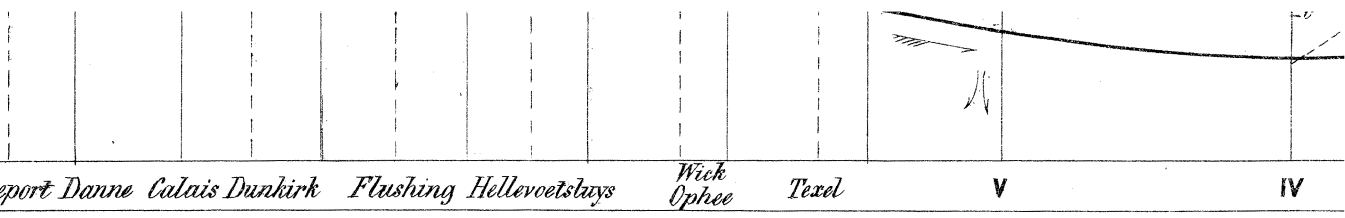
of the foot of the

Parent or Outer Wave

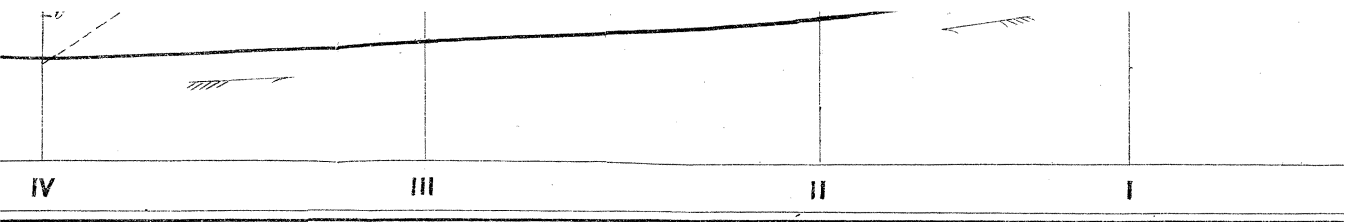




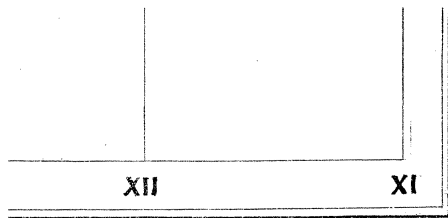




To accompany Capt Beechey's report upon the Tides of the English Channel

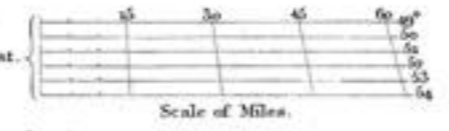


et



J. Basire, Litho.

CHART Showing the situation of the Places at which TIDAL OBSERVATIONS have been made; and also the direction in which the streams (ebb & flood) turn.



- References.
- Revolving Stream.
 - Inward stream turn.
 - Outward stream turn.

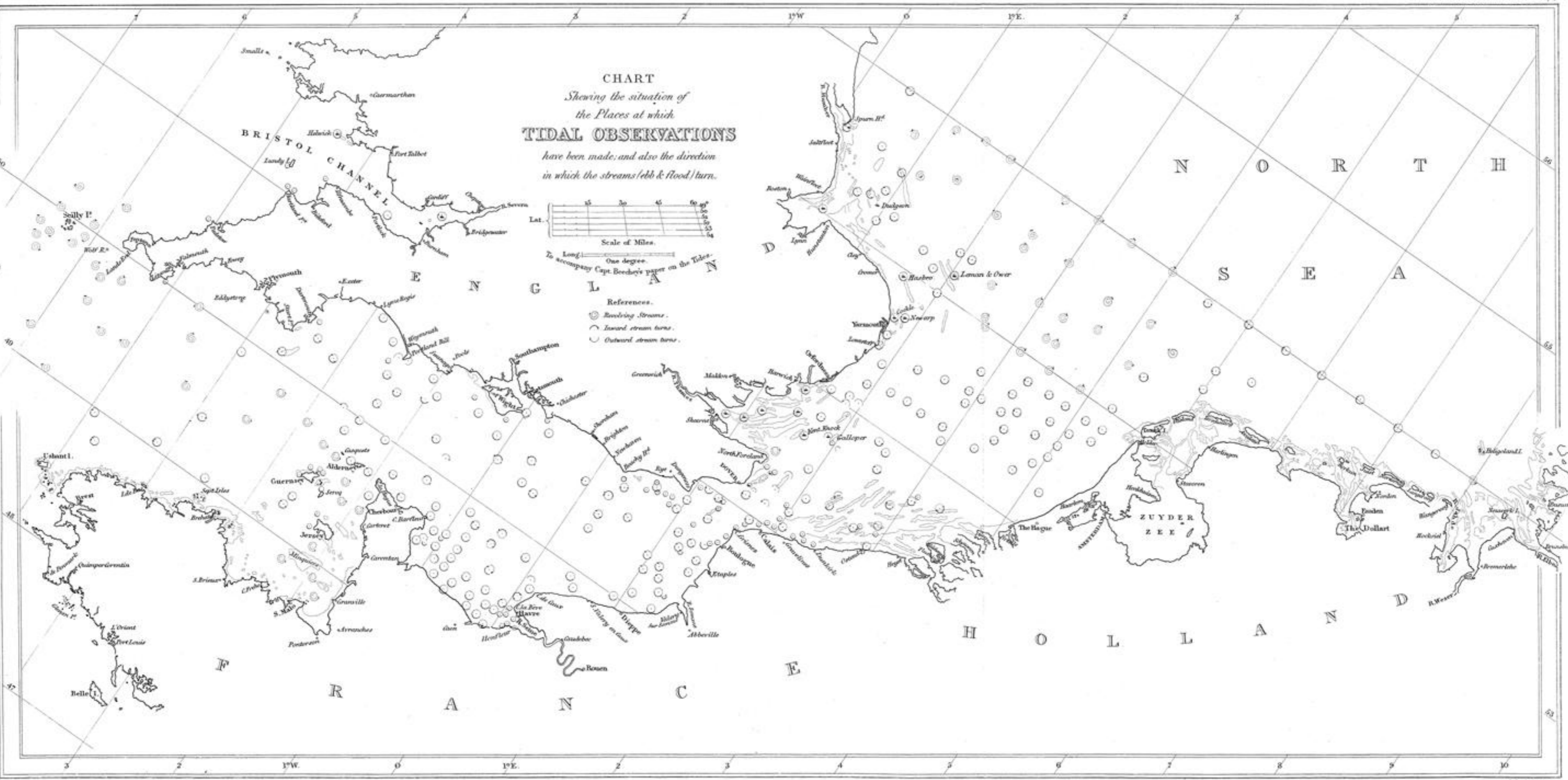
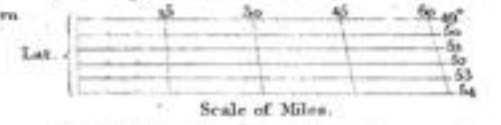


CHART Shewing the situation of the Places at which TIDAL OBSERVATIONS have been made: and also the direction in which the streams run at 1 Hour after High Water at Dover.



- References.
● Receiving Streams.
○ Inward stream turns.
○ Outward stream turns.

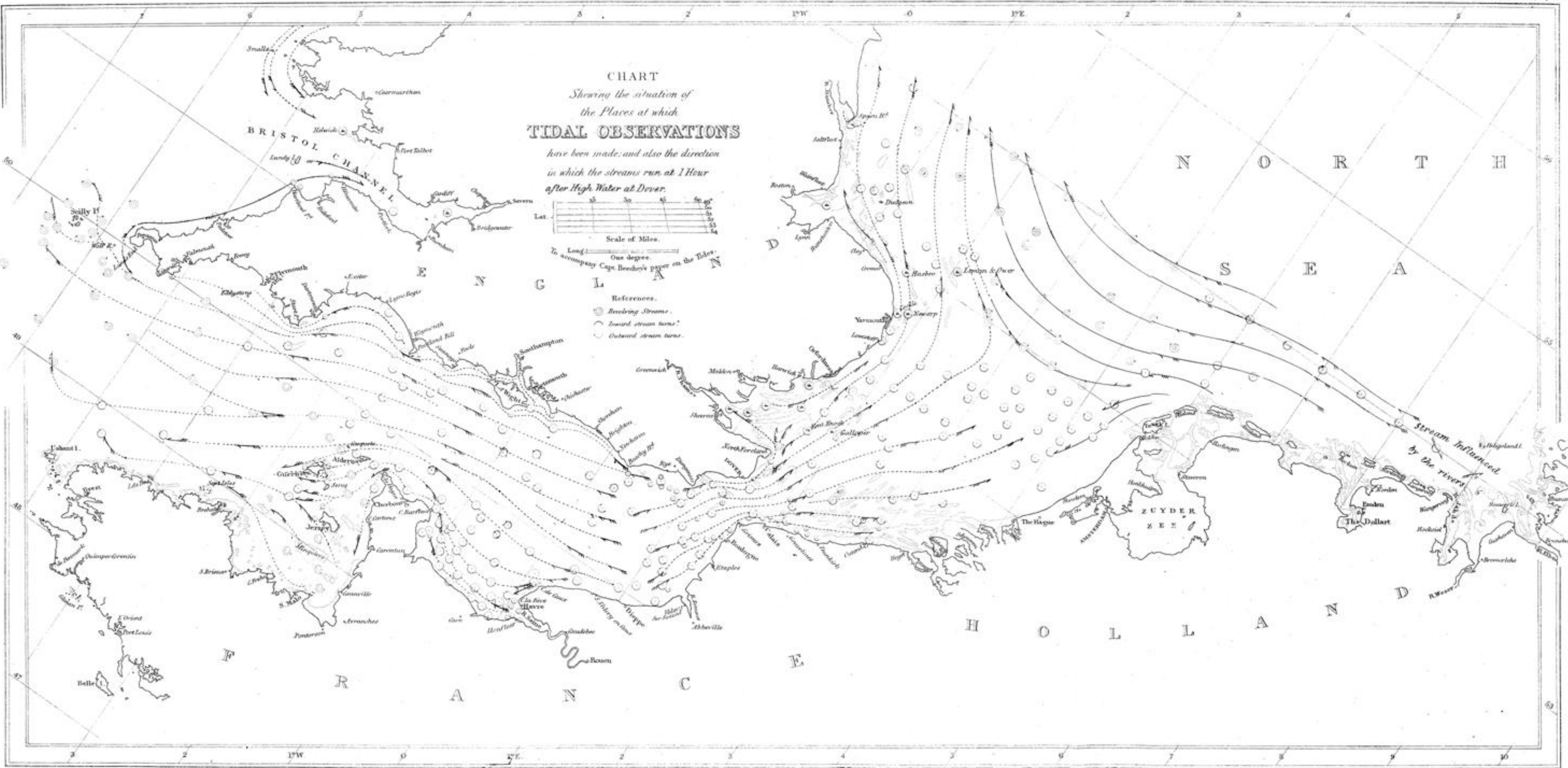
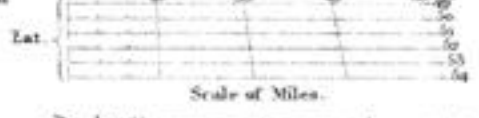


CHART Shewing the situation of the Places at which TIDAL OBSERVATIONS have been made: and also the direction in which the streams run at 2 hours after High Water at Dover.



- References.
- Rounding stream.
 - Inward stream bars.
 - Outward stream bars.

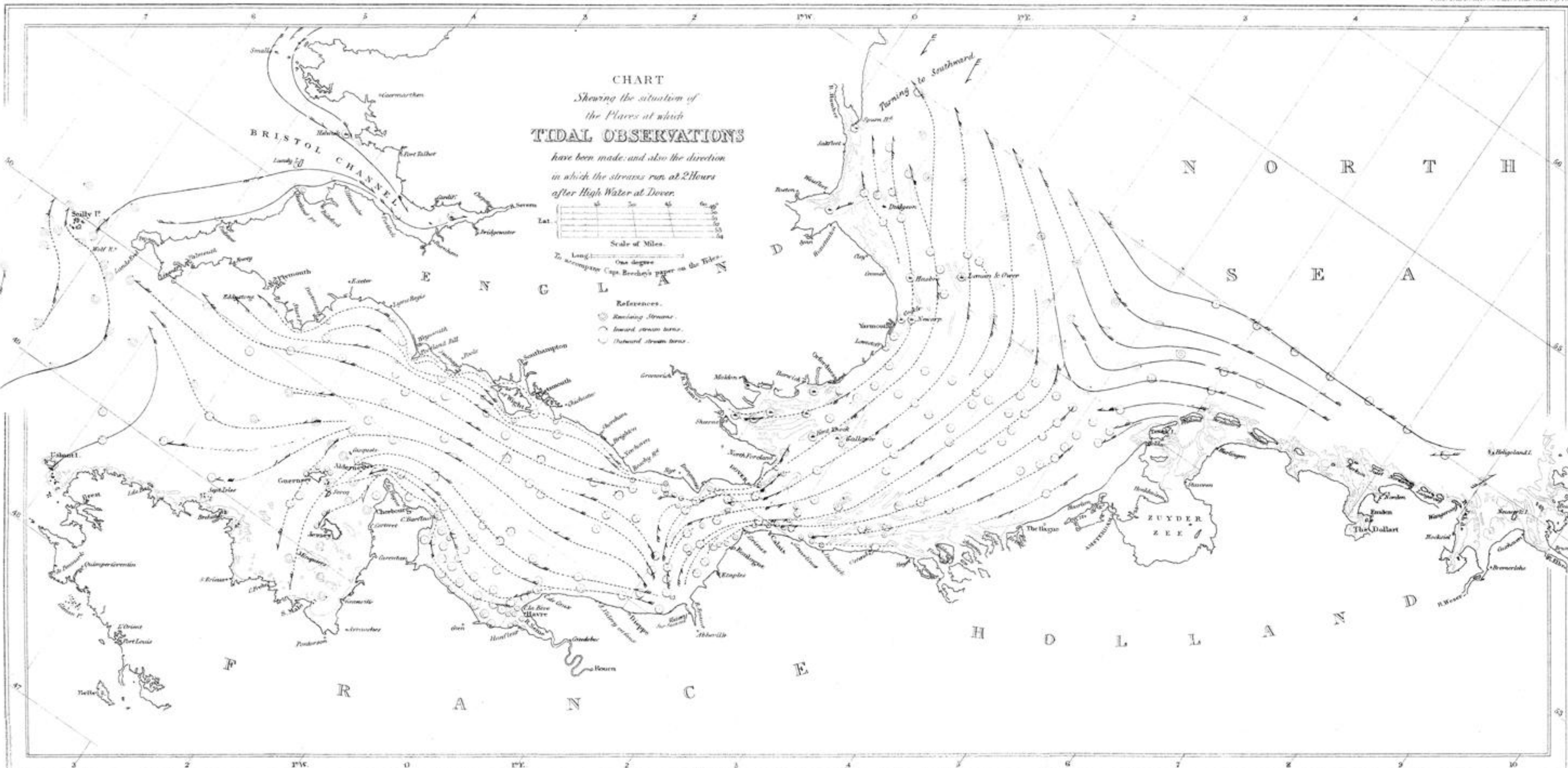
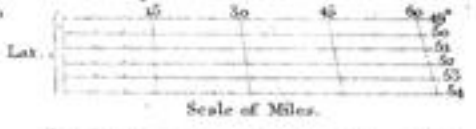


CHART Showing the situation of the Places at which TIDAL OBSERVATIONS have been made, and also the direction in which the streams run at 3 Hours after High Water at Dover



To accompany Capt. Beecher's paper on the Tides

References.

- Rowing Stream.
- Inward stream borne.
- Outward stream borne.

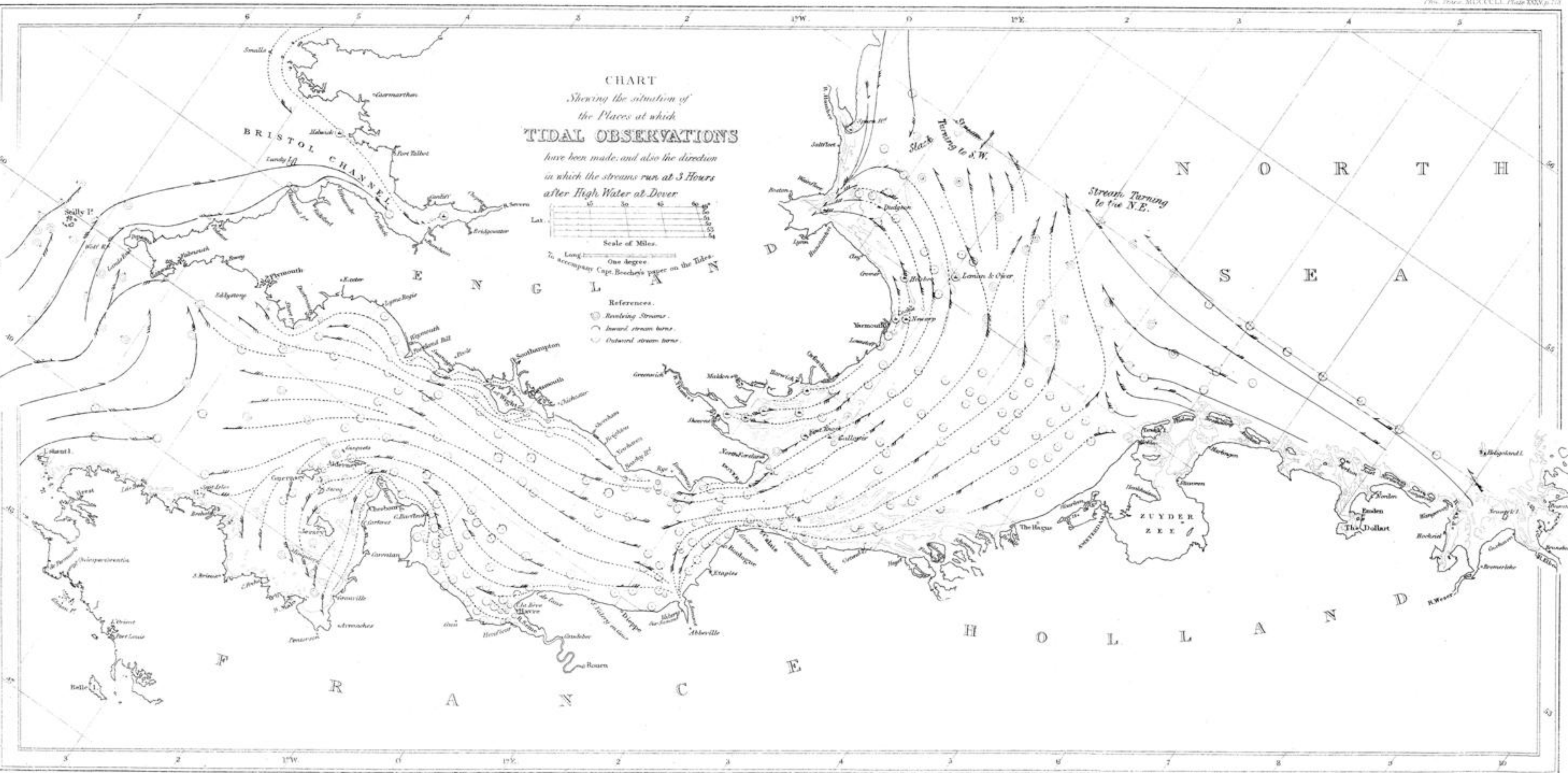
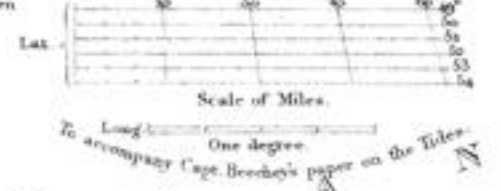


CHART Shewing the situation of the Places at which **TIDAL OBSERVATIONS**

*have been made, and also the direction
in which the streams run at 6 hours
after High Water at Dover*



- References.
- Reaching Streams.
 - Inward stream turns.
 - Outward stream turns.

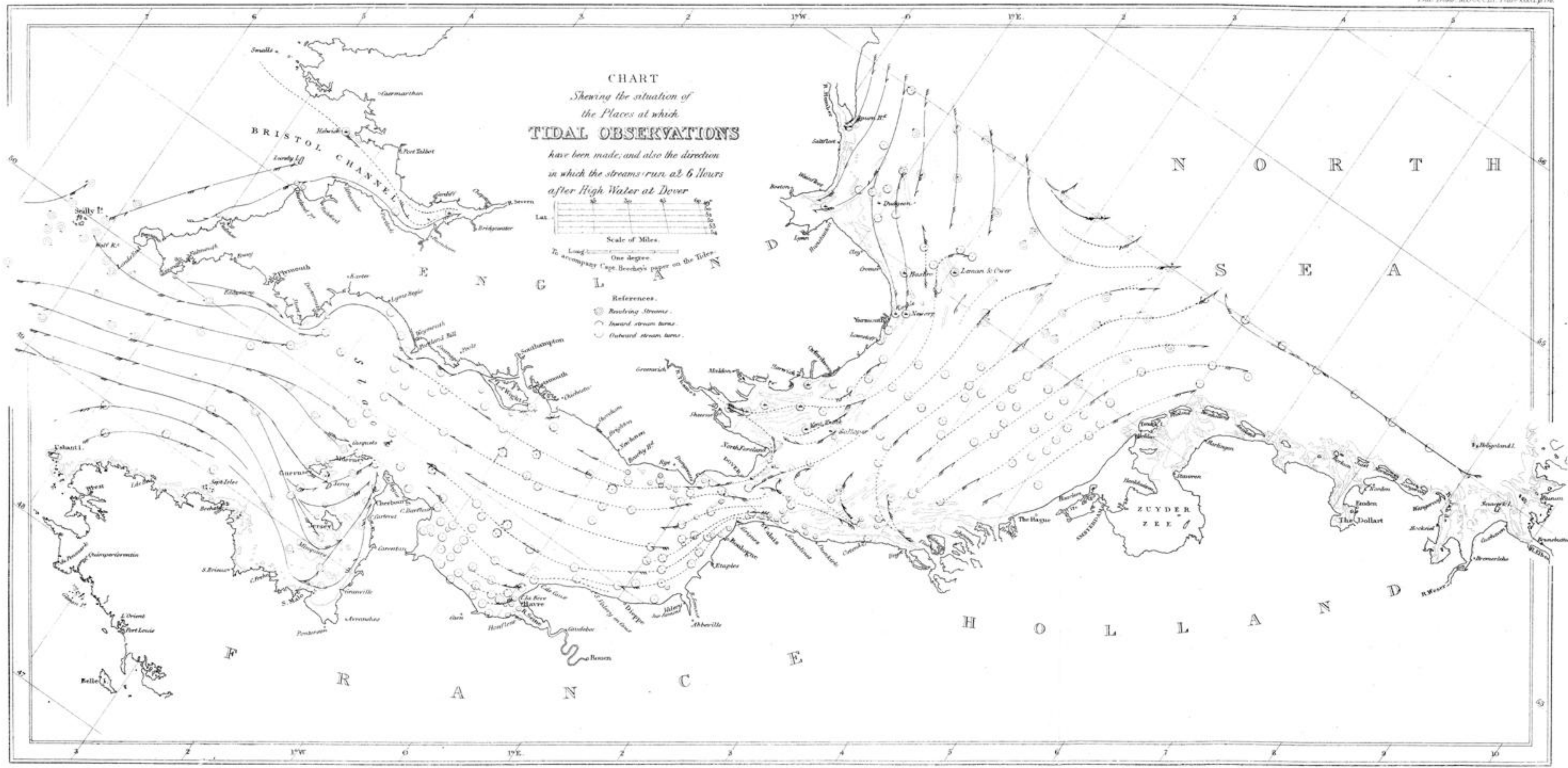
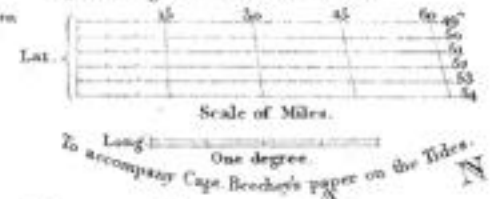


CHART Shewing the situation of the Places at which TIDAL OBSERVATIONS have been made; and also the direction in which the streams run at 5 hours before High Water at Dover.



- References.
- Receiving Stream.
 - Inward stream borne.
 - Outward stream borne.

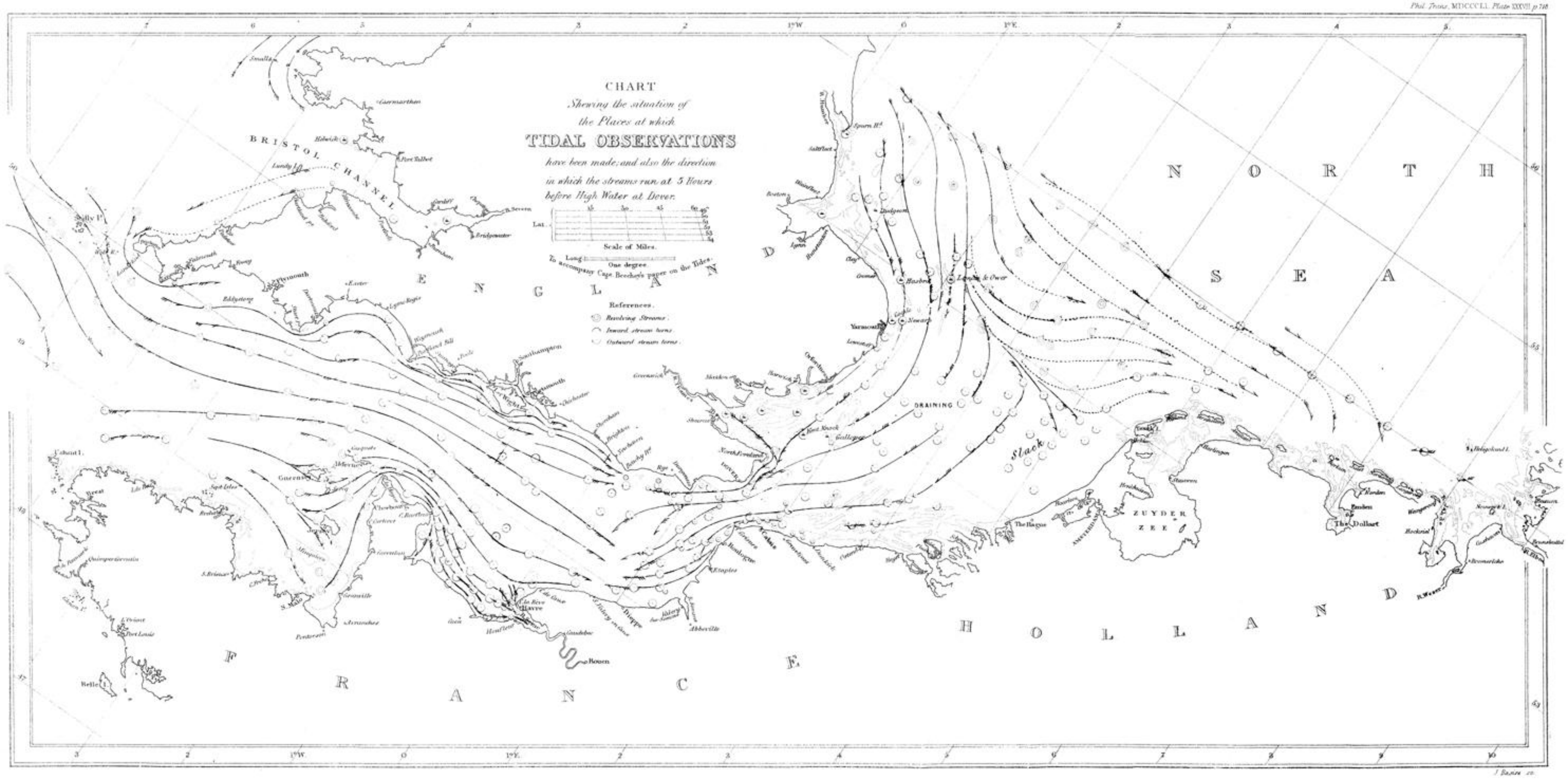
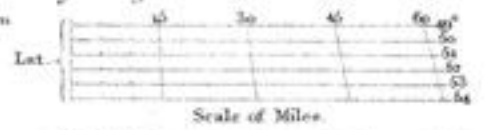


CHART Showing the situation of the Places at which TIDAL OBSERVATIONS have been made: and also the direction in which the streams run at 3 hours before High Water at Dover.



- References
- Reversing Streams.
 - Inward stream turns.
 - Outward stream turns.

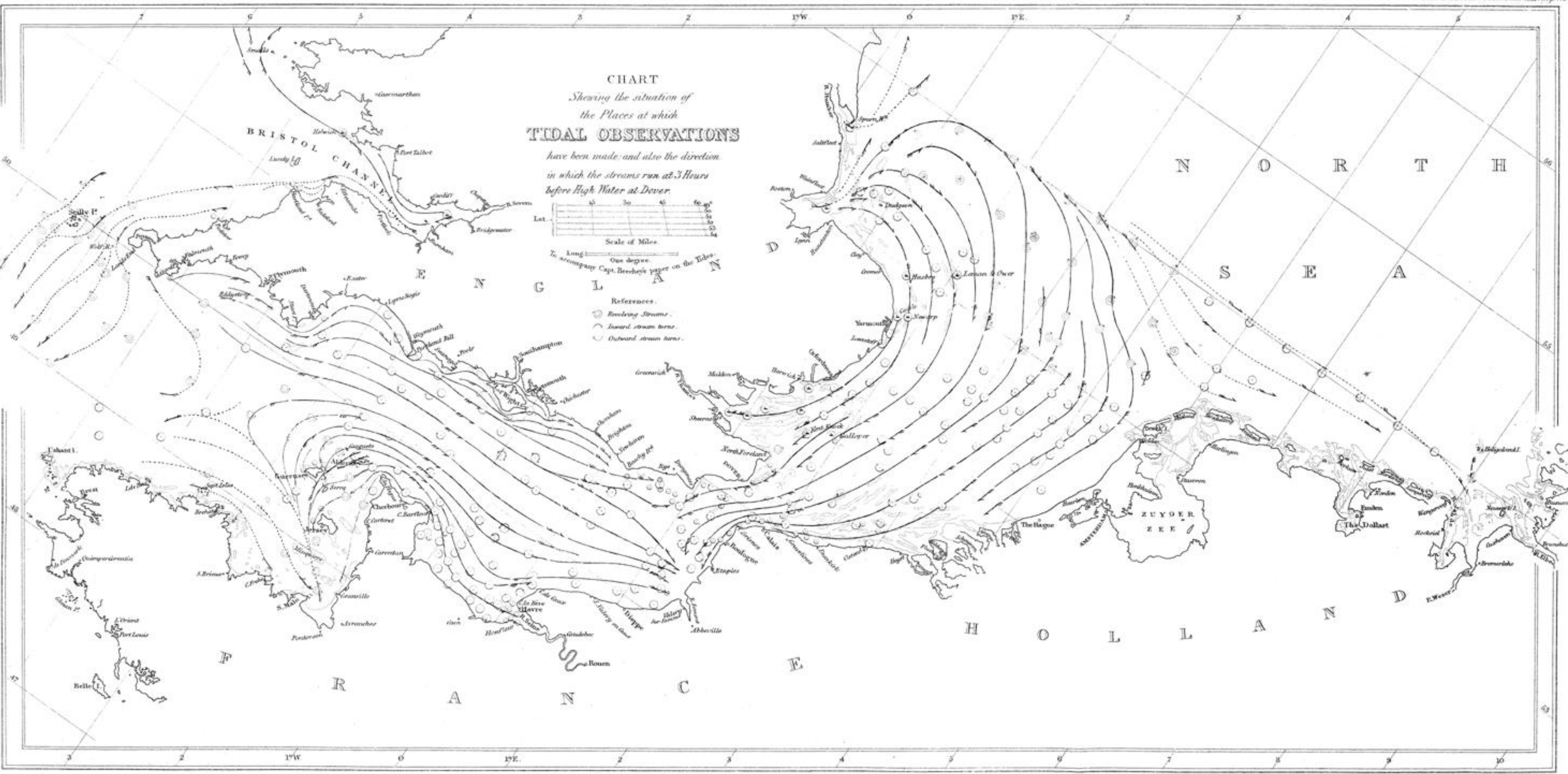
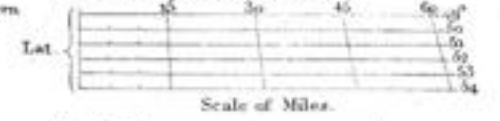


CHART Shewing the situation of the Places at which **TIDAL OBSERVATIONS**

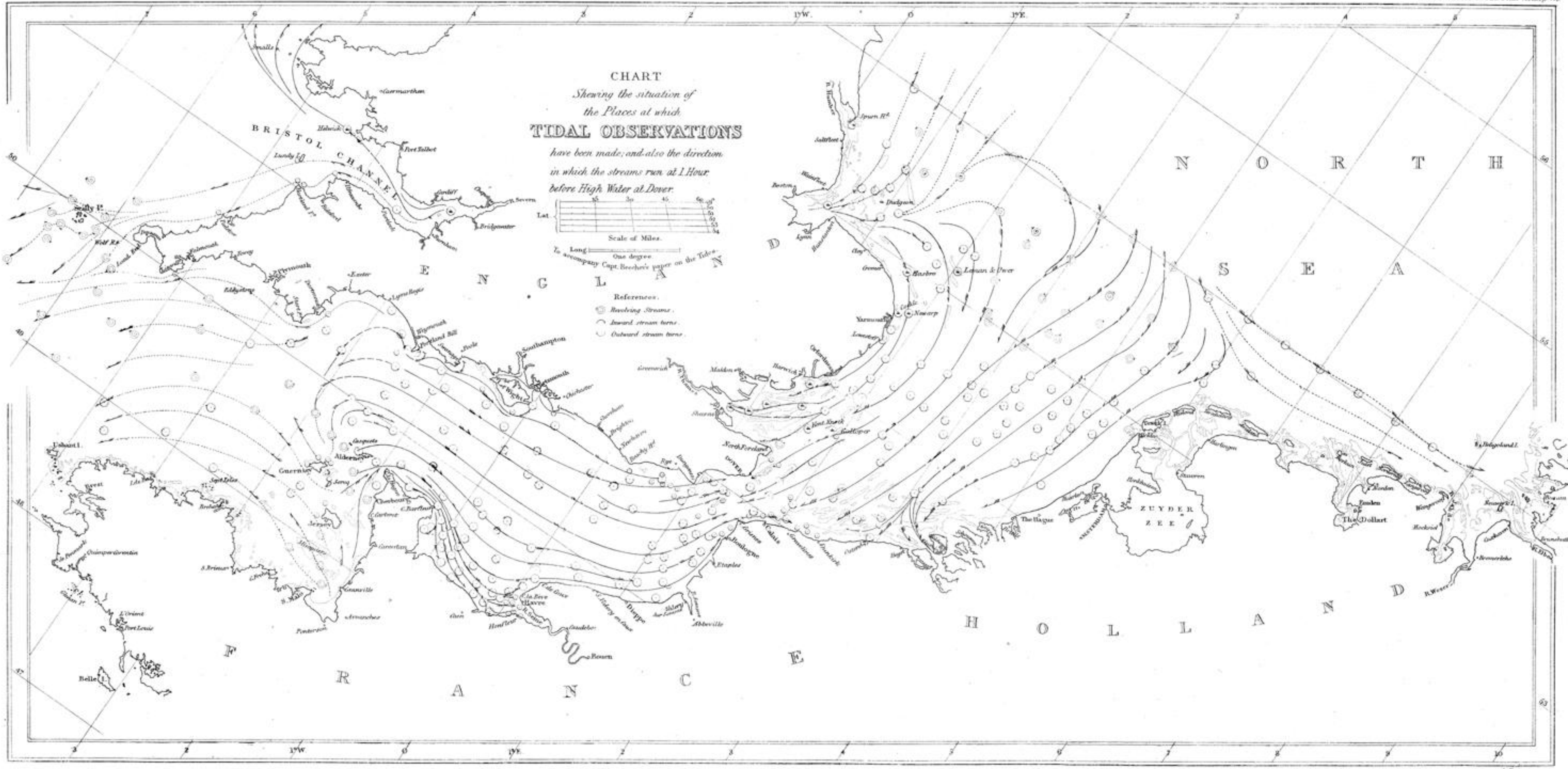
have been made; and also the direction
in which the streams run at 1 Hour
before High Water at Dover.



Lat. ————
Long. ————
to accompany Capt. Beecher's paper on the Tides

References.

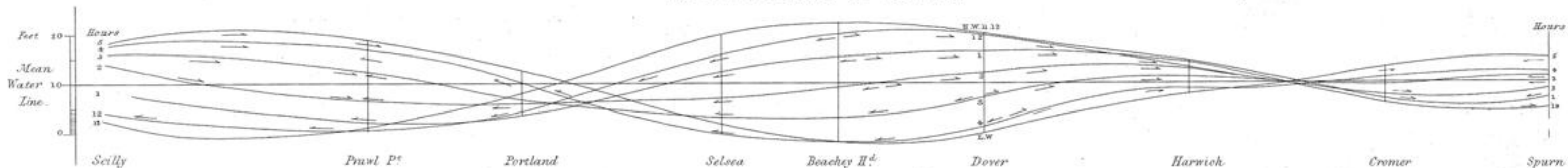
- ⊙ Reaching Streams.
- Inward stream turns.
- Outward stream turns.



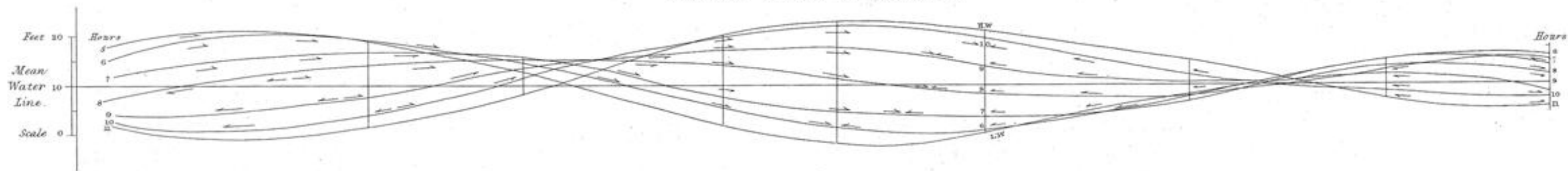
PLAN 2.

Shewing the form of the surface of the water, and the direction of the stream between Scilly and Spurn P^{ts} at each hour of the Tide.

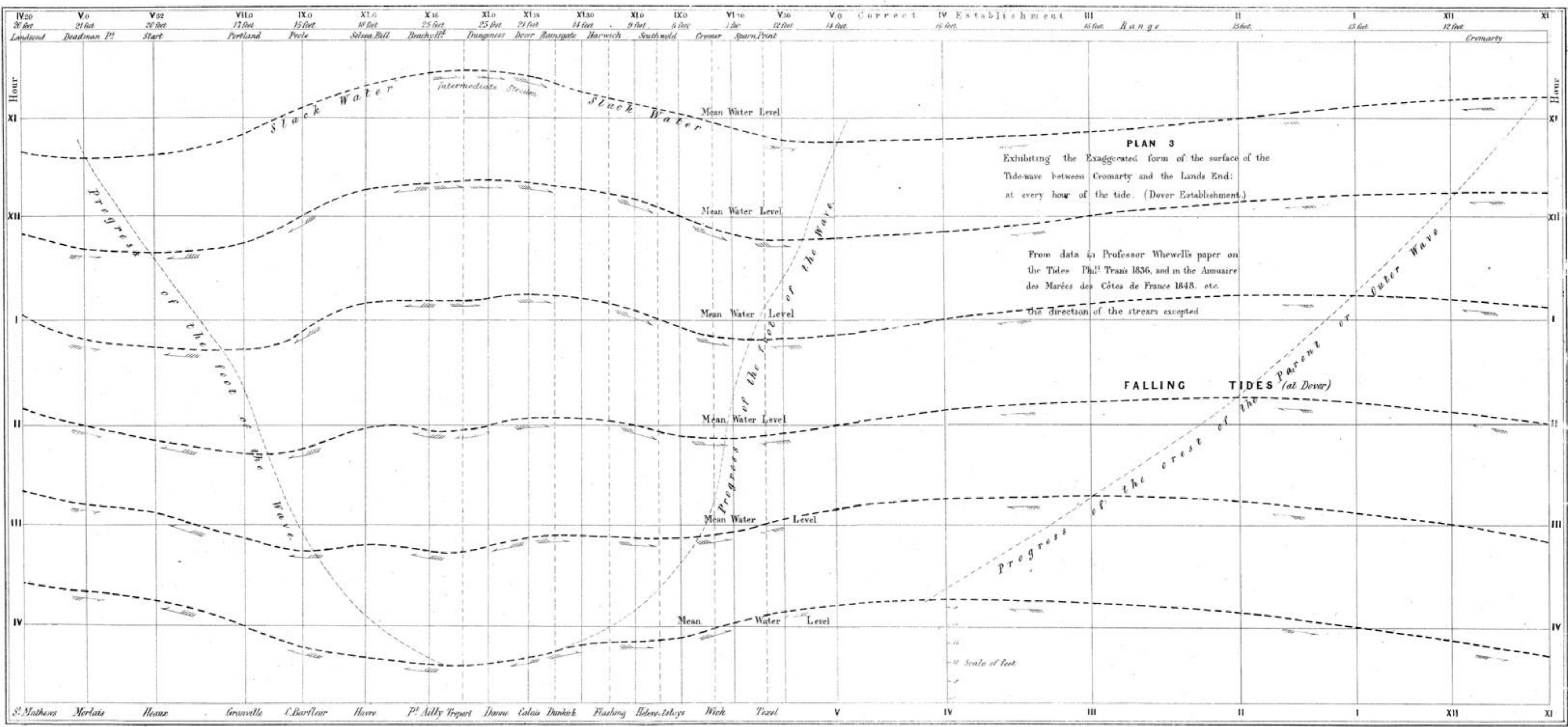
FALLING TIDES AT DOVER.



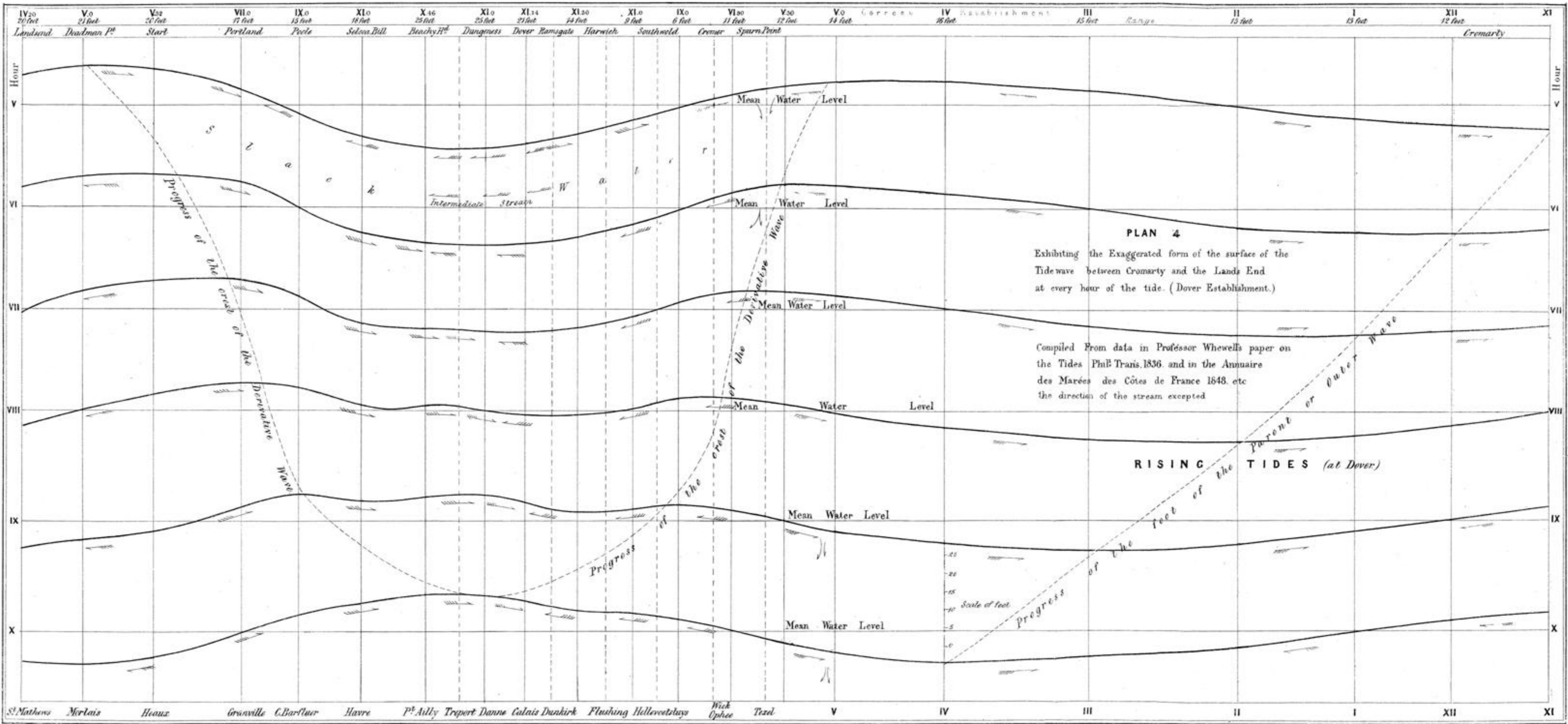
RISING TIDES AT DOVER.



These sections are THE MEAN of the Wave Lines as they occur upon the English and French Coasts.



To accompany Cap^t. Beechey's report upon the Tides of the English Channel.



To accompany Capt Beechey's report upon the Tides of the English Channel