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TIDES AND CURRENTS IN SOUTHEAST ALASKA

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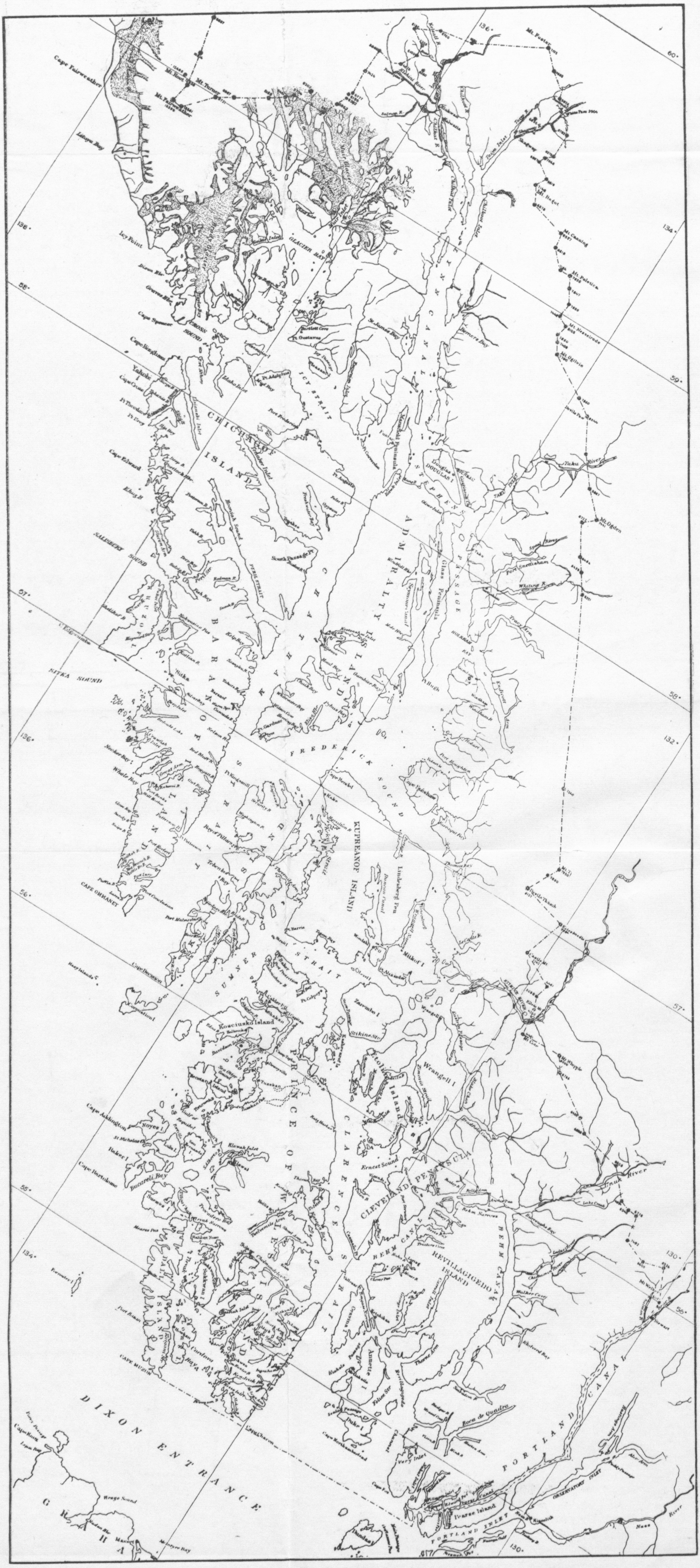

10556—26. (Face p. 1.)

FIG. 1.—Southeast Alaska

TIDES AND CURRENTS IN SOUTHEAST ALASKA

INTRODUCTION

Tidal and current observations have been made at different stations along the many navigable waterways of southeast Alaska, that narrow strip of sea islands and coastland bordering British Columbia, from Dixon Entrance on the south to Glacier Bay and Lynn Canal 300 miles to the north. The earliest tide observations on record for Alaska were taken at Sitka in 1827, from which time until the present day numerous other observations have supplied a comprehensive knowledge of tidal action throughout this area. In connection with hydrographic surveys some few current observations had been made prior to 1925. During this year the first systematic current survey was made, consisting of a reconnaissance of the current action through all the more important waterways of southeast Alaska.

Tidal observations were first needed for the establishment of a plane of reference to which soundings might be reduced, thus permitting all Coast and Geodetic Survey charts of southeast Alaska to show depths of water definitely related to one common datum plane. Aside from their use in the derivation of this datum plane, tides and tidal phenomena were considered of little importance in the early years. With the advancing years the methods of observing were improved by the advent of the automatic tide gauge in 1854, and the adoption of standard time belts about 1885. These improvements made easier the derivation of certain tidal constants from the observations, by means of which future times and heights of tides could be predicted for the tide tables. The large range of tide, and the strong currents characteristic of southeast Alaska are most important factors to be considered in ship navigation, and in the construction and maintenance of docks, wharfs and fish traps.

The purpose of this publication, the first to deal with Alaskan waters, is to make available the tidal and current data collected by, and in the files of the Coast and Geodetic Survey for the use of the scientist, the engineer, the mariner, and the public generally.

This volume constitutes the fourth of a series of similar publications dealing with tidal and current observations made through the more important waterways of the United States and its territories. The first volume of this series was "Tides and Currents in New York Harbor," Special Publication No. 111; the second was "Tides and Currents in San Francisco Bay," Special Publication No. 115; and the third was "Tides and Currents in Delaware Bay," Special Publication No. 123. In the first volume of this series two chapters are devoted to a discussion of the general features of tides and currents. These chapters are reprinted in this volume as an appendix.

Attention is also called to two other Coast and Geodetic Survey publications relating to Alaska, namely, "Tide Tables, Pacific Coast," and "Current Tables, Pacific Coast." These volumes are issued annually in advance of the year for which their tables are computed. Another publication of particular interest to the engineer, dealing with the tidal bench marks of Alaska, will be available to the public at a later date.

Part I.—TIDES IN SOUTHEAST ALASKA

By R. W. Woodworth, *Lieutenant (j. g.), United States Coast and Geodetic Survey*

THE WATERWAYS OF SOUTHEAST ALASKA

1. GENERAL CHARACTERISTICS

Southeastern Alaska, embracing a land and water area of approximately 35,000 square miles with its intercommunicating system of waterways and numerous islands, forms the northern link in that great chain of protected waterways popularly known as the Inside Passage, which stretches 800 sea miles along the Pacific coast of North America from Puget Sound to the Gulf of Alaska.

Five deep-water entrances, four large and one small, give ingress to the open-ocean tides. The largest and most southerly of these passageways from the sea is Dixon Entrance, 30 miles in average width, through which the tide flows into Clarence Strait and the various small passages and canals contiguous to Revillagigedo Channel. A hundred miles to the north are the adjoining large passageways of Sumner and Chatham Straits. The former and southerly of these two carries the incoming open-ocean tidal flow in a northerly direction to Point Barrie, where Keku Strait diverts a small part, while the main flow continues eastward to Zarembo Island, where it divides to follow three passages—south through Snow Passage to Clarence Strait, north into Wrangell Narrows, and eastward toward Wrangell. Chatham Strait entrance opens a wide and unobstructed passage running almost due north to the head of Lynn Canal, 200 miles distant. Past Kuiu Island the main incoming tidal flow splits, part moving eastward up Frederick Sound to Stephens Passage, and part continuing north through Chatham Strait. Two more diverting passages enter Chatham Strait from the sea; one, the narrow waterway of Peril Strait, which separates Baranof and Chichagof Islands, the other the large deep-water passage through Icy Strait and Cross Sound. Several extremely narrow, though navigable passages, serve as highways between the main waterways heretofore mentioned. The more important of these are: Snow Passage, which connects Sumner and Clarence Straits; Wrangell Narrows, connecting Sumner Strait and Frederick Sound; and Sergius Narrows, a part of Peril Strait. In all these narrows the tidal action is materially affected by the sudden constriction of the large volumes of water forced through them by the pressure of the tidal flow coming in from the large water bodies which they connect.

Many differing tidal characteristics may be expected through the passages of southeast Alaska, with its different types of waterways and varying local conditions which exert influences on the action of the tides. The characteristics found in a long arm of the sea, open at either end as is Peril Strait, will differ from those found in an inlet open at one end only as is Lynn Canal. Islands and shoals blocking the tidal flow and converging channel shores are other factors disturbing the normal times and heights of tides. Fresh water discharging into the heads of bays and inlets exerts marked influences on the local tides, these influences proportionate to the quantity of discharge and the size of the tidal waters into which it empties. Small streams are numerous throughout southeast Alaska, but only three rivers of any magnitude are found, these being the Unuk flowing into Behm Canal, the Stikine into Sumner and Stikine Straits, and the Taku River into Taku Inlet. Even these do not discharge any great volumes of water except during the spring flood season. They do, however, discharge quantities of mud and silt with which their waters are laden, this being deposited as the swift river current is halted by the sea. The consequent filling in and shoaling of the salt-water channels off the river mouths is another factor, though an exceedingly slow one, in bringing about changes in the tidal action of the waterways affected. A striking example is the slow encroachment of the Stikine River Delta as it gradually builds out from the river mouth to fill in the once deep-water passage adjoining Wrangell.[1]

Eastern Passage, separating Wrangell Island from the mainland, has had its 2-mile-wide entrance blocked over one-half its width by the advancing mud delta of the Stikine River. Unless the tidal currents through this passage are sufficiently strong to scour out the remaining channel, at some future year Eastern Passage will be sealed at its northern end, converting it into an inlet fed only by the tidal flow from Clarence Strait on the south. This will mean a change in the tidal flow immediately to the north, inasmuch as the volume of water once carried into Eastern Passage must be diverted to some other waterway near by.

Undoubtedly the far-reaching ice fields of the Glacier Bay region contribute definite disturbing effects upon the tide of the immediate vicinity. Unfortunately the commercial unimportance of this area has not permitted the establishment of tidal stations from which to study the tidal action of the waters adjoining this glacier.

In the sections which follow the tides are discussed in detail for the main ship channels; for the principal ports of Ketchikan, Wrangell, Petersburg, Juneau, and Skagway on the inner passages, and Sitka on the outer coast; also for numerous minor waterways. These ports, with the addition of Craig, have been or are at present tidal stations of fairly long duration, allowing their tidal values to be used as standards with which to compare and correct those values obtained for the many short-period stations.

Of these stations, Ketchikan, at which the longest series of tidal observations in southeast Alaska has been recorded, will be considered the principal station for that area, and as such its various tidal characteristics will be treated separately and in greater detail than those of any other station.

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[1] See Fig. 1.

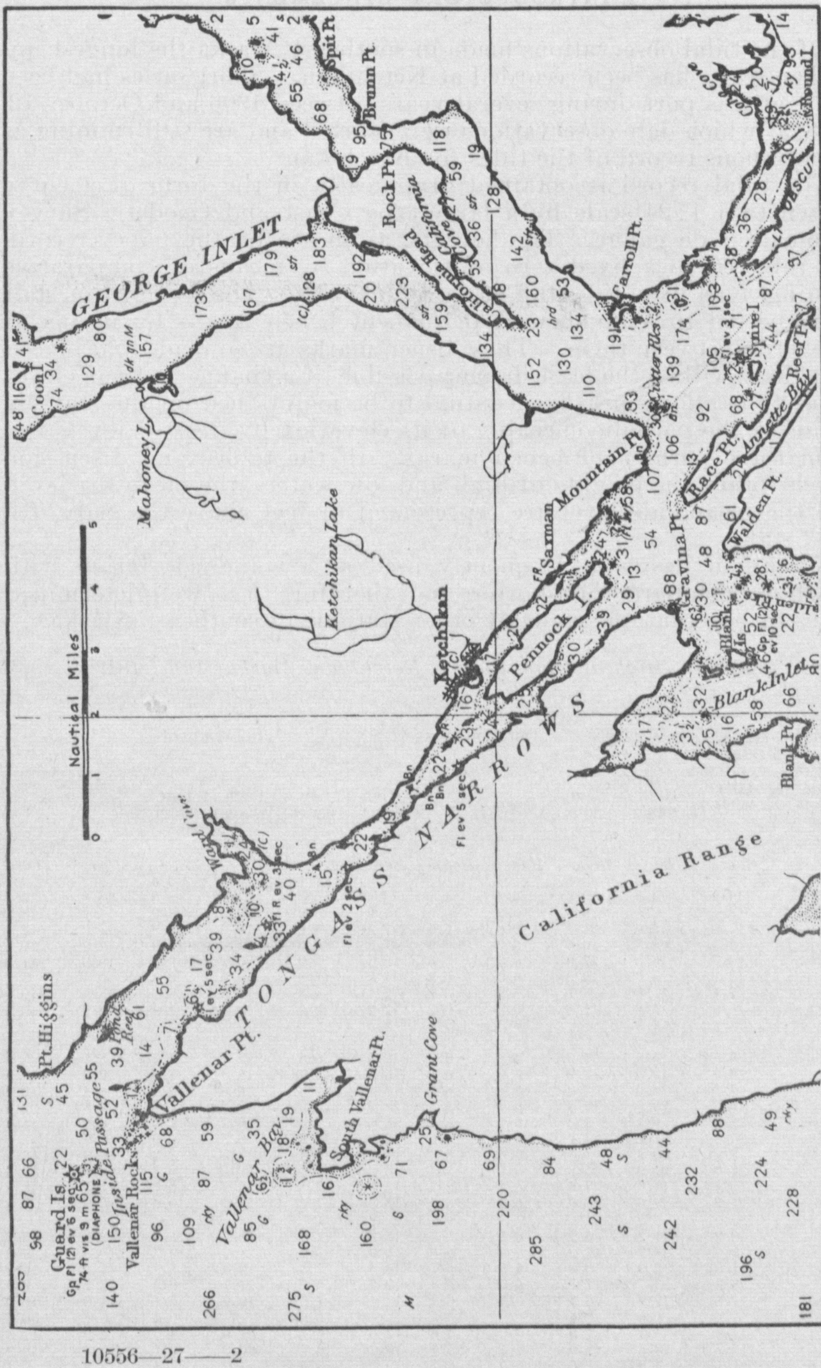

FIG. 2.—Ketchikan and Tongass Narrows

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THE TIDES AT KETCHIKAN

2. INTRODUCTORY STATEMENTS

Of the tidal observations made in southeast Alaska the longest unbroken series has been recorded at Ketchikan. Short series had been made at this port during several years between 1906 and October 12, 1918, at which date observations were started and are still running as a continuous record of the tides for Ketchikan.

The tidal record is obtained graphically in the form of a curve drawn to a 1:24 scale by a large-type Coast and Geodetic Survey automatic tide gauge. The heights, as shown by the paper record, are referred to a fixed zero of elevation by means of comparative readings on a fixed tide staff at daily intervals. The zero of this staff is connected to a number of permanent bench marks by means of levels run between them. These bench marks are so made and placed that there will be the least danger possible of a change in their elevations, thus allowing a fixed datum to be maintained on the staff by means of the periodic checking of its elevation by lines of levels run from these permanent bench marks. In the tables and discussion which follow the heights of high and low waters, the mean sea level, and the mean tide level are represented in feet above the zero of a fixed staff.

Ketchikan has been frequently used as a standard station with which to compare the shorter and therefore less well-determined series of observations made at other stations in southeast Alaska.

TABLE 1.—*High and low waters, Ketchikan, Alaska, June, 1919*

Date	Moon's transit, meridian of Greenwich	Time of— High water	Time of— Low water	Duration of— Rise	Duration of— Fall	Lunitidal intervals High water	Lunitidal intervals Low water	Staff height of— High water	Staff height of— Low water	Range Rise	Range Fall
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Feet*
June 1	(2.5)	1.9	8.6	--------	6.7	11.9	(6.1)	23.5	2.8	--------	20.7
	14.9	14.9	20.6	6.3	5.7	(12.4)	5.7	21.7	8.5	18.9	13.2
2	(3.4)	2.8	9.3	6.2	6.5	11.9	(5.9)	22.7	3.9	14.2	18.8
	15.9	15.9	21.5	6.6	5.6	(12.5)	5.6	20.9	8.8	17.0	12.1
3	(4.3)	3.7	10.3	6.2	6.6	11.8	(6.0)	21.0	4.9	12.2	16.1
	16.7	16.6	22.6	6.3	6.0	(12.3)	5.9	20.2	9.2	15.3	11.0
4	(5.1)	4.6	10.9	6.0	6.3	11.9	(5.8)	19.6	6.3	10.4	13.3
	17.4	17.5	23.7	6.6	6.2	(12.4)	6.3	19.8	9.7	13.5	10.1
5	(5.8)	5.6	11.8	5.9	6.2	12.2	(6.0)	18.5	7.8	8.8	10.7
	18.2	18.3	--------	6.5	--------	(12.5)	--------	19.2	--------	11.4	--------
6	(6.5)	6.8	1.0	5.8	6.7	12.6	6.8	17.4	9.3	8.1	9.9
	18.9	19.5	12.9	6.6	6.1	(13.0)	(6.4)	18.8	8.6	10.2	8.8
7	(7.3)	8.0	2.2	5.8	6.7	13.1	7.3	16.8	8.4	8.4	10.4
	19.6	20.5	13.8	6.7	5.8	(13.2)	(6.5)	19.2	9.4	9.8	7.4
8	(8.0)	9.1	3.0	6.1	6.5	13.5	7.4	16.9	7.9	9.0	11.3
	20.3	21.2	14.7	6.5	5.6	(12.8)	(6.7)	19.8	9.9	9.9	7.0
9	(8.7)	10.3	3.7	6.6	6.5	14.0	7.4	17.5	7.3	10.2	12.5
	21.1	21.9	15.8	6.1	5.5	(13.2)	(7.1)	20.5	10.2	10.3	7.3
10	(9.4)	11.0	4.6	6.4	6.7	13.9	7.5	18.2	6.7	11.5	13.8
	21.8	22.6	16.6	6.0	5.6	(13.2)	(7.2)	20.9	10.0	10.9	8.2
11	(10.2)	11.7	5.2	6.5	6.6	13.9	7.4	18.7	5.9	12.8	15.0
	22.6	23.2	17.2	6.0	5.5	(13.0)	7.0	21.2	9.7	11.5	9.0
12	(11.0)	12.4	5.9	6.5	6.7	13.8	7.3	19.3	5.3	14.0	15.9
	23.4	23.7	17.7	6.0	5.3	(12.7)	(6.7)	21.7	9.5	12.2	9.8
13	(11.8)	12.9	6.4	6.5	6.7	13.5	7.0	19.9	5.1	14.8	16.6
	--------	--------	18.4	--------	5.5	--------	(6.6)	--------	9.4	--------	10.5
14	.3	.4	7.0	6.0	6.6	(12.6)	6.7	22.0	4.7	12.6	17.3
	(12.7)	13.5	18.9	6.5	5.4	13.2	(6.2)	20.0	9.1	15.3	10.9
15	1.1	.9	7.6	6.0	6.7	(12.2)	6.5	21.9	4.5	12.8	17.4
	(13.5)	14.1	19.6	6.5	5.5	13.0	(6.1)	20.2	9.1	15.7	11.1

TABLE 1.—*High and low waters, Ketchikan, Alaska, June, 1919*—Continued

Date	Moon's transit, meridian of Greenwich	Time of—		Duration of—		Lunitidal intervals		Staff height of—		Range	
		High water	Low water	Rise	Fall	High water	Low water	High water	Low water	Rise	Fall
	Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Feet*
June 16	1.9	1.5	8.6	5.9	7.1	(12.0)	6.7	21.7	4.7	12.6	17.0
	(14.3)	14.7	20.2	6.1	5.5	12.8	(5.9)	20.2	9.0	15.5	11.2
17	2.7	2.2	8.8	6.0	6.6	(11.9)	6.1	21.1	4.7	12.1	16.4
	(15.1)	15.2	21.0	6.4	5.8	12.5	(5.9)	19.9	9.1	15.2	10.8
18	3.5	3.0	9.3	6.0	6.3	(11.9)	5.8	20.5	5.3	11.4	15.2
	(15.9)	15.9	21.9	6.6	6.0	12.4	(6.0)	20.0	9.3	14.7	10.7
19	4.3	3.8	10.2	5.9	6.4	(11.9)	5.9	20.1	6.9	10.8	13.2
	(16.7)	16.6	22.7	6.4	6.1	12.3	(6.0)	20.4	9.7	13.5	10.7
20	5.1	4.8	10.2	6.1	5.4	(12.1)	5.1	19.2	7.2	9.5	12.0
	(17.5)	17.6	23.9	7.4	6.3	12.5	(6.4)	20.2	9.2	13.0	11.0
21	5.9	5.8	11.7	5.9	5.9	(12.3)	5.8	18.6	8.6	9.4	10.0
	(18.3)	18.5		6.8		12.6		20.7		12.1	
22	6.8	7.2	1.1	6.1	6.6	(12.9)	(6.8)	18.4	8.6	9.8	12.1
	(19.2)	19.5	12.6	6.9	5.4	12.7	5.8	21.2	9.3	11.9	9.1
23	7.6	8.2	2.2	6.0	6.7	(13.0)	(7.0)	18.2	7.3	10.9	13.9
	(20.1)	20.6	14.0	6.6	5.8	13.0	6.4	21.7	9.7	12.0	8.5
24	8.6	9.5	3.2	6.3	6.6	(13.4)	(7.1)	18.4	5.7	12.7	16.0
	(21.1)	21.6	15.2	6.4	5.7	13.0	6.6	22.6	9.6	13.0	8.8
25	9.6	10.5	4.1	6.4	6.5	(13.4)	(7.0)	19.5	4.6	14.9	18.0
	(22.1)	22.4	16.4	6.0	5.9	12.8	6.8	23.6	9.3	14.3	10.2
26	10.6	11.5	5.0	6.5	6.6	(13.4)	(6.9)	20.5	3.5	17.0	20.1
	(23.1)	23.3	17.3	6.0	5.8	12.7	6.7	24.2	8.6	15.6	11.9
27	11.7	12.5	5.9	6.6	6.6	(13.4)	(6.8)	21.3	2.5	18.8	21.7
			18.0		5.5		6.3		7.9		13.4
28	(0.2)	.2	6.7	6.2	6.5	12.5	(6.5)	24.4	2.3	16.5	22.1
	12.7	13.2	18.9	6.5	5.7	(13.0)	6.2	21.9	7.4	19.6	14.5
29	(1.1)	1.0	7.5	6.1	6.5	12.3	(6.4)	24.1	2.3	16.7	21.8
	13.6	13.9	19.6	6.4	5.7	(12.8)	6.0	22.0	7.2	19.7	14.8
30	(2.1)	1.7	8.3	6.1	6.6	12.1	(6.2)	23.2	2.8	16.0	20.4
	14.5	14.6	20.4	6.3	5.8	(12.5)	5.9	21.9	7.3	19.1	14.6
				(57)	(58)	(58)	(58)	(58)	(58)	(57)	(58)
Sum				358.6	355.9	738.3	374.1	1,187.7	421.5	750.0	766.2
Mean				6.29	6.14	12.73	6.45	20.48	7.27	13.16	13.21
Correction to intervals						−.08	−.08				
Corrected intervals						12.65	6.37				

3. THE LUNITIDAL INTERVALS

The high and low waters at any given station do not occur at the same time as the moon's meridian passage over that place, but tend to lag by a fairly constant interval. This difference between the time of the moon's transit and the succeeding high or low water is known as the lunitidal interval. This interval is liable to slight variance caused by the changing positions of the moon and sun and the consequent changes in the intensity of their tide-producing forces. Other variations are also introduced by the changing condition of wind and weather affecting the tidal flow.

Eliminating the latter effects as much as possible by taking the lunitidal intervals for a summer month, June, 1919, when meteorological conditions are most nearly constant, Table 1, columns 7 and 8, show variations of 2.2 hours in the high-water lunitidal intervals from day to day and 2.4 hours between the low-water intervals. These variations in a single month are brought about and are dependent upon the different phases of the moon as explained in the Appendix. On June 5, and again on June 19, at which times the moon is directly over the Equator, there is but little variation in the times of the high or the low water intervals for the day. On June 12 and 26, when the moon is at its maximum north and south declination, respectively, the intervals exhibit the largest variations for the month. Thus we may assume that for a month stable as to conditions of wind and weather, the greatest daily variance in the times of high and low waters will occur with the moon at its maximum declinations, the least variances when the moon is crossing the Equator.

The true lunitidal interval would be the difference between the mean local time of the moon's transit and the mean local time of the succeeding high or low water. However, inasmuch as standard time is in common usage, and the moon's transits are given for the Greenwich meridian in astronomic tables, as a matter of convenience in computation a lunitidal interval is derived for the standard time of the tide and the moon's transit over Greenwich. The interval value obtained is corrected to the true lunitidal interval by the application of a correction factor that is constant for any given longitude.[2] This correction of Ketchikan equals (—0.08 hour).

TABLE 2.—*Lunitidal intervals, Ketchikan, 1919 and 1922*

Month	High-water intervals		Low-water intervals		Month	High-water intervals		Low-water intervals	
	1919	1922	1919	1922		1919	1922	1919	1922
	Hours	*Hours*	*Hours*	*Hours*		*Hours*	*Hours*	*Hours*	*Hours*
January	0.27	0.35	6.42	6.46	August	0.31	0.35	6.49	6.40
February	.25	.42	6.35	6.52	September	.42	.38	6.49	6.45
March	.40	.35	6.41	6.43	October	.40	.38	6.50	6.49
April	.30	.34	6.42	6.43	November	.20	.24	6.49	6.46
May	.28	.31	6.37	6.45	December	.28	.17	6.49	6.41
June	.24	.35	6.38	6.44					
July	.24	.22	6.42	6.38	Mean	.30	.32	6.44	6.44

In Table 2 are given the monthly and yearly means of high-water intervals (HWI) and low-water intervals (LWI) for 1919 and 1922 corrected to the moon's transit across the meridian for Ketchikan. As the annual means for either interval differ by negligible amounts, it was not deemed necessary to derive the intervals for the other 4 years of the Ketchikan series, as for all practical purposes the average mean values obtained from the 2 years' observations are as reliable as those which would be derived from 6 years. The accepted average mean value of the HWI is 0.31 hours, that of the LWI is 6.44 hours. It is interesting to note the very close agreement of the similar values as derived from the harmonic constants for 1920, which gave 0.28 hour for the HWI, and 6.41 hours for the LWI.

In a period of approximately 19 years all the more important motions of the moon have gone through complete cycles, so that tidal constants derived from a 19-year series are considered as absolute values. The Ketchikan intervals having been obtained from but two years' observations can not be considered as values not liable to some slight change, but they may be accepted as the best values available for the station at the present time.

[2] The derivation and tables of this factor will be found in U. S. Coast and Geodetic Survey Special Publication No. 26, paragraphs 494–499.

The mean monthly lunitidal intervals listed in Table 2 bring out the fact that both intervals are subject to periodic variations of approximately six months' duration. From this table it is seen that both high and low water intervals exhibit "highs" during the spring and fall months, and "lows" during the summer and winter months. The LWI differs materially in the range of annual variations exhibited, the monthly values of LWI tending to remain more nearly constant. The HWI, as illustrated graphically by the curve of figure 3, more pronouncedly exhibits the variational periods. From the greater HWI in March there is a fairly steady lessening to the smaller interval in July, then the interval gradually increases to its maximum yearly value in September, from which it again decreases steadily to a minimum yearly value in November.

The periodic change in the lunitidal intervals at Ketchikan is also exhibited by the range of the tide at the same station. Figure 3, showing both the range and the HWI curves for 1919, illustrates most clearly the relationship of interval to range. The marked simi-

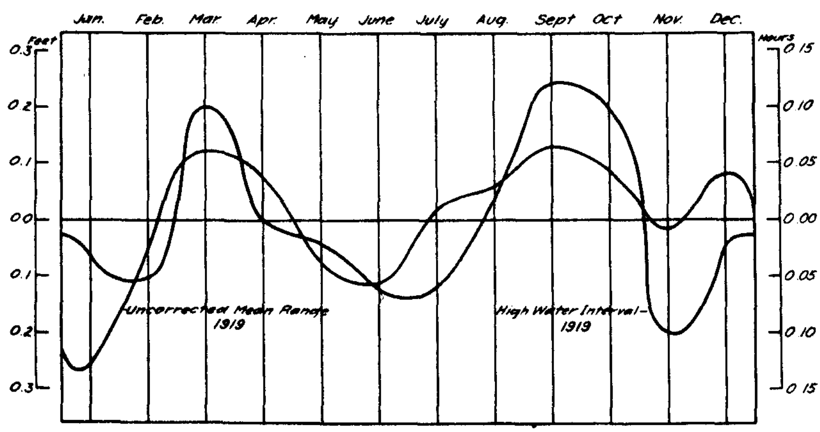

FIG. 3.—Relation of high water interval to mean range, Ketchikan

larity of these curves, in which an increase or decrease in range is followed by a corresponding change in the HWI, illustrates most conclusively the fact that at Ketchikan the variation in the time intervals is largely dependent upon the variations in the mean range of the tide.

It does not follow from the preceding discussion that the mean range and time intervals are so related at all stations in southeast Alaska. Conditions prevailing elsewhere might cause some other factor to be the controlling element in the variation of the lunitidal intervals. To serve as an illustration of this last statement reference is made to the preceding volume of this series dealing with the tides in Delaware Bay. In this the tides under discussion are of the river type, and the variations in the lunitidal intervals are found to be contingent upon the height of river level.

4. THE DURATION OF RISE AND FALL

As signified by the name, the duration of rise is the time during which the tide is rising, or the time elapsing between a low water and the next succeeding high water. This value may be obtained by subtracting the time of a low water from the time of its succeeding high water. The duration of fall is similarly obtained by subtracting the time of a high water from the time of its succeeding low water.

However, the method in common usage is to derive the duration of rise and fall from the lunitidal intervals. In this way the duration of rise is obtained by subtracting the LWI from HWI. Then, taking the difference in the times of successive high or low waters to equal the mean tidal cycle of 12.42 hours, the duration of fall is obtained by subtracting the duration of rise already derived from 12.42, this figure representing the average time elapsing between the upper and lower transit of the moon.

A comparison of daily values of the duration of rise and fall as given in columns 5 and 6 of Table 1, with similar values obtainable from the lunitidal intervals of columns 7 and 8 will show a lack of agreement between the values as obtained by the two different methods. While the daily values may differ, dependent upon their derivation, the mean monthly values will agree almost exactly in all cases. Summing the mean monthly values of duration of rise and fall for June, 1919, the mean value of 12.43 hours obtained is but 0.01 hour different from the true mean value of the tidal cycle of 12.42 hours which will be derived from the lunitidal intervals.

TABLE 3.—*Duration of rise and fall, Ketchikan, 1919 and 1922*

Month	Duration of rise		Duration of fall		Month	Duration of rise		Duration of fall	
	1919	1922	1919	1922		1919	1922	1919	1922
	Hours	*Hours*	*Hours*	*Hours*		*Hours*	*Hours*	*Hours*	*Hours*
January	6.27	6.31	6.15	6.11	August	6.24	6.37	6.18	6.05
February	6.32	6.32	6.10	6.10	September	6.35	6.35	6.07	6.07
March	6.41	6.34	6.01	6.08	October	6.32	6.31	6.10	6.11
April	6.30	6.33	6.12	6.09	November	6.13	6.20	6.29	6.22
May	6.33	6.28	6.09	6.14	December	6.21	6.18	6.21	6.24
June	6.28	6.33	6.14	6.09					
July	6.24	6.26	6.18	6.16	Mean	6.28	6.30	6.14	6.12

Table 3 lists the monthly and yearly means of the duration of rise and the duration of fall for two years of the tidal series at Ketchikan. The monthly values of duration of rise are seen to differ as much as 0.28 hours, but the annual values are very consistent, the average means of the 2 years being accepted as standard values. The duration of rise equals 6.29 hours; the duration of fall equals 6.13 hours. These values correspond exactly to similar values obtained from the lunitidal intervals derived by the use of the 1920 harmonic constants.

In Figure 4 the annual variations in the duration of rise and in the duration of fall are illustrated graphically. The curve for duration of rise is seen to resemble closely that for the HWI variation in Figure 3. As the duration of fall is the difference between a constant and the duration of rise, obviously the curve of the former must be complementary to the curve of the duration of rise.

5. MEAN SEA LEVEL

The plane of mean sea level (MSL) may be defined as that plane about which the tide oscillates. It is the average level of the sea, or the surface the sea would assume if undisturbed by the rise and fall of the tide. The determination of this plane requires averaging the successive hourly heights of the tide, for a period of time dependent upon the degree of accuracy required.

As a datum plane, mean sea level is of major importance for engineering and scientific purposes, being readily obtainable and universally understood. In its determination, as in the derivation of all tidal values, a well-determined mean value can only be obtained from a continuous 19-year series of observations. Even this 19-year constant is liable to changes brought about by subsequent natural or artificial alteration in the depths and widths of the adjacent waterways through river deposits, dredging, jetty construction, etc.

For projects of minor importance a fairly satisfactory mean sea-level value may be obtained from a week's observations. Such a value is liable to those errors introduced by wind and weather, or by the periodical changes in the tide-producing forces. The so-called

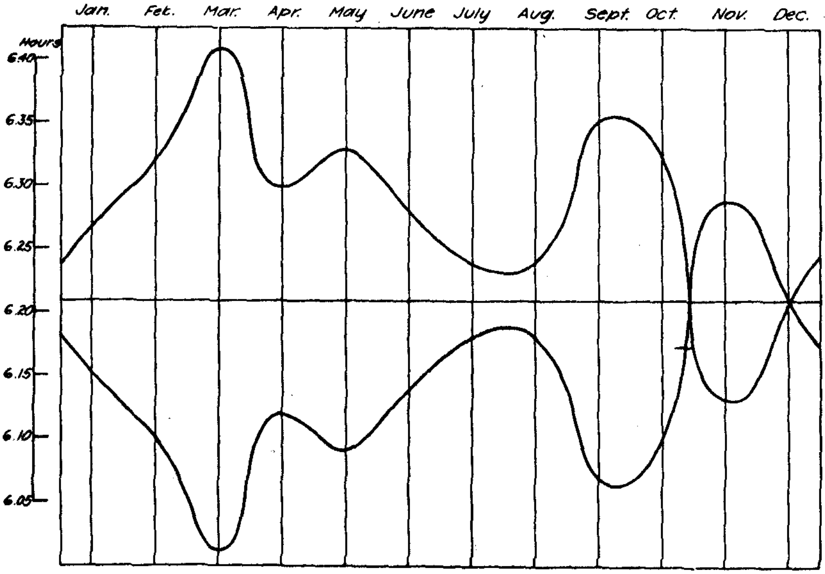

FIG. 4.—Duration of rise and fall, Ketchikan

long-period tides, caused by those tidal forces having periods of one-half month or more, introduce a variation in mean sea level. The daily variation in sea level is illustrated in Table 4 for a summer month when meteorological conditions are most nearly stable.

TABLE 4.—*Daily sea level on staff, Ketchikan, July, 1919*

Day	Feet	Day	Feet	Day	Feet
1	13.74	11	14.08	21	14.01
2	13.91	12	13.85	22	13.93
3	14.11	13	13.74	23	13.93
4	14.47	14	13.71	24	13.82
5	14.39	15	13.53	25	13.44
6	14.21	16	13.52	26	13.20
7	14.12	17	13.53	27	13.43
8	14.02	18	13.67	28	13.62
9	13.88	19	13.84	29	13.63
10	13.99	20	13.99	30	13.65
Mean	14.08	Mean	13.75	Mean	13.67

These daily values will show that mean sea level may not be reliably ascertained at Ketchikan from the observations of a single day, as in this one month there is a maximum daily variation of 1.3 feet.

Neither may too much reliance be placed on the value of mean sea level derived from a month's observations, for, as shown in Table 5, the monthly means during a single year differ by as much as 1.37 feet. Mean sea level derived from 12 months' observations is subject to much smaller variations, 0.19 foot being the maximum difference between 2 years of this 6-year series.

TABLE 5.—*Monthly sea level on staff, Ketchikan, 1919–1924*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual means
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1919	15.21	14.73	14.26	14.35	14.36	14.06	14.04	13.93	14.14	13.84	14.39	14.42	14.31
1920	14.30	13.76	14.23	13.84	14.00	14.21	14.03	14.01	14.41	14.58	14.55	15.03	14.25
1921	14.61	14.59	14.03	14.00	13.79	14.31	13.96	13.96	14.32	14.89	14.56	14.51	14.29
1922	14.24	14.15	14.28	13.59	14.03	13.85	13.61	13.85	14.21	14.43	14.82	14.44	14.12
1923	14.59	13.91	13.78	14.18	14.08	13.97	13.81	13.97	14.25	14.52	14.93	15.10	14.26
1924	14.56	14.87	13.85	13.87	13.87	13.80	13.85	13.86	14.19	14.72	14.76	14.36	14.21
Mean	14.58	14.34	14.07	13.97	14.02	14.03	13.88	13.93	14.25	14.50	14.67	14.64	14.240

The mean of these 6 years, 14.24 feet, has been accepted and used in this volume as the best available mean sea-level value at Ketchikan for all tidal computations previous to 1925. This value will be subject to correction as each succeeding year's value of mean sea level is obtained, until the completion of a 19-year series allows the acceptance of a standard value for Ketchikan.

Aside from possible permanent changes in the plane of mean sea level caused by natural or artificial altering of waterways, the height of this plane is constantly subject to the temporary variations brought about by meteoroligical conditions; high winds, extreme barometric pressures, and the quantity of fresh-water discharge—all factors tending to raise or lower this plane. The year of 1919 gives the highest annual value for mean sea level, this increased height being attributed to the exceptionally high sea level maintained from January to June of that year, mean sea level attaining its maximum value of 15.21 feet during January, 1919. The low annual sea level recorded for 1922 is apparently due to the extremely low values for April and July, the former month exhibiting the minimum value of mean sea level for the 6-year series, the monthly height being 13.59 feet.

A study of the barometric pressures recorded in the vicinity of Ketchikan shows the existence of an almost direct relationship between the plane of mean sea level and the pressure, the higher the value of the latter the lower being the plane of mean sea level. This fact is fully discussed later in this volume. During January, 1919, there was recorded the lowest monthly barometric pressure for the entire 6-year period; whereas April and July, 1922 were months of exceptionally high pressures.

Undoubtedly the strong winter winds prevailing from a westerly direction tend to pile up the water all along the coast, thereby raising the sea level somewhat during this season.

An examination of the graphs of Figure 5 brings out quite clearly the annual variation in mean sea level. The curves for the individual years 1923 and 1924 follow closely the trend of the average curve of the mean values for the entire series. The period of May and June as shown by the average curve is one of slightly heightened sea level, which is not to be attributed to pressure or winds, but rather to the sudden and excessive influx of fresh water from the melting snows. These months are notable for the rapid disappearance of the mountain snows and the consequent flood conditions that prevail in all the fresh-water streams along the coast.

While the variations from month to month exhibit periodicity, it is not evident that the annual values of mean sea level are in themselves subject to any definite periods of change.

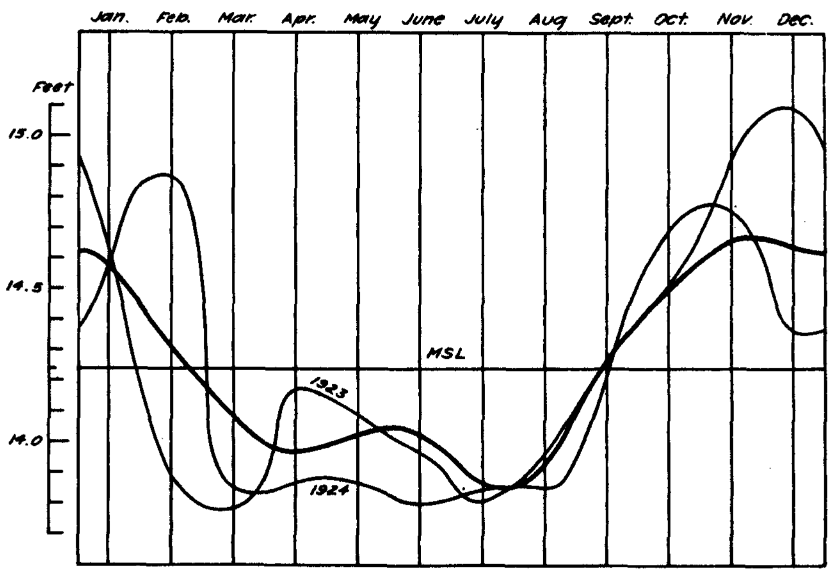

FIG. 5.—Annual variation in mean sea level, Ketchikan

It is interesting to note the similarity between the average annual mean sea-level curve for Ketchikan and that for Seattle, Wash., during the same years as illustrated in Figure 6.

Evidently the local conditions which affect the heights of sea level are much alike at these two stations, inasmuch as their variations run through the same periods with similar fluctuations in height. The range of the annual variation at Seattle is slightly less than the range at Ketchikan. From July to December the height of sea level at the former station shows a slow increase, with a continued "low" in November that is not matched at Ketchikan.

Following this relationship between the tidal characteristics of two so widely separated stations it might be expected that the other southeast Alaska stations would exhibit variations in sea level akin to those of Ketchikan. This is not a fact, however, for as shown in Figure 10 of this volume the curves of annual sea level are markedly dissimilar in many respects.

6. THE PLANE OF HALF-TIDE LEVEL

The plane of half-tide level, or as it is more often named, mean tide level (MTL), is that plane lying exactly halfway between the plane of mean high water and mean low water.

From the foregoing definition the derivation of this tidal plane is made apparent. The mean of the daily high and low waters, summed for a period of time dependent upon the accuracy required, will establish a plane of half-tide level.

This plane is a datum more easily obtained than is mean sea level, through the fewer daily observations necessary for its determination, as the tides need be recorded only at the high and low water stages. For this reason it is often used for practical purposes when the slight

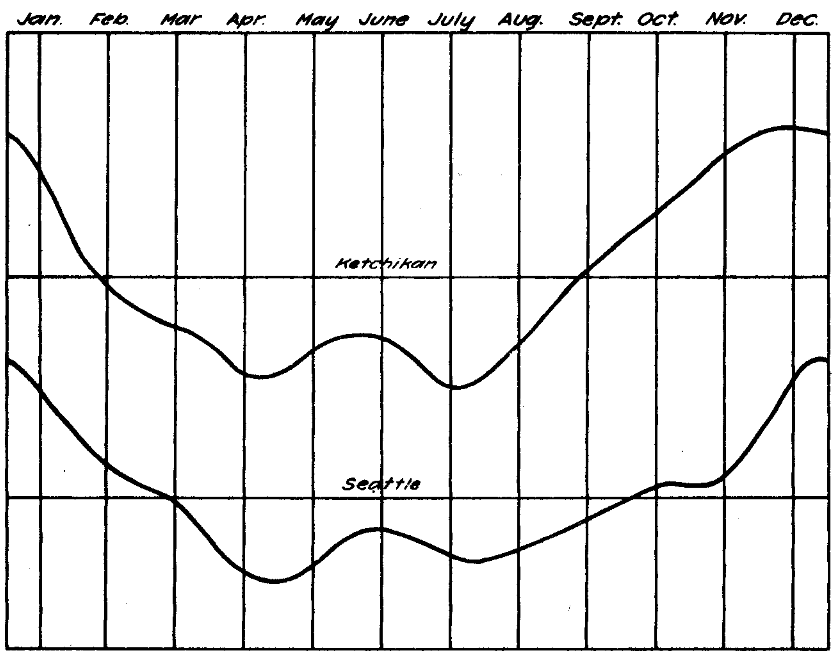

FIG. 6.—Annual variation in sea level, Ketchikan and Seattle

difference between MSL and MTL need not be taken into account. For the 6-year series at Ketchikan this difference amounts to 0.017 foot, as shown by the mean values of Tables 5 and 6.

TABLE 6.—*Half-tide level on staff, annual means, Ketchikan, 1919–1924*

Year	Feet
1919	14.30
1920	14.23
1921	14.28
1922	14.09
1923	14.25
1924	14.19
Half-tide level, 6 years' mean	14.223

The terms "mean sea level" and "half-tide level" are at times confusing, as many assume them to be synonymous. Such would be the case only if the rise of mean high water above mean sea level equaled the fall of mean low water below mean sea level. This is seldom true. At Ketchikan the fall exceeds the rise, thereby causing the value of mean sea level to exceed that for half-tide level. The annual variations of either will follow parallel curves, so the monthly differences are practically constant between the two datum planes.

7. THE HIGH AND LOW WATER PLANES

The daily heights of both high and low waters vary with changing astronomic and storm conditions which give rise to the numerous tidal planes in use. These are the planes of mean high water and mean low water, spring high water and spring low water, neap high water and neap low water, perigean high water and perigean low water, apogean high water and apogean low water, higher high water and lower low water. lower high water and higher low water, tropic higher high water and tropic lower low water, tropic lower high water and tropic higher low water, and that due to the so-called storm tides.

To avoid any confusion or ambiguity in the use of these many planes of high and low waters it is necessary to designate precisely the exact plane in question, as "mean high water" or "mean higher high water," etc.

The plane of mean lower low water (MLLW) is of major importance in Alaska through its use as a datum to which all charted soundings are reduced, except through one small waterway. In Wrangell Narrows the charted depths are referred to a datum 3 feet below mean lower low water.

TABLE 7.—*Monthly mean high water on staff, Ketchikan, 1919–1924*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual means
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1919	21. 62	21. 30	20. 90	21. 02	20. 90	20. 60	20. 60	20. 52	20. 75	20. 46	20. 90	21. 02	20. 88
1920	20. 96	20. 40	20. 90	20. 47	20. 51	20. 71	20. 60	20. 65	21. 10	21. 27	21. 17	21. 66	20. 87
1921	21. 27	21. 27	20. 72	20. 64	20. 34	20. 90	20. 64	20. 70	21. 12	21. 72	21. 19	21. 04	20. 96
1922	20. 78	20. 72	20. 83	20. 18	20. 62	20. 50	20. 35	20. 61	20. 97	21. 15	21. 36	20. 96	20. 75
1923	21. 06	20. 50	20. 41	20. 95	20. 83	20. 59	20. 46	20. 64	20. 96	21. 24	21. 62	21. 77	20. 92
1924	21. 25	21. 51	20. 56	20. 59	20. 51	20. 32	20. 35	20. 36	20. 81	21. 38	21. 38	20. 91	20. 83
Mean	21. 16	20. 95	20. 72	20. 64	20. 62	20. 60	20. 50	20. 58	20. 95	21. 20	21. 27	21. 23	20. 87

TABLE 8.—*Monthly mean low water on staff, Ketchikan, 1919–1924*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual means
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1919	8. 72	8. 20	7. 62	7. 78	7. 81	7. 55	7. 42	7. 30	7. 46	7. 21	7. 75	7. 78	7. 72
1920	7. 64	7. 06	7. 52	7. 19	7. 41	7. 70	7. 42	7. 35	7. 67	7. 82	7. 91	8. 39	7. 59
1921	7. 85	7. 83	7. 33	7. 37	7. 28	7. 65	7. 26	7. 17	7. 52	8. 06	7. 96	7. 96	7. 60
1922	7. 68	7. 51	7. 63	6. 98	7. 42	7. 13	6. 82	7. 00	7. 36	7. 65	8. 15	7. 86	7. 43
1923	8. 08	7. 31	7. 03	7. 41	7. 38	7. 37	7. 17	7. 28	7. 50	7. 79	8. 23	8. 41	7. 58
1924	7. 83	8. 14	7. 10	7. 13	7. 21	7. 22	7. 30	7. 23	7. 51	7. 97	8. 10	7. 80	7. 54
Mean	7. 97	7. 67	7. 37	7. 31	7. 42	7. 44	7. 23	7. 21	7. 50	7. 75	8. 02	8. 03	7. 58

The most easily determined planes are those of mean high water and mean low water, as they are obtained by averaging all the high or all the low waters over a period of time dependent upon the accuracy required. As shown in columns 9 and 10 of Table 1 there is considerable daily fluctuation in the heights of both high and low waters. The monthly values of mean high water and of mean low water likewise exhibit marked differences as shown in Tables 7 and 8. The annual means differ also but to a much lesser degree. Although several factors conspire in bringing about the annual variation in both these planes, one factor alone is clearly the controlling influence. That the changing height of sea level from month to month has most

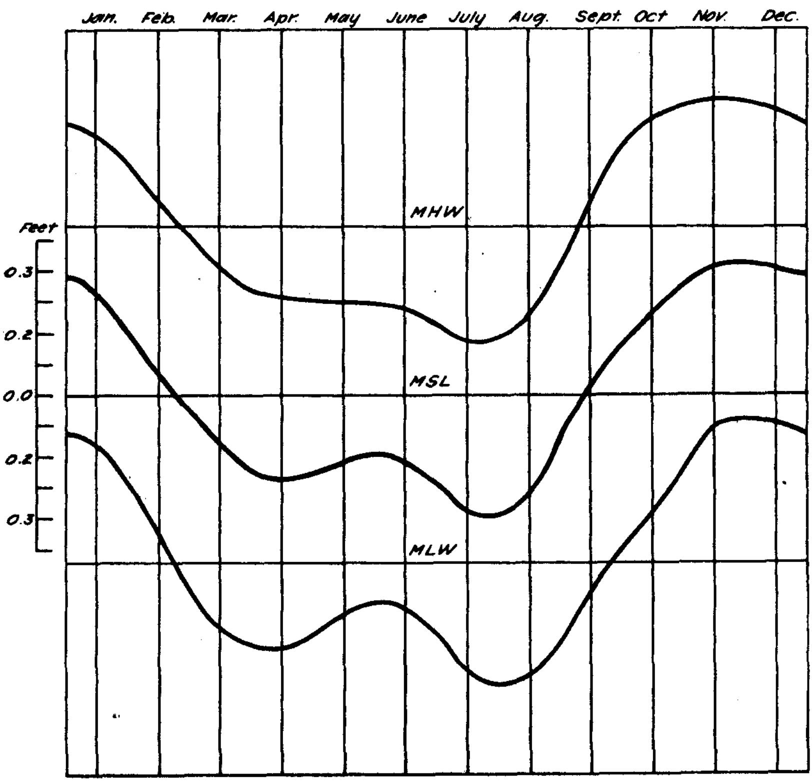

FIG. 7.—Relation of high and low water to sea level, Ketchikan

to do with the variations in the monthly height of high and low water is graphically illustrated by the annual curves for the three planes shown in Figure 7.

In general the three curves tend to parallel each other, with a "high" during midwinter and a "low" in July. A comparison of the curves will show that if the heights of the high and low waters for each month were referred to sea level for that same month there would remain but very slight annual variations in either plane.

With only 6 years' observations available it is not possible to illustrate by graphs or figures the periodic change that occurs in the annual means of high and low waters in approximately 19 years.

There is a change in the inclination of the lunar orbit to the plane of the earth's Equator which varies from 18.3° to 28.6° over an average period of 18.6 years. The tidal forces emanating from the moon are less than the average at the time of maximum inclination, hence the rise of the tide is less than the average at such times. The opposite is true of times of minimum inclination. It is possible to correct the mean values of the high and low water planes as determined from a series of less than 19 years' duration, so as to obtain values of these planes akin to that value which would be derived as the direct mean of the 19 years' values. This correction for the longitude of the moon's node is customarily applied to the ranges of the tide,[3] but may also be applied to the heights of high and low waters when these are referred to mean sea level.

TABLE 9.—*Mean high water and mean low water referred to standard sea level, Ketchikan, 1919–1924*

Mean high water above standard sea level	Uncorrected	Corrected	Mean low water below standard sea level	Uncorrected	Corrected
	Feet	*Feet*		*Feet*	*Feet*
1919	6.64	6.57	1919	6.52	6.46
1920	6.63	6.50	1920	6.65	6.51
1921	6.72	6.52	1921	6.64	6.44
1922	6.51	6.31	1922	6.81	6.61
1923	6.68	6.48	1923	6.66	6.46
1924	6.59	6.46	1924	6.70	6.57
Mean	6.63	6.47	Mean	6.66	6.51

Table 9 contains the annual values, both corrected and uncorrected for mean high water and mean low water as referred to the accepted mean sea level of 14.24 feet. As corrected, the accepted value of the mean high-water plane at Ketchikan is 6.47 feet above mean sea level; the mean low-water plane is 6.51 feet below mean sea level. These values are used as standard for all purposes of this volume.

It is sometimes desirable to be able to anticipate the height of the spring high and low water planes, they as a rule being the planes of the highest and lowest normal tides occurring during a month. To obtain these planes it is necessary to average, over a considerable period of time, all the high and low waters, respectively, occurring when the effects of the new and full moon are at a maximum in increasing the range of tide. As discussed in the Appendix this maximum range increase causing the spring tides does not take place in coincidence with the time of new or full moon, but lags by a definite interval known as the phase age. The phase age of the tide is discussed later in connection with other "ages" of the tide.

To determine the height of the spring high and low waters it is customary to take the two high and two low waters, respectively, which occur nearest the time obtained by adding the phase age of the tide to the times of new and full moon. This will give four monthly values each for the determination of the planes of spring high and low waters. These values will vary considerably from month to month through the effects of the moon's parallax and declination, and any incidental meteorological disturbances, all of

[3] See U. S. Coast and Geodetic Survey Special Publication No. 26, paragraphs 502–505.

which make it necessary to average the results of a number of months in order to obtain reliable values for these tidal planes.

The observations at Ketchikan have not been reduced for the spring tides, or as they are sometimes termed, phase tides. However, a derivation from the harmonic constants (by means of the formula of R. A. Harris)[4] for 1920 gives the following values: Spring high water on the staff, 22.69 feet; spring low water on the staff, 5.71 feet. This brings the plane of spring high water 8.45 feet above mean sea level, an increase of 30 per cent above the mean high-water plane. The spring low-water plane is 8.53 feet below mean sea level, a decrease of 31 per cent below the plane of mean low water. These values, derived as they are from harmonic constants, may differ slightly from the values which would be obtained through direct tabulation, but are more readily obtainable and entirely satisfactory for all practical purposes.

The planes of the neap high and low waters are derived in a manner similar to the spring planes, by substituting for "new and full moon" in the preceding paragraphs the "moon's first and third quarters." The rise and fall of the neap tides equals 8.60 feet as derived from the 1920 harmonic constants. This range is approximately 50 per cent that of the spring tides.

The moon makes a revolution about the earth in approximately 27½ days, its course tracing an elliptical path. The earth is not located at the center of this orbit but is so situated within the ellipse that once during the period of revolution the moon is nearest the earth and once farthest from it. This periodic change in the proximity of the two bodies gives rise to the perigean and apogean tides; the former occurring when the moon is nearest the earth and its tidal forces bring about greater than average tidal fluctuations; the latter occurring when the moon is farthest removed and the effect the least. As the periods between perigee or between apogee are approximately 27½ days, there will be but thirteen times yearly from which to obtain mean values for either plane. These tides occur somewhat later than the time of the moon's perigean or apogean position. The lag in the occurrence of the tides is known as their parallax age. There being no direct derivation of either plane, the harmonic constants were again utilized to obtain these values. The perigean planes are 7.77 feet and 7.81 feet, respectively, above and below mean sea level; the apogean planes 5.49 feet above and 5.57 feet below mean sea level.

The periodic fortnightly changes in the moon's declination give rise to eight tidal planes, known as the declinational planes from the factor causing their origin. These planes are: Higher high water, lower high water, higher low water, lower low water, tropic higher high water, tropic lower high water, tropic higher low water, and tropic lower low water. The plane of the tropic higher high water is determined by averaging the higher high water heights that occur at the times of tropic tides, these tides accompanying the moon's extreme north and south declinations. The other tropic planes are derived in a similar manner.

The averaging of the higher of the two daily high waters over a considerable period of time determines the mean higher high water

[4] See Manual of Tides, Part III, U. S. Coast and Geodetic Survey Report for 1894, p. 144.

plane, while in a similar way can be obtained the planes of lower high water, higher low water, and lower low water. The differences between the heights of the two daily high waters and between the heights of the two daily low waters are quite marked at Ketchikan. This fact is shown by comparing the daily heights in columns 9 and 10 of Table 1.

As the planes of higher high water and lower low water are more often used than the other two diurnal planes, they alone will be discussed. The monthly and annual values used to derive these first-named planes are listed in Tables 10 and 11.

TABLE 10.—*Monthly mean higher high water on staff, Ketchikan, 1919–1924*[1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual means
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1919	22.77	22.16	21.57	21.68	21.80	21.44	21.49	21.37	21.58	21.20	21.92	22.18	21.76
1920	22.00	21.33	21.67	21.04	21.43	21.69	21.56	21.39	21.63	21.71	21.91	22.26	21.64
1921	22.27	22.23	21.49	21.54	21.43	21.99	21.64	21.45	21.61	22.01	21.73	21.81	21.77
1922	21.68	21.57	21.41	20.78	21.42	21.46	21.28	21.52	21.64	21.74	22.13	21.96	21.55
1923	22.03	21.23	21.03	21.45	21.45	21.44	21.23	21.40	21.56	21.80	22.47	22.86	21.66
1924	22.32	22.41	21.29	21.20	21.32	21.27	21.30	21.13	21.19	21.66	21.94	21.72	21.56
Mean	22.18	21.82	21.41	21.28	21.47	21.55	21.42	21.38	21.53	21.69	22.02	22.13	21.66

[1] Uncorrected for longitude of moon's node.

TABLE 11.—*Monthly mean lower low water on staff, Ketchikan, 1919–1924*[1]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual means
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1919	7.23	7.13	6.59	6.78	6.56	6.10	6.06	6.05	6.28	5.64	5.85	5.75	6.34
1920	5.82	5.82	6.45	6.29	5.90	6.05	5.82	6.24	6.78	6.69	6.28	6.60	6.23
1921	6.10	6.48	6.21	5.90	5.63	5.89	5.58	5.99	6.77	7.09	6.48	6.17	6.19
1922	6.13	6.33	6.73	5.86	6.03	5.68	5.47	5.71	6.23	6.24	6.46	5.90	6.06
1923	6.50	6.33	6.10	6.45	6.24	6.17	5.81	5.96	6.41	6.44	6.57	6.51	6.29
1924	6.63	6.81	5.96	5.94	5.72	5.62	5.68	5.98	6.72	7.01	6.56	5.94	6.16
Mean	6.30	6.48	6.34	6.20	6.01	5.92	5.74	5.99	6.53	6.52	6.37	6.14	6.21

[1] Uncorrected for longitude of moon's node.

The variations in the heights of the higher high and of the lower low waters are large enough to preclude the reliable establishment of these planes from a short series of observations. This fact is of importance in connection with the establishment of a plane of lower low water which, as previously stated, is used as the datum to which all soundings on Coast and Geodetic Survey charts for this region are referred. It is customary at all short-period, or subordinate tidal stations, to refer the plane of lower low water, as determined from observations, to the plane of some near-by long-period tidal station, such as Ketchikan, where a well-determined value of mean lower low water has been derived. This reference is made possible by observations taken simultaneously at the two stations. By use of the ratios of the ranges and of the low water inequalities applied to the standard values of the long-period station,[5] there is obtained

[5] See U. S. Coast and Geodetic Survey Special Publication No. 26, paragraphs 509–511.

a corrected value of lower low water for the short-period station that is a more well-determined mean than is the uncorrected value.

As shown in Tables 10 and 11 the values of mean lower low and mean higher high water on the staff at Ketchikan are, respectively, 6.21 feet and 21.66 feet, obtained as the average means of the 6 years' observations. These, of course, are liable to correction for the longitude of the moon's node, for, as has been stated before, only the mean of a 19 years' series may be accepted directly as a correct tidal constant for any plane dependent upon astronomic conditions. By noting the variations in the yearly means, 0.28 foot between annual mean lower low waters, and 0.22 foot between annual mean higher high waters, it is readily seen how much influence 1 or 2 years of unusual mean values may have upon the average, especially over a short period of years.

For the 6 years the plane of mean higher high water was 7.42 feet above mean sea level, the plane of lower low water 8.03 feet below it. This high-water plane lies almost exactly halfway between the planes of mean high water and spring high water. Mean lower low water, however, approaches spring low water more closely. These values of the diurnal ranges are not corrected for the longitude of the moon's node. To obtain the corrected mean values for the higher high water and lower low water planes as referred to mean sea level it will be necessary to combine the corrected values of the mean high water and high-water inequality, also the mean low water and low-water inequality. This has been done to derive the values listed in Table 16, and in the tidal summary, Table 18, at the close of this section.

Values for two of the tropic planes have been derived from the harmonic constants. Tropic higher high water equals 21.60 feet on the staff, and tropic lower low water equals 5.85 feet. These planes do not differ materially from those of the higher high and of the lower low waters.

Two other tidal planes, dependent not upon astronomic conditions but upon storm effects, are the planes of the monthly extreme tides, or the storm tides as they are sometimes called. These planes of high and low waters are derived as the means of the highest and of the lowest tides, respectively, for each month of the year. Such a derivation is bound to yield a somewhat arbitrary plane, as a single month might register several tidal heights in excess of all others during the year, yet only the one value each of the high and low waters would be used.

TABLE 12.—*Yearly extremes, Ketchikan, 1919–1924*

Storm high water above standard sea level				Storm low water below standard sea level			
Year	Average	Highest tide		Year	Average	Lowest tide	
	Feet	*Date*	*Feet*		*Feet*	*Date*	*Feet*
1919	10.33	Nov. 8	11.3	1919	11.41	Dec. 8	13.1
1920	10.55	Dec. 26 and 27	11.9	1920	11.62	Jan. 6	12.7
1921	10.45	Jan. 23	11.8	1921	11.37	Aug. 4	12.4
1922	10.43	Sept. 23	12.0	1922	11.64	Jan. 14	12.5
1923	10.43	Dec. 6	12.0	1923	11.36	May 31	12.1
1924	10.69	Nov. 27	12.0	1924	11.43	May 20	12.8
Mean	10.48	Maximum tide	12.0	Mean	11.47	Minimum tide	13.1

The annual values of these storm water planes referred to mean sea level are listed in Table 12, columns 2 and 6. They exhibit such slight differences from year to year that it is quite feasible, from the viewpoint of the water-front engineer, to predict a working value for this plane from but a single year of observations.

In the event that the maximum rise and fall at Ketchikan is desired, the highest and lowest tides for each year are listed in columns 4 and 8 of Table 12. From 1919 to 1924 the maximum high tide rose 12.0 feet above mean sea level, while the minimum low tide fell 13.1 feet below mean sea level, fluctuations approximately 100 per cent greater than the mean high and low water planes.

For convenience in referring the extreme tides to the soundings as shown on a Coast and Geodetic Survey chart for Ketchikan, these tides are referred to the chart datum of mean lower low water as listed in Table 13.

TABLE 13.—*Yearly extremes, Ketchikan, 1919–1924*

Storm high water above standard lower low water				Storm low water below standard lower low water			
Year	Average	Highest tide		Year	Average	Lowest tide	
	Feet	*Date*	*Feet*		*Feet*	*Date*	*Feet*
1919	18.36	Nov. 8	19.3	1919	3.38	Dec. 8	5.1
1920	18.58	Dec. 26 and 27	19.9	1920	3.59	Jan. 6	4.7
1921	18.48	Jan. 23	19.8	1921	3.34	Aug. 4	4.4
1922	18.46	Sept. 23	20.0	1922	3.61	Jan. 14	4.5
1923	18.46	Dec. 6	20.0	1923	3.33	May 31	4.1
1924	18.72	Nov. 27	20.0	1924	3.40	May 20	4.8
Mean	18.51	Maximum tide	20.0	Mean	3.44	Minimum tide	5.1

If the depths of water are desired at extreme high tides for any particular location along the Ketchikan water front or in Tongass Narrows it is only necessary to add 18.51 feet to the charted depth. For extreme low tides subtract 3.44 feet from the charted depth. If the greatest and least depths that may be expected are desired, the maximum value of 20.0 feet added to the charted depth will give the maximum rise experienced in six years, while 5.1 feet subtracted from the depth will give the maximum fall for the same period.

8. DIURNAL INEQUALITIES

The diurnal inequalities are not, as might be inferred, the difference in height between the two high waters or between the two low waters of a day, but as derived are the difference between mean high and mean higher high waters and between mean low and mean lower low waters. The former difference is known as the high water inequality, or DHQ; the latter as the low water inequality, or DLQ.

The variations, as obtained by subtracting the related values of Table 7 from those of Table 10, and the related values of Table 8 from those of Table 11, are listed in Table 14, columns 2 and 5.

TABLE 14.—*Diurnal inequalities, annual means, Ketchikan, 1919–1924*

Diurnal high-water inequality			*Diurnal low-water inequality*		
Year	Uncorrected DHQ	Corrected DHQ	Year	Uncorrected DLQ	Corrected DLQ
	Feet	*Feet*		*Feet*	*Feet*
1919	0.88	0.94	1919	1.38	1.47
1920	.77	.88	1920	1.36	1.50
1921	.81	.93	1921	1.41	1.62
1922	.80	.93	1922	1.37	1.61
1923	.74	.89	1923	1.29	1.50
1924	.73	.83	1924	1.38	1.56
Mean	.79	.90	Mean	1.36	1.54

Inasmuch as the mean high and low waters, also the mean higher high and lower low waters are all subject to the periodic variations caused by the changing longitude of the moon's node, it follows that the diurnal inequalities will likewise be subject to a correction for the same variation. The correction factor to be applied to the inequalities is that known as 1.02 F_1,[6] as computed by Harris. The direct inequalities as modified by the application of this factor are listed in Table 14, columns 3 and 6. As with the corrected annual mean ranges, these corrected inequality values still exhibit variations after the elimination of the periodic variational effect, the remaining variations being attributed to the meteorological effects on yearly tidal values.

9. THE TIDAL RANGES

The range of tide is defined as the difference in height between high and low waters. It is the extent of the tidal fluctuation measured between any two related planes of high and low water. As with the other tidal constants, the ranges are subject to daily, monthly, and yearly variations caused mainly by the changing positions of moon and sun relative to the earth. The different ranges, as classified, are self-explanatory in their relation to the tidal datum planes already discussed. Those which will be treated herein are: The mean range, or difference between the mean high and low water planes; the great diurnal range, or difference between the mean higher high and lower low water planes; the small diurnal range; the spring and neap ranges; the perigean and apogean ranges; the great and small tropic ranges; the storm range; and the greatest range.

The daily variations in range during a typical summer month at Ketchikan are shown by the height differences in columns 11 and 12 of Table 1. The monthly and yearly values of the mean range, as obtained by subtracting the values of Table 8 from those corresponding in Table 7, or by adding together the values of Table 9, are listed in Table 15.

[6] See Manual of Tides, Part III, U. S. Coast and Geodetic Survey Report for 1894, p. 260; also U. S. Coast and Geodetic Survey Special Publication No. 26, paragraphs 506–507.

TABLE 15.—*The mean range, Ketchikan, 1919–1924*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual means	
													Uncorrected	Corrected
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1919	12.90	13.10	13.28	13.24	13.09	13.05	13.18	13.22	13.29	13.25	13.15	13.24	13.16	13.03
1920	13.32	13.34	13.38	13.28	13.10	13.01	13.18	13.30	13.43	13.45	13.26	13.27	13.28	13.01
1921	13.42	13.44	13.39	13.27	13.06	13.25	13.38	13.53	13.60	13.66	13.23	13.08	13.36	12.96
1922	13.10	13.21	13.20	13.20	13.20	13.37	13.53	13.61	13.61	13.50	13.21	13.10	13.32	12.92
1923	12.98	13.19	13.38	13.54	13.45	13.21	13.29	13.41	13.46	13.45	13.39	13.36	13.34	12.94
1924	13.42	13.37	13.46	13.46	13.30	13.10	13.05	13.13	13.30	13.41	13.28	13.11	13.29	13.03
Mean	13.21	13.27	13.35	13.33	13.20	13.16	13.27	13.37	13.45	13.45	13.25	13.19	13.29	12.98

The mean range of the tide is subject to the same 19-year periodic variations that have been discussed in connection with the high and low waters; that is, variations that bring greater ranges at times of the smaller inclinations of the moon's orbit and smaller ranges when its inclination is increased. The mean range for each year has been corrected by a factor, F(Mn),[7] which takes into account the variations in the longitude of the moon's node. The corrected means are listed in the last column of Table 15.

Following the discussion of the preceding paragraph it would be expected that the uncorrected values of yearly mean range exhibit a periodic change. This is not always the case, however, as the meteorological conditions of a year may affect the mean range value sufficiently to mask completely the periodic changes. Then, too, the corrected yearly values of mean range fail to adhere to the mean of the corrected values for the 6 years.

This is further proof of the disturbance caused by wind and weather. The corrected mean range of the tide as accepted at Ketchikan for all years prior to 1925 equals 12.98 feet. Even with the inherent variations due to meterological effect, this value may be expected to conform very closely to the standard value of mean range that would be obtained as an average of 19 years' uncorrected mean range values.

An examination in the variations of the mean range from month to month for any one year, or for the mean monthly values for the 6-year series will show the Ketchikan range values to pass through well-defined six months' periods of variation. The fluctuation between the maximum and minimum ranges is not great, 0.4 foot at the most, but even this slight variation appears to cause appreciable changes in the times of the tides, as has been discussed at the beginning of this section. The periods of the range are strikingly exhibited in the curves of Figure 8. Two of these are drawn for individual years and one as a mean of the six years' values. All show similar definitely marked variational periods of six months' duration.

The great diurnal range, as obtained by subtracting the lower low water values of Table 11 from the corresponding higher high water values of Table 10, is likewise subject to correction for the longitude

[7] See Manual of Tides, Part III, U. S. Coast and Geodetic Survey Report for 1894, p. 247; also U. S. Coast and Geodetic Survey Special Publication No. 26, paragraph 503–505.

of the moon's node. To obtain the corrected great diurnal range the corrected mean range value of 12.98 feet of Table 15 was added to the corrected mean values of the diurnal inequalities of Table 14, yielding 15.42 feet as the accepted value of Ketchikan's great diurnal range.

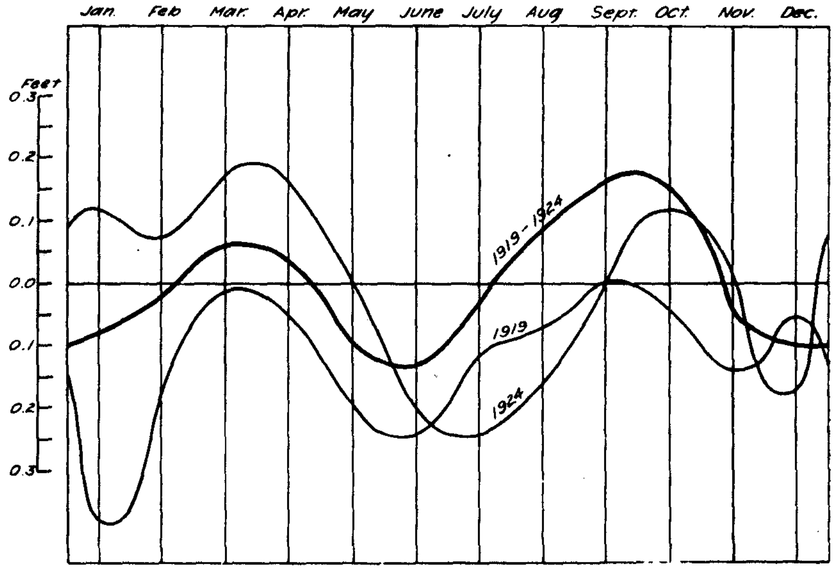

FIG. 8.—Annual variation in mean range, Ketchikan

The ranges already discussed, with other ranges at Ketchikan, are compiled in Table 16. Those values inclosed in parentheses were derived by the use of the harmonic constants for 1920.

TABLE 16.—*Ranges of tide at Ketchikan, 1919–1924*

[Values inclosed in parentheses derived from 1920 harmonic constants]

Designation	Feet	Designation	Feet
Mean range	12.98	Small diurnal range	10.54
Spring range	(16.98)	Great tropic range	(15.75)
Neap range	(8.60)	Small tropic range	(8.56)
Perigean range	(15.54)	Storm range	21.95
Apogean range	(11.07)	Greatest range	25.1
Great diurnal range	15.42		

10. HARMONIC CONSTANTS

The Coast and Geodetic Survey uses the harmonic constants primarily to give settings on its tide-predicting machine, by means of which the tides are predicted for many places throughout the world.

To obtain values for these constants at Ketchikan, there has been made a harmonic analysis of the hourly ordinates for the year 1920, the series used commencing on January 1, 1920, and continuing for 369 days. The method of analysis used is fully explained in the book " Harmonic Analysis and Prediction of Tides," [8] by Paul Schureman. The results of the 1920 analysis are listed in Table 17, the amplitudes being given in feet under the column heading H, and the epochs as referred to the local meridian given in degrees under the column heading κ.

TABLE 17.—*Harmonic constants, Ketchikan, 1920*

Component	H	κ	Component	H	κ
	Feet	*Degrees*		*Feet*	*Degrees*
J_1	(0.092)	(136.6)	Q_1	0.174	100.9
K_1	1.648	129.0	2Q	(0.026)	(98.5)
K_2	.506	28.8	R_2	(0.016)	38.3
L_2	.139	7.6	S_1	.021	280.1
M_1	.066	1.449	S_2	2.014	38.3
M_2	6.137	6.91	S_4	.013	223.4
M_3	.122	297.0	S_6	.002	316.8
M_4	.065	123.1	T_2	.144	193.2
M_6	.006	31.7	λ_2	.015	347.5
M_8	.003	274.7	μ_2	.141	326.8
N_2	1.241	341.6	ν_2	.248	349.2
2N	.140	318.9	ρ_1	(0.038)	(107.1)
O_1	1.012	113.7	MS	.033	158.7
OO	(0.051)	(144.3)	Sa	.485	226.9
P_1	.510	125.0	SSa	.186	133.2

Among the tidal characteristics which may readily be derived from the harmonic constants [9] are the ages of the tide, the type of the tide, and the order of occurrence of the tides.

The ages of the tide are determined from the following formulas:

Phase age, in hours $= 0.984\ (S°_2 - M°_2)$
Parallax age, in hours $= 1.837\ (M°_2 - N°_2)$
Diurnal age, in hours $= 0.911\ (K°_1 - O°_1)$

The phase age of the tide is the time elapsing from the occurrence of new and full moon to the spring tides, or the time between the moon's first and third quarter, and the following neap tides. Substituting the values of the harmonic constants from Table 17 in the proper formula, the phase age of the tide at Ketchikan is derived as 30.9 hours.

The parallax age of the tide is the time by which the perigean and apogean tides follow the corresponding positions of the moon on its orbit around the earth. The value of the age as derived for Ketchikan is 46.5 hours.

The diurnal age of the tide is the time by which the tropic tides follow the moon's semimonthly maximum north and south declinations, equaling 13.9 hours as derived from the formula.

The type of the tide is obtained by the use of the ratio $(K_1+O_1 \div (M_2+S_2)$. From this there is derived a value of 0.30. When the ratio obtained from this formula lies between 0.25 and 1.25 the tide is of the mixed type. This is clearly the type prevailing at Ketchikan, for the two high waters and two low waters occurring each day both exhibit marked height differences, that between the low waters being the greater.

The order of occurrence of the tides may also be determined from the harmonic constants,[10] but inasmuch as the formulas used are

[8] U. S. Coast and Geodetic Survey Special Publication No. 98.
[9] See formulas, Manual of Tides, U. S. Coast and Geodetic Survey Report, 1894.
[10] Manual of Tides, Part III, U. S. Coast and Geodetic Survey Report for 1894, p. 145.

somewhat involved they are not reproduced herein. These formulas give the order of occurrence of the tides at Ketchikan to be higher high water, lower low water, lower high water, higher low water. This fact is readily discernible from an inspection of a few days' tidal curves as recorded on the automatic gauge paper.

11. SUMMARY OF TIDAL DATA

For ready reference the Ketchikan tidal characteristics derived and discussed in the preceding pages have been summarized in Table 18. These tabulated results are the best values obtainable at present from the tidal observations to the close of 1924. They have been derived either as the means of the 6 years' observations or from the harmonic constants for 1920. The latter values are inclosed in parentheses.

TABLE 18.—*Summary of tidal data, Ketchikan, Alaska*

[Mean sea level on staff=14.240 feet. Values in parentheses derived from harmonic constants for 1920.]

TIME RELATIONS

	Hours
High-water interval	[11] 0.31
Low-water interval	[11] 6.44
Duration of rise	[11] 6.29
Duration of fall	[11] 6.13
Phase age	(30.9)
Parallax age	(46.5)
Diurnal age	(13.9)
Sequence of tides is HHW to LLW.	

RANGES AND RATIOS

	Feet
Mean range	12.98
Great diurnal range	15.42
Small diurnal range	10.54
Great tropic range	(15.75)
Small tropic range	(8.56)
Spring range	(16.98)
Neap range	(8.60)
Perigean range	(15.54)
Apogean range	(11.07)
Storm range	21.95
Greatest range	25.1

	Ratio
Spring range÷mean range	1.31
Great tropic range÷mean range	1.21
Perigean range÷mean range	1.20
Great diurnal range÷mean range	1.19

HEIGHT RELATIONS

	Mean sea level, feet	Mean lower low water, feet
Mean high water above	6.47	14.52
Mean higher high water above	7.37	15.42
Mean lower high water above	5.57	13.62
Tropic higher high water above	(7.36)	(15.41)
Tropic lower high water above	(4.91)	(12.96)
Spring high water above	(8.45)	16.50

[11] Derived from tabulations of 2 years only, 1919 and 1922.

	Mean sea level, feet	Mean lower low water, feet
Storm high water above	10.48	18.53
Highest high water above	12.00	20.00
Mean sea level above	0.00	8.05
Mean low water below	6.51	-----
Mean lower low water below	8.05	0.00
Mean higher low water below	4.97	-----
Tropic lower low water below	(8.39)	(0.34)
Tropic higher low water below	(3.65)	-----
Spring low water below	(8.53)	(0.48)
Storm low water below	11.47	3.42
Lowest low water below	13.1	5.1
Mean tide level	0.02	-----

12. METEOROLOGICAL EFFECTS

As has been briefly mentioned in the foregoing pages meteorological changes are influences tending to act upon the water surface, their effects being marked by fluctuations in the height of sea level and therefore corresponding changes in the heights of high and low waters as they oscillate about sea level. In regions of small tidal range, sudden changes in wind, barometer, or fresh-water discharge, are ofttimes of sufficient influence to cause tidal changes which completely mask the normal heights and times of the astronomic tides.

To illustrate the effect of changing barometric pressures upon the height of sea level over long periods of time, the two curves of Figure 9 have been plotted to show mean monthly barometric pressures and heights of sea level for the period 1919–1924. As records of barometric pressures for Ketchikan were not available those for Sitka have been utilized. Daily conditions of weather at Sitka and Ketchikan are usually enough alike to permit the use of the Sitka mean pressures as standard for Ketchikan. The monthly mean barometric pressures recorded at Sitka were taken twice daily, at 8 a. m., and again at 8 p. m. The a. m. and p. m. values show very slight differences throughout the series, the maximum difference for any one month equaling but 0.012 inch. For the plotting of the pressure curve in Figure 9, the 8 p. m. monthly mean values were used. These values of the barometer are listed in Table 19.

TABLE 19.—*Average monthly barometric pressure, Sitka, Alaska, 1919–1924*

[Observations taken daily at 8 p. m. To reduce these data to sea level add 0.100 inch]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1919	29.453	29.565	29.742	29.746	29.772	29.971	29.974	29.959	29.854	29.934	29.744	29.797
1920	29.876	30.105	29.635	29.850	29.865	29.842	30.043	29.892	29.625	29.647	29.649	29.325
1921	29.536	29.567	29.901	29.761	29.913	29.743	30.008	29.895	29.699	29.557	29.716	29.777
1922	29.817	29.829	29.598	29.887	29.808	30.008	30.073	29.875	29.714	29.699	29.605	29.749
1923	29.586	29.993	29.861	29.730	29.821	29.898	29.988	29.859	29.793	29.726	29.580	29.465
1924	29.680	29.568	29.879	29.762	29.903	29.989	29.967	29.860	29.696	29.527	29.660	29.865
Mean	29.695	29.754	29.769	29.789	29.844	29.910	30.009	29.890	29.730	29.682	29.659	29.663

The two curves of Figure 9 bring out clearly the relationship between the height of the sea level and the air pressure, for as the pressure curve indicates an increase from month to month, the sea-level curve manifests a corresponding decrease in the height of sea level, and vice versa. There are, of course, minor incidental disturbances that slightly modify this almost direct relationship at Ketchikan. However, only for one short period is there a disturbing factor of any magnitude. During the months of May and June there is noted a considerable increase of the sea-level height above the general trend of the curve. This change can not be accounted for by any decrease in barometric pressure, for the latter is steadily rising from January until July, when it has reached its maximum.

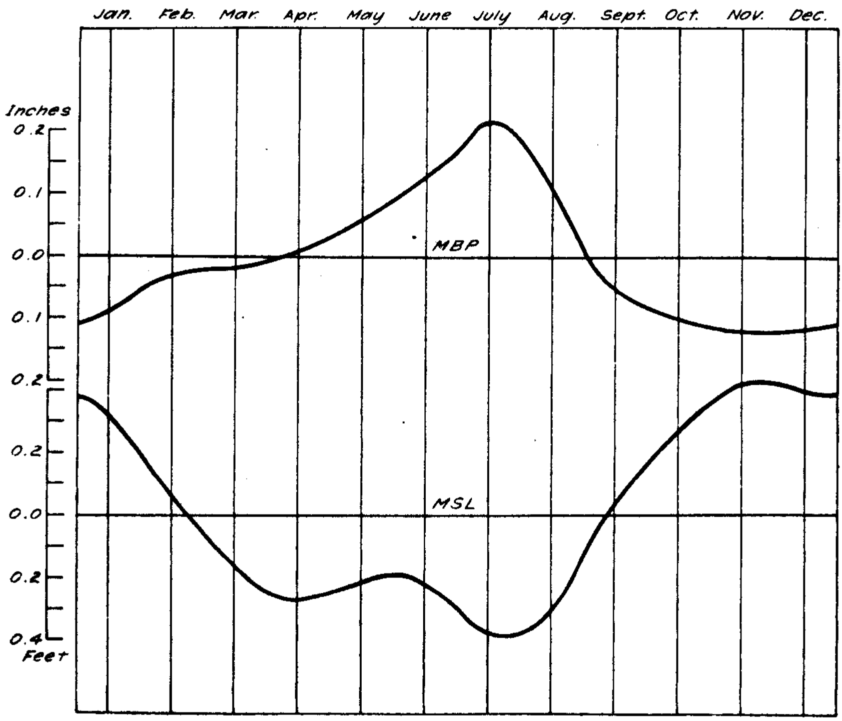

FIG. 9.—Relation between sea level and barometric pressure

The augmented sea level during these two spring months is quite evidently caused by the sudden influx of large quantities of fresh water from the rapidly melting snows of the mountains along the coast. During these early summer months the snow line moves upward from sea level to between 2,000 and 3,000 feet elevation, as the heavy winter snows are rapidly melted and drained away to the sea. The great quantity of fresh water which is suddenly discharged into the sea during May and June may be readily judged by an observer noting the prevailing flood conditions in all streams along the coast. By July all the heavy winter snows have disappeared and the streams have diminished in size and numbers; many that were wide, roaring torrents but a week before are but small brooks spanned by a single step, or simply dried-up stream beds.

The extreme variations in the height of tide listed for each year of the 6-year series in Tables 12 and 13 show that the large majority of these excessive tides occurred during the winter months. From this fact alone the conclusion might be drawn that storm conditions are largely responsible for the extreme fluctuations in sea level.

The lack of weather reports concerning wind conditions along the Alaskan coast prohibit a discussion of the effects of gales upon the heights of the tide. It may only be inferred that the wind is one of the several factors combining to bring about the extreme, or storm tides.

However, there are other factors available for study. The barometric pressures recorded at Sitka for the days of the storm tides show that in every instance an extreme low tide was accompanied by an unusually high barometer. Taking the average of the daily barometric pressures recorded for each of the annual lowest tides listed in Table 12, the average pressure for these six days is found to be 0.39 inch higher than is the mean pressure found by averaging together the monthly barometric pressures for those six months in which these extreme tides occurred.

Considering that the mean yearly barometric pressure variation of 0.35 inch brings about an annual range in the variation of sea level of 0.8 of a foot, it may be presumed that the barometric increase at the times of these storm tides will account for approximately 1 foot of the decreased height of sea level recorded at these times.

A study of the pressures recorded at times of the extreme high tides shows that in most cases a considerable decrease in pressure accompanied the storm tide.

From the height relation of the tides listed in Table 18, the storm low-water plane is seen to be 11.5 feet below mean sea level, while the next lowest tidal plane, that of spring low water, is but 8.5 feet below, a difference of 3 feet. If 1 foot of this difference is accounted for by barometric pressure increases, the remaining height difference must be ascribed to the other factors.

It is noted that invariably the highest or lowest tides for a year occur during periods when two, or all, of the spring, perigean, and tropic tides combine, so that their large tidal fluctuations form a second factor tending to increase the rise and fall of the tide. This conjunction of the stronger tidal forces plus the wind effects must account for the extra 2 feet decrease in the average plane of the storm tides.

To sum up the foregoing discussion, we may conclude that the extreme, or storm tides, are mainly caused by the combined effects of unusual barometric pressures, the conjunction of spring, perigean, and tropic tides, and heavy winds.

ANNUAL VARIATIONS

13. VARIATIONS IN MEAN SEA LEVEL

Following the preceding discussion dealing with the factors influencing the height of sea level, Figure 10 has been prepared to illustrate the annual variations in sea level at various southeast Alaska tidal stations, where differing local conditions of pressure, winds, river discharge, and location cause differing annual variation curves.

These graphs of sea level are drawn for the five principal tidal stations at Ketchikan, Skagway, Craig, Juneau, and Sitka. Due

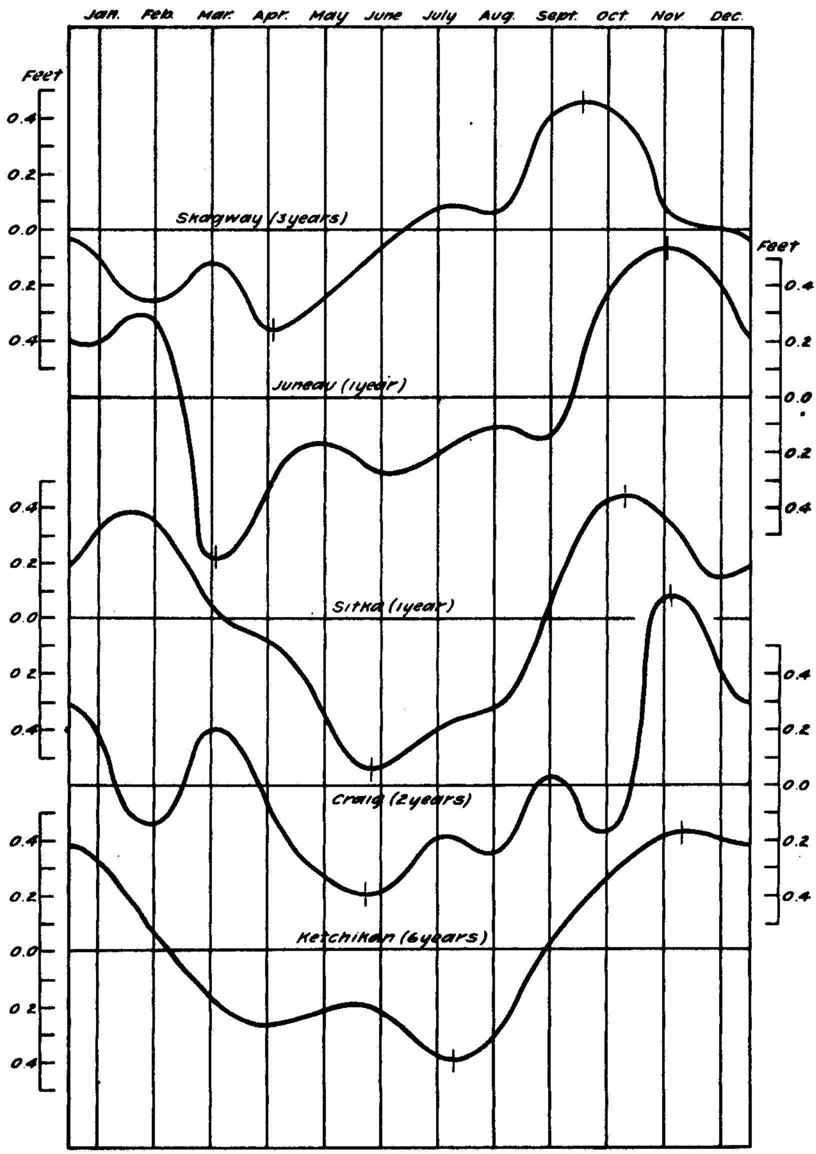

FIG. 10.—Annual variation in sea level, principal Alaska tide stations

allowance must be made for the curves of the shorter period stations, as it is manifestly improbable that these represent quite accurately the mean graphs that can only be obtained from longer series of observations. An inspection of the individual yearly curves for the sea level at Ketchikan, as shown in Figure 5, will illustrate the amount the individual yearly curve may differ from a curve of 6 years' averages. Also, to make the curves of Figure 10 strictly comparable they should be based upon simultaneous series, i. e. observations taken during the same years. However, we may accept them as sufficient for purposes of this comparison.

It is noted that the curves of sea level for the extreme northerly and southerly stations differ materially as regards the time of lowest sea level for the year, which occurs at Skagway in April but not until July at Ketchikan. There has already been assigned a cause for the time of occurrence at Ketchikan's lowest sea level, it being due to the season of highest barometric pressures. It is quite possible that a like cause affects the height of sea level at Skagway. An absence of any pressure readings at or near the station precludes any discussion upon the pressure effects at Skagway.

Another factor, one which undoubtedly exerts considerable influence upon Skagway's tidal characteristics is the belt of far-reaching ice fields surrounding Lynn Canal and extending to the northward. These would tend to maintain more equable air and water temperatures throughout the year, and would also bring about barometric conditions differing from those farther south at Sitka.

As Skagway is at the head of a narrow inlet into which two sizeable rivers discharge, its height of sea level is increased by the opposition of river current to the incoming tide, causing an increased height of the high waters, and the river discharges raising the height of the low waters on the outgoing tides. Thus we may explain the gradual rise of sea level at Skagway from the month of April, for at this time the ice goes out of the rivers and a heavy fresh-water discharge fed by the melting snows and ice fields pours into the head of the canal until the midsummer months. Even if we presume the barometric pressure variation at Skagway to resemble that of Sitka, the pressure effect upon the sea level might be masked by the greater effect of the river discharge. If fresh-water discharge can mask the barometric pressure effect upon sea level at Ketchikan, which, through its freer accessibility to the open ocean, is less subject to the influences of river discharge, it is quite reasonable to assume that Skagway is still more liable to the influences of fresh-water discharge from its adjacent rivers.

A comparison of the curves for Ketchikan, Craig, and Sitka shows them to be somewhat similar. All these stations are subject to much the same conditions of barometric pressure, river discharge, and accessibility to the open-ocean tides. The curves for the two northerly stations, Juneau and Skagway, also follow each other in general contour. This might be expected, inasmuch as both stations are situated well inland from the sea at the heads of long inlets, and are presumably subject to somewhat similar conditions of river discharge and barometric pressures.

Minimum annual sea level occurs in June and July for the three southerly stations, and in April and May for the two northerly stations. Maximum sea level exhibits less variation in time of occurrence, ranging from October at Skagway to December at Ketchikan.

The extreme height variations in sea level during the 12 months are much the same for the five stations, ranging from a minimum of 0.79 of a foot at Ketchikan to a maximum of 1.12 feet at Juneau.

In conclusion it may be stated that where station locations are similar with respect to (1) accessibility to the open sea, (2) river discharge, and (3) barometric pressure, it may be expected that the individual annual sea-level curves for each station will be very much alike. This statement is borne out in connection with a discussion upon the similarity in the annual sea-level variations of certain Atlantic and Pacific coast stations in an article, "Mean Sea Level and its Variations,"[12] by H. A. Marmer.

14. VARIATIONS IN MEAN RANGE

In a preceding discussion of the tidal range at Ketchikan there was found to be a definite periodicity exhibited in its annual variation. The graphs for this station and the other principal southeast Alaska tidal stations at Craig, Sitka, Juneau, and Skagway have been drawn on Figure 11. It is noted that all show periodic variations somewhat similar to the range at Ketchikan.

With a view toward utilizing this known periodical range variation as a means whereby the range at uncompared stations of at least a month's tidal series may be corrected, the following tables have been drawn up. Table 20 lists the monthly variations from the mean range at the five aforenamed tidal stations.

TABLE 20.—*Variation in mean range, principal southeast Alaska tide stations*

Station	Years	Uncorrected mean	Variations from mean range											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
		Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Ketchikan	6	13.29	−0.08	−0.02	+0.06	+0.04	−0.09	−0.13	−0.02	+0.08	+0.16	+0.16	−0.04	−0.10
Craig	2	7.88	+.05	+.16	+.08	+.05	−.11	−.12	−.13	+.00	+.09	+.13	−.13	−.08
Sitka	1	7.76	+.03	+.14	−.10	−.06	−.06	−.15	−.13	−.06	+.07	+.10	+.13	+.11
Juneau	1	13.41	+.01	+.10	+.41	+.31	−.09	−.35	−.56	−.03	+.36	+.27	−.12	−.15
Skagway	3	13.93	−.36	−.08	+.07	−.02	−.35	−.29	−.17	+.07	+.73	+.67	+.03	−.33

TABLE 21.—*Range correction factors for uncompared stations*

Standard station	Factor of correction to monthly mean range											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Ketchikan	1.006	1.002	0.995	0.997	1.007	1.010	1.002	0.994	0.988	0.988	1.003	1.008
Craig and Sitka	.995	.981	.993	.999	1.012	1.018	1.017	1.006	.990	.984	1.006	1.002
Juneau and Skagway	1.019	1.003	.989	.995	1.020	1.022	1.020	.997	.956	.960	.999	1.021

Table 21 contains the range correction factors, which are later utilized to correct the mean range at the few tidal stations through southeast Alaska at which observations were made during periods

[12] September number "Annals of the Association of American Geographers," 1925.

when no standard station was being occupied. To best use the range variations of Table 20, those of certain stations having similar characteristics, as shown by their curves of annual variation, have been combined and weighted to give the monthly range correction factors of Table 21. To use these latter values it is only necessary to choose those of the station group most nearly resembling the uncompared station in location and tidal characteristics, then apply

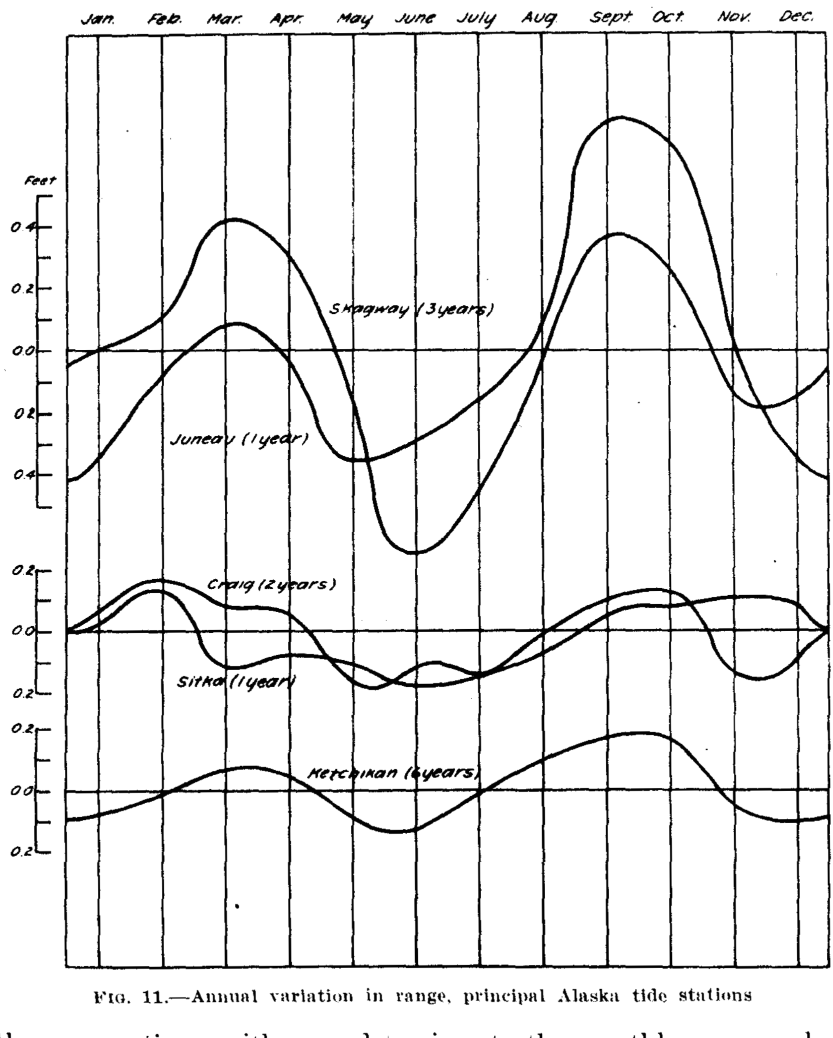

FIG. 11.—Annual variation in range, principal Alaska tide stations

these corrections, with regard to sign, to the monthly range values to be corrected. The result will, however, still need to be corrected for the longitude of the moon's node.

To be well determined, the correction factors of these tables should be the product of 19-year tidal series. However, the application of the corrections will generally yield better range values than are to be had simply by accepting the range as obtained for the direct observations.

This section has been included mainly to illustrate a possible method of correcting short-period, noncomparable tidal stations. In an entirely similar manner correction factors may be obtained for the great diurnal range, the lunitidal intervals, and also the heights of certain of the tidal planes.

THE TIDES IN THE VARIOUS WATERWAYS

15. GENERAL REMARKS

The area embraced in southeast Alaska is too great to permit of discussion as a whole, for which reason arbitrary divisions have been made. Insofar as it was possible these divisions were so made as to embrace an area, or connecting waterways, throughout which the tidal characteristics may be expected to bear close relationship. The divisions are 10 in number, and will be discussed in the following order: (1) Outer coast (Dixon Entrance to Cross Sound); (2) Revillagigedo Channel, Portland and Behm Canals; (3) Clarence Strait; (4) Sumner Strait; (5) Wrangell Narrows; (6) Frederick Sound and Stephens Passage; (7) Chatham Strait and Keku Strait; (8) Peril Strait; (9) Lynn Canal; (10) Icy Strait, Glacier Bay and Cross Sound.

Each of these divisions is illustrated by a separate outline map on which are located and named all of the various tidal stations established and occupied therein. To correlate the 10 divisions reference should be made to Figure 1.

For each of the various tide stations certain characteristics have been listed in tabular form, these including the lunitidal intervals and duration of rise, the mean and the great diurnal ranges, the length of observations, and the name of the standard station with which the observations were compared. Except for those few stations for which no standard comparison station is listed, the values of the intervals and rise, and the values of the ranges were corrected to the best values obtainable by comparison with simultaneous observations[13] taken at some long-period station, such as Ketchikan, Skagway, Sitka, or Craig. The same values for all uncompared stations have been corrected[14] as fully as possible, the intervals by the correction to longitude, the mean range by the correction factors of Table 21 and both ranges for the longitude of the moon's node. Those stations for which no great diurnal range is tabulated are stations at which the series were not continuous throughout three days or longer, stations where no automatic gauge was established, so that readings were perforce obtained from a tide staff and for the daylight hours only. Many of the tidal observations have been carried over a considerable period of years by broken series, the station being occupied but a few days or a few months of a year with a considerable gap in time before the station was reoccupied. The periods over which observations have been carried, whether made up of one continuous series or of a number of broken series, are listed in the column headed "Series," while the actual number of observation days are

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[13] For the method of comparison by simultaneous observations, see U. S. Coast and Geodetic Survey Special Publication No. 26, paragraphs 509–511.

[14] These corrections are explained in U. S. Coast and Geodetic Survey Special Publication No. 26, paragraphs 494–499 and 502–507.

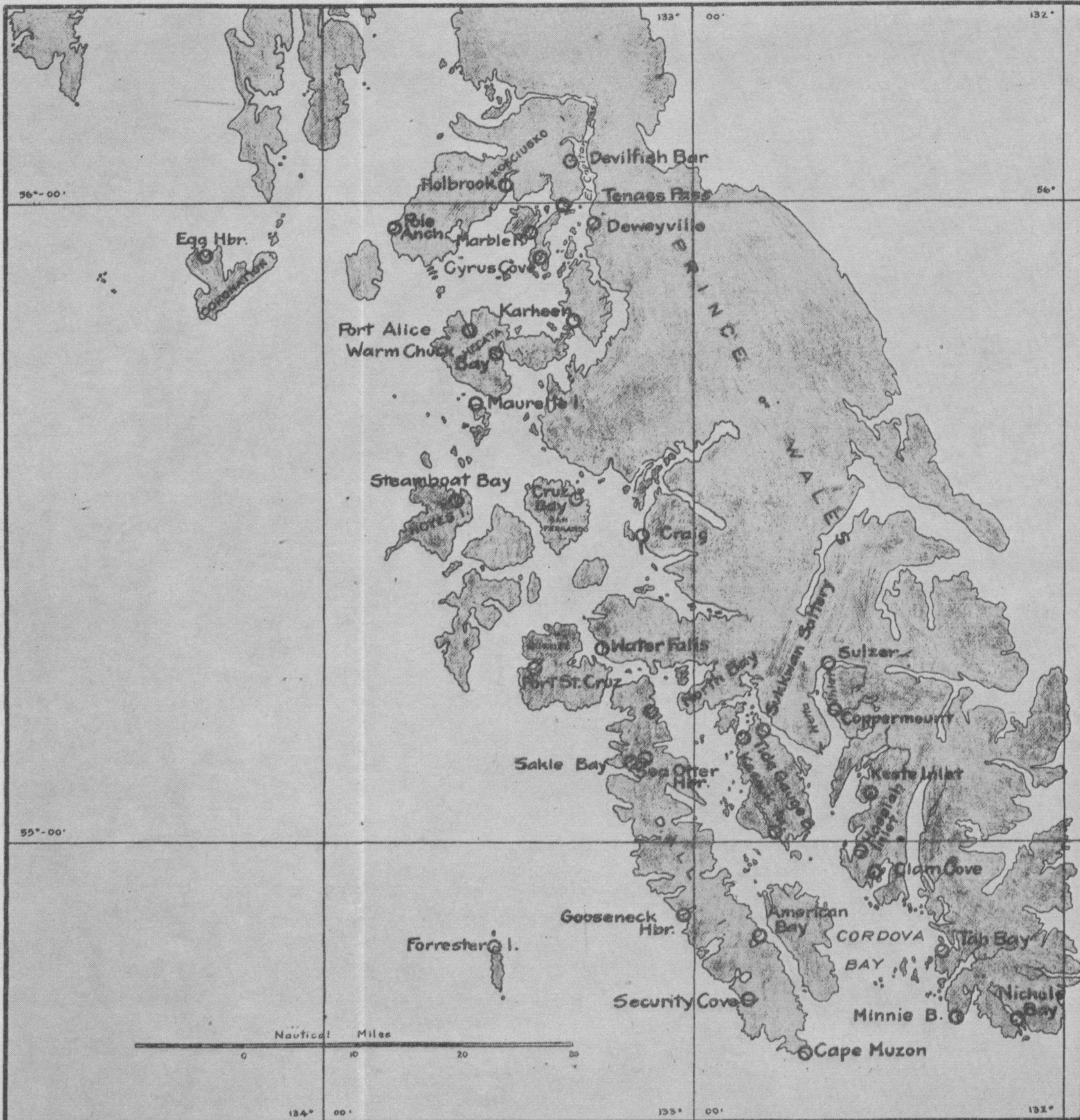

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FIG. 12.—Tide stations, outer coast (lower part)

listed under "Length." Obviously tidal values obtained from the shorter length series can not be given as much weight as those derived from the longer series at some other station, so that due consideration must be given to this fact in the use of the tables of tidal characteristics. The value of the greatest range observed at a station is not to be accepted as the extreme that may be expected at that station, for series of but a few months' duration are not of sufficient length to permit the acceptance of any of their derived values as absolute. Even Ketchikan's 6-year series value for the greatest range may be exceeded at some time by excessive storm conditions occurring simultaneously with a spring tide. Therefore this range value as tabulated for any station can only be considered as an indication of the greatest range that may be expected for that station. There is also an element of uncertainty entering into the time relations of the older stations, where observations were made previous to the adoption of the standard-time zones about 1885.

From the lunitidal intervals, the difference in the time of tide between two stations is readily obtainable, a simple equation being used for the derivation.

Time difference$=(I_{11}-I_1)+0.069\ (L_{11}-L_1)$. In this equation I_1 and I_{11} are, respectively, the intervals in hours for the reference station and the secondary station, while L_1 and L_{11} are the respective longitudes in degrees. If the final result is positive the tide occurs later at the secondary station than at the reference station, if minus it occurs earlier at the secondary station. It is readily apparent from an inspection of the equation that the time difference may only be obtained as a direct result of the time-interval differences in the event of both stations having the same longitude.

16. THE TIDE ALONG THE OUTER COAST

As shown in Figures 12 and 13, tidal stations have been well distributed from the southern extremity of Prince of Wales Island along its outer coast and amongst the numerous smaller islands bordering it, and north through the outer bays of Baranof and Chichagof Islands to Cross Sound. The data obtained from the numerous stations afford a comprehensive study of tidal action along the 250-mile extent of southeast Alaska's outer coast. It is true that the period of occupation of the majority of these stations was short, so that the results obtained from such can not be accepted as being free from small errors; but these errors have been minimized by correcting the tidal values derived at the short-period stations through comparison with the better-determined values of such stations as Ketchikan, Craig, or Sitka. These tidal values for all the outer coast stations are listed in Table 22.

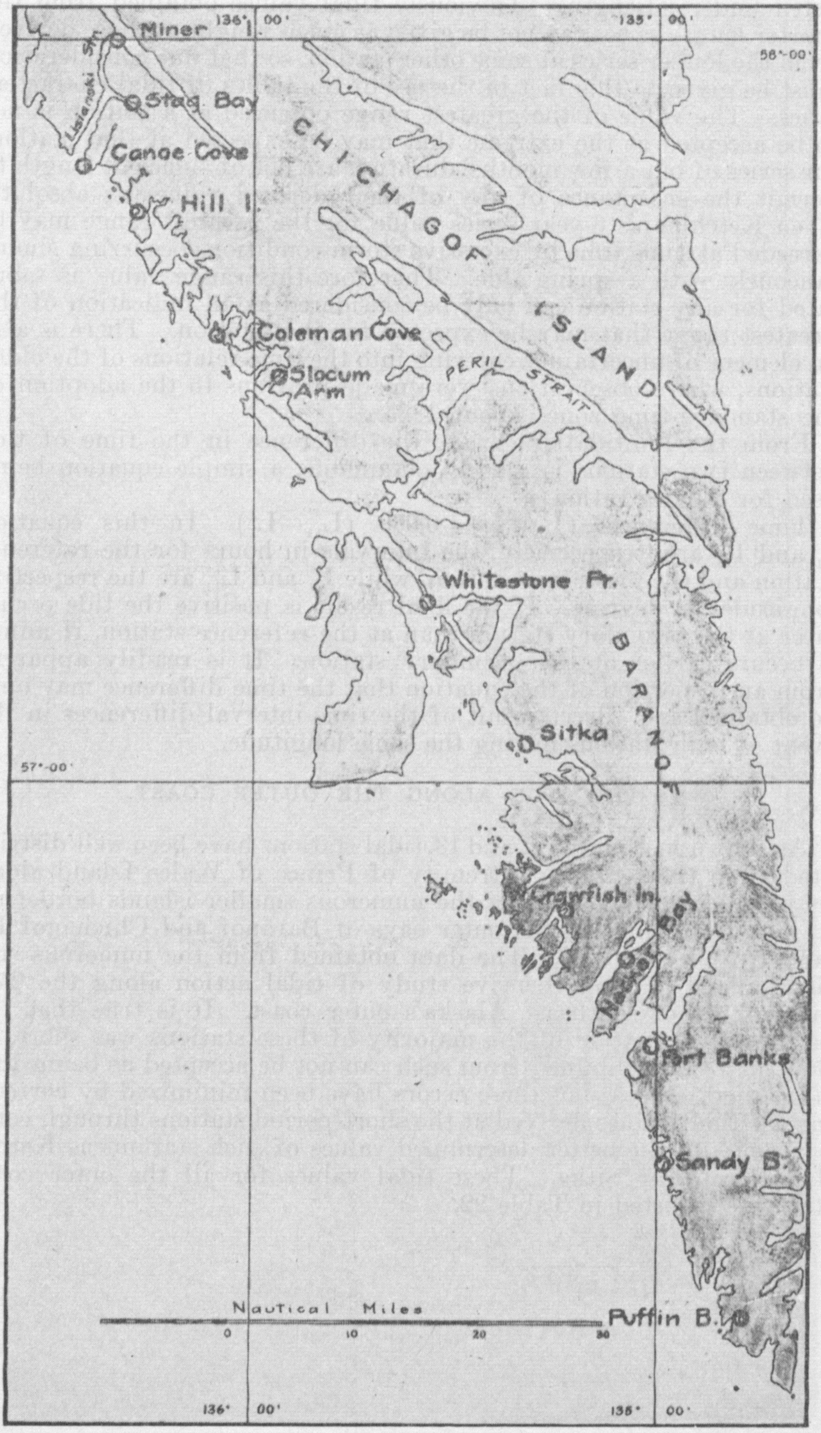

FIG. 13.—Tide stations, outer coast (upper part)

TABLE 22.—*Tidal data, Outer Coast (Dixon Entrance–Cape Spencer)*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′	*Prince of Wales Island and vicinity*		*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Year*	*Days*	
54 43 N 132 08 W	Nichols Bay		0.32	6.41	6.33	10.90	13.67	20.3	1920	58	Ketchikan.
54 43 N 132 18 W	Minnie Bay		.18	6.29	6.31	10.18			1909	60	Tah Bay.
54 50 N 132 20 W	Tah Bay		.22	6.37	6.27	10.13	12.52	16.4	1909	60	Skagway.
54 57 N 132 30 W	Clam Cove	Kassa Inlet	.14	6.34	6.22	9.69	11.94		1905	5	Sitka.
54 59 N 132 33 W	Hassiah Inlet		.00	6.23	6.19	9.91	12.19		1905	8	Do.
55 05 N 132 29 W	Keete Inlet		.42	6.52	6.32	10.77	13.11		1918	4	Craig.
55 13 N 132 38 W	Coppermount	Hetta Inlet	.35	6.48	6.29	11.03	13.35		1905	9	Sitka.
55 17 N 132 40 W	Sulzer	do	.22	6.49	6.15	11.18	13.61		1905	5	Do.
55 10 N 132 52 W	Tide Gauge Bay	Sukkwan Strait	.37	6.46	6.33	10.71	13.54	18.9	1912	59	Juneau.
55 10 N 132 48 W	Sukkwan Saltery	do	.31	6.46	6.27	10.53	12.93		1914	3	Ketchikan.
55 01 N 132 47 W	Kazook Inlet	Sukkwan Island	.11	6.45	6.08	10.28	13.09		1912	2	Tide Gauge Bay.
54 51 N 132 49 W	American Bay	Dall Island	.31	6.49	6.24	10.18	12.60		1916	3	Craig.
54 40 N 132 40 W	Cape Muzon	do	.51	6.74	6.19	10.18	11.85		1917	6	Do.
54 45 N 132 51 W	Security Cove	do	.21	6.19	6.44	9.54	11.85		1916	3	Do.
54 50 N 133 32 W	Forrester Island	East of Dall Island	.24	6.27	6.39	8.74	10.50		1916	3	Do.
54 53 N 133 00 W	Gooseneck Harbor	Dall Island	.02	6.27	6.17	8.51	10.75		1917	9	Do.
55 08 N 133 08 W	Sakie Bay	do	.38	6.54	6.26	7.95	10.20		1917	8	Do.
55 08 N 133 10 W	Sea Otter Harbor	do	.31	6.55	6.18	7.71	9.88	12.4	1920	45	Do.
55 12 N 133 07 W	North Bay	do	.26	6.36	6.28	10.67	12.78		1912	33	Tide Gauge Bay.

TABLE 22.—*Tidal data, Outer Coast (Dixon Entrance–Cape Spencer)*—Continued

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
55 16 N, 133 24 W	Port Santa Cruz	Suemez Island	0.14	6.50	6.26	7.87	10.64		1915	3	Craig.
55 18 N, 133 15 W	Water Falls	Ulloa Channel	.34	6.75	6.01	8.19	10.29		1914	3	Do.
55 32 N, 133 38 W	Steamboat Bay	Noyes Island	.19	6.37	6.24	7.98	10.13	16.2	1921–22	300	Ketchikan.
55 32 N, 133 19 W	Cruz Bay	San Fernando Island	.10	6.27	6.25	7.94	10.13	15.3	1913	116	(1).
55 29 N, 133 09 W	Craig		.21	6.37	6.26	7.95	10.14	18.0	1913–20	1,340	(1).
55 41 N, 133 35 W	Maurelle Island	Anguilla Islands	.37	6.42	6.37	8.16	10.32		1922	3	Steamboat Bay.
55 46 N, 133 32 W	Warm Chuck Bay	Heceta Island	12.10	5.98	6.12	8.19	10.35		1914	3	Craig.
55 49 N, 133 19 W	Karheen Cannery	Tuxekan Island	.02	6.02	6.42	8.67	10.82		1914	6	Do.
55 48 N, 133 36 W	Port Alice	Heceta Island	.05	6.20	6.27	8.41	10.54	15.1	1904	29	(1).
55 55 N, 133 24 W	Cyrus Cove	Sea Otter Sound	.18	6.26	6.24	8.76	10.86	14.7	1904	60	(1).
55 57 N, 133 26 W	Marble Passage	do	.03	6.23	6.22	8.89	11.27		1913	3	Sitka.
56 02 N, 133 30 W	Holbrook	Kosciusko Island	.03	6.25	6.20	8.41	10.58		1904	3	Port Alice.
56 00 N, 133 21 W	Tenass Pass	do	.02	6.11	6.33	8.65	11.02		1923	3	Deweyville.
55 57 N, 133 15 W	Deweyville	El Capitan Pass	.13	6.32	6.23	8.83	11.10	16.0	1923	58	Ketchikan.
55 04 N, 133 19 W	Devilfish Bar	do	.00	6.21	6.21	8.96	10.93		1922	3	Shakan Dock.
56 15 N, 134 32 W	Pole Anchorage	Kosciusko Island	.08	6.16	6.34	8.98	11.16	18.5	1916	15	Craig.
55 55 N, 134 19 W	Egg Harbor	Coronation Island	.00	6.12	6.28	8.22	10.95		1923	9	Port Walter.
	Baranof Island										
56 16 N, 134 46 W	Puffin Bay		.08	6.20	6.30	7.65	9.92	15.1	1924	60	Ketchikan.
56 28 N, 134 58 W	Sandy Bay		.00	6.12	6.30	7.51	9.65	13.0	1924	34	Sitka.
56 34 N, 134 59 W	Port Banks	Whale Bay	.03	6.16	6.29	7.81	10.17		1924	3	Do.
56 43 N, 135 04 W	Necker Bay		12.23	6.12	6.11	7.40	9.61		1924	7	Do.
56 50 N, 135 11 W	West Crawfish Inlet		.31	6.59	6.14	7.47	9.65	15.1	1925	60	Do.
57 02 N, 135 20 W	Sitka	Sitka Sound	.05	6.20	6.27	7.66	9.92	15.9	1827–1925	365	Ketchikan.
57 15 N, 135 34 W	Whitestone Point	Neva Strait	.15	6.25	6.32	7.67	9.88	13.4	1896	30	Sitka.
	Chichagof Island										
57 33 N, 135 56 W	Slocum Arm		.12	6.29	6.25	8.57	11.02	13.0	1906	29	Do.
57 36 N, 136 05 W	Coleman Cove		.32	6.56	6.18	8.22	10.35	13.1	1906	55	Do.
57 46 N, 136 17 W	Hill Island	Lisianski Strait	.41	6.30	6.53	7.55	10.38		1917	6	Craig.
57 50 N, 136 25 W	Canoe Cove	do	.27	6.32	6.37	7.77	10.00		1917	25	Do.
57 55 N, 136 18 W	Stag Bay	do	.21	6.19	6.44	7.78	10.00		1917	14	Miner Island.
58 00 N, 136 20 W	Miner Island	do	.34	6.34	6.42	8.37	10.57	15.8	1917	29	Craig.

[1] Tidal constants not corrected by simultaneous observations.

From Cape Muzon in Dixon Entrance to Hill Island at the entrance to Lisianski Strait the outermost stations, those at which open-ocean tidal conditions may be expected, exhibit mean range values varying from 7.40 feet to 10.18 feet. Even though the most of these stations have of necessity been established within bays rather than on the seacoast, their locations have been so chosen in wide-mouth deep-water bays that there is practically no divergence between the tidal characteristics at the station and immediately without the bay along the open seacoast.

An examination of the characteristics at the outermost stations discloses the existence of certain definite variations in the mean range along the coast. From 10.18 feet at Cape Muzon the range steadily decreases northward along the outer coasts of Dall and Suemez Islands to a minimum of 7.87 feet at Port Santa Cruz on the south coast of Noyes Island. From this last station the mean range commences to increase to the northward along Maurelle and Hecate Islands until it attains 8.98 feet at Pole Anchorage, on Kosciusko Island's outermost coast. Egg Harbor, on Coronation Island, which is farther out toward the open sea, exhibits a lessened mean range of 8.22 feet. Along the seacoast of Baranof Island the mean range varies but slightly from station to station, excepting for the higher values derived for Slocum Arm and Coleman Cove.

The tidal stations located throughout the bays and passageways of the west coast of Prince of Wales Island and the inner coasts of the smaller islands to the westward are liable to influences that tend to affect their tidal characteristics. As Cordova Bay divides to form Tlevak Strait, Sukkwam Strait, Hetta Inlet, and other long, narrow waterways, the volume of the rising tide is constricted and the water surface heightened as the waters flow into and along the narrowing passages. As the waters turn to flow outward with the falling tide, the flow progresses into passages growing steadily larger, so that the outbound tidal waters are permitted free and unrestricted passage. Thus the falling tide is enabled to attain the lowest plane. It is in these ways that the tidal ranges at the inner stations are increased. Coppermount and Sulzer, in Hetta Inlet, illustrate these facts very well, their mean ranges of 11.03 and 11.18 feet, respectively, being materially greater than the ranges at the tidal stations immediately to the south along the wider channel nearer the sea.

All along Prince of Wales Island the stations farthest removed from the open ocean exhibit this same increase in mean range over that found at the outermost stations. Another illustration of this fact is shown by the stations progressing inland from Hecate Island toward and into El Capitan Passage.

The time relations give evidence of considerable similarity over definite stretches of the outer coast. At the great majority of stations from Cape Muzon northward to Noyes Island the duration of rise is consistently longer than for the stations from Noyes Island northward to Whitestone Narrows, Baranof Island. For the lower group the average value of the duration of rise is found to be 6.25 hours, whereas the average for the more northerly group is but 6.08 hours, 0.17 hour less. Continuing north from Whitestone Narrows along the outer coast through Lisianski Strait the duration of rise again increases to an average value of 6.30 hours.

There are but two outer coast stations of long-period observations—one on Prince of Wales Island and the other on Baranof Island. Craig, on the former island, has been occupied as a tidal station over a total period of almost four years, two of which formed an unbroken series of observations. Sitka, on Baranof Island, has been occupied for 21 months of continuous observations, only 12 months of which were available for the purpose of this volume. These two tidal stations, together with Juneau, Skagway, and Ketchikan, are the only stations in southeast Alaska at which the period of continuous observations were in excess of a year. As such, the values derived as the tidal characteristics at these places are to be accepted as more reliable than those derived from the many shorter-period tide stations remaining. Therefore, in so far as simultaneous observations were available at any of these five major stations, their tidal values have been used as standards of comparison with which to correct the direct observational values of these other stations.

TABLE 23.—*Tidal data—Revillagigedo Channel, Portland and Behm Canals*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
55 15 N 130 06 W	Halibut Bay	Portland Canal	0.42	6.70	6.14	13.37	15.95		1888	19	Somerville Bay, British Columbia.
54 48 N 130 42 W	Nakat Harbor	Nakat Bay	.29	6.58	6.13	13.33	15.53	20.2	1883–1912	39	Kodiak.
	Revillagigedo Channel										
55 03 N 130 59 W	Kah Shakes Cove	Mainland	.16	6.29	6.29	12.85	15.36		1915	22	Ketchikan.
55 03 N 130 47 W	Vixen Bay	Boca de Quadra	.33	6.45	6.30	12.54	14.79	21.8	1892	29	(1).
54 55 N 131 15 W	Morse Cove	Duke Island	.45	6.60	6.27	13.26		20.5	1892	58	(1).
55 01 N 131 16 W	Cat Island	Cat Island	.10	6.38	6.14	12.72	15.11		1915	23	Ketchikan
55 07 N 131 12 W	Mary Island Anchorage	Mary Island	.37	6.35	6.44	12.96	15.46	21.5	1882	29	(1).
55 13 N 131 26 W	Hassler Harbor	Annette Island	.25	6.48	6.19	12.94	15.24	22.5	1882–1915	75	Ketchikan.
55 23 N 131 20 W	Gnat Harbor	Carroll Inlet	.42	6.38	6.46	12.36			1891	13	(1).
55 20 N 131 40 W	Clam Cove	Gravina Island	.30	6.36	6.36	12.86	15.18	20.6	1910	45	Skagway.
55 21 N 131 39 W	Ketchikan	Tongass Narrows	.31	6.44	6.29	12.98	15.42	25.1	1906–1924	2,660	(1).
55 24 N 131 44 W	Ward Cove	do	.27	6.24	6.45	13.11	15.42	24.6	1882–1914	54	Ketchikan. Clam Cove.
	Behm Canal										
55 36 N 131 38 W	Loring	Naha Bay	.35	6.43	6.34	13.42			1905	6	Yes Bay.
55 52 N 131 42 W	Convenient Bay	Hassler Island	.57	6.37	6.62	10.87	15.13		1891	18	(1).
55 56 N 131 50 W	Yes Bay	Cleveland Peninsula	.20	6.42	6.20	13.42	15.71	22.9	1905	29	(1).
55 59 N 131 25 W	Bell Arm	Bell Island	.33	6.37	6.38	13.58	16.12		1891	9	Burroughs Bay.
56 02 N 131 07 W	Burroughs Bay	Mainland	.33	6.45	6.30	13.53	15.95	22.1	1891	29	(1).
55 26 N 130 55 W	Shoalwater Pass	do	.47	6.30	6.59	12.51	15.13		1891	25	(1).

[1] Tidal constants not corrected by simultaneous observations.

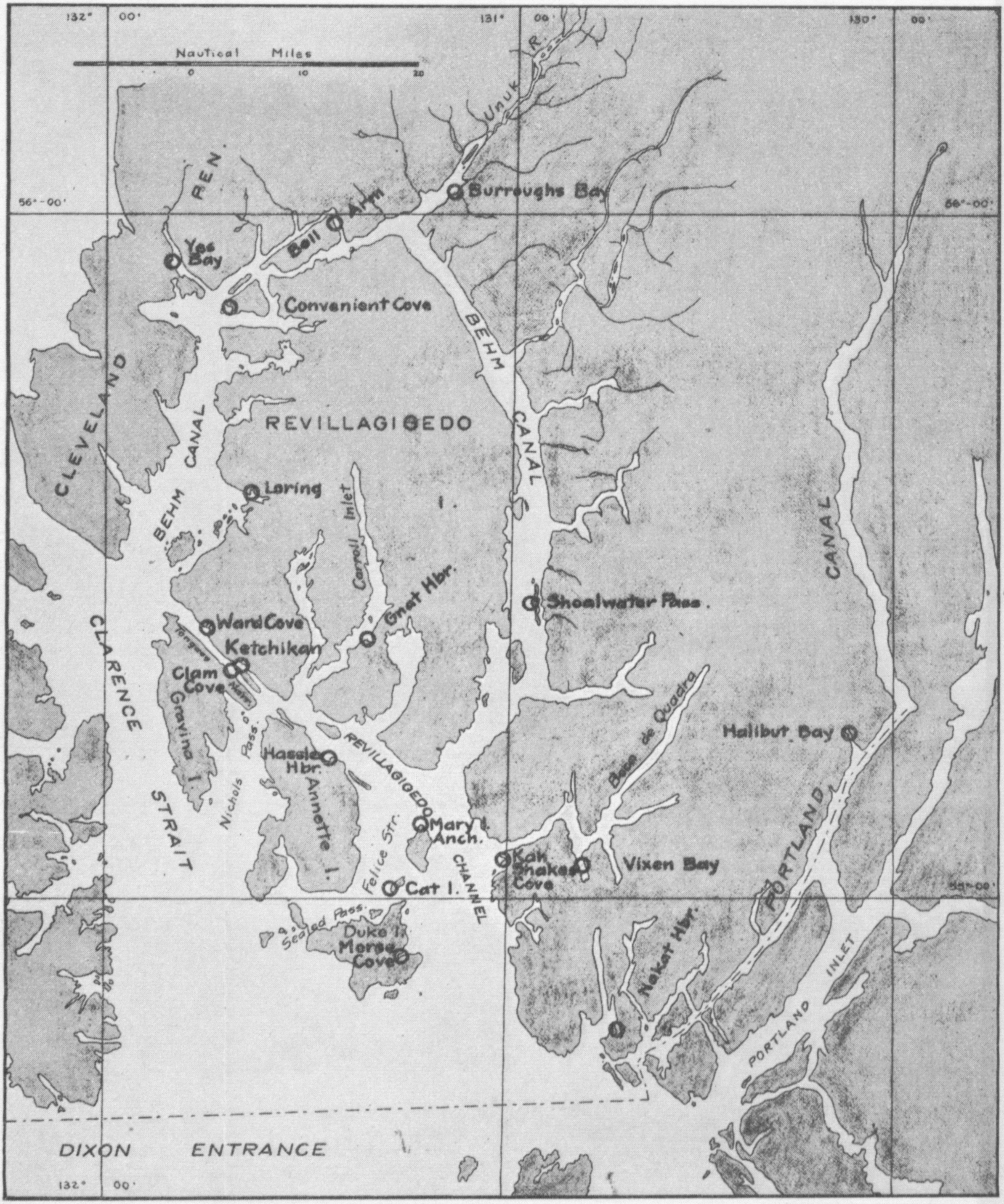

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FIG. 14.—Tide stations, Revillagigedo Channel, Portland and Behm Canals

17 THE TIDE IN REVILLAGIGEDO CHANNEL, PORTLAND AND BEHM CANALS

The tidal stations for this section, as listed in Table 23, are, with the sole exception of Ketchikan, all short-period stations, for the tidal values of which allowance must be made for small errors, taking into account the greater likelihood of inaccuracies in such values as have not been corrected by comparison with the mean values of standard, or longer-period stations. Variations in tidal values are therefore to be expected between adjoining stations at which the observations were made during different years or different months of the same year. The annual variations in mean range and in the time intervals, as shown by Figures 3 and 11, will serve as illustrations of this statement. The greatest deviation from the mean value which might be expected is shown by the value of the mean range derived at Convenient Cove in Behm Canal. This value is obviously too low, for there are no unusual shore-line configurations or natural causes to which this small range value might be attributed. Four near-by stations subject to similar tidal conditions exhibit but minor deviations amongst the respective values of mean range. The lack of agreement of this one tidal constant derived from an 18-day series of observations which was not possible of correction by comparison with some standard station value shows very strikingly the possible effects of combined astronomical and meteorological conditions upon short-period tidal observations.

Comparing the mean-range values derived for the Revillagigedo Channel stations, there is found to be very slight differences from the standard Ketchikan value of 12.98 feet. Morse Cove shows a maximum variation of 0.28 foot in excess of the Ketchikan range. At this subordinate station the series, though two months in duration, was very broken and also could not be corrected by simultaneous comparison.

Omitting the Convenient Cove station, the mean range values derived from the four stations along the west arm of Behm Canal are consistently higher than the mean range along Revillagigedo Channel. This increase may be attributed to the lifting effect exerted by the converging shores of the canal upon the volume of water forced in by the rising tide which flows in from Clarence Strait. The outgoing or falling tide, flowing as it does into steadily enlarging channels, is permitted a free and unrestricted flow that attains its minimum at low-water stages. Similar conditions are found at the Halibut Bay station in Portland Canal.

The greatest ranges observed approximate twice the mean range throughout this area, which fact only emphasizes the great importance of allowing for this extreme rising and falling at the time of storm tides when planning water-front construction in these localities.

The lunitidal intervals and the duration of rise are too much at variance to permit drawing any facts as to changes in the time of the tides along these waterways. The variations are not extreme, the maximum difference being 0.49 hour, but there is not sufficient uniformity amongst the time relations to allow a discussion as to the causes of the variations. This same lack of uniformity is common at all short-period tidal stations, the duration of rise seemingly remaining more nearly constant than do the lunitidal intervals. Neither of the time relations are as dependable, however. as are the values of mean range.

It will be noticed that two tidal stations without the limits of southeast Alaska have been used as standards with which to compare certain local stations. Of these two stations, Somerville, British Columbia, and Kodiak, southwest Alaska, the former is used but this once, whereas the latter station has been frequently used in the derivation of the forthcoming tidal data. In the early years of tidal work in Alaska, from the year 1882 to 1906, the tidal station at Kodiak was the only long-period station throughout the Territory, in other words the sole standard station which might be used to compare subordinate observations.

TABLE 24.—*Tidal data, Clarence Strait*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′	*West shore of Clarence Strait*		*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
54 48 N 132 03 W	McLean Island	Prince of Wales Island				11.87			1912	2	Juneau.
54 50 N 132 00 W	Gardner Bay	do	0.30	6.30	6.42	11.87	14.19		1920–21	24	Juneau. Ketchikan. Menefee Anchorage.
54 52 N 132 04 W	Short Arm	Kendrick Bay, Prince of Wales Island.	.04	6.30	6.16	11.87	14.09		1912	8	Juneau.
54 56 N 132 00 W	Hidden Bay	Prince of Wales Island	.17	6.25	6.34	11.82	13.73		1921	5	Menefee Anchorage.
55 01 N 132 01 W	Menefee Anchorage	do	.30	6.40	6.32	11.94	13.85		1921	144	Ketchikan.
55 04 N 132 09 W	Niblack Bay	do	.24	6.44	6.22	12.29	14.41		1912	16	Juneau.
55 09 N 132 10 W	Clarno Cove	North arm, Prince of Wales Island.	.32	6.56	6.18	11.80	13.44		1905	4	Niblack Bay.
55 08 N 132 03 W	Dolomi	Port Johnson, Prince of Wales Island.	.04	5.94	6.52	12.06			1905–1921	11	Menefee Anchorage
55 13 N 132 05 W	Lancaster	Cholmondeley Sound, Prince of Wales Island.	.28	6.21	6.49	12.52			1908	18	Skagway.
55 18 N 132 10 W	Clover Bay	Prince of Wales Island	.32	6.41	6.33	12.86	15.34		1921	12	Ketchikan.
55 24 N 132 19 W	Saltery Cove	Skowl arm, Prince of Wales Island.	.11	6.18	6.35	13.12	15.56		1921	4	Do.
55 21 N 132 22 W	Mackenzie Inlet	do	.20	6.58	6.04	13.15	15.99		1905	7	Yes Bay.
55 32 N 132 23 W	Kaasan	Kaasan Bay, Prince of Wales Island.	.31	6.30	6.43	13.24	15.68		1911–1924	78	Ketchikan.
55 34 N 132 29 W	It Mine	do	.39	6.47	6.34	12.94	15.12		1906	13	Skagway.
55 38 N 132 34 W	Karta Bay (large)	do	.63	6.78	6.27	13.45	16.03		1885	13	Kodiak.
55 30 N 132 24 W	Karta Bay (small)	do	.69	6.62	6.49	13.93	16.52		1885	6	Do.
55 29 N 132 40 W	Hollis	Kaasan Bay, Twelve Mile Arm, Prince of Wales Island.	.28	6.38	6.32	13.24	15.68		1924	22	Yes Bay. Ketchikan.
55 33 N 132 17 W	Hadley	Lyman Anchorage, Prince of Wales Island.	.33	6.36	6.39	13.29	16.02		1905–1915	15	Ketchikan.
55 53 N 132 38 W	Ratz Harbor	Prince of Wales Island				13.50			1916	2	Wrangell.
56 01 N 132 55 W	Lake Bay		.44	6.41	6.45	13.67	16.01	21.4	1905–1916	133	Craig.

TABLE 24.—*Tidal data, Clarence Strait*—Continued

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
	East shore of Clarence Strait										
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
54 58 N 131 25 W	Ryus Cove	Duke Island	0.23	6.33	6.32	12.53	14.95	22.0	1915	58	Ketchikan.
55 00 N 131 32 W	Hotspur Island		.30	6.38	6.34	12.46	14.88		1914	15	Do.
55 04 N 131 33 W	Tamgass Harbor	Annette Island	.63	6.73	6.32	12.76	15.37		1883	19	Kodiak.
55 08 N 131 34 W	Metlakatla	do	.26	6.37	6.31	12.34	14.62	21.9	1883–1914	164	Kodiak. Ketchikan.
55 09 N 131 44 W	Dall Bay	Gravina Island				18.00	21.86		1906	4	(1).
55 23 N 131 52 W	Vallenar Bay	do	.19	6.14	6.47	12.98	15.47		1921	12	Ketchikan.
55 45 N 132 12 W	Union Bay	Cleveland Peninsula	.18	6.22	6.38	13.77	16.36		1885–1922	66	Menefee Inlet.
55 56 N 132 23 W	Dewey Anchorage	Near Onslow Island	.62	6.67	6.37	14.08	16.52		1886	17	Kodiak.
56 00 N 132 23 W	McHenry Inlet	Etolin Island	.31	6.40	6.33	14.08	16.42		1916	23	Lake Bay.
56 04 N 132 29 W	Burnett Inlet	do	.35	6.39	6.38	13.89	16.35		1913	15	Ketchikan.
56 09 N 132 41 W	Steamer Bay	do	.38	6.43	6.37	14.02		21.2	1886–1915	31	Do.
55 59 N 132 12 W	Santa Anna Inlet	Ernest Sound	.39	6.39	6.42	13.90	16.25		1916	2	Wrangell.
56 04 N 132 12 W	Menefee Inlet	do	.28	6.32	6.38	13.63	15.76	25.0	1922	145	Ketchikan.
56 14 N 131 56 W	Ham Island	Blake Channel	.32	6.40	6.34	13.95	16.77		1916–1922	6	Wrangell. Menefee Inlet.

[1] Tidal constants not corrected by simultaneous observations.

18. THE TIDE IN CLARENCE STRAIT

The tidal stations established along this waterway are plotted on the chart of Figure 15 and their respective characteristics listed in Table 24. None of these may properly be termed long-period stations, as the maximum length of series at any one station is that of five months' observations at Metlakatla. Menefee Inlet, Menefee Anchorage, and Lake Bay are other stations with series almost as long.

All but one station along Clarence Strait permitted of correction by comparison with simultaneous values obtained at some longer period, or standard station. The direct results obtained at this station in Dall Bay, Gravina Island, serve to illustrate the extreme divergence from true mean values that may be obtained through uncomparable observations made at periods of extreme tides. The mean range as derived from the four days' observations at Dall Bay, equals 18 feet, some 5 feet in excess of the reasonable mean range for that locality. These observations were taken from June 5 until June 9, 1906, during which period there occurred a perigean moon on the 5th and a full moon on the 6th, both phases causing large tidal ranges. By adding the respective phase ages, as derived for Ketchikan, to obtain the times of the spring and the perigean tides, they are found to occur on the same day, the 7th. Both are tides of large fluctuation in themselves, and in this instance their combined effects were mainly responsible in bringing about the extreme mean range recorded at Dall Bay.

An interesting tidal action is manifested by the steady increase in the mean range from 11.87 feet at MacLean Arm in Dixon Entrance to 14.02 feet at Steamer Bay, 90 miles northward through Clarence Strait. This 2-foot increase in the mean range along the strait is explainable by the resistance offered to the rising tide flowing in from the large maw of Dixon Entrance, as its volume is constricted by the narrow passage afforded it by the strait. As in Behm Canal, here, too, the constriction of the incoming flood tends to increase the heights of the high waters, thereby increasing the mean range. Then as the tidal flow approaches the northerly end of Clarence Strait the flow coming in from Sumner Strait through Snow Passage offers an opposing force. A study of the current tables and diagrams included in this volume will show these two conflicting flows combining and veering off in an easterly direction through Stikine Strait. The interruption and consequent combining of these two opposing tidal flows form a factor accounting for the increased height of tide at near-by stations such as Steamer Bay.

There is a noticeable difference in the range values on either side of Clarence Strait along its lower stretches—the stations on Sealed and Nichols Passages having mean ranges averaging 0.6 foot greater than have the stations westward across the strait on Prince of Wales Island.

This increase in range on the eastern shore of Clarence Strait is to be attributed primarily to the earth's rotation, which impresses moving bodies in the Northern Hemisphere with a force deflecting them to the right. Thus on a rising tide flowing northward through the strait the water is deflected toward the right-hand or eastern shore, tending to raise the height of the high waters along that shore

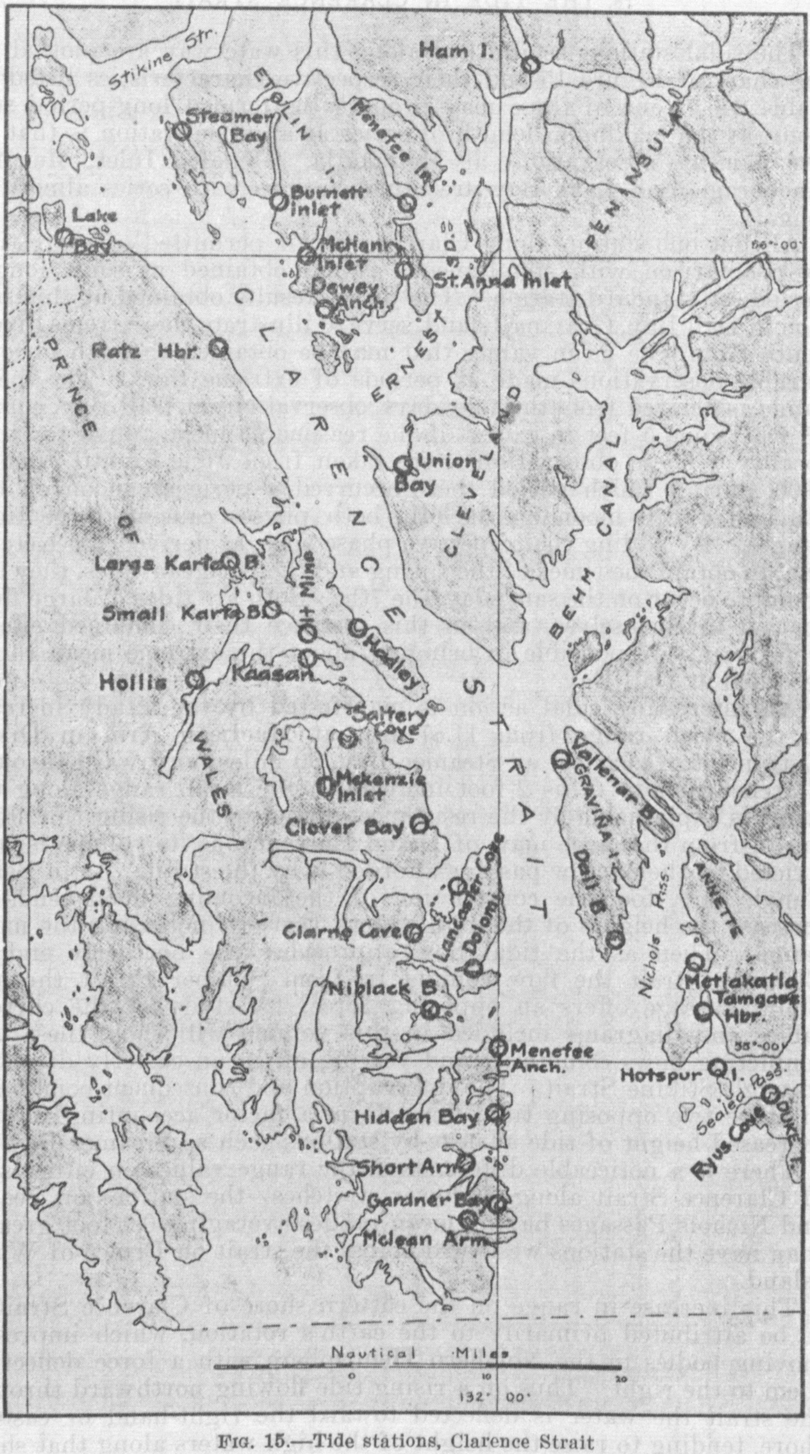

FIG. 15.—Tide stations, Clarence Strait

above those along the western shore of the strait. Similarly on a falling tide, as the waters are flowing southward, the deflection would force them to the right, and in this instance the western shore, thus tending to lower the height of low waters along the eastern shore. Therefore the mean tidal range on the eastern side of Clarence Strait is increased as compared with the range on the western side, both by the high and by the low stages of the tide.

The lunitidal intervals are not sufficiently consistent over this area to draw any conclusions therefrom. Unlike the mean range, they do not exhibit any definite variations. If the time of the tide changed while the range remained fairly constant along Clarence Strait, it might be expected that the wave action was of the progressive type. If these conditions were reversed and the time were the constant quantity, a stationary type of wave might be expected.

TABLE 25.—*Tidal data, Sumner Strait and contiguous waterways*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
56 15 N 134 32 W	Pole Anchorage	Kosciusko Island	0.08	6.16	6.34	8.98	11.16	18.5	1916	15	Craig.
56 08 N 133 36 W	High Water Island	Shakan Bay	.31	6.32	6.41	9.70	11.93		1915	6	Port Protection.
56 08 N 133 28 W	Shakan Dock	do	.14	6.25	6.31	9.67	11.73	17.5	1886–1923	73	Ketchikan.
56 10 N 133 25 W	West Dry Pass	Kosciusko Island	.31	6.40	6.33	9.71	11.72		1922	23	Shakan Dock.
56 18 N 133 54 W	Port Beauclerc	Kuiu Island	.42	6.66	6.16	10.00	11.87		1886	7	Kodiak.
56 18 N 133 36 W	Port Protection	Prince of Wales Island	.24	6.34	6.32	10.26	12.60	18.6	1866–1915	124	Craig.
56 21 N 133 36 W	Point Baker	do	.22	6.39	6.25	11.18	14.10		1912–1915	8	Port Protection.
56 33 N 133 52 W	Seclusion Harbor	Kuiu Island	.26	6.31	6.37	10.31	12.37	17.6	1892	29	(1).
56 19 N 133 17 W	Red Bay	Prince of Wales Island	.59	6.55	6.46	11.59	13.95		1886	25	Kodiak.
56 20 N 133 13 W	Point Colpoys	do	.30	6.43	6.29	11.16	13.36		1925	3	Ketchikan.
56 12 N 133 04 W	Exchange Cove	do	.39	6.50	6.31	12.71	15.03		1916	20	Lake Bay.
56 16 N 132 59 W	Bushy Island	Snow Passage	.37	6.26	6.53	12.72	14.82		1916	4	Wrangell.
56 13 N 132 55 W	Shrubby Island Cove	do	.43	6.48	6.47	13.64	15.52		1925	4	Ketchikan.
56 26 N 132 57 W	St. Johns Harbor	Zarembo Island	.54	6.44	6.52	12.56	14.65	21.5	1916	90	Craig.
56 28 N 132 22 W	Wrangell	Wrangell Island	.53	6.39	6.56	13.99	16.36	26.5	1882–1916	220	Do.
56 11 N 132 19 W	Olive Cove	Zimovia Strait	.40	6.31	6.49	14.09	16.48		1916–1922	16	Wrangell. Menefee Inlet.

[1] Tidal constants not corrected by simultaneous observations.

19. THE TIDE IN SUMNER STRAIT AND CONTIGUOUS WATERWAYS

The tidal stations along Sumner Strait and the smaller passages adjoining are plotted on the chart of Figure 16, their characteristics are listed in Table 25. Of these stations, Wrangell's 220 days' observations constitute the longest series at any one station in this area. The tidal values for this and the other stations, excepting Seclusion Harbor, have been corrected by comparison with standard long-period stations.

As in Clarence Strait, so along Sumner Strait does the mean range increase as the distance from the sea increases; varying from a value of 8.98 feet for Pole Anchorage at the sea entrance of the strait to 13.99 feet at Wrangell and 14.09 feet at Olive Cove, the farthest inland station.

The greatest range of 26.5 feet at Wrangell was derived from an extreme high water in September, 1887, which rose to 29.2 feet on the staff, and an extreme low water of June, 1886, that fell to 2.7 feet on the same staff. It can not be expected that these extremes may not be exceeded at some later date, especially as these observations were recorded during summer months when tidal conditions are notably more stable than in the winter.

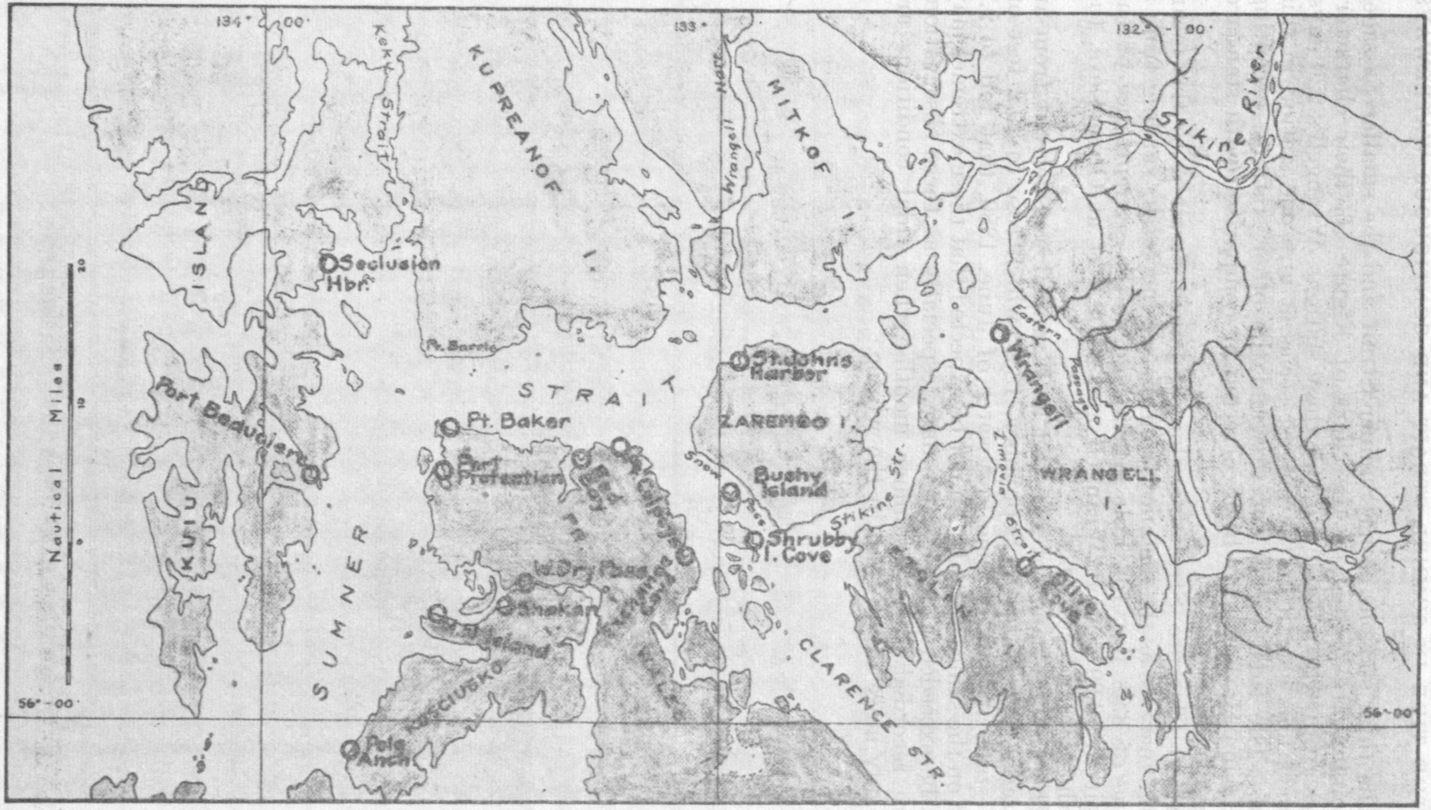

FIG. 16.—Tide stations, Sumner Strait

TABLE 26.—*Tidal data, Wrangell Narrows*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
56 33 N 132 58 W	Point Lockwood	Wrangell Narrows	0.54	6.50	6.46	12.85	15.27		1925	14	Petersburg.
56 36 N 132 59 W	Keene Island	do	.49	6.46	6.45	12.77	14.91		1910	4	Do.
56 39 N 132 56 W	Woody Island	do				14.04			1925	4	Do.
56 41 N 132 56 W	Finger Point	do	.57	7.04	6.00	14.13	16.45	23.8	1886–1910	31	Do.
56 43 N 132 57 W	Tonka Wharf	do	.62	7.09	5.95	14.13	16.59		1910	6	Do.
56 49 N 132 58 W	Petersburg	do	.68	6.92	6.18	13.53	16.05	23.4	1910–1925	225	Craig. Skagway.

20. THE TIDE IN WRANGELL NARROWS

Wrangell Narrows is a 20-mile navigable passage linking Sumner Strait on the south to Frederick Sound on the north of Kupreanof and Mitkof Islands. For vessels bound through the Inside Passage to Petersburg, Juneau, or Skagway, the use of this highway permits a saving of some 75 miles from the distance that otherwise must be traveled via Sumner and Chatham Straits.

The constricted passage with its attendant strong currents requires the larger steamers to run the narrows at times of slack water. The shoal near Petersburg limits the use of the narrows to high-water slack only in the case of the largest vessels. For many reasons a thorough knowledge is necessary of the tidal and current action throughout this small but commercially important waterway.

Figure 17 shows Wrangell Narrows with the location of the various tidal stations that have been occupied during different years from 1886 to 1925. The characteristics of the tides at these different points along the waterway are listed in Table 26.

With the exception of the tidal series at Petersburg the observation periods are all short, although the Finger Point and Point Lockwood stations were occupied for sufficient lengths of time so that the characteristics derived for these compare favorably with those derived at Petersburg. Even omitting the results of the other shorter-period stations, the three stations already named, located as they are at the extremities and the middle of the narrows, are ideally situated to illustrate the changing characteristics of the tide through the length of Wrangell Narrows.

In this long tidal channel of fairly constant cross-sectional area, fed simultaneously at either end by the rising tide, the mean range tends to increase from the ends toward a point midway along the waterway. As the conflicting tides flow in from Sumner Strait and from Frederick Sound there is brought about a gradual increase in the heights of the high waters progressing inward from either entrance to the narrows. This increased height attains a maximum at the meeting place of the tides near Finger Point. This increase is due to the constriction of large volumes of water and the consequent lifting of the water surface as the tidal flow is forced through the narrow channel. Near Finger Point this effect is accentuated by the opposing tidal flows from the north and south entrances meeting and tending to further heighten the water surface. The falling tide, being unrestricted in the flow from Finger Point outward through the north and south entrances, is thereby allowed to attain its lowest depth throughout the length of the narrows. From the foregoing discussion the reason is apparent for the amplification in tidal range from the entrance to the vicinity of the meeting tides near Finger Point.

The duration of rise decreases from either entrance of the narrows to Finger Point, the value for the latter station being 0.46 hour less than at Point Lockwood, and 0.18 hour less than at Petersburg. This is a similar effect to that found wherever the rising tide is restricted and the falling tide unrestricted in flow. As in rivers influenced by the tides, where the river current opposing the rising tide shortens its duration of rise and flowing with the falling tide lengthens the duration of fall, so in Wrangell Narrows

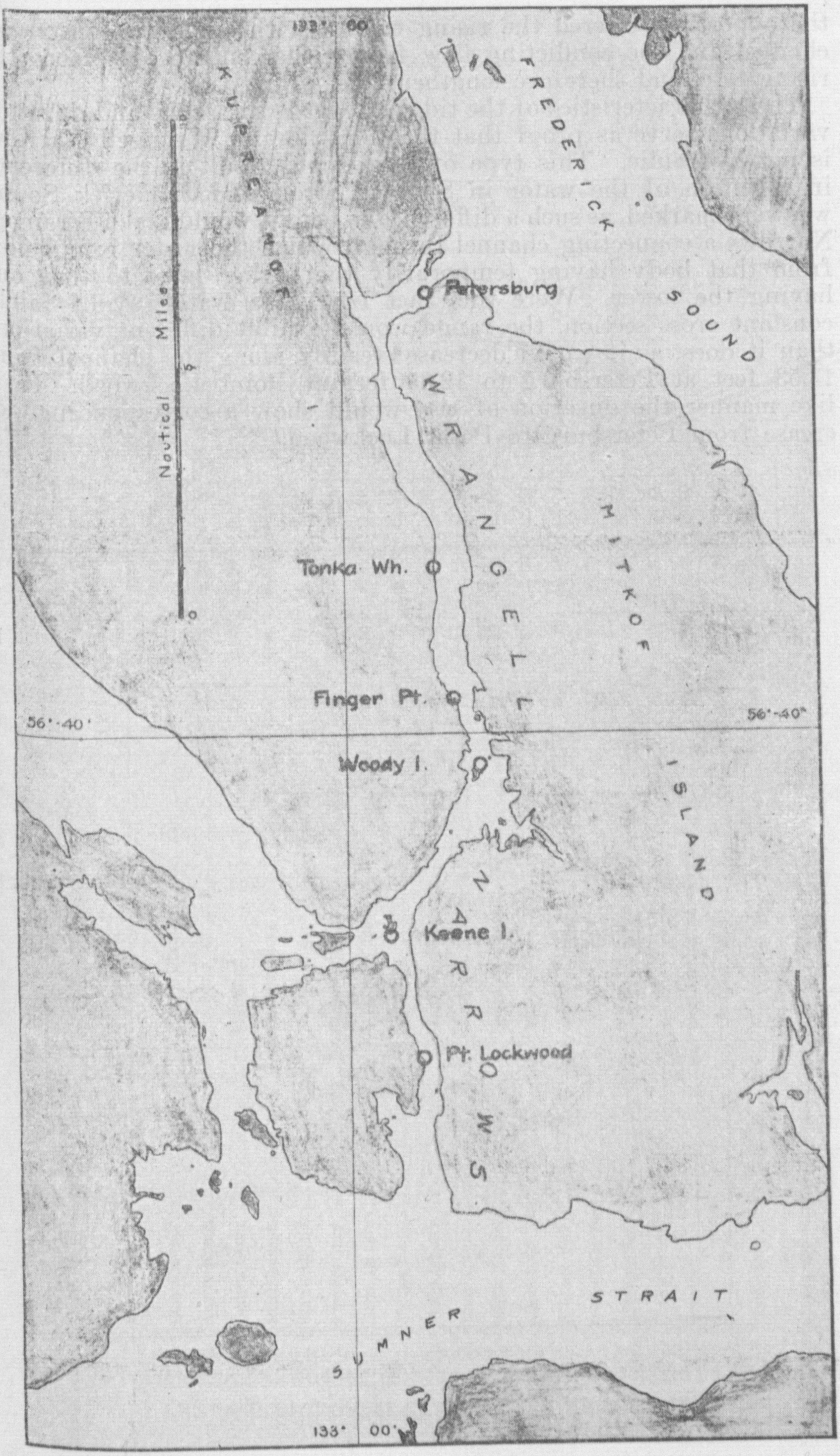

FIG. 17.—Tide stations, Wrangell Narrows

the opposition offered the rising tide both through the constricted channel and the conflicting flow from either entrance shortens the rising tide, and therefore lengthens the falling tide.

These characteristics of the tide as regards the range and duration variations serve as proof that the tidal flow in Wrangell Narrows is not hydraulic. This type of tide would result if the difference in elevation of the water in Sumner Strait and Frederick Sound was very marked, as such a difference in height would make Wrangell Narrows a connecting channel through which the water would flow from that body having temporarily the higher level to that one having the lower. Were this fact true in a waterway of fairly constant cross section, the range would exhibit different variations than it does, as it would decrease steadily along the channel from 13.53 feet at Petersburg to 12.85 feet at Point Lockwood. In a like manner the duration of rise would show a corresponding decrease from Petersburg to Point Lockwood.

TABLE 27.—*Tidal data, Frederick Sound and Stephens Passage*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
56 40 N 132 39 W	Ideal Cove	Mitkof Island	0.56	6.78	6.20	13.52			1887	15	Kodiak.
56 48 N 132 55 W	Sandy Beach	do	.56	6.78	6.20	13.33	15.87		1910	3	Petersburg.
56 53 N 132 48 W	Brown Cove	Mainland	.47	6.62	6.27	13.49	15.80	22.0	1887	60	(1).
57 00 N 132 51 W	Ruth Island	Thomas Bay	.69	6.90	6.21	13.38	15.94		1923–24	11	Ketchikan. Spray Island.
57 06 N 132 47 W	Spray Island	do	.75	6.93	6.24	13.63	16.09		1887	16	Ketchikan.
57 00 N 133 18 W	Portage Bay	Kupreanof Island	.49	6.72	6.19	13.06	15.54		1882–1887	53	Kodiak.
57 10 N 134 17 W	Eliza Harbor	Admiralty Island	.47	6.50	6.39	11.70	14.09		1899	20	Cleveland Pass.
57 18 N 134 01 W	Pybus Bay	do	.49	6.51	6.40	12.59			1920	5	Taku Harbor.
57 29 N 133 54 W	Good Island	Gambier Bay	.48	6.62	6.28	12.59			1920	13	Do.
57 25 N 133 57 W	Snug Cove	do	.72	6.75	6.39	12.69			1899	27	(1).
57 40 N 134 04 W	Mole Harbor	Seymour Canal	.61	6.40	6.63	13.15			1889	11	Sitka.
57 16 N 133 32 W	Cleveland Pass	Mainland	.56	6.68	6.30	12.65	15.17	22.6	1899	32	Do.
57 24 N 133 25 W	Hobart Bay	do	.56	6.58	6.40	12.72			1920–21	10	Taku Harbor.
57 33 N 133 30 W	Windham Bay	do	.47	6.60	6.29	12.98			1920	7	Do.
57 43 N 133 36 W	Holkam Bay	do	.38	6.56	6.24	12.98			1889–1920	34	Do.
58 04 N 134 01 W	Taku Harbor	do	.49	6.62	6.29	13.15	15.69	24.6	1888–1921	290	Ketchikan.
58 18 N 134 24 W	Juneau	Gasteneau Channel	.54	6.72	6.24	13.80	16.19	26.2	1911–1921	570	(1).
58 20 N 134 36 W	Fritz Cove	Douglas Island	.54	6.72	6.24	13.56	16.26		1890	13	Kodiak.
58 23 N 134 39 W	Auke Bay	Mainland	.56	6.83	6.15	13.75	16.35		1917	116	Skagway.

[1] Tidal constants not corrected by simultaneous observations.

21. THE TIDE IN FREDERICK SOUND AND STEPHENS PASSAGE

Frederick Sound receives the rising tide as it flows in from the open sea through lower Chatham Strait. From the sound a part of the incoming flow is diverted to the north through Stephens Passage, the remainder flowing southeasterly toward Dry Strait at the head of Frederick Sound. The tidal stations along these two waterways are plotted on the chart of Figure 18, and their individual characteristics listed in Table 27.

These two large waterways afford deep and unrestricted passage for the tidal flow, except for a gradual narrowing of both waterways in the direction of the rising tidal flow. These slight constrictions result in the usual increase of the tidal range from the wider entrances toward the narrower heads of the passages. In Frederick Sound the mean range increases from 11.70 feet at Eliza Harbor to 13.52 feet at Ideal Cove near the north end of Dry Strait. Through Stephens Passage there is a steady increase from 12.65 feet at Cleveland Passage just north of Cape Fanshaw to 13.15 feet at Taku Harbor 55 miles northward. Juneau, still farther to the north and situated at the inner end of narrow Gastineau Channel, shows a greater increase, the mean range there equaling 13.80 feet.

As the tidal constants derived for Juneau were obtained from a series of observations extending over a year's time, they may be considered as mean values subject to but slight change. It is noted that the duration of rise values for the other stations of these waterways do not vary appreciably from the Juneau value of 6.24 hours.

Juneau is one of the few tidal stations through southeast Alaska at which changes in the characteristics of the tide might be expected because of physical changes in the waterways. Just to the south of Juneau the waste rock from a large gold stamp mill is being dumped out into the channel to form a long breakwater which narrows the channel and thus restricts the tidal flow. At present this rock mole has been extended normal to the shore over one-quarter-way across the channel. This artificial barrier to the waters will undoubtedly exert influences tending to alter the tidal constants obtained at Juneau from a year's series of observations made in 1912. This assumption may only be proved when in later years other long series of tidal observations grant data which may be compared with those for the year of 1912, at which time Gastineau Channel was not so obstructed.

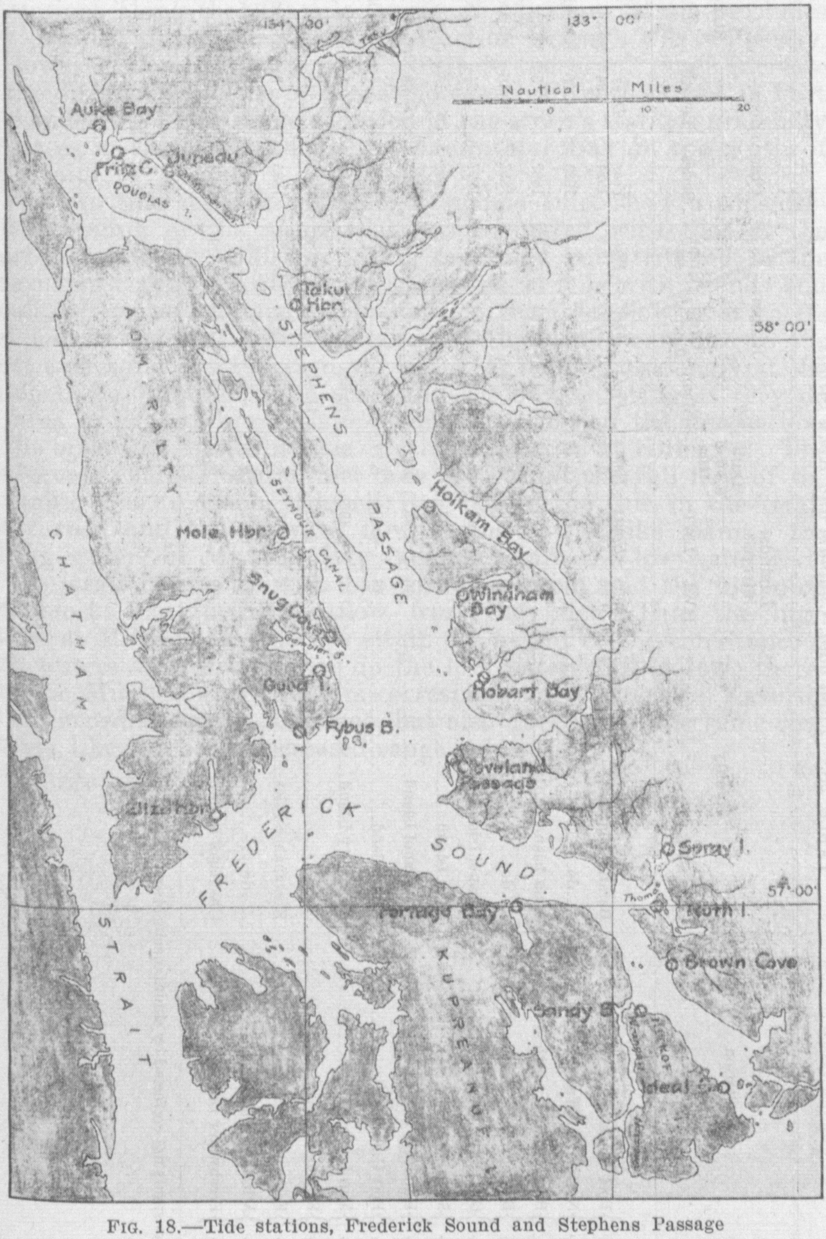

FIG. 18.—Tide stations, Frederick Sound and Stephens Passage

TABLE 28.—*Tidal data, Chatham and Keku Straits*

Geographic position	Station	Locality	Lunitidal intervals: HWI	Lunitidal intervals: LWI	Duration of rise	Ranges: Mean	Ranges: Great diurnal	Ranges: Greatest	Observations: Series	Observations: Length	Standard station
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Year*	*Days*	
56 15 N 134 39 W	Port Alexander	Baranof Island	0.06	6.23	6.25	8.98	11.52	15.9	1924	34	Sitka.
56 23 N 134 40 W	North Port Walter	do	.35	6.62	6.15	9.09	11.57	16.3	1923	200	Ketchikan.
56 37 N 134 12 W	Bay of Pillars, south arm	Kuiu Island	.36	6.26	6.52	10.11	12.34	-------	1897	3	Sitka.
56 39 N 134 15 W	Bay of Pillars, north arm	do	.15	6.30	6.27	10.47	13.01	-------	1897	16	Do.
56 44 N 134 29 W	Gut Bay	Baranof Island	.19	6.49	6.12	10.26	13.03	-------	1897	24	Do.
56 51 N 134 21 W	Security Bay	Kuiu Island	.37	6.37	6.42	11.00	-------	-------	1892	15	([1]).
56 55 N 133 50 W	Hamilton Bay	Kupreanof Island	.40	6.55	6.27	11.02	-------	-------	1892	38	([1]).
56 44 N 133 55 W	Port Camden	Kuiu Island	.45	6.10	6.77	11.50	-------	-------	1892	3	Hamilton Bay.
57 02 N 134 32 W	Murder Cove	Admiralty Island	.14	6.49	6.07	10.95	13.51	-------	1897	24	Sitka.
57 26 N 134 34 W	Killisnoo	do	.33	6.48	6.27	11.64	14.10	22.6	1895	144	([1]).
57 29 N 134 33 W	Favorite Bay	Kootznahoo Inlet	.75	6.90	6.27	10.79	12.92	-------	1895	3	Killisnoo.
57 32 N 134 24 W	Mitchells Bay	do	1.92	8.22	6.12	9.5	12.5	-------	1897	19	Do.
57 51 N 135 04 W	Freshwater Bay	Chichagof Island	.39	6.58	6.23	12.26	14.59	21.4	1894	29	Sitka.

[1] Tidal constants not corrected by simultaneous observations.

22. THE TIDE IN CHATHAM AND KEKU STRAITS

The tidal stations located along these waterways are plotted on Figure 19, and their characteristics listed in Table 28. The scarcity of stations along the 120-mile length of Chatham Strait precludes any detailed discussion of the tidal action through this waterway. However, the few stations do illustrate the usual range increase as the distance from the open sea increases. From 8.98 feet at Port Alexander the mean range recorded at the strait's stations gradually increases in value to 12.26 feet at Freshwater Bay on the north of the strait.

The two tide stations within Kootznahoo Inlet show a considerable lessening of the mean range as compared with that at the nearby station of Killisnoo. This fact may be attributed to the long narrow entrance of the inlet, blocked as it is with islands and shoals, acting as a retarding medium on the tidal flow as it enters and leaves the inlet. The influence of the 3-mile entrance to the inlet, averaging but 100 yards in width, is felt most strongly at the Mitchell Bay station. The waters in the bay, covering as they do an area of several square miles, are not permitted the fluctuations of the open waters in Chatham Strait as recorded at Killisnoo. The inadequate channel of the inlet does not permit the full flow of the incoming tide to reach Mitchell Bay before the tide in the strait has turned and the outward flow begins. In a like manner the falling waters of Mitchell Bay can not attain the low-water level of the strait before the tide has turned without and the incoming flow blocks the further outflow from the inlet. Thus the high waters at Mitchell Bay do not attain the height of the simultaneous high waters at Killisnoo, nor do the low waters fall as low; therefore the Mitchell Bay range is correspondingly lessened. Favorite Bay, somewhat nearer Killisnoo, but also affected by the same conditions, likewise has a decreased range value.

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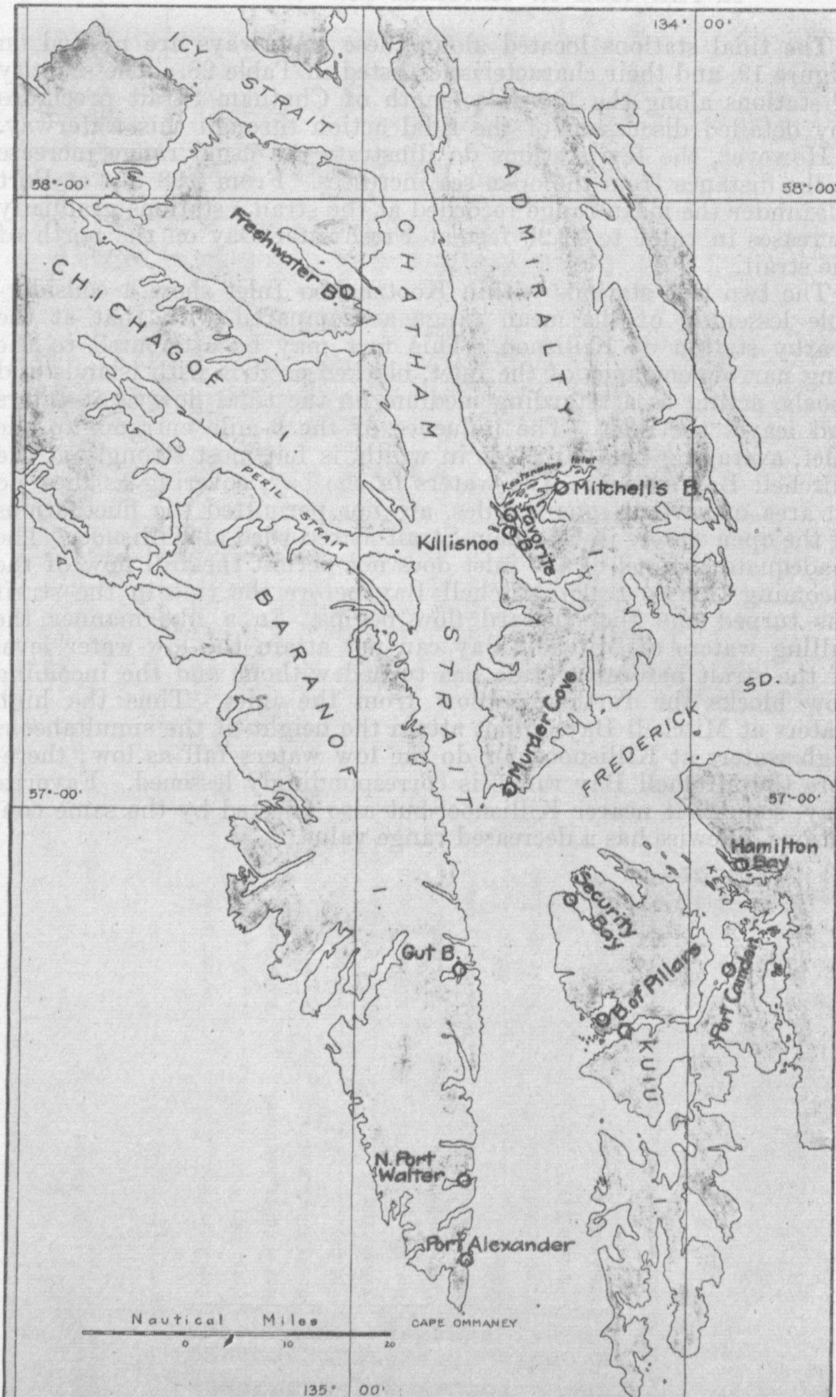

FIG. 19.—Tide stations, Chatham and Keku Straits

TABLE 29.—*Tidal data, Peril Strait*

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Year*	*Days*	
57 22 N 135 37 W	Haley Anchorage	Fish Bay	0.25	6.15	6.52	8.00	10.33		1896	29	Sitka
57 24 N 135 38 W	Sergius Narrows	North Rapids	.38	6.53	6.27	10.60	13.08	20.0	1897	162	Do.
57 25 N 135 29 W	Bear Bay		.33	6.80	5.95	10.73	13.71		1895	3	Killisnoo.
57 30 N 135 32 W	Pogibshi Anchorage		.35	6.68	6.09	12.45	14.95	21.8	1895	29	Do.

23. THE TIDE IN PERIL STRAIT

Peril Strait, of which Sergius Narrows constitutes an important part, is a 40-mile navigable passage connecting Chatham Strait with the open ocean midway between Cape Ommaney and Cross Sound. For vessels calling at Sitka, and also at such inner ports as Juneau or Skagway, there is a considerable saving of time and distance to be had by the use of this waterway.

Its westerly end is formed by a narrowing passage which closes down to a minimum width at Sergius Narrows. As in Wrangell Narrows here too the constriction of the shores causes strong currents prohibitive to the passage of small, underpowered boats, or of large steamers, except at times of slack water.

Figure 20 shows the narrows and Peril Strait, with the locations of the tidal stations established along the waterway. The tidal characteristics for this station are listed in Table 29.

The tidal station near North Rapids at the heart of the narrows, located as it is at the most important point in the waterway, was occupied for a much longer period of time than were the subordinate tidal stations at either side.

A lack of tidal data throughout the easterly arm of Peril Strait does not permit a proper illustration of the tidal action all along the extent of this waterway. A study of the currents through the Strait indicates that the rising tidal flow enters practically simultaneously at either end of the Strait.

The range value of Table 29 for Killisnoo, in conjunction with ranges at the tidal stations westward through the Strait to Haley Anchorage, will bear out this fact, for as is true in Wrangell Narrows, so too in this similar waterway does the mean range increase from either end of the passage to the meeting place of the tides. Here it increases steadily from a value of 8 feet at Haley Anchorage to 12.45 feet at Pogobshi Anchorage. Were data also available for the eastern arm of the Strait, there, too, would be shown a similar gradual increase in the mean range from the value of 11.60 feet at Killisnoo to 12.45 feet at Pogobshi Anchorage.

The duration of rise likewise evidences the same tendencies as in Wrangell Narrows—a decreasing value in accord with an increasing range from the ends toward the mid-point of the Strait.

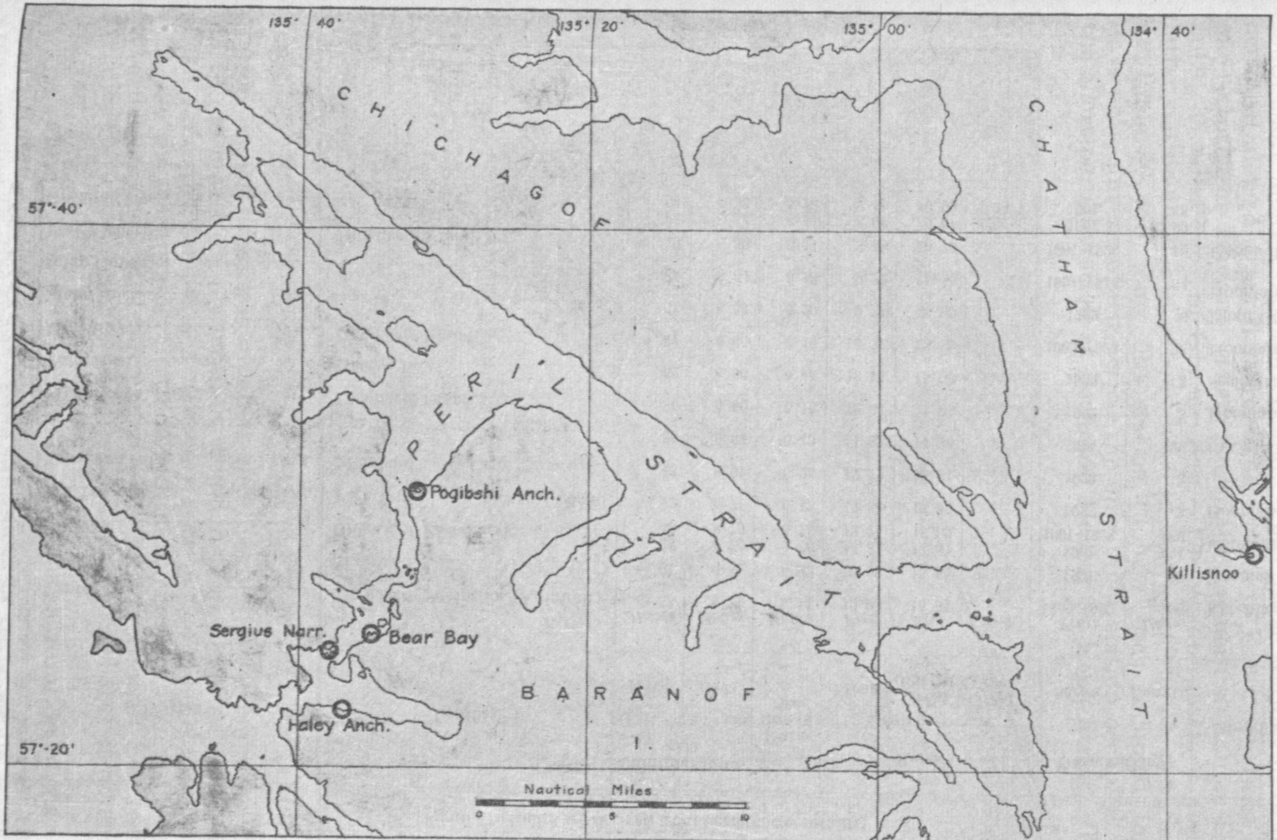

FIG. 20.—Tide stations, Peril Strait

TABLE 30.—*Tidal data, Icy Strait, Glacier Bay, and Cross Sound*

[Figures in italics are derived from harmonic constants]

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
58 15 N 134 55 W	Funter Bay	Mansfield Peninsula, Admiralty Island.	0.53	6.81	6.14	12.98	15.54	-------	1890–1922	100	Ketchikan.
58 13 N 135 07 W	Swanson Harbor	Mainland	.61	6.81	6.22	13.08	15.54	-------	1901	20	Hooniah.
58 07 N 135 26 W	Hooniah	Chichagof Island	*.48* .43	*6.70* 6.70	*6.20* 6.15	*12.84* 12.74	*14.81* 15.39	------- -------	1901 1901–1923	104 162	Ketchikan.
57 58 N 135 38 W	Salt Lake Bay	Port Frederick, Chichagof Island	.42	6.71	6.13	12.84	15.42	-------	1923	3	Hooniah.
58 25 N 135 27 W	Excursion Inlet	Mainland	.43	6.61	6.24	12.72	15.21	-------	1923	3	Do.
58 29 N 135 29 W	----do	----do	.35	6.64	6.13	11.83	14.36	21.0	1914	29	Craig.
58 12 N 135 35 W	Flynn Cove	Chichagof Island	.36	6.60	6.18	12.34	14.65	-------	1902	3	Hooniah.
58 50 N 136 23 W	Tidal Inlet	Glacier Bay	.69	6.66	6.45	13.75	15.96	-------	1892	3	Seclusion Harbor.
58 13 N 135 57 W	Mud Bay	Chichagof Island	.44	6.65	6.19	10.87	13.23	-------	1902–1923	38	Hooniah.
58 09 N 136 13 W	Idaho Inlet	----do	.31	6.53	6.20	9.31	11.96	-------	1902	6	Inian Cove.
58 16 N 136 19 W	Inian Cove		.35	6.64	6.13	9.22	11.46	-------	1901–1914	34	Hooniah. Craig.
58 07 N 136 17 W	Port Althorp	Chichagof Island	.19	6.50	6.11	8.48	10.75	-------	1901–1923	18	Hooniah.
58 12 N 136 24 W	Granite Cove		*.23* .04	*6.44* 6.23	*6.21* 6.23	*8.66* 8.40	*10.67* 10.59	------- 14.7	1901 1901	29 48	Do.

24. THE TIDE IN CROSS SOUND, GLACIER BAY, AND ICY STRAIT

As shown by Figure 21, the tidal stations along the main waterway from Cross Sound through Icy Strait are confined mainly to the south shore along Chichagof Island. Only three stations have been occupied along the north shore, two of them in Excursion Inlet and one in Swanson Harbor. There is also the northern station at Tidal Inlet, 35 miles back in Glacier Bay. The results obtained at this latter station are not to be considered as true mean values, as a glance at Table 30 will show this station to have been occupied for 3 days only, during which period the only other station occupied was the short-period station at Seclusion Harbor in Keku Strait. This

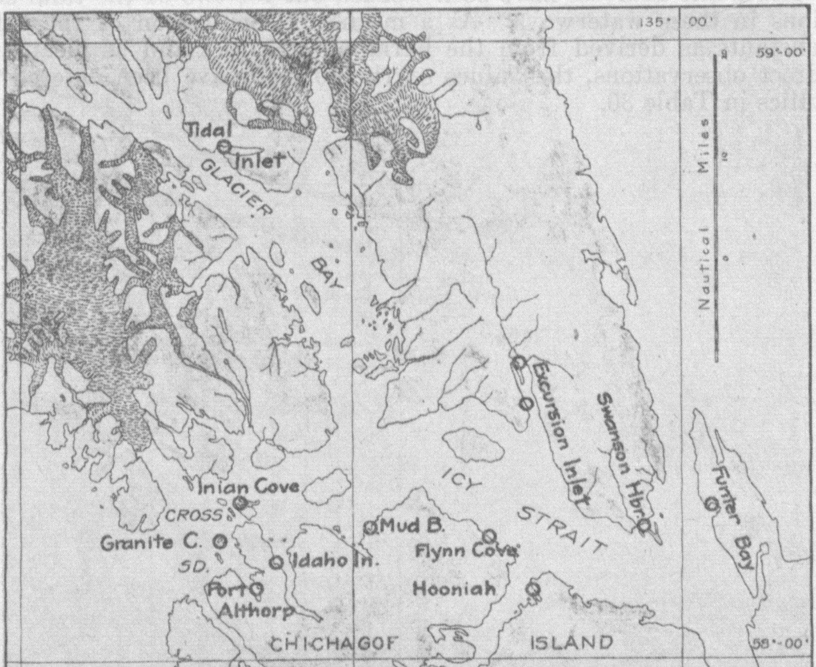

FIG. 21.—Tide stations, Icy Strait, Glacier Bay, and Cross Sound

station in itself was not of great worth as a standard inasmuch as its single month of observations could not be corrected to reliable mean values by comparison with any long-period tidal station.

Along the main waterway the mean range shows a normal increase inward from the sea, steadily increasing from a value of 8.40 feet at Granite Cove in Cross Sound to 13.08 feet and 12.98 feet at Swanson Harbor, and Funter Bay, respectively.

The values of the lunitidal intervals and the duration of rise exhibit greater consistency throughout this area than for any of those areas previously discussed. By application of the formula given in a preceding chapter, the difference in the times of high and low waters, respectively, between Inian Cove and several of the inland stations have been derived, as follows: At Idaho Inlet high tide occurs 3 minutes before high tide at Inian Cove, low tide 6 minutes before; at Funter Bay high and low tides occur, respectively, 5 and 4 minutes later than at Inian Cove.

The fact that the high and low water stages of the tide occur earlier at Idaho Inlet than at Inian Cove, which is 8 miles nearer the open sea, is an indication that the tidal flow through South Inian Pass precedes the flow through the North Pass. A study of the local current tables in the latter part of this volume will show this to be the case. Those stations at a greater distance from the open sea, as Funter Bay, can be expected to have somewhat later tides than has the Inian Cove station.

Harmonic analyses have been worked out for two of the tidal stations in these waterways. As a means of comparison of the tidal constants as derived from the harmonic analyses and as means of direct observations, the values of the former have been entered in italics in Table 30.

TABLE 31.—Tidal data, Lynn Canal

Geographic position	Station	Locality	Lunitidal intervals		Duration of rise	Ranges			Observations		Standard station
			HWI	LWI		Mean	Great diurnal	Greatest	Series	Length	
° ′			*Hours*	*Hours*	*Hours*	*Feet*	*Feet*	*Feet*	*Years*	*Days*	
58 20 N 132 53 W	Barlow Cove	Admiralty Island	0.56	6.79	6.19	12.56	14.66	22.1	1890	40	Kodiak.
58 43 N 135 14 W	William Henry Harbor	Mainland	.29	6.53	6.18	13.71	16.07		1890–1922	30	Skagway.
58 56 N 135 19 W	Sullivan Island	Sullivan Island	.17	6.36	6.23	13.94			1921–1922	9	Do.
59 11 N 135 28 W	Pyramid Harbor	Chilkat Inlet	.30	6.43	6.29	13.89			1890–1922	63	Do.
59 14 N 135 26 W	Haines	Portage Cove	.35	6.50	6.28	14.05	16.25	23.7	1890–1922	72	Ketchikan Kodiak.
59 27 N 135 18 W	Skagway	Mainland	.46	6.64	6.24	14.07	16.65	27.7	1908–1911	1,100	(1).

1 Tidal constants not corrected by simultaneous observations.

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25. THE TIDE IN LYNN CANAL

For the tidal stations along Lynn Canal from William Henry Harbor to Skagway the variations in mean range and duration of rise, as shown in Table 31, are very slight. These stations are plotted on the chart of Figure 22.

Skagway is the primary tidal station for the northerly section of southeast Alaska, it being second to Ketchikan in its length of series of observations. For this reason, and also to allow of a comparison of the tidal characteristics of both places, a summary of the tidal data derived for Skagway is listed in Table 32.

TABLE 32.—*Summary of tidal data, Skagway, Alaska*

[Values inclosed in parentheses are derived from harmonic constants]

TIME RELATIONS	Hours
High-water interval	0.46
Low-water interval	6.64
Duration of rise	6.24
Duration of fall	6.18
Phase age	33.3
Parallax age	45.4
Diurnal age	13.4
Sequence of tides is HHW to LLW.	
RANGES	Feet
Mean range	14.07
Great diurnal range	16.63
Great tropic range	17.49
Spring range	(18.49)
Neap range	(9.21)
Storm range	24.13
Greatest range	27.7
RATIOS OF RANGES	Feet
Great diurnal range÷mean range	1.18
Great tropic range÷mean range	1.24
Spring range÷mean range	1.31
HEIGHT RELATIONS	Feet
Mean high water above standard sea level	6.91
Mean higher high water above standard sea level	7.89
Tropic higher high water above standard sea level	(7.79)
Tropic lower high water above standard sea level	(5.24)
Spring high water above standard sea level	(9.13)
Neap high water above standard sea level	(4.49)
Storm high water above standard sea level	11.45
Greatest high water above standard sea level	13.58
Storm high water above standard lower low water	20.18
Highest high water above standard lower low water	22.31
Mean sea level above mean tide level	0.13
Mean low water below standard sea level	7.15
Mean lower low water below standard sea level	8.73
Tropic lower low water below standard sea level	(8.88)
Tropic higher low water below standard sea level	(3.96)
Spring low water below standard sea level	(9.35)
Neap low water below standard sea level	(4.71)
Storm low water below standard lower low water	3.95
Lowest low water below standard lower low water	5.39
Mean sea level on staff (3 years)	17.02
Mean lower low water on stuff (3 years)	8.29

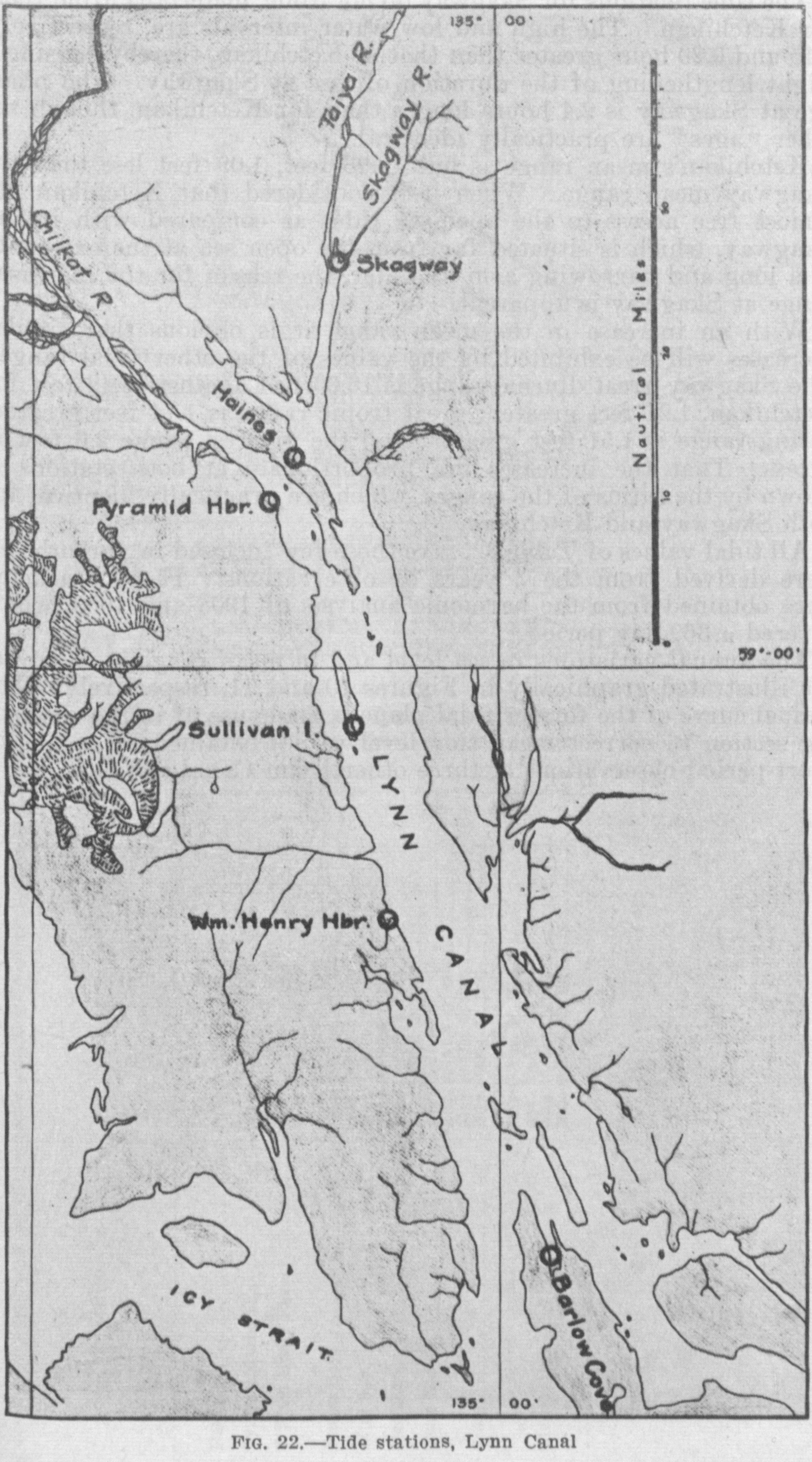

FIG. 22.—Tide stations, Lynn Canal

The time relations for Skagway do not differ materially from those for Ketchikan. The high and low water intervals are, respectively, 0.15 and 0.20 hour greater than that at Ketchikan, thereby causing a slight lengthening of the duration of rise at Skagway. The phase age at Skagway is 2.4 hours longer than for Ketchikan, though the other "ages" are practically identical.

Ketchikan's mean range is but 12.98 feet, 1.09 feet less than the Skagway mean range. When it is considered that Ketchikan has almost free access to the open-sea tides as compared with inland Skagway, which is situated far from the open sea at the extremity of a long and narrowing arm of water, the reason for the increased range at Skagway is apparent.

With an increase in the mean range it is obvious that similar increases will be exhibited by the values of the other tidal ranges. The Skagway great diurnal range is 16.63 feet against 15.42 feet for Ketchikan, 1.21 feet greater; great tropic range is 1.74 feet greater; spring range is 1.51 feet greater; and the greatest range 2.6 feet in excess. That the increases are proportionate at both stations is shown by the ratios of the ranges, which are practically identical for both Skagway and Ketchikan.

All tidal values of Table 32, save those few inclosed in parentheses, were derived from the 3 years of observations. Those bracketed were obtained from the harmonic analysis of 1908 and 1909, which covered a 369-day period.

The annual variations in sea level and in mean range at Skagway are illustrated graphically in Figures 10 and 11, respectively. The annual curve of the former tidal plane is made use of in the succeeding section to correct mean tide level values obtained by means of short-period observations at three other Lynn Canal stations.

TABLE 33.—*Changes in land elevation evidenced by plane of mean tide level*

Station	Observations	Bench mark No.	Elevation above zero of tide staff	Mean tide level: From observations	Mean tide level: Corrected	Bench mark elevation above mean tidal level	Change in elevation	Quality of bench mark
			Feet	*Feet*	*Feet*	*Feet*	*Feet*	
Haines	July 23–Aug. 6, 1890	3	32.65	16.91	16.93	15.82		Good; center of circle cut in bowlder.
	Apr. 20–June 18, 1922	3	32.92	14.36	14.57	18.35	+2.53	Do.
Pyramid Harbor	July 14–July 25, 1890	1	27.80	13.70	13.62	14.18		Do.
	May 10–June 29, 1922	1	29.35	12.61	12.80	16.55	+2.37	Do.
William Henry Harbor	June 24–July 16, 1890	1	28.47	11.57	11.53	16.94		Excellent; cut on face of rock cliff.
	July 27–Aug. 25, 1921	1	32.19	13.09	13.01	19.18		Do.
	Apr. 21–Apr. 23, 1922	1	34.31	14.51	14.87	19.44	+2.37	Do.
Funter Bay	Aug. 25–Sept. 17, 1890	0	25.05	12.65	12.35	12.70		Good; center of circle cut in bowlder.
	July 25–Sept. 20, 1922	0	26.963	12.51	12.39	14.57	+1.87	Do.
Mud Bay	Sept. 7–Sept. 25, 1902	1	18.57	7.48	7.06	11.51		Excellent; copper bolt in buried bowlder.
	May 16–Sept. 1, 1923	1	24.056	11.16	11.16	12.90	+1.39	Do.
Hooniah	June 11–Oct. 4, 1901	1	27.46	11.08	11.01	16.45		Excellent; copper bolt in cliff face.
	Apr. 1–Sept. 29, 1923	1	31.33	13.94	13.92	17.41	+.96	Do.
Taku Harbor	Apr. 28–June 26, 1888	1	19.3	13.10	13.30	6.0		Good; cross cut in bowlder.
	Aug. 11–Aug. 21, 1890	1	21.2	14.62	14.73	6.5		Do.
	May 18–Oct. 9, 1920	1	21.76	14.82	14.98	6.78	+.53	Do.
Sitka	July 1–Aug. 31, 1893	1	17.63	10.01	10.36	7.27		Excellent; copper bolt in bedrock.
	Apr. 15–Apr. 15, 1924–25	1	22.75	14.90	14.90	7.85	+.58	Do.
	July 1–Aug. 31, 1893	2	16.85	10.01	10.36	6.49		Good; brass spike in rock.
	Apr. 15–Apr. 15, 1924–25	2	21.97	14.90	14.90	7.07	+.58	Do.
Metlakatla	Aug. 11–Oct. 1, 1883	1	29.41	13.84	13.98	15.43		Good; iron spike in dead tree.
	June 6–Sept. 29, 1914	1	29.41	13.66	14.02	15.39	+.04	Do.

PHYSIOGRAPHIC CHANGES

26. APPARENT CHANGE IN MEAN TIDE LEVEL

In deriving tidal data for the west coast of Lynn Canal there were brought to light apparent differences in the elevations of various datum planes as determined for the years of 1890, 1921, and 1922. In Table 33 are given the elevations of the plane of mean (half) tide level as determined at these different periods, these elevations being correlated through bench-mark connections.

If we assume that the bench marks remained constant in elevation from 1890 to 1922 it is impossible that the plane of mean tide level would be altered by the amounts evidenced in column 8 of Table 33 for the tidal stations of Haines, Pyramid Harbor, and William Henry Harbor. The average difference in elevation at these stations, derived from levels in 1890 and 1922, amounts to 2.4 feet. To bring about such a great lowering of the plane of mean tide level enormous physical changes would have had to take place in the cross sections of the waterways leading up to these tidal stations. No changes of note have occurred. Therefore this first assumption is disproved and we may accept the tidal plane as constant.

A study of the establishment of the three bench marks at these tidal stations shows that they were well enough located so that it was utterly impossible for them to have been raised over 2 feet in elevation excepting by a vertical displacement of all the surrounding land mass.

Following this second assumption a study of earth movements in Alaska discloses but one earthquake of such magnitude that it could have been the cause of changes in level along Lynn Canal. This was the earthquake in the region of Yakutat Bay in September, 1899.

Quoting Tarr and Martin's "Earthquakes at Yakutat Bay, Alaska, in September, 1899," a publication of the U. S. Geological Survey, the following facts are noted:

> During the month of September, 1899, the region near Yakutat Bay, Alaska, was shaken by a series of severe earthquakes. * * * These earthquakes were attended by two notable results—great changes in the level of the land, incidental to faulting, and remarkable accompanying and subsequent changes in the adjacent glaciers. * * * The changes of level are the greatest recorded in historical times, *the maximum uplift amounting to over 47 feet.* The changes in the glaciers include a rapid retreat of Muir Glacier, 150 miles to the southeast. * * * By 1903 it had retreated from 2½ to 3 miles, and by 1907 *from 7½ to 8 miles, perhaps partly as an indirect result of the earthquake.*

Figure 23 portrays upper southeast Alaska north to the Yakutat Bay region. From this map will be seen the near proximity of Muir Glacier to the Lynn Canal district. Inasmuch as this glacier was apparently materially disturbed by the earthquake of 1899, it is reasonable to assume that the west shore of Lynn Canal, only 30 miles distant from Muir Glacier, might also have been affected by the same earth movements that produced a 47-foot local uplift.

Residents of Skagway, at the head of Lynn Canal 160 miles east of Yakutat, reported six or seven shocks, "the vibrations increasing until everyone felt the motion distinctly." There were literal earth waves, both motion and feeling being exactly as if on board a vessel." Many cracked chimneys and gaping walls resulted from these earth tremors.

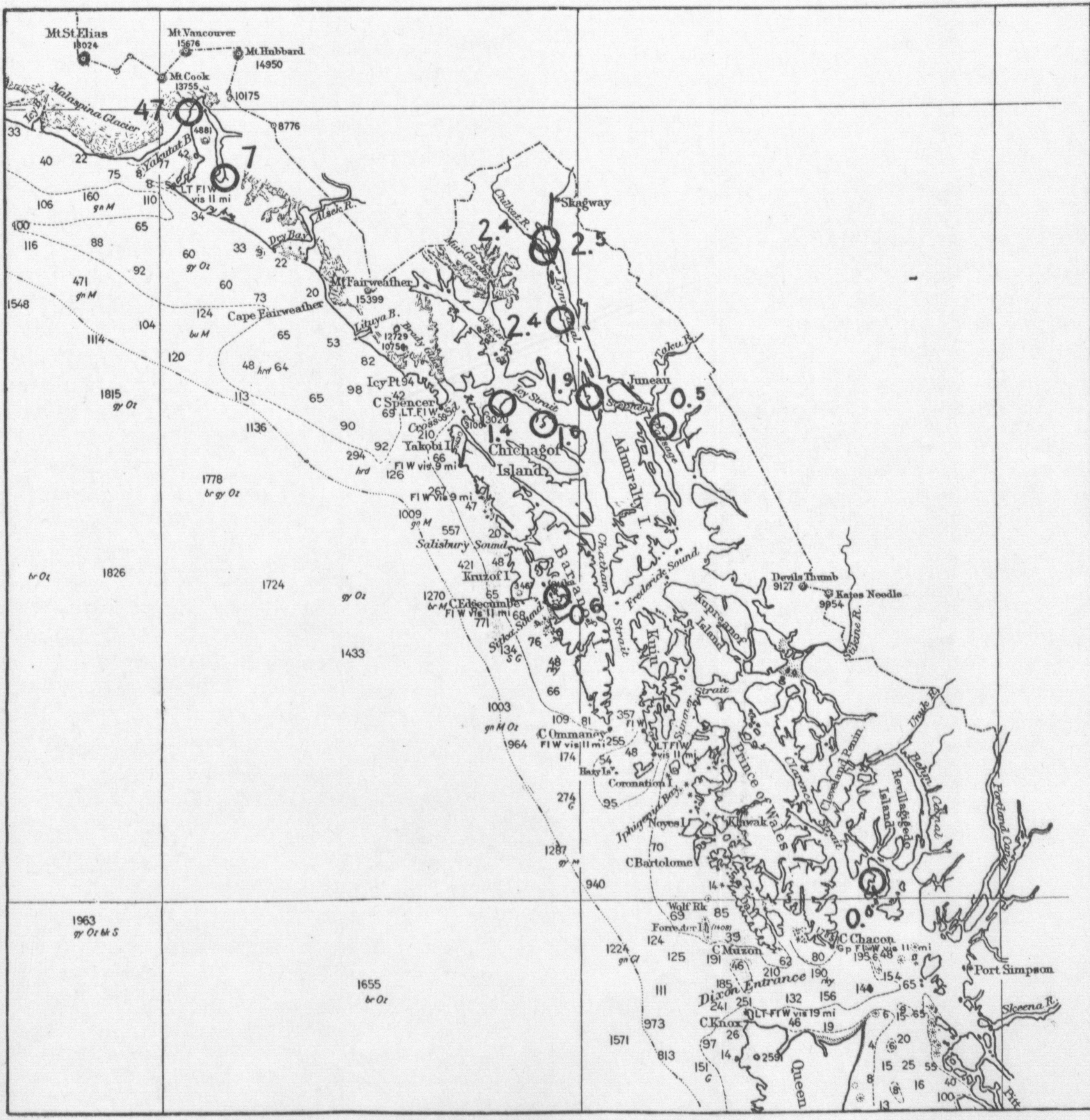

FIG. 23.—Tide stations, Alaska—Regions affected by Yakutat earthquake of 1898 10556—26. (Face p. 74.)

Juneau reported three hard shocks, one very severe. Taku Inlet, Stephens Passage, and Gastineau Channel were filled with icebergs from Taku Glacier for some time after the shocks.

These observations of persons experiencing the Yakutat quake at distant stations are further evidence of the far-reaching effects and likelihood of earth movement along Lynn Canal.[15]

Another statement in Tarr and Martin's report of the earthquake shows that they looked for earth movements at points distant from the center of disturbance but found none.

"We were able to make hasty observations in 1905 at Dundas Bay, near the entrance to Glacier Bay, and at Juneau and Sitka, where we found no changes in level."

However, they did not have the tidal observations and bench-mark elevations now available for a further study of the subject.

At each of the aforenamed tidal stations, and also at the near-by stations of Funter Bay, reliable series of tidal observations, and levels run in 1890 allow the establishment of the bench-mark elevations prior to the Yakutat earthquake.

Tidal observations taken and levels run in 1922 at the same stations show the bench marks to have undergone a rise in elevation ranging from 1.87 feet at Funter Bay to 2.53 feet at Haines. Of course the datum (mean tide level) to which these elevations are referred is liable to the variations affecting any tidal constant derived from short-period series of tidal observations. A study of the annual variation in sea level at the five long-period tidal stations in southeast Alaska shows the height of sea level to vary from month to month from a minimum annual variation of 1.28 feet at Sitka to a maximum annual variation of 1.62 feet at Skagway. With this variation in mind the direct derivations of mean tide level as listed in column 5 of Table 33 for the Lynn Canal stations has been corrected by comparison with the annual sea-level variation curve for Skagway, as represented in Figure 10. The corrected values of mean tide level, which are used to derive all elevations discussed herein, are listed in column 6. Even omitting this correction and deducting the probable maximum annual variation of 1.62 feet from the bench-mark elevation differences at the three Lynn Canal stations there yet remains approximately a foot of increased elevation to be accounted for. Therefore we must conclude that an actual raising of the land mass did occur as evidenced by the bench-mark elevation from 1890 to 1922.

Taku Harbor and Sitka both exhibit a one-half foot increase in the elevation of reliable bench marks established before the Yakutat earthquake. The relatively small change might, however, be caused entirely by the annual variation in the height of the sea level, rather than by any shifting of the land mass.

Metlakatla, farthest from the seat of the earthquake, shows no change in level of a bench mark established in 1883 and recovered in 1914.

To assign the earthquake of 1899 as the immediate factor which brought about the changes in level noted, it would have been necessary to have had tidal observations and levels made just previously

[15] See p. 82, Tarr and Martin's "Earthquakes in Yakatat Bay, Alaska, in September, 1899."

to, and immediately following the disturbance. In an effort to ascertain if any subsequent changes in elevation might have occurred, the elevations of reliable bench marks established at Hooniah and Mud Bay in 1901 and 1902, respectively, were rechecked in 1923. Here, too, were found increases in elevation, amounting to 0.96 and 1.39 feet. One might assume that these figures came within the allowable limit of annual sea-level variation, and therefore that factor could be assigned as the sole cause of the differing elevations. This may be the case, though the tidal elevations at Hooniah were of 4 months' duration in 1901 and 6 months in 1923, both sufficiently long series to obviate most of the error in planes of mean tide level derived from series of tidal observations less than a year in length. Therefore we must grant the possibility of the occurrence of earth movements subsequent to those of 1899, which may or may not have been due indirectly to the disturbance of that year. Such an assumption is strengthened by the knowledge of the vast and rapid change which took place in Muir Glacier between 1899 and 1907, and the occurrence of a severe earthquake in 1907, which was reported chiefly from the Lynn Canal region, notably at Skagway.[16]

This section has been written to illustrate the value of a tidal plane as a datum from which earth movements may be studied. Vast uplifts, such as occurred in the Yakutat Bay region, are far from common, though minor changes caused by earth movements are fairly frequent in a region of growth, such as the young (geologically speaking) mountain ranges of St. Elias, Fairweather, and Chuyach of the region we have discussed. The large changes in level are readily discernible and easily studied by the visible displacement of land masses, evidenced by submerged forests, sea growths attached to rocks far above the reach of the highest tides, etc. The smaller and more frequent changes in level are usually too slight to be noted by such natural phenomena, so herein lies the value of a plane of mean tide level, or of mean sea level, as a means of determining these minor disturbances of the earth's crust.

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[16] See Tarr and Martin's "Earthquakes in Yakutat Bay, Alaska, in September, 1899," p. 96.

Part II.—CURRENTS IN SOUTHEAST ALASKA

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OBSERVATIONS AND REDUCTIONS

1. EXTENT OF OBSERVATIONS

For the purposes of this discussion, southeast Alaska will be taken as that part of Alaska lying between Dixon Entrance on the south and Cape Spencer and Lynn Canal on the north. Figure 1 shows that the major part of this area is composed of islands, together with numerous intercommunicating straits and passages separating these islands from each other and from the mainland. The straits of this region, together with their various communicating passages, form an intricate network of waterways which differ materially from each other in hydrographic features and in their connection with the sea. The tide from the Pacific entering this network of waterways produces a complicated system of tidal currents, the current in each passage being influenced by the hydrographic features of the passage itself as well as by the tidal movement in connecting waters.

Prior to the year 1925, current observations by the Coast and Geodetic Survey in southeast Alaska were taken by parties engaged in hydrography or other survey work and in most cases consisted of but a few hours of observations at each station. At a few stations observations of the times of slack water were obtained for considerable periods of time, the usual procedure being to observe the slack waters occurring during the daylight hours. By this method, two and often three slacks were observed each day during the period covered by the observations. The longest series of slack-water observations taken in this region was obtained at Sergius Narrows by the party of E. K. Moore in 1897. It covered a period of 5 months, a total of 441 slack waters being observed during that time. Records of current observations at 31 stations which were occupied in southeast Alaska during the 30-year period 1895 to 1924, inclusive, are on file in the office of the Coast and Geodetic Survey. These observations were all taken at or near the surface of the water, no attempt being made to obtain the velocity or direction of the current at depths greater than the draft of vessels.

In the summer of 1925 a current survey party in charge of L. M. Zeskind occupied 21 new stations extending from Tongass Narrows on the south to Cross Sound, Icy Strait, and Lynn Canal on the north. In addition five of the old stations were reoccupied by this party. The length of the series of observations at each station varied from a few hours to 16 days, which was the period covered by observations at the north end of Wrangell Narrows. Observations besides being taken near the surface were obtained for 3 subsurface depths at 16 of the stations, the subsurface depths chosen usually being two-tenths, five-tenths, and eight-tenths of the total depth of water at the station. Hourly observations were made of the velocity and direction near the surface, and half-hourly observations of velocity only at the subsurface depths. At 10 stations surface observations only were obtained, and at 5 of these only times of slack water were observed. It may be well to mention here that all of the observations made in this region, the earlier as well as the more recent ones, were obtained during the summer season. Current phenomena peculiar to the winter months would, therefore, not be brought out by these observations.

It is desired to place emphasis on the fact that the current work done up to the present time in southeast Alaska does not constitute a detailed current survey, but is rather in the nature of a reconnaissance, a comparatively few widely separated stations being occupied. In the comprehensive current survey of New York Harbor, for example, more than one hundred times as many current stations per unit area were occupied as in the waterways of southeast Alaska.

2. METHODS OF OBSERVING

Three general methods of observing currents employed in the recent survey in southeast Alaska are briefly outlined below. The first two of these methods also apply to observations taken prior to 1925.

1. In the current-pole method of observing currents a pole is so weighted with lead at one end that it will submerge for most of its length and assume a vertical position when placed in the water. It is then attached to a log line and allowed to drift with the current. The log line is marked off in divisions and tenths. Each large division bears the same ratio to a nautical mile that the time the pole is allowed to drift bears to an hour. By this means the velocity in nautical miles per hour or knots is read direct from the log line. The direction of drift is observed by compass or pelorus on the vessel. The velocity obtained by this method is taken as the velocity at a depth equal to one-half the length of the submerged portion of the pole.

2. The float method of taking current observations is used in narrow passages or swift currents where it is not practicable to anchor a vessel. A free float of wood is thrown into the current either from shore or from a launch. The time required for the float to drift a known distance between two fixed ranges on shore is observed. From this observation the velocity is readily calculated. The general direction is obtained by observing the course taken by the float.

3. The Price or Gurley type of current meter was used for taking subsurface observations. The working parts of this meter consist of a set of conical metal cups arranged on the periphery of a wheel which is mounted on a vertical shaft. The upper end of this shaft actuates a recording mechanism which makes and breaks an electrical circuit, producing clicks in a telephone receiver connected in the circuit. When the meter is lowered into the water, the current striking the metal cups causes the wheel to rotate, the speed of rotation depending upon the velocity of the current. To obtain the velocity of the current, therefore, it is only necessary to count the clicks in the telephone receiver for a specified length of time and

from a previously prepared rating table take the velocity corresponding to the observed number of clicks.

The photograph, Figure 24, was taken from a vessel used in the 1925 current survey of southeast Alaska. A current pole is floating astern with its attached log line trailing from the vessel. In the foreground is suspended a Price current meter with weight attached ready for lowering into the water. The weight serves to hold the meter in position and to keep it from being carried astern by the current.

3. METHODS USED IN REDUCING OBSERVATIONS

As a first step in the reduction of the observations the hourly or half-hourly observed velocities for each depth were plotted on cross-section paper. The times of observation were taken as abscissæ and

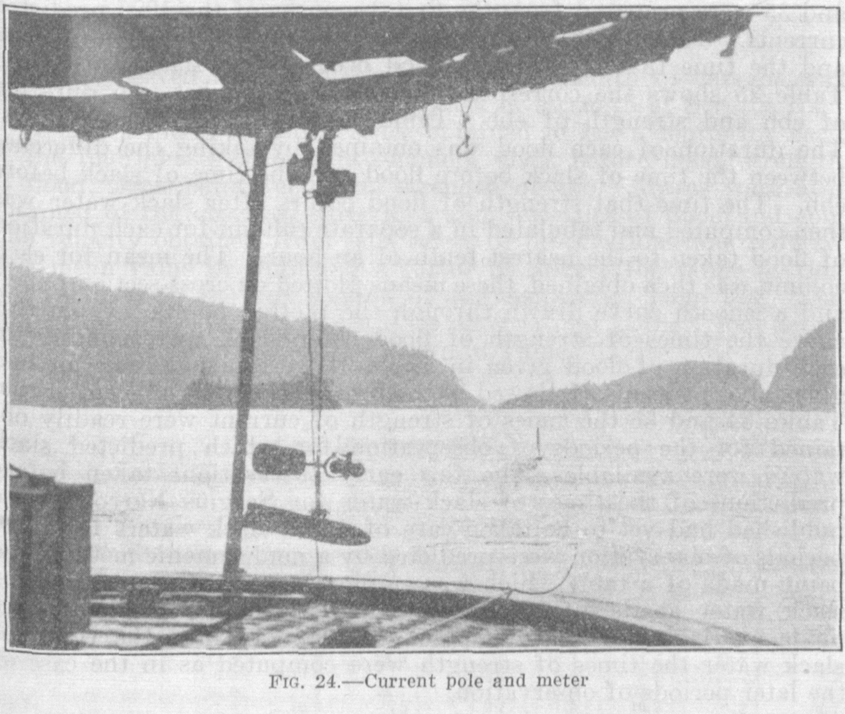

FIG. 24.—Current pole and meter

the flood and ebb velocities plotted as ordinates above and below the axis of X respectively. From smooth curves drawn through these plotted points the times of slack water and the times and velocities of strength of flood and ebb were taken. These values were tabulated for each depth and in the case of the pole observations the true direction corresponding to the time of each strength was interpolated from the nearest observed directions, and tabulated.

To make possible a comparison of the results of the observations at the different stations it was necessary to refer the times of current at each station to the corresponding times at a common reference station. Trial showed that in most cases the times of current could not be satisfactorily referred to times of tide. It was, therefore, decided that a current station should be used, and Sergius Narrows was selected as the station best adapted to this purpose.

In addition to the few short series of observations taken at Sergius Narrows the only data available at that station for the comparison consisted of the predicted times of slack water for each day of the year for the period 1899 to 1925, inclusive, and predictions of the times of slack water and the times and velocities of strengths of flood and ebb for each day of the year 1926. The harmonic constants used in making the 1926 predictions were, however, available for use. From these constants predictions of the times of strength of flood and ebb were made by means of the tide-predicting machine for the period covered by the 1925 survey. This method involved so much labor that it was considered inadvisable to use it for obtaining the times of strength corresponding to all the observations taken prior to 1925.

For the purpose of obtaining these times of strength Tables 34 and 35 were prepared from the first 3 months of the 1926 predicted currents. Table 34 shows the relation between the duration of flood and the time that strength of flood occurs after slack water, and Table 35 shows the corresponding time relation between duration of ebb and strength of ebb. Table 34 was prepared as follows: The duration of each flood was obtained by taking the difference between the time of slack before flood and the time of slack before ebb. The time that strength of flood occurs after slack water was then computed and tabulated in a separate column for each duration of flood taken to the nearest tenth of an hour. The mean for each column was then obtained, these means plotted on cross-section paper, and a smooth curve drawn through the plotted points. From this curve the times of strength of flood after slack corresponding to each duration of flood given in Table 34 were taken. The method given above was also followed in the preparation of Table 35. From Tables 34 and 35 the times of strength of current were readily obtained for the periods of observation for which predicted slack waters were available. The few early observations taken before predictions of the times of slack water for Sergius Narrows were published had yet to be taken care of. The slack waters for these periods of observation were predicted by a nonharmonic method, use being made of a table which was employed for predicting times of slack water at Sergius Narrows before harmonic constants were made available for that purpose. Having obtained the times of slack water the times of strength were computed as in the case of the later periods of observation.

TABLE 34.—*Relation between duration of flood and time that strength of flood occurs after slack water at Sergius Narrows*

Duration of flood	Corresponding time of strength of flood after slack water	Duration of flood	Corresponding time of strength of flood after slack water	Duration of flood	Corresponding time of strength of flood after slack water
Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
5.7	2.91	6.3	3.22	6.9	2.80
5.8	2.98	6.4	3.20	7.0	2.71
5.9	3.04	6.5	3.16	7.1	2.63
6.0	3.10	6.6	3.09	7.2	2.57
6.1	3.17	6.7	2.99	7.3	2.50
6.2	3.20	6.8	2.89		

TABLE 35.—*Relation between duration of ebb and time that strength of ebb occurs after slack water at Sergius Narrows*

Duration of ebb	Corresponding time of strength of ebb after slack water	Duration of ebb	Corresponding time of strength of ebb after slack water	Duration of ebb	Corresponding time of strength of ebb after slack water
Hours	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
4.9	2.00	5.9	2.88	6.9	3.41
5.0	2.23	6.0	2.93	7.0	3.46
5.1	2.37	6.1	2.98	7.1	3.51
5.2	2.46	6.2	3.03	7.2	3.56
5.3	2.54	6.3	3.08	7.3	3.60
5.4	2.60	6.4	3.13	7.4	3.63
5.5	2.67	6.5	3.18	7.5	3.66
5.6	2.72	6.6	3.24	7.6	3.68
5.7	2.77	6.7	3.30	7.7	3.70
5.8	2.83	6.8	3.36		

Each observed time of slack water and strength of current was next referred to the corresponding slack or strength at Sergius Narrows and a mean time difference obtained at each depth for each of the four phases of current—namely, slack before flood, strength of flood, slack before ebb, and strength of ebb. Means were also obtained of the observed directions and velocities of flood and ebb. The velocity obtained from each series of observations was reduced to a mean value by applying a factor to correct for range of tide as explained in the last section of the Appendix, page 144. The tabulation and reduction as made for observations at the 7-foot depth at station 40 in Peril Strait are shown in Table 36.

TABLE 36.—*Currents at 7-foot depth, station 40, Peril Strait*

[Pole observations]

Date	Time of current				Time of current at Sergius Narrows			
	Slack before flood	Strength of flood	Slack before ebb	Strength of ebb	Slack before flood	Strength of flood	Slack before ebb	Strength of ebb
1925	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
July 22	17.8	21.2	23.9	----------	18.1	21.1	23.8	----------
July 23	6.9	10.0	----------	3.3	6.5	9.6	----------	3.2
	19.0	21.7	13.1	16.2	18.6	21.7	12.8	15.6
July 24	7.4	10.4	.5	4.2	7.0	10.3	.3	3.7
	19.8	22.8	13.8	16.6	19.2	22.4	13.2	16.2
July 25	7.9	11.2	1.3	4.6	7.6	10.9	.9	4.2
	20.4	23.6	14.4	17.0	19.8	23.1	13.9	16.8
July 26	8.9	----------	2.0	5.0	8.2	11.6	1.6	4.8
	----------	12.0	----------	----------	----------	----------	----------	----------

TABLE 36.—*Currents at 7-foot depth, station 40, Peril Strait*—Continued

Date	Time of current with reference to current at Sergius Narrows				Strength of flood		Strength of ebb	
	Slack before flood	Strength of flood	Slack before ebb	Strength of ebb	True direction	Velocity	True direction	Velocity
1925	*Hours*	*Hours*	*Hours*	*Hours*	°	*Knots*	°	*Knots*
July 22	−0.3	+0.1	+0.1	----------	75	1.7	----------	----------
July 23	+.4	.4	----------	+0.1	78	2.0	228	2.3
	.4	.0	.3	.6	69	2.4	232	1.9
July 24	.4	.1	.2	.5	46	1.6	231	2.3
	.6	.4	.6	.4	80	1.9	234	1.7
July 25	.3	.3	.4	.4	43	1.6	241	1.6
	.6	.5	.5	.2	41	1.5	228	2.0
July 26	.7	----------	.4	.2	----------	----------	239	1.5
	----------	.4	----------	----------	41	1.4	----------	----------
Sum	3.1	2.2	2.5	2.4	473	14.1	1,633	13.3
Mean	+.39	+.28	+.36	+.34	59	1.76	233	1.90
					N. 59 E.		S. 53 W.	
Corrected for predicted range at Juneau (factor 0.98)	----------	----------	----------	----------	----------	1.72	----------	1.86

DISCUSSION OF RESULTS

4. INTRODUCTORY STATEMENTS

For convenience in discussing the results of the various series of current observations in southeast Alaska, the areas within which observations were taken have been divided into eight sections as follows: (1) Tongass Narrows; (2) West coast of Prince of Wales Island; (3) Sumner Strait and connecting waterways; (4) Wrangell Narrows; (5) Frederick Sound and vicinity; (6) Peril Strait and neighboring passages; (7) Icy Straight and Cross Sound; (8) Lynn Canal and vicinity.

For each section there have been prepared a table giving the current data derived from observations at each station, and one or more charts on which the location of each station is plotted. The data contained in the tables are taken from the tabulations and reductions already described. The values for duration of flood and ebb were computed by applying the time differences for slack waters obtained from observations as shown in Table 36 to the mean durations of flood and ebb at Sergius Narrows as derived from the series of 441 slack-water observations previously mentioned. The times are given to hundredths of hours, the velocities to hundredths of knots, and the true directions to whole degrees. The times and velocities are given to hundredths, not because they can be considered as determined with this degree of precision from short series of observations, but for uniformity, since for purposes of comparison it seems desirable in some cases to have them given to hundredths. In the tables a minus (−) sign indicates that the time of the given phase of current is earlier than that of the corresponding phase of current at Sergius Narrows. Where no sign is given the plus (+) sign is understood and indicates that the current is later than at Sergius Narrows.

In discussing the results of current observations there is often a question as to which is the flood and which is the ebb current. In general the current flowing upstream or away from the sea is a flood current and the one flowing downstream or toward the sea is an ebb current. This definition leads to uncertainty in a waterway which communicates with the sea through two or more channels. The flood current is therefore here defined as the current which reaches its strength on a rising tide or near high water, and the ebb current as the current which reaches its strength on a falling tide or near low water.

5. THE CURRENT IN TONGASS NARROWS

Tongass Narrows is a passage approximately 12 nautical miles in length and from one-third to 1½ nautical miles in width. It extends in a northwest and southeast direction and connects the northerly ends of Revillagigedo Channel and Nichols Passage with

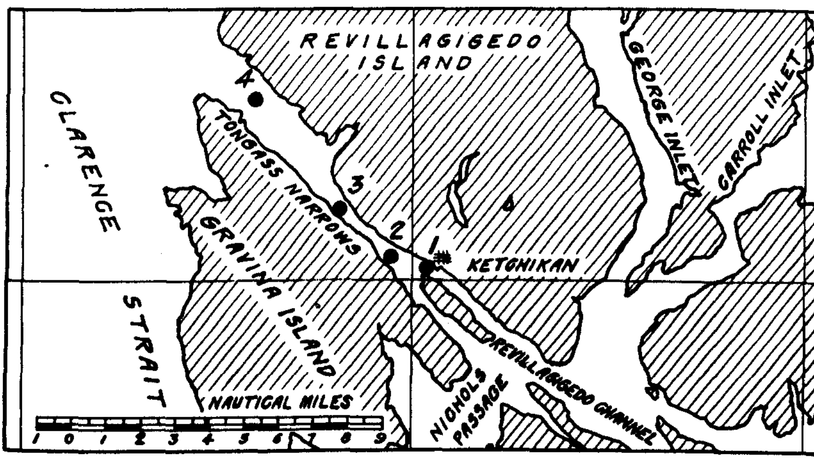

FIG. 25.—Current stations, Tongass Narrows

Clarence Strait and Behm Canal. For most of its length it has a depth of approximately 20 fathoms.

The four stations at which current observations have been taken in Tongass Narrows are plotted on Figure 25 and the data derived from the observations are given in Table 37. In comparing these results it should be borne in mind that they are derived from short periods of observation. The six days of observations at station 1 were not continuous but were scattered over a period of more than three months. Tidal observations taken in this vicinity show that the tide is very nearly simultaneous throughout the narrows and adjacent waterways with practically the same range at the two ends of the narrows. Having in mind this simultaneous tidal movement we would expect a flow of water into both ends of the narrows when the tide is rising and a corresponding outflow in both directions when the tide is falling. Observations indicate, however, that this simple condition is considerably modified by a permanent nontidal current flowing through the narrows in a northwest direction.

TABLE 37.—*Current data, Tongass Narrows*

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observation with—	Depth	Slack before flood	Flood strength			Flood duration	Slack before ebb	Ebb strength			Ebb duration	Length of observations
							Time	Direction	Velocity			Time	Direction	Velocity		
					Feet	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
1	Off Ketchikan	June-September, 1915, August, 1925.	C. G. Quillian; L. M. Zeskind	Pole		1.01	1.96	N. 44° W.	1.12	7.43	2.52	1.86	S. 45° E.	0.35	4.99	6
				do	7	.30	2.10	N. 57° W.	1.17	7.62	2.00	.70	S. 42° E.	.67	4.80	½
				Meter	6	.70	2.10		1.31	7.22	2.00	.90		.81	5.20	½
				do	15	.90	2.40		1.07	7.32	2.30	1.00		.77	5.10	½
				do	24	1.60	2.70		.55	6.82	2.50	1.10		.45	5.60	½
2	Off Bar Point	do	do	Pole	7		2.80	N. 45° W.	1.43							½
				Meter	20		2.80		1.43							½
				do	50		2.50		.91							½
				do	80		2.50		.91							½
3	⅝ mile southeast of Lewis Reef Light.	do	do	Pole	7		3.40	N. 56° W.	1.16			3.60		.16		½
4	½ mile north of Rosa Reef.	do	do	do	7		5.67	N. 27° W.	.67			5.15		.10		2
				Meter	14		5.53		.67			4.98		.10		2
				do	35		5.33		.39			4.88		.06		2
				do	56		4.93		.32			4.78		.05		2

Stations 1, 3, and 4 plainly show this permanent current, the velocity of the flood or northwesterly stream being considerably greater in each case than that of the ebb. Its effect is also shown at station 1 in the durations of flood and ebb, the flood running longer than the ebb at each of the four depths. The northwesterly current has been taken as the flood through the whole length of the narrows as the observations show that it attains its strength on a rising tide at stations 1, 2, and 3, and near high water at station 4.

The half day of observations at station 2 showed a very irregular current, a single strength of flood at each depth being the only phase well enough defined to admit of tabulation. A similar condition prevailed at the subsurface depths of station 3 where a maximum current of about half a knot and an average current of two or three tenths of a knot was observed at each of the three subsurface depths.

The observations obtained in Tongass Narrows in 1925 were taken near the time of neap tides. The velocity of the tidal current was therefore near its minimum and consequently the relative effect of the nontidal current was near its maximum. Considering the results for the 7-foot depth given in Table 37 we find that the flood current enters the southeast end of the narrows and reaches its strength at station 1, off Ketchikan, 2.10 hours after strength of flood at Sergius Narrows. At stations 2, 3, and 4 strength of flood occurs, 2.80 hours, 3.40 hours, and 5.67 hours, respectively, after strength of flood at Sergius Narrows, or 0.70 hour, 1.30 hours, and 3.57 hours later than at station 1. These times are roughly proportional to the distances of the respective stations from station 1. As the times of ebb strength show a similar relation to distance from station 1, we may conclude that the time of current becomes later with approximate uniformity from the southeastern to the northwestern end of the narrows.

TABLE 38.—*Tidal and nontidal current velocities in Tongass Narrows*

Station	Length of observations	Depth	Observed velocity		Corrected velocity		Tidal current velocity		Nontidal current velocity
			Flood	Ebb	Flood	Ebb	Uncorrected	Corrected to mean	
	Days	*Feet*	*Knots*	*Knots*	*Knots*	*Knots*	*Knots*	*Knots*	*Knots*
1	6	-------	1.05	0.28	1.12	0.35	0.66	0.74	0.38
	½	7	.90	.40	1.17	.67	.65	.92	.25
	½	6	1.00	.50	1.31	.81	.75	1.06	.25
	½	15	.80	.50	1.07	.77	.65	.92	.15
	½	24	.40	.30	.55	.45	.35	.50	.05
3	½	7	1.00	.00	1.16	.16	.50	.66	.50
4	2	7	.57	.00	.67	.10	.28	.38	.28
	2	14	.57	.00	.67	.10	.28	.38	.28
	2	35	.33	.00	.39	.06	.16	.22	.17
	2	56	.27	.00	.32	.05	.14	.18	.14

Table 38 gives for each depth at stations 1, 3, and 4 the following data: The observed velocities of flood and ebb, the flood and ebb velocites reduced to a mean by correcting for range of tide, the uncorrected and corrected values for the velocity of the tidal component of the current, and the velocity of the nontidal component of the current. In each case the velocity of the tidal current is taken as one-half the sum, and that of the nontidal current one-half the difference, of the flood and ebb velocities. The table shows that at the time the observations were taken the tidal and nontidal streams were of equal strength at stations 3 and 4 and the resultant current was therefore doubled at the time of flood strength and reduced to zero at the time of ebb strength. In other words, the current did not ebb at these stations but came to a stand the time of which corresponded to a time of ebb strength and then started flooding again. At station 1, where the tidal current was relatively stronger with respect to the nontidal current, the velocity of the flood was increased and that of the ebb decreased but not reduced to zero by the nontidal current. Since the velocity observations were taken near the time of neap tides, in reducing the observed tidal current velocity to a mean value it is increased. A like increase must be applied to the flood and ebb velocities as shown in the table. This gives a positive velocity for strength of ebb at stations 3 and 4 and leads to the conclusion that the current actually reverses in all parts of the narrows during the greater part of the lunar month; but near the times of the moon's quadrature, at which times the tidal current strength is considerably less than its mean value, the observations indicate that it does not reverse in the northwestern half of the narrows.

Comparing the velocities given in Table 37 for the strengths of flood and ebb at stations 1, 2, and 4, we find that in general the velocity of the current decreases as the depth increases, the velocity near the bottom being in each case approximately one-half as great as that near the surface. Referring to Table 38, we note that at stations 1 and 4 both the tidal and nontidal components of the current show this decrease in strength from the surface to the bottom.

At station 1, if we disregard the 6-foot depth at which the hull of the vessel probably modified the current observed with the meter, we find that the duration of flood decreases from 7.62 hours at the 7-foot depth to 7.32 hours at the 15-foot depth and 6.82 hours at the 24-foot depth. The duration of the ebb shows a corresponding increase with depth and consequently the flood current which runs 2.82 hours longer than the ebb at the 7-foot depth runs only 1.22 hours longer at the 24-foot depth.

The permanent or nontidal current which all the observations indicate to be flowing in a northwest direction through Tongass Narrows has, as shown in Table 38, a velocity at the 7-foot depth varying from one-half knot at station 3 in the narrow part of the passage to about one-fourth knot at station 4 in the wider portion. This current will be taken up later in connection with the discussion of similar phenomena in other waterways of southeast Alaska.

6. CURRENTS OFF THE WEST COAST OF PRINCE OF WALES ISLAND

Current observations have been made along the west coast of Prince of Wales Island at four stations: Two in Tlevak Narrows, one in Tonowek Narrows, and one in Dry Pass. These passages are widely separated and will be taken up independently in the following paragraphs.

Tlevak Narrows separates the northern end of Dall Island from Prince of Wales Island and connects the northerly end of Tlevak Strait with Meares Passage and Ulloa Channel. At its narrowest part it has a width of ⅓ mile and a maximum depth of about 15 fathoms. The two stations at which current observations have been made in this passage are shown on Figure 26 and the results derived from the observations are given in Table 39. A total of 28 slack waters were observed at station 6, but no observations of velocity were made. Most of the slack waters were observed by noting from shore the movements of a buoy moored in mid-channel with a long line. A few observations at the beginning and end of the series were taken by watching the motion of the water surface from a launch.

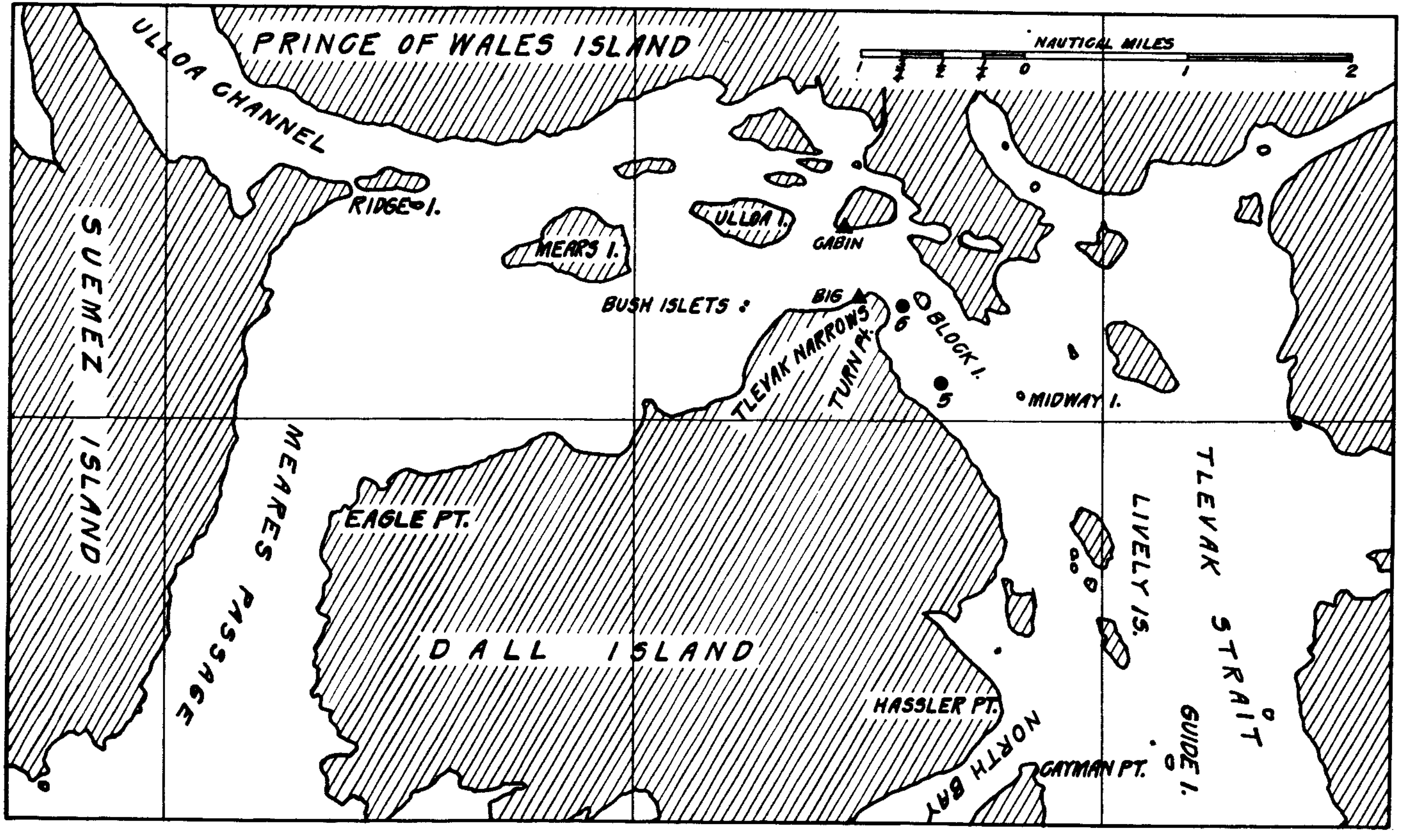

Fig. 26.—Current stations, Tlevak Narrows

TABLE 39.—*Current data, west coast of Prince of Wales Island*

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observation with—	Slack before flood	Flood strength			Flood duration	Slack before ebb	Ebb strength			Ebb duration	Length of observations
						Time	Direction	Velocity			Time	Direction	Velocity		
					Hours	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
5	Tlevak Strait, ½ mile south of Block Island.	September, 1912	R. B. Derickson	Pole	-------	0.00	S. 16° E.	4.20	-------	−0.10	−0.50	N. 50° W.	1.00	-------	⅓
6	Tlevak Narrows, off Turn Point.	September-October, 1912.	do	Anchored float.	−0.54	-------	-------	-------	5.91	−.55	-------	-------	-------	6.51	7
7	Tonowek Narrows	June, 1914	F. H. Hardy	Pole	1.05	.42	N. 36° E.	2.81	5.99	1.12	.33	S. 50° W.	2.52	6.43	2
8	El Capitan Passage, Dry Pass.	November, 1922	T. J. Maher	do	5.80	5.25	Easterly	1.81	4.92	4.80	7.65	Westerly	.91	7.50	1

The tidal movement at Tlevak Narrows is similar to that at Tongass Narrows in that the rise and fall of the water surface is simultaneous at the two ends of the passage. However, the mean range of the tide in the northern portion of Tlevak Strait is 11 feet while in the vicinity of Ulloa Island it is 8.5 feet. There is, therefore, a difference of 2.5 feet in range in a distance of about 2 miles, and if it is assumed that the tide oscillates uniformly with respect to the plane of mean sea level, the water surface at the time of high water will be on the average 1.25 feet higher and at the

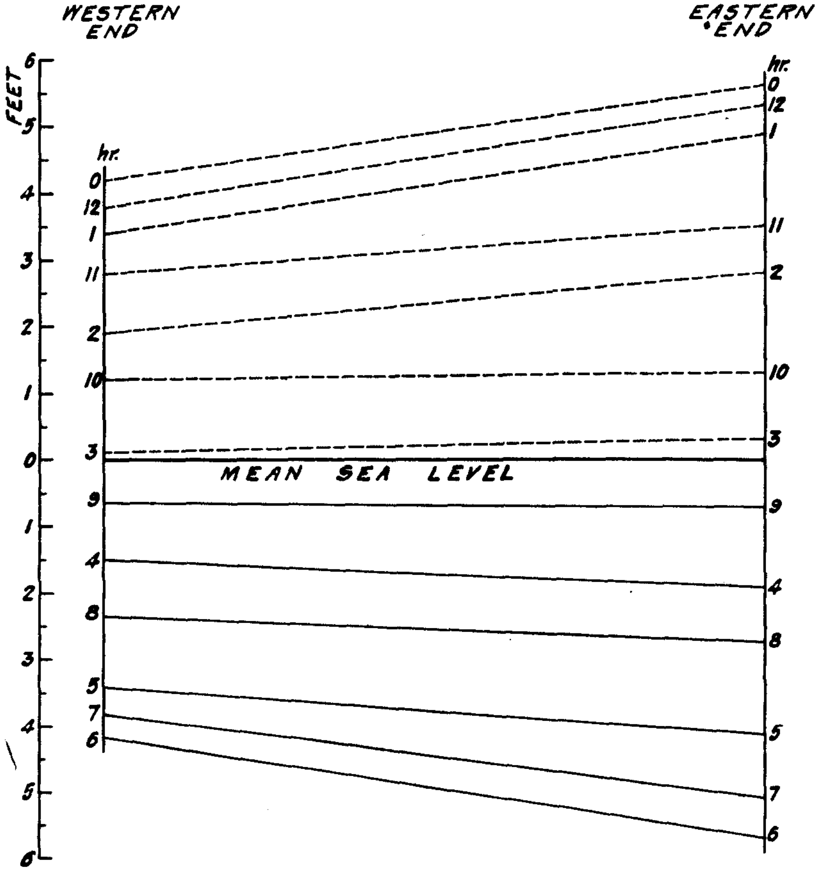

FIG. 27.—Slope diagram. Tlevak Narrows

time of low water 1.25 feet lower at the eastern end of the narrows than at the western.

In Figure 27 the hourly heights of the water surface at the two ends of Tlevak Narrows are plotted on the vertical lines, the heights for the western end being plotted on the left-hand line, and those for the eastern end on the right-hand line. The heights are measured in feet from mean sea level, the height scale being shown at the left of the diagram. The times corresponding to the plotted heights are given at the side of each vertical line. They are reckoned from high water at Sitka, which is simultaneous with local high water at Tlevak

Narrows. The heavy horizontal line represents mean sea level. The sloping lines which are drawn between the plotted points of simultaneous height represent the slope of the water surface in the narrows. These lines are dashed when the slope is from the eastern end to the western and solid when it is from the western end to the eastern. It will be seen from the diagram that when the water surface is at mean sea level at the two ends of the narrows the slope is zero. As the water surface rises above mean sea level at the two ends the slope from the eastern to the western end becomes greater, and reaches a maximum at the time of high water. A corresponding slope in the opposite direction reaches its maximum at the time of low water.

If the current through Tlevak Narrows is due entirely to the difference in the water level at the two ends, the maximum current-producing force occurs at the times of maximum slope, or at high and low water, the current-producing force decreasing to zero when the slope is zero or at a time midway between the times of high and low water. A comparison of the slack waters observed at station 6 with Sitka tides shows that on the average slack before flood occurs 3.7 hours after high water, and slack before ebb occurs 3.7 hours after low water, flood and ebb being taken as the easterly and westerly streams, respectively. Taking one-fourth of the tidal cycle, or 3.1 hours, as the average time after high or low water that the slope becomes zero in the narrows, it will be seen that slack water occurs 0.6 hour after the hydraulic force due to the difference in head has ceased. A lag of this sort is to be expected since the inertia of the moving water is a sufficient force in itself to keep the current flowing for a time.

The series of observations at station 5, while too short to be of much value in drawing conclusions, indicates that the strengths occur at this station about 1 hour after the times of maximum slope through the narrows.

The above considerations appear to indicate that the current through Tlevak Narrows is in part at least a hydraulic current due to an alternating difference in head between the two ends of the narrows.

The following statements relative to the currents in this vicinity are based on reports from the survey party that made the observations at stations 5 and 6.

The currents in and around Tlevak Narrows run very strong during spring tides, the strength being greatest in the part between Block Island and Turn Point where the west-going stream has an estimated velocity at strength of 7 to 8 knots. The current from west to east is comparatively light at all times. The time differences between the tides and the slack waters are very regular and uniform. The period of slack water lasts from 5 to 10 minutes. During the first of the flood with the current setting to the southeast an eddy is formed in the small bight southeast of Turn Point and the current follows the channel southwest of the Lively Islands becoming almost imperceptible a short distance southeast of Guide Island. In that part lying northeast of the Lively Islands a constant set to the northwest was experienced, this set being stronger when the main stream was setting to the northwest and vice versa.

The local fishing craft, most of which pass to the northeast of the Lively Islands and close around Midway Island when approaching the narrows on the first of the flood, do so to take advantage of the northwesterly countercurrent. The first of the ebb setting to the northwest spills into the small bight southeast of Turn Point and through the Narrows over toward triangulation station Cabin and Ulloa Island. Here the stream divides, one part setting around to the north of Ulloa Island and the other setting strongly into Meares Passage, past Bush Islets and the eastern end of Meares Island. During this stage of the current an eddy of roughly triangular shape is formed off the Dall Island shore, in the part lying between triangulation station Big and the point lying a half mile southwest by west of triangulation station Big.

The results of the observations at station 6 show that the ebb or westerly stream runs 0.6 hour longer than the flood or easterly stream. This difference in the durations of flood and ebb as well as statements given in the preceding paragraph indicate a strong westerly nontidal set of the current through Tlevak Narrows. The observed velocities at station 5 given in Table 39 show a flood strength of 4.2 knots and an ebb strength of 1 knot. These velocities are based on a single observed strength in each direction and are therefore not to be considered as well-determined mean values. It appears, however, that station 5 lies directly in the path of the flood stream and therefore experiences its full force, whereas the main part of the ebb stream setting into the narrows from the area northeast of the Lively Islands passes to the northward of this station.

Tonowek Narrows separates the eastern end of Heceta Island from Prince of Wales Island and connects Tonowek Bay with Karheen and Tuxekan Passages. It is approximately 1 nautical mile in length with an average width of one-half mile. A channel from 100 to 200 yards in width with an average depth of about 20 fathoms extends through the passage.

Two days of current observations were taken at station 7 shown in Figure 28. The data derived from these observations are given in Table 39. Tidal observations taken in this vicinity indicate that the tide is practically simultaneous in Tonowek Bay and Karheen Passage, and that the mean range is about 0.4 foot greater in the latter waterway. This difference in range produces a difference in head analogous to that at Tlevak Narrows but less pronounced since the difference in range is only about one-sixth as great. From a comparison of the times of current at station 7 with the times of local tide it is found that slack waters precede the high and low waters by about ½ hour, and strengths of current follow the high and low waters by approximately 2 hours. The fact that times of slack come near the times of high and low water seems to indicate a stationary wave movement. (See Appendix, p. 141.)

It has been seen in the case of Tlevak Narrows that simultaneous tides having different ranges at two ends of a passage tend to produce hydraulic currents which reverse at times midway between the times of high and low water. It appears that in Tonowek Narrows a hydraulic effect of this sort combined with the stationary wave movement causes the times of current to be advanced. It seems reasonable to conclude, therefore, that the movement in Tonowek

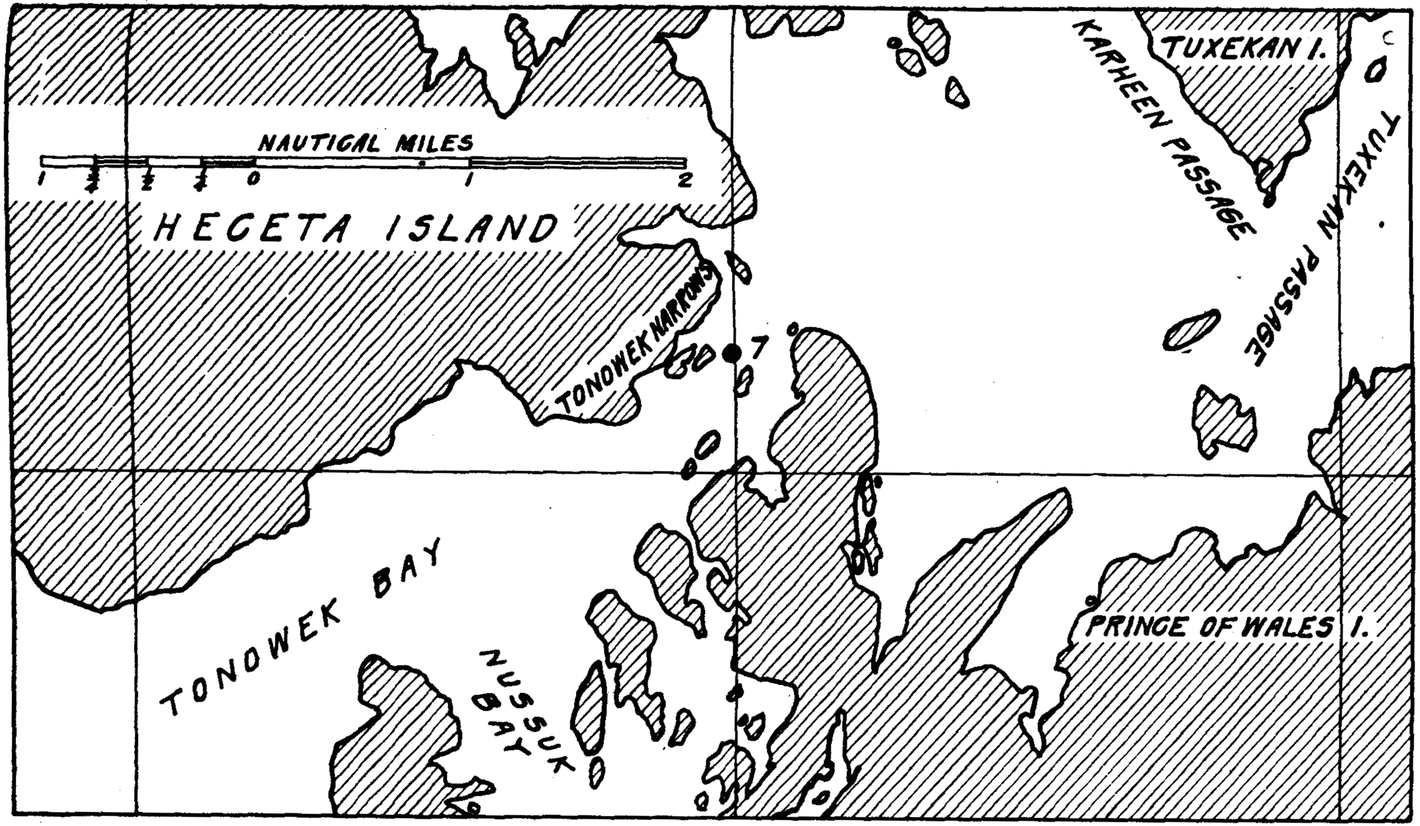

FIG. 28.—Current station, Tonowek Narrows

Narrows is of the stationary wave type modified by the above mentioned hydraulic condition.

The values for velocity given in Table 39 show a flood velocity 0.29 knot greater than the ebb velocity. This difference would seem to indicate a nontidal northwesterly current. It will be noted, however, that the ebb runs 0.44 hour longer than the flood, and since the weaker current has the longer duration it is probable that no considerable nontidal current occurs in this passage. Results of observations show that the current at station 7 increases from a slack to a strength in about two and one-half hours while approximately three and one-half hours are required for it to diminish to another slack. This peculiarity obtains for both the flood and ebb streams and causes the times after current at Sergius Narrows given in Table 39 to be considerably smaller for the strengths than for the slack waters.

El Capitan Passage separates Kosciusko Island from Prince of Wales Island. Dry Pass, the narrowest and shoalest part of El Capitan Passage, is about one-third mile in length and less than 50 yards in width at its narrowest part. It is extremely shoal and a portion of it is said to be entirely dry at times of very low tide. The position of station 8 near the center of Dry Pass is plotted in Figure 29, and the data derived from the one day of current observations at this station are given in Table 39. The tides in El Capitan Passage on either side of Dry Pass are shown by observation to be practically simultaneous, with a range 0.7 foot greater in the basin west of Dry Pass than at Devilfish Bay near the center of El Capitan Passage. The results of observations at station 8 indicate that the strength of the flood or easterly stream occurs about one-half hour after local high water. In other words this strength follows the maximum hydraulic effect with a lag of one-half hour. The ebb stream, however, instead of increasing in velocity as the tide approaches a low water and the hydraulic head consequently becomes greater, remains weak and approximately constant in velocity until about one hour after low water. At this time it begins to increase in velocity and reaches its strength approximately three hours after low water. This peculiarity of the ebb stream appears to be due to a marked shoaling of the water in the pass as the tide nears a low water. Since the depth of water in the pass is least at the time of low water, only a small quantity of water can flow through at this time. As the tide rises, however, the depth in the pass becomes greater, and since a part of the diminishing difference in head yet remains the current increases in strength for a time.

It will be noted from the values given in Table 39 that although the ebb stream has a velocity at strength only about one-half as great as that of the flood, it runs 2.58 hours longer than the flood.

Following are statements based on a descriptive report from the field party that made observations at station 8. About 3.8 hours after low water the direction of the current in Dry Pass changes from west to east, and about three hours after high water the direction of current changes from east to west. Currents from Shakan Strait and Dry Pass meet and separate in the basin west of Dry Pass. Immediately after high water there is a westerly current in that stretch of water between the basin and the entrance to Shakan

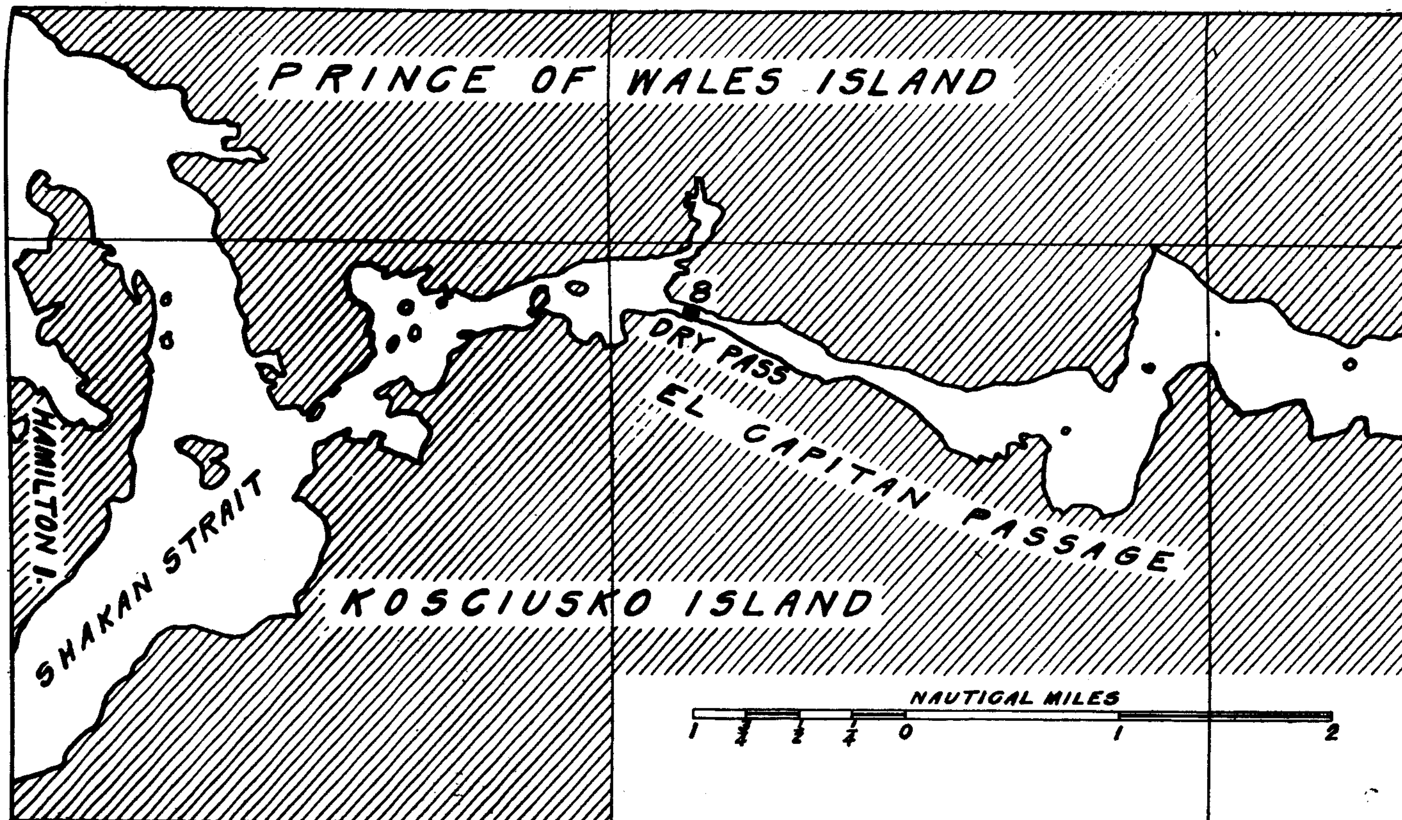

FIG. 29.—Current station, Dry Pass

Strait while at the same time there is an easterly current through Dry Pass and the passage east of Dry Pass. Three hours after high water the current in Dry Pass and the area east of Dry Pass changes from east to west and a westerly current flows through the entire length from east of Dry Pass to Shaken Strait. Immediately after low water the current flows into the basin west of Dry Pass from both directions, but about 3.8 hours after low water the current in Dry Pass changes from west to east and an easterly current flows in the stretch from Shakan Strait through Dry Pass.

7. CURRENTS IN SUMNER STRAIT AND CONNECTING WATERWAYS

Under this heading are discussed the results derived from current observations in Sumner Strait, the northern part of Clarence Strait, and passages in the immediate vicinity of Wrangell Island. The data for stations in these waterways are given in Table 40, and the positions of the stations are plotted in Figures 30 to 33. Each passage is taken up separately in the following paragraphs.

Current observations have been taken in Sumner Strait only in the upper part which extends in an easterly and westerly direction. This portion of the strait is approximately 35 nautical miles in length and of varying width and depth. The least width is about 2½ miles, and the depth, which is considerable in nearly all parts, shows a general increase from the eastern to the western extremity. The positions of three current stations which have been occupied in Sumner Strait are shown on Figure 30. At station 9 observations were obtained at four depths, while at stations 10 and 11 pole observations only were made.

At the 7 and 20 foot depths of station 9 and at station 11 the current did not flood during the period covered by the observations. At station 10 a flood and ebb occurred, but the results show a nontidal westerly current of over half a knot. Observations at stations 9 and 11 were taken at times of neap tide, and the velocities when corrected for range of tide became positive as given in the table. The inference is, therefore, that the unidirectional current observed at these stations is a phenomenon which occurs only during neap tides. It will be recalled that for stations 3 and 4 in Tongass Narrows a similar case was discussed.

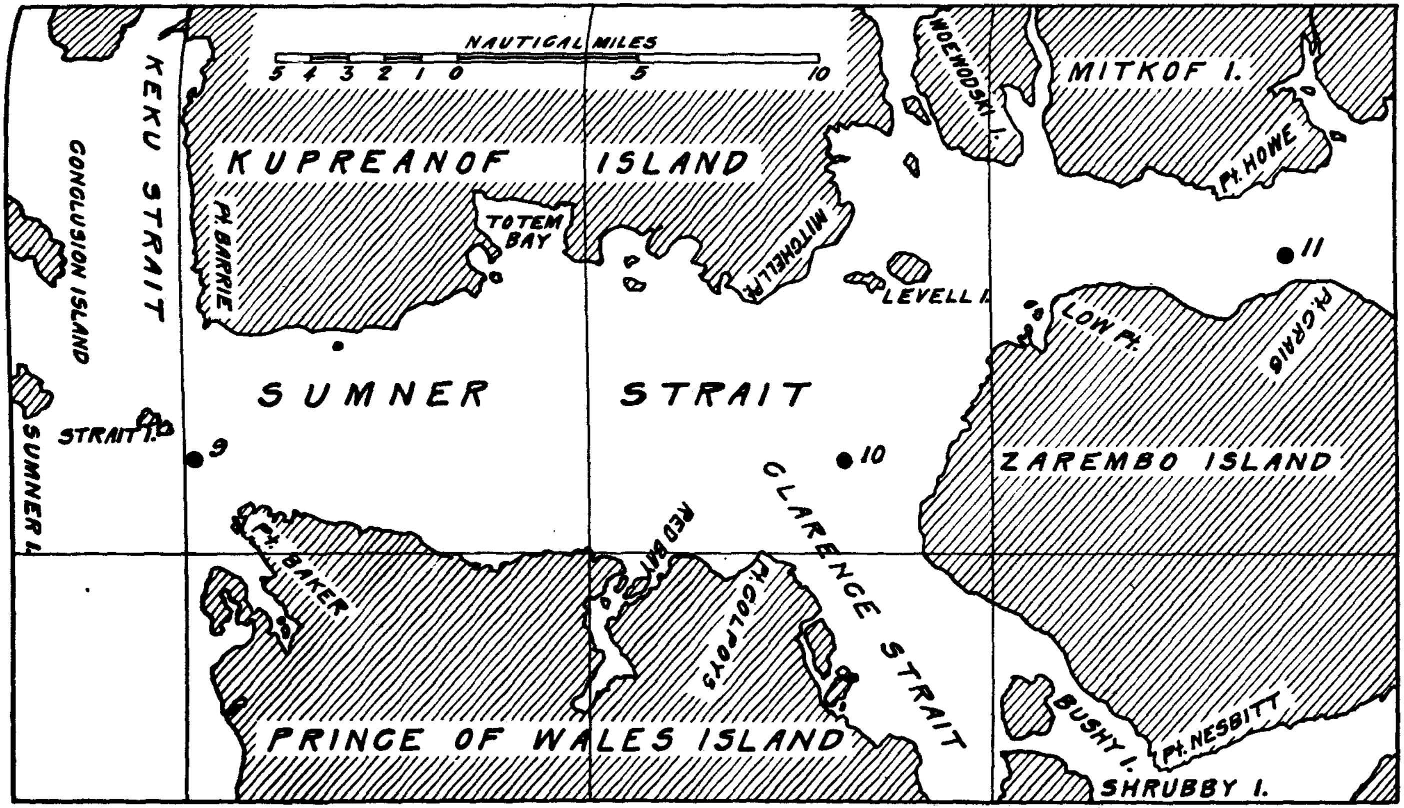

FIG. 30.—Current stations, Sumner Strait

TABLE 40.—*Current data, Sumner Strait and connecting waterways*

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observation with—	Depth	Slack before flood	Flood strength			Flood duration	Slack before ebb	Ebb strength			Ebb duration	Length of observations
							Time	Direction	Velocity			Time	Direction	Velocity		
					Feet	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
9	Sumner Strait, 1 mile southeast of Strait Island.	August, 1925	L. M. Zeskind	Pole	7		1.82		0.50			1.32	S. 70° W.	2.98		2
		Do	do	Meter	20		1.40		.40			1.25		2.93		2
		Do	do	do	50	1.50	.58		1.44	3.30	−1.12	1.22		2.96	9.12	2
		Do	do	do	80	1.15	.58		2.04	4.29	−.48	1.22		2.88	8.13	2
10	Sumner Strait, off Point Colpoys.	September, 1916	L. O. Colbert	Pole	10	2.25	1.83	N. 76° E.	1.04	5.37	1.70	2.27	S. 62° W.	2.21	7.05	1½
11	Sumner Strait, off Point Craig.	do	do	do	10		2.80		.06			3.53	S. 71° W.	1.96		1½
12	Clarence Strait, 1 mile north of Fire Island.	July, 1916	C. G. Quillian	do		−5.57	−5.40	N. 21° W.	1.91	6.54	−4.95	−5.45	S. 26° E.	1.51	5.88	1
13	Clarence Strait, 1½ miles northeast of Tide Island.	August, 1925	L. M. Zeskind	do	7	.88	.13	S. 58° E.	1.38	5.51	.47	1.20	N. 78° W.	3.08	6.91	3
		Do	do	Meter	20	.92	.08		1.31	5.45	.45	1.30		3.00	6.97	3
		Do	do	do	50	.97	.17		1.44	5.45	.50	1.54		2.86	6.97	3
		Do	do	do	80	.98	.22		1.47	5.47	.53	1.64		2.69	6.95	3
15	Snow Passage, narrows	do	do	Float		.65	.00	Southeasterly.	3.36	5.33	.06	.40	Northwesterly.	3.96	7.09	1½
16	Snow Passage, off Bushy Island Light.	do	do	Pole	7	.80						.50	N. 11° W.	5.10		¼
17	Snow Passage, Shrubby Island Cove.	do	do			2.12				5.96	2.16				6.46	2
18	Clarence Strait, Burnett Inlet.	July, 1916	C. G. Quillian	Pole		3.93	3.05	N. 14° E.	.42	5.01	3.02	4.31	S. 29° W.	.97	7.41	6½
19	Off Wrangell	July–October, 1916	do	do		−.14	.78	N. 14° W.	.54	7.74	1.68	.81	S. 14° W.	.31	4.68	14
21	Blake Channel, off Point Capel.	September, 1916	L. O. Colbert	do	10	−2.60	1.20	S. 12° E.	1.19	8.27	−.25	−2.15	N. 4° W.	.69	4.15	1
22	Blake Channel, 1 mile north of Ham Island.	do	do	do	10	3.40	2.40	N. 15° W.	.66	4.82	2.30				7.60	⅓

The rise and fall of the tide is practically simultaneous throughout the area under discussion, the tide occurring but a few minutes later at station 11 than at station 9. The mean range, however, increases from about 10.5 feet at station 9 to approximately 13 feet in the vicinity of station 11. A comparison of the times of current with the times of tide at stations 9 and 10 shows that the strengths of current occur very nearly midway between the times of high and low water. At station 11 the relation of current to tide shows less regularity, and the strengths precede the high and low waters by an average time of about two hours. A consideration of the above relations leads to the conclusion that the movement in that part of Sumner Strait north of Prince of Wales Island is of the stationary-wave type. It appears, however, that in the vicinity of station 11 a progressive-wave movement is combined with that of the stationary wave. The presence of a progressive wave is evidenced by a slight retardation in the times of tide and a marked retardation in the times of current with respect to the times of tide.

The effect of the hydraulic condition which exists due to the difference in range of a practically simultaneous tide between the two ends of this passage, appears to be obliterated by stronger current-producing forces; for at stations 9 and 10 the strengths occur midway between high and low water, at which times the hydraulic force is zero, and at station 11 the strengths of flood and ebb occur when the tide is approaching high and low water respectively; that is, at times when a current due to the existing hydraulic condition would be nearing its strength in the opposite direction.

Referring to Table 40 it will be noted that at station 9 the flood velocity is considerably greater at the two lower depths than near the surface and the ebb velocity decreases slightly with increased depth. During the period covered by the observations floods of 3.30 hours' and 4.29 hours' duration occurred at the 50 and 80 foot depths, respectively, while the current ebbed continuously at the 7 and 20 foot depths.

Computing the velocities of the permanent or nontidal current at the three stations from the velocities given in Table 40, it is found to have at station 9 a velocity of 1.24, 1.26, 0.76, and 0.42 knots at the 7, 20, 50, and 80 foot depths, respectively. At station 10 its velocity is 0.58, and at station 11, 0.93 knot. These data show that the permanent current in general decreases with depth, and consequently the flood and ebb streams become more nearly equal as the bottom is approached. This condition would seem to indicate that the permanent current is due in part at least to a considerable quantity of fresh water flowing through the strait, for the fresh water, being less dense than the salt water outside, tends to remain near the surface.

In that part of Clarence Strait between Prince of Wales Island and Zarembo Island current observations have been taken at the six stations plotted on Figure 31. The time and range of the tide are shown by observations to be approximately uniform throughout this area. At the stations where velocity observations were taken the strengths of flood and ebb occur on the average from one to two hours after the times of low and high water, respectively. This relation of current to tide indicates the presence of a combined stationary and

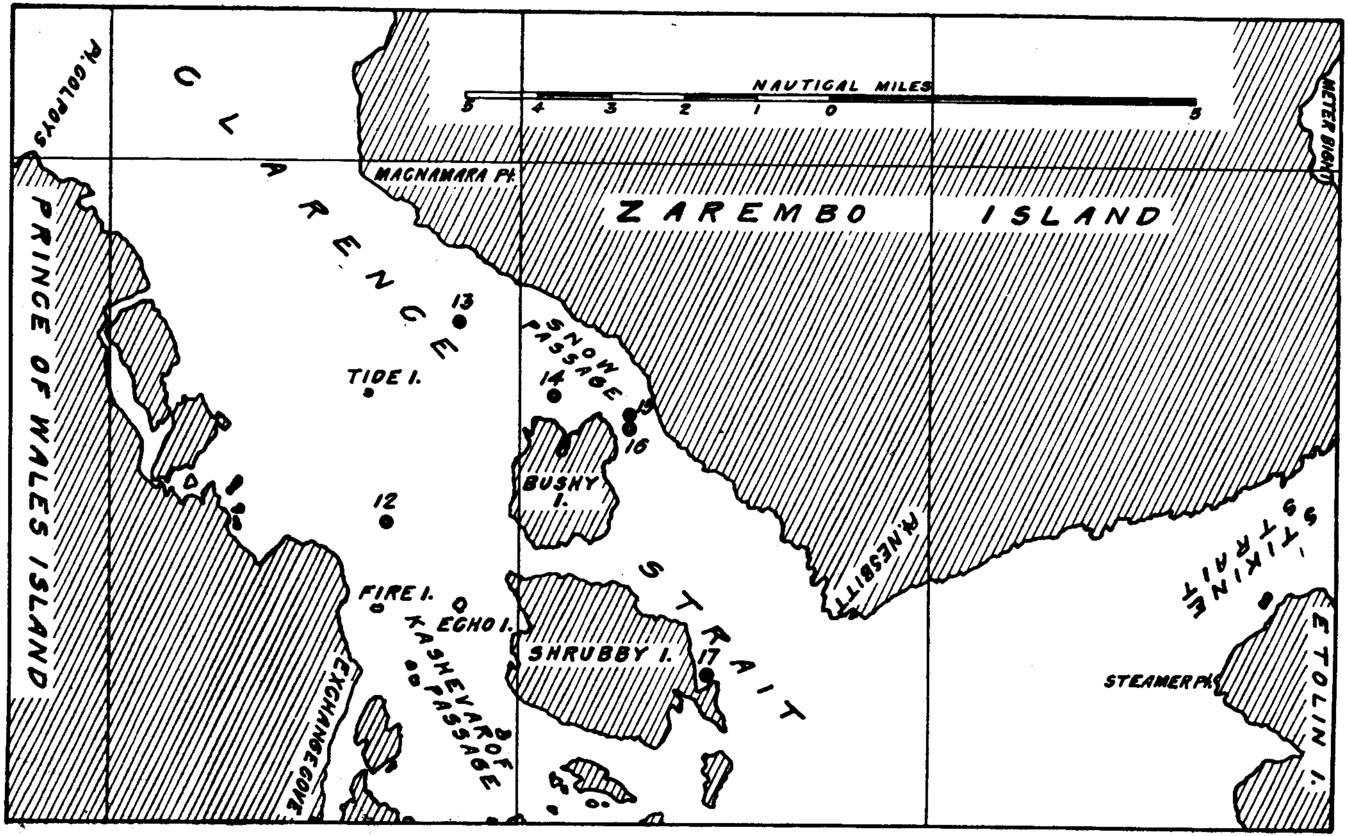

Fig. 31.—Current stations, Clarence Strait

progressive wave movement. Referring to Table 40 it will be seen that at station 12 the flood stream flows in a northwesterly direction, while at the stations in the vicinity of Snow Passage the flood runs southeasterly. These two streams running in opposite directions reach their maximum strength at about the same time. This condition appears to be due to a flood stream coming from each direction, the stream from Sumner Strait following the Zarembo Island shore, and the one from Clarence Strait flowing to the westward of the Kashevarof Islands. On the ebb these currents are reversed in direction, the ebb streams in the vicinity of Bushy Island flowing northwestward through Snow Passage and southeastward into Kashevarof Passage.

At station 14 a series of pole observations covering a period of two and three-fourths days was obtained. A maximum velocity of 1.1 knots was observed during this time. The observations of both velocity and direction were too irregular to admit of the usual tabulation and reduction. Data for this station, therefore, do not appear in the table.

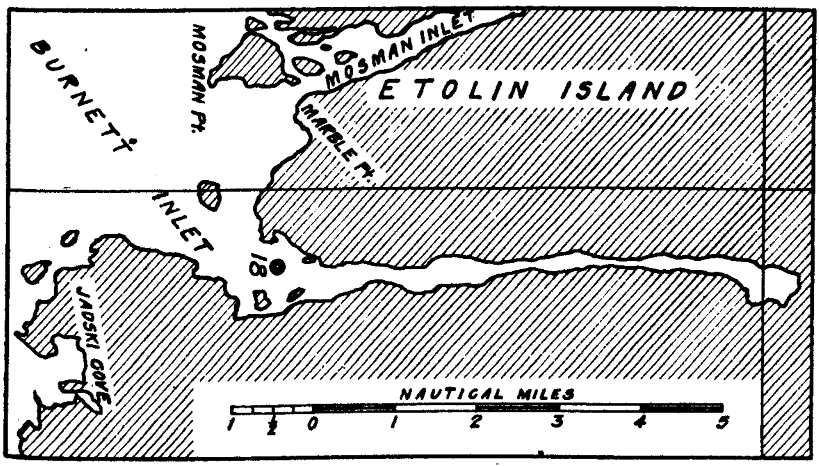

FIG. 32.—Current station, Burnett Inlet

It will be noted that the values for both velocity and duration at each station are greater for the northwesterly than for the southeasterly direction. It appears, therefore, that Clarence Strait, in common with similar passages in southeast Alaska, experiences a permanent northwesterly set of the current. Subsurface observations at station 13 show conditions similar to those existing at station 9 in Sumner Strait, the flood velocity increasing and the ebb velocity decreasing as the bottom is approached. The duration of flood and ebb are, however, approximately the same at the different depths. The permanent current, as at several stations previously discussed, shows some decrease with increased depth.

Burnett Inlet is a small arm of Clarence Strait extending northward into Etolin Island. It is about 7 nautical miles in length and has an average width of about one-fourth mile. Current observations covering a period of six and one-half days were taken at station 18, shown on Figure 32. The data derived from the observations are given in Table 40. The current at this station seems to be rather complex in its nature and irregular with respect to the tide. The strength of flood occurs on the average about 1.8 hours before high water and the strength of ebb about 0.8 hour before low water. The results of observation show a permanent southerly current of about one-fourth knot, due no doubt to fresh-water run-off.

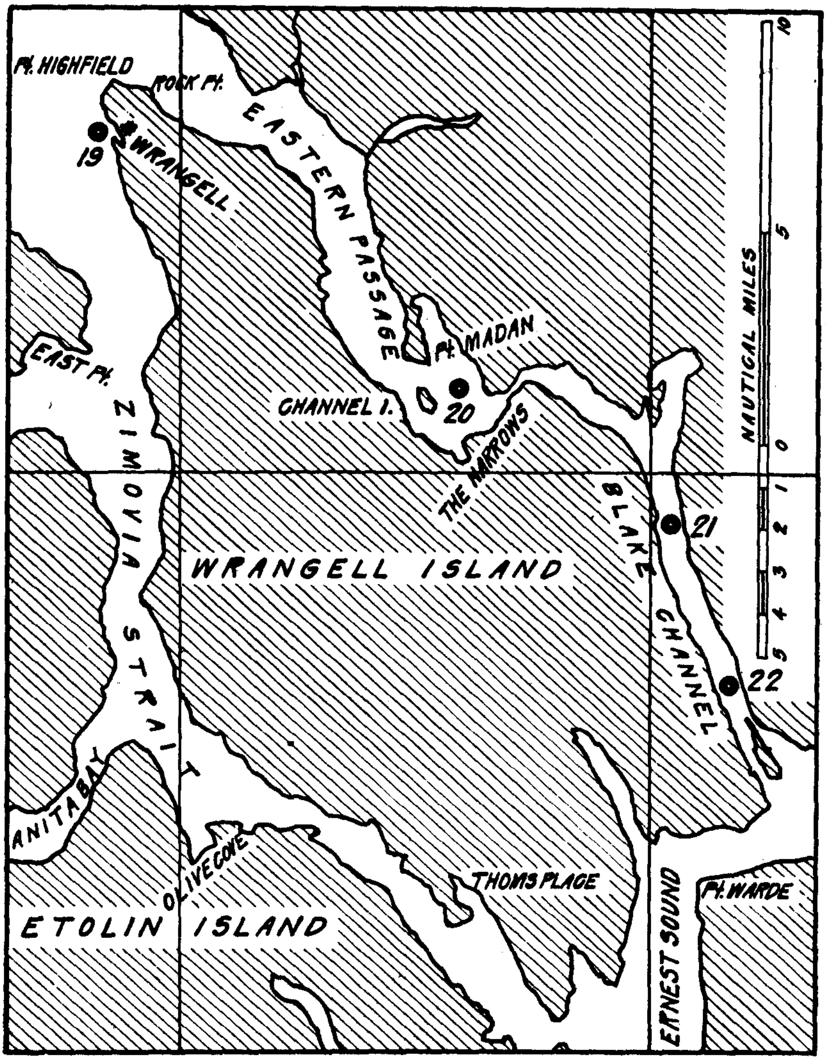

FIG. 33.—Current stations, vicinity of Wrangell Island

Four current stations have been occupied in the vicinity of Wrangell Island, one off the town of Wrangell, one in the southern part of Eastern Passage and two in Blake Channel. Figure 33 shows the location of these stations, and the data for stations 19, 21, and 22 are given in Table 40. Station 20 was occupied but seven hours and an irregular current of about half a knot maximum velocity occurred during that period. At station 19 the observed current was weak and very irregular at times, and it seems probable that this station is located too near the shore to experience the full strength of the current. The velocities given in the table indicate a permanent northerly set of about 0.12 knot, and the values for duration of flood and ebb show that the northerly stream at this station flows 3.06 hours longer than the southerly stream.

At station 21 in Blake Channel 25 hours of observations were obtained and during 8 hours of this time observations were being made at station 22. These observations show that the flood current enters Blake Channel from both ends, reaching its strength at station 22 about 1½ hours before high water. At station 21 the flood stream from Eastern Passage begins to flow about 1½ hours after high water and requires approximately 7 hours to reach its strength. Having reached its flood strength the current diminishes to another slack in about 1¼ hours, this slack being followed by a period of ebb of approximately 4.2 hours' duration. The long, slow increase in the strength of flood is apparently due to the constricted nature of the narrows between Eastern Passage and Blake Channel, whereas the sudden decrease from strength of flood to slack is evidently caused by the flood current from the south meeting that from the north. It was noted by the observing party at station 21 that at the time these two currents meet the current from the south follows the eastern shore of the channel and that from the narrows clings to the western shore. The data derived from observations at stations 21 and 22 indicate a very pronounced nontidal set to the southward in Blake Channel. This set is probably due in part at least to fresh water from streams emptying into this passage.

8. THE CURRENT IN WRANGELL NARROWS

Wrangell Narrows is a passage approximately 20 nautical miles in length connecting the eastern portion of Sumner Strait with Frederick Sound. It has a least width of about 400 yards and varies considerably in depth, the shoaler parts having a depth in mid-channel of about 2½ fathoms at mean lower low water. Six stations at which current observations have been obtained in Wrangell Narrows are plotted on Figure 34 and the results derived from the observations are given in Table 41. In making use of this table it should be borne in mind that currents observed with a meter at depths of only a few feet were probably considerably modified by the hull of the observing vessel. At stations 24 and 25 times of slack water only were observed.

The tidal movement is practically simultaneous at the two ends of the narrows, the tide occurring only about 0.2 hour earlier at Point Lockwood than at Petersburg. The range of tide is approximately 13.5 feet at the northern entrance and 13.1 feet at the southern, while near the center it is about 14 feet. A comparison of the observed currents with the tides indicates that throughout Wrangell Narrows the slack waters occur near the times of high and low water, the strengths occurring approximately midway between these times. The flood streams enter from both ends and meet somewhere north of station 26, the reported meeting place being the stretch of water between Green Point and Tonka.

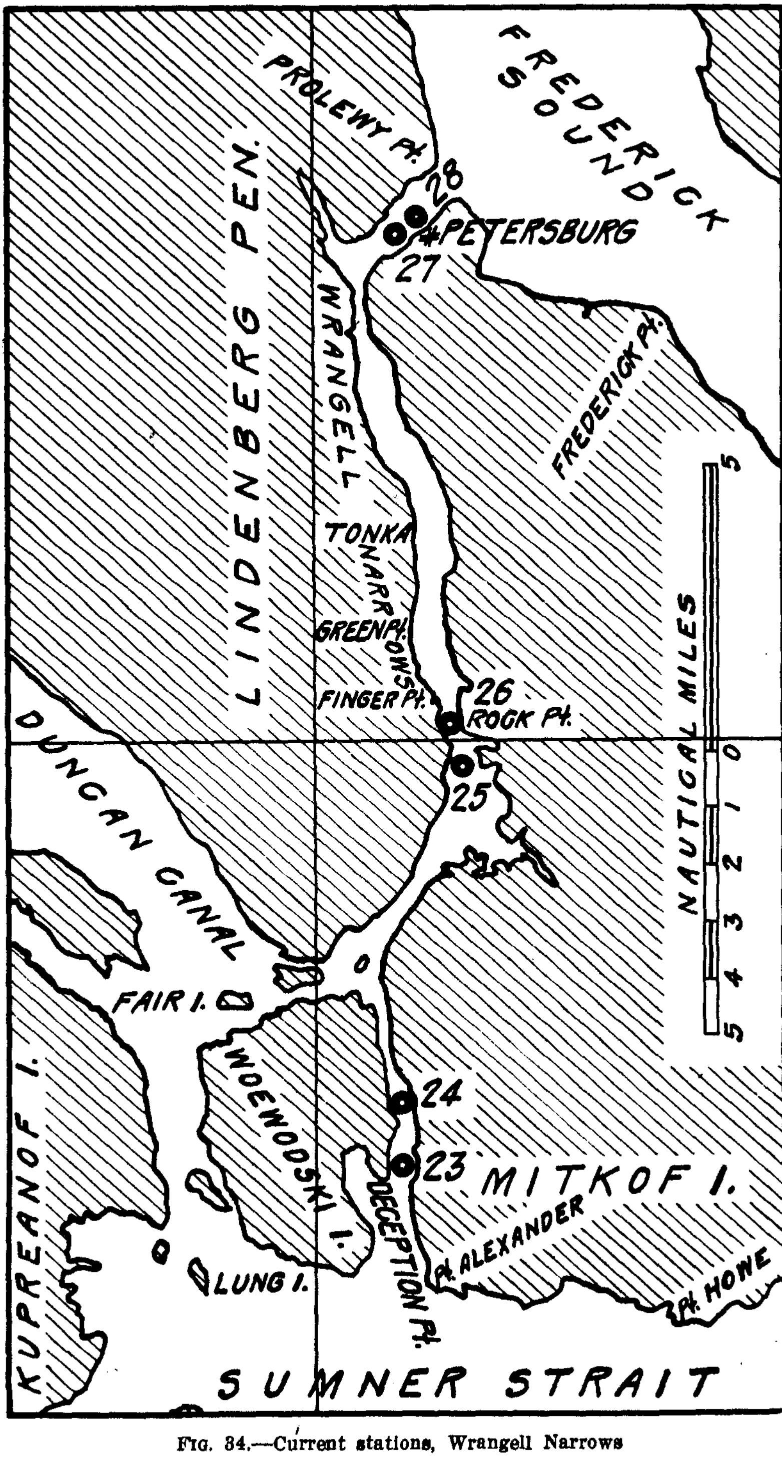

FIG. 34.—Current stations, Wrangell Narrows

TABLE 41.—*Current data, Wrangell Narrows*

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observations with—	Depth	Slack before flood	Flood strength			Flood duration	Slack before ebb	Ebb strength			Ebb duration	Length of observations
							Time	Direction	Velocity			Time	Direction	Velocity		
					Feet	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
23	Off Deception Point	October, 1923	J. H. Hawley	Pole		3.10	2.80	N. 4° W.	0.82	6.02	3.20	2.60	S. 15° W.	1.32	6.40	½
	Do	August, 1925	L. M. Zeskind	do	7	2.45	2.37	N. 8° W.	.68	5.70	2.23	2.09	S. 1° W.	1.11	6.72	4
	Do	do	do	Meter	16	2.56	2.64		.59	5.75	2.39	1.94		1.16	6.67	4
	Do	do	do	do	40	2.34	2.50		.63	5.98	2.40	1.81		.97	6.44	4
	Do	do	do	do	64	2.00	2.47		.53	5.98	2.06	1.54		.67	6.44	4
24	¼ mile north-northwest of Point Lockwood.	do	do			2.06				6.29	2.43				6.13	8
25	¼ mile north of Woody Island.	do	do			2.05				5.87	2.00				6.55	1
26	Off Rock Point	do	do	Pole	7	2.30	1.92	N. 26° W.	1.25	5.80	2.18	2.90	S. 23° E.	1.00	6.62	2
	Do	do	do	Meter	5	2.22	1.95		.88	5.92	2.22	3.00		.50	6.50	2
	Do	do	do	do	12	2.18	1.95		1.15	6.12	2.38	2.80		.95	6.30	2
	Do	do	do	do	20	2.12	2.05		1.22	6.18	2.38	2.70		.95	6.24	2
27	¼ mile west of Petersburg.	October, 1923	J. H. Hawley	Pole		2.60	2.70	S. 52° W.	2.06	5.62	2.30	3.10	N. 47° E.	1.76	6.80	½
28	¼ mile north of Petersburg.	September, 1910	R. B. Derickson	do		2.50	2.60	S. 52° W.	4.70	6.07	2.65	3.00	N. 62° E.	4.10	6.35	½
	Do	August, 1925	L. M. Zeskind	do	7	2.56	2.91	S. 57° W.	3.41	5.76	2.40	2.69	N. 62° E.	3.10	6.66	16
	Do	do	do	Meter	4	2.48	2.90		2.94	5.87	2.43	2.64		2.53	6.55	10
	Do	do	do	do	8	2.47	2.91		3.34	5.85	2.40	2.59		3.00	6.57	10
	Do	do	do	do	12	2.55	2.93		2.68	5.72	2.35	2.62		2.43	6.70	16
	Do	do	do	do	20	2.79				5.50	2.37				6.92	5

Values given in Table 41 show that the current occurs at practically the same time at stations 23 to 26, inclusive, the average time of current at these stations being about 0.4 hour earlier than at station 28. Sixteen days of continuous observations were taken at station 28, and the values from this series may be considered as relatively well determined.

It will be noted that the velocities in the vicinity of Petersburg are considerably greater than at the stations in the southern half of the narrows. The velocities given in the table are, with the exception of those for station 26, greater for the south-going than for the north-going stream. At station 26, however, the southerly stream has the greater duration, and it seems safe to conclude that there is an appreciable southerly nontidal set of the current through Wrangell Narrows.

Considering the times of flood and ebb strength for the various depths at stations 23 and 26, it will be seen that in general the time of strength of flood is approximately the same at the different depths, while the time of ebb strength becomes earlier with increasing depth. At station 28 the times of flood and ebb strength are approximately constant from the 4-foot depth to the 20-foot depth, as are also the duration of flood and ebb. At stations 23 and 26, however, the duration of the flood stream shows an increase and that of the ebb stream a corresponding decrease as the bottom is approached. At all three stations at which subsurface observations were taken, if the 4 and 5 foot meter observations are disregarded, the velocities of both flood and ebb show a decrease with increasing depth.

For the purpose of predicting the times and velocities of the current in Wrangell Narrows current harmonic constants (see Appendix, pp. 135 and 144) for the channel off Petersburg have been determined from the tidal harmonic constants[1] for Petersburg. The amplitudes of the current components were derived by applying to the amplitude of each corresponding tidal component, first, a factor representing the speed of the component, and, second, a factor representing the ratio of the average velocity at strength of current to the product obtained by applying the first-mentioned factor to the tidal amplitude of the principal lunar component M_2. In deriving the epochs of the current components two corrections were applied to the epoch of each tide component; a correction of 90° to take care of the approximate phase difference between the tide and the current and a smaller correction representing the lag of the current with respect to the tide. The latter correction was obtained for each component by applying to the speed of the component a factor representing the average lag.

In Table 42 are given the results of the determination. The amplitudes are expressed in knots and the epochs in degrees, the epochs being referred to the local meridian.

[1] For a detailed discussion of harmonic analysis, see Special Publication No. 98, Harmonic Analysis and Prediction of Tides, by Paul Schureman, U. S. Coast and Geodetic Survey.

TABLE 42.—*Harmonic constants, off Petersburg, Wrangell Narrows*

Component	H	κ	Component	H	κ
	Knots	*Degrees*		*Knots*	*Degrees*
M_2	3.30	299.0	$Q\mu_2$	0.06	308.4
S_2	1.11	337.0	M_1	.02	32.3
N_2	.65	278.6	Q_1	.04	32.1
K_1	.44	49.8	P_1	.15	49.8
M_4	.07	175.0	M_3	.04	243.1
O_1	.25	36.1	L_2	.11	302.6
M_6	.13	331.6	K_2	.25	301.6
S_4	.02	23.6	M_8	.04	223.1

Predictions of the times of slack water and the times and velocities of strength of current in Wrangell Narrows, off Petersburg, for each

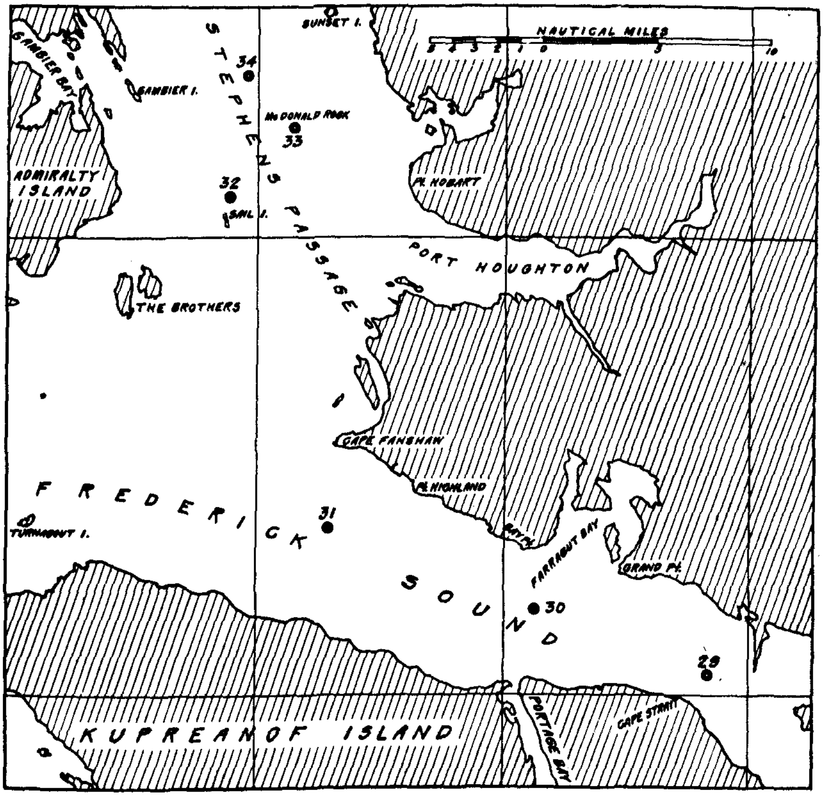

FIG. 35.—Current stations, Frederick Sound and vicinity

day of the year, made by means of harmonic constants are included in the Pacific coast current tables, published annually in advance by the Coast and Geodetic Survey.

9. CURRENTS IN FREDERICK SOUND AND VICINITY

On Figure 35 are plotted 6 current stations, 3 in the eastern half of Frederick Sound and 3 in the southern end of Stevens Passage. Data derived from observations at four of these stations are given in Table 43. The currents at stations 32 and 34 appear to be irregular and comparatively weak. At station 32 the current flowed in a southerly direction with a velocity varying from 0.5 to 0.8 knot during a period of observation covering 5½ hours, while at station 34, 26 hours of observations distributed over a period of 4 days showed a southerly current of from 0.0 to 0.8 knot during 25 of the 26 hours and a northerly current running about 1 hour with a maximum velocity of 0.2 knot.

At stations 29 and 30 the current flowed continuously westward during the periods covered by the observations and the negative values given for the velocity of flood strength in Table 43 represent minimum velocities in an ebb direction which occur at the times of flood strength of the tidal current. These velocities have been reduced to a mean value by correcting for range of tide and they lead to the conclusion that at these stations the current flows continuously in a westerly direction during the greater part of, if not throughout, the lunar month.

Table 43.—Current data, Frederick Sound and vicinity

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observations with—	Depth	Slack before flood	Flood strength			Flood duration	Slack before ebb	Ebb strength			Ebb duration	Length of observations
							Time	Direction	Velocity			Time	Direction	Velocity		
					Feet	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
29	1¾ miles northeast of Cape Strait Light.	August, 1917	A. Joachims	Pole	6½		3. 60		−0. 36			3. 85	N. 38° W.	1. 84		1
30	Midway between Portage and Farragut Bays.	do	do	do	6½		4. 53		−. 17			4. 70	N. 72° W.	. 80		1½
31	4 miles south of Cape Fanshaw Light.	do	do	do	6½	2. 45	2. 45	S. 70° E.	. 37	6. 10	2. 63	2. 83	N. 80° W.	. 75	6. 32	1⅓
33	McDonald Rock, Stephens Passage.	July–August, 1925	L. M. Zeskind	do	7	1. 04	2. 16	N. 21° E.	. 59	8. 61	3. 73	2. 27	S. 40° W.	. 38	3. 81	2
	Do	do	do	Meter	11	1. 52	2. 32		. 67	8. 20	3. 80	2. 70		. 48	4. 22	2
	Do	do	do	do	27	3. 02	4. 18		. 61	8. 13	5. 23	3. 53		. 48	4. 29	2
	Do	do	do	do	54	3. 24	4. 60		. 69	8. 41	5. 73	3. 80		. 41	4. 01	2

Computing the nontidal current from the values given in Table 43 for stations 29, 30, and 31, it is found to have a velocity of 1.10, 0.48, and 0.19 knots, respectively. These values for the velocity of the nontidal current together with the corrected observed velocities given in Table 43 show that both the nontidal and tidal velocities decrease from station 29 westward. Tidal observations indicate that both the time and range of the tide are practically the same for all the stations in Table 43. At station 31 observed strengths occurred approximately midway between the times of high and low water. At this station the observed current was somewhat rotary in character (see Appendix, p. 139), the current changing from flood to ebb and vice versa by a clockwise shift in direction rather than by passing through a slack to a reversal in direction. The velocity, however, became relatively small at the times given for slacks in the table, the direction at these times being approximately 90 degrees from the direction at times of strength.

The times of strength given in Table 43 show that at station 30 the current occurs 2 hours and at station 29, 1 hour later than at station 31. It is not apparent why the current should be later at station 30 than at station 29. Both stations are in deep water and in mid-channel, and it seems probable that longer series of observations at these stations would give more consistent results.

Referring to the data for station 33, it will be seen that here the current strength near the surface occurs roughly 0.4 hour earlier than at station 31. The time of current at this station became later from the surface to the bottom, the average retardation in the time of strength being about 0.04 hour per foot of depth. No marked change in velocity or duration of flood and ebb from the 7-foot to the 54-foot depth is shown by the table. The flood or northerly stream has a greater velocity and runs longer than the ebb. This seems to indicate a northerly nontidal set in Stephen Passage, but it will be noted that observations at stations 32 and 34 indicated a permanent southerly set. All three of these stations are located near shoals and it is likely that eddies and countercurrents prevail in these areas. Moreover, the currents in this vicinity are weak and therefore easily modified by prevailing meteorological conditions.

10. CURRENTS IN PERIL STRAIT AND NEIGHBORING PASSAGES

Under this heading currents in Killisnoo Harbor, Kootsnahoo Inlet, Peril and Neva Straits, and Klag Bay will be discussed.

Killisnoo Harbor and the entrance to Kootsnahoo Inlet are on the eastern shore of Chatham Strait opposite the entrance to Peril Strait. Killisnoo Harbor lies between Killisnoo Island and Admiralty Island, and has an area of about one-half square mile. Kootsnahoo Inlet consists of a group of narrow rocky passages extending several miles into the interior of Admiralty Island, and terminating in Favorite, Mitchell, and Kanalku Bays.

Two current stations in Killisnoo Harbor, and one in the entrance to Kootsnahoo Inlet are shown in Figure 36, and data derived from the observations are given in Table 44. At station 35 the times of 121 slack waters were obtained and referred to Sitka tides. From a mean of the differences thus obtained and the relation between Sergius Narrows currents and Sitka tides determined from five months of observations, the time differences given for this station in Table 44 were deduced. At both stations in Killisnoo Harbor the

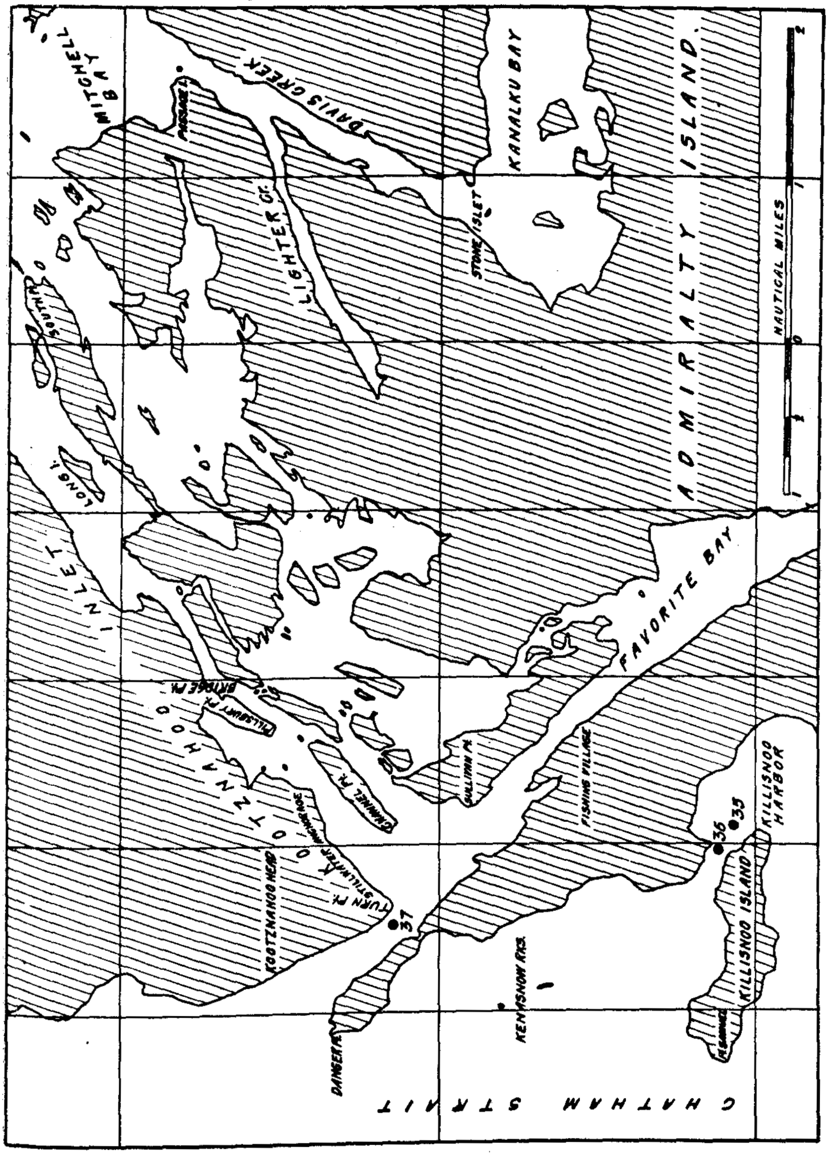

FIG. 36.—Current stations, Killisnoo Harbor and Kootznahoo Inlet

current exhibited great irregularity, velocity observations at station 36 being too irregular to allow of the usual comparison. The series at this station covered a period of 22 hours and showed velocities at strength varying from 0.5 to 2.9 knots. The values given for station 37 are based on a single observation of strength of flood.

The following statements, based on the report of the survey party that obtained the current observations at stations 35, 36, and 37, are consistent with the observational data.

In Killisnoo Harbor the current is very irregular. The average current, however, during the last half of the falling and the first half of the rising tide sets into the harbor from the south and out through the north channel. During the last half of the rising and the first half of the falling tide the current sets eastward through the north channel and out through the southern entrance.

The currents have great velocity in the narrow passages of Kootsnahoo Inlet. Off Turn Point an estimated velocity of 8 knots is attained at times of spring tides. Rapids occur in the area south of Turn Point. In the vicinity of station 37 the current slackens about one and one-half hours after high water at Killisnoo. Passing Turn Point the flood current divides and sets strongly into the various passages. Off Bridge Point in the channel leading to Mitchell Bay a probable velocity of 10 knots occurs, accompanied by much eddying and swirling.

Peril Strait separates Baranof Island from Chichagof Island, and forms a connecting waterway approximately 40 miles in length between Chatham Strait and Salisbury Sound. The narrow part of the passage extends about 12 miles in a northeasterly direction from Salisbury Sound to Povorotni Island. Here the strait broadens to about 2 miles in width, continues in a northeasterly direction for about 5 miles, and extends for the remainder of its length in a general southeasterly direction to Chatham Strait.

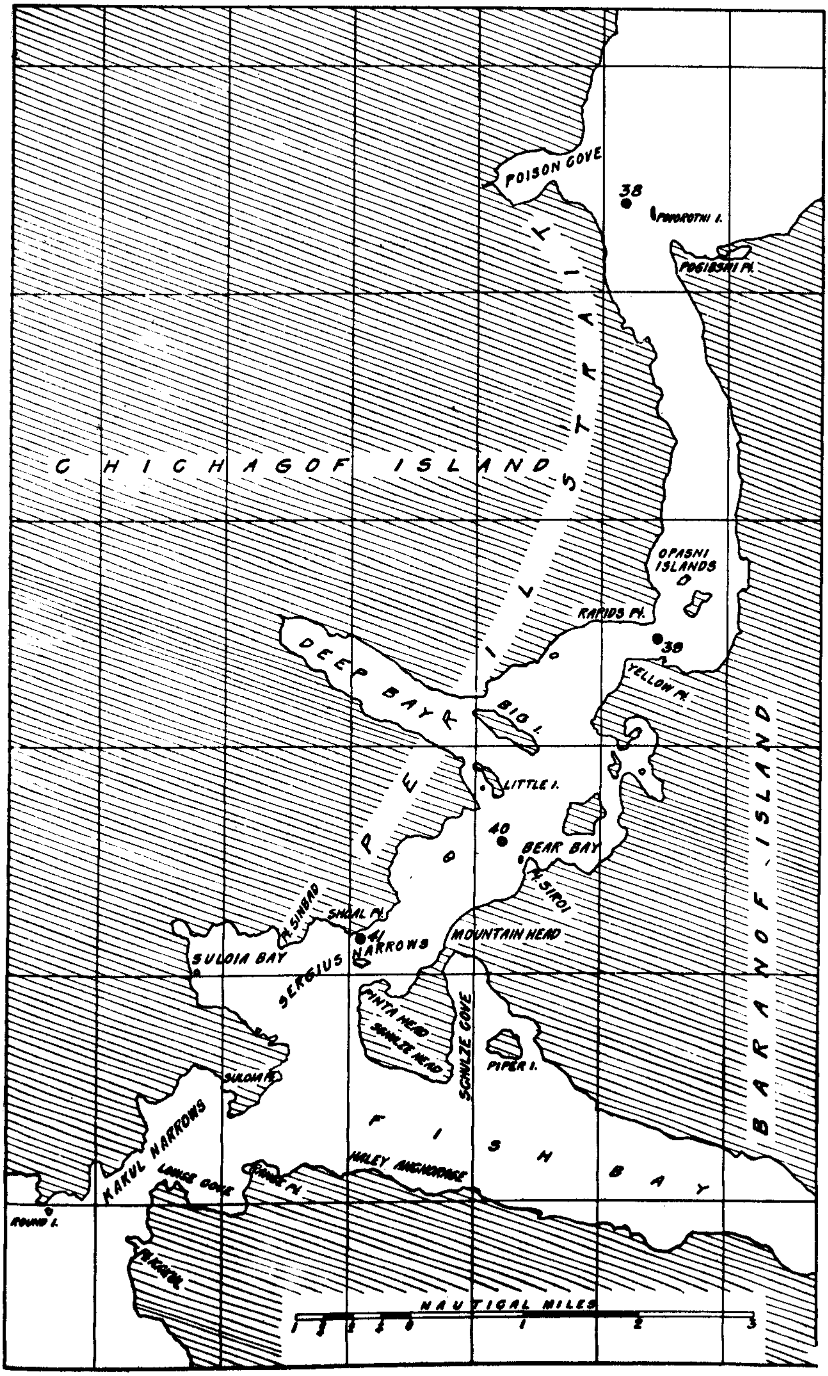

FIG. 37.—Current stations, Peril Strait

TABLE 44.—*Current data, Peril Strait and neighboring passages*

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observation with—	Depth	Slack before flood	Flood strength			Flood duration	Slack before ebb	Ebb strength			Ebb duration	Length of observations
							Time	Direction	Velocity			Time	Direction	Velocity		
					Feet	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
35	Killisnoo Harbor off end of wharf.	May–June, 1895	E. K. Moore			3.86		Easterly		6.88	4.82		Westerly		5.54	30
37	Kootznahoo Inlet	August, 1895	do	Pole			3.50	do	4.27							1/8
38	Peril Strait, off Povorotni Island.	July, 1895	do	do		−.20				4.42	−1.70	−1.00	Southerly.	1.51	8.00	1/8
39	Peril Strait, off Rapids Point.	do	do	do						5.72	−.20	−.10	do	2.52	6.70	1/8
40	Peril Strait, ½ mile northeast of Liesnoi Island.	do	do	do		.42				5.70	.20				6.72	2
		July, 1925	L. M. Zeskind	do	7	.39	.28	N. 59° E.	1.72	5.89	.36	.34	S. 53° W.	1.86	6.53	4
		Do	do	Meter	20	.35	.29		1.62	5.91	.34	.13		1.95	6.51	4
		Do	do	do	50	.38	.20		1.64	5.75	.21	.19		1.97	6.67	4
		Do	do	do	80	.36	.28		1.71	5.76	.20	.24		2.02	6.66	4
42	Neva Strait, Whitestone.	September–October, 1896	E. K. Moore			1.87				5.95	1.90				6.47	15
	Narrows	September, 1896	do	Pole			1.60	Southeasterly	1.62		2.00	2.70	Northwesterly	1.72		1/4
43	Klag Bay, Elbow Passage.	July–October, 1906	E. F. Dickins	do		2.90				6.45	3.43				5.97	25

TABLE 45.—*Current data, Sergius Narrows, Peril Strait*

[Referred to times of tide at Sitka]

Date	Party of—	Observation with—	Slack before flood			Flood strength			Flood duration	Slack before ebb			Ebb strength					Ebb duration	Length of observations
						Time	Direction	Velocity					Time			Direction	Velocity		
			Hours before LLW	*Hours before HLW*	*Hours before LW*	*Hours after LLW*		*Knots*	*Hours*	*Hours before HHW*	*Hours before LHW*	*Hours before HW*	*Hours after HHW*	*Hours after LHW*	*Hours after HW*		*Knots*	*Hours*	
July, 1895	E. K. Moore	Pole	1.90	1.40	1.65	0.60	Northerly	4.97	5.59		2.30	2.30		0.60	0.60	Southerly	6.97	6.83	½ day.
August - September, 1896.	do		1.82	1.32	1.46				5.73	1.68	2.48	1.97						6.69	18 days.
May–October, 1897	do		2.00	1.45	1.68				5.92	1.58	2.30	2.00						6.50	5 months.
July, 1925	L. M. Zeskind	Float	1.90	1.60	1.78	.97	Northerly	5.15	5.82	2.10	2.25	2.20	2.00	.75	1.00	Southerly	4.67	6.60	2 days.

Current observations have been obtained at four stations in the narrow portion of Peril Strait. The stations are plotted on Figure 37 and the results for three of the stations are given in Table 44. The fourth station, Sergius Narrows, is used as a reference station for currents in this publication, and the data derived from four series of observations at this station, referred to the times of tide at Sitka, are given in Table 45. The time differences given in this table for the 5-month series of slack-water observations are quite well determined and may be used in connection with the differences for other stations referred to Sergius Narrows to obtain the approximate time relation between the current at those stations and the tide at Sitka. In general, however, the currents of this region conform more closely to Sergius Narrows currents than to Sitka tides.

The results of tide observations show that the tidal range is more than 4 feet greater and the high and low waters occur about 0.3 or 0.4 hour later in the vicinity of Povorotni Island than in Salisbury Sound. Hence there is a practically simultaneous tide with a marked difference in range at the two ends of the narrow portion of Peril Strait. It has been shown in the discussion for Tlevak Narrows that such a tidal condition produces reversing hydraulic currents which reach their strengths soon after the times of high and low water. That the current in the western part of Peril Strait is of this sort is shown by the observations. The two days of float observations at station 41 indicate that the strengths of current at this station follow the high and low waters by about 0.8 hour.

At station 40 the lag of the strengths after high and low waters is shown by 4 days of observations to be slightly more than an hour, whereas the short series at stations 38 and 39 seem to indicate that the lag decreases toward the northern end of the passage.

Referring to Tables 44 and 45 it will be noted that the ebb or southerly stream flows considerably longer than the flood at all the stations, and at station 40 where a 4-day series of velocity observations was secured the ebb stream shows a slightly greater velocity than the flood. It seems safe to conclude, therefore, that there is a nontidal set of the current in an ebb direction in Peril Strait. The values given for station 40 shows no marked change in the current at the subsurface depths, the times, velocities, and durations being approximately the same from the 7-foot to the 80-foot depths.

Harmonic constants for the prediction of currents in Sergius Narrows have been derived from tidal harmonic constants for Sitka and Sergius Narrows. The current constants given in Table 46 represent the instantaneous difference in heights of tide between Sergius Narrows and Sitka, the difference being positive when the level at Sergius Narrows is higher than that at Sitka. The amplitudes are expressed in feet and the epochs in degrees are referred to the local meridian. Since the velocity of the current is a function of the hydraulic head, an empirical factor is applied to the amplitudes in the table when the velocities are to be expressed in knots. The epochs must also be corrected for the lag due to the inertia of the water. Current predicitions for Sergius Narrows made by the harmonic method are included in the Pacific Coast Current Tables, published in advance annually by the Coast and Geodetic Survey.

TABLE 46.—*Harmonic constants, station 41, Sergius Narrows*

[Constants represent the instantaneous difference in heights of tide between Sergius Narrows and Sitka the difference being positive when the level at Sergius Narrows is higher than that at Sitka]

Component	H	κ	Component	H	κ
	Feet	*Degrees*		*Feet*	*Degrees*
M_2	1.511	34.8	λ_2	0.012	50.3
S_2	.583	67.7	M_1	.070	109.0
N_2	.367	17.1	J_1	.011	204.6
K_1	.154	187.9	ρ_1	.005	105.2
M_4	.101	237.6	Q_1	.046	116.5
O_1	.132	122.9	T_2	.034	68.2
M_6	.044	89.3	R_2	.004	68.1
ν_2	.068	9.0	$(2Q)_1$	.003	80.1
μ_2	.046	14.3	P_1	.089	162.0
$(2N)_2$	.054	359.6	L_2	.034	63.5
$(OO)_1$	.007	219.0	K_2	.231	90.0

Neva Strait is one of a group of narrow inland passages which connect Sitka and Salisbury Sounds. It extends about 4 miles in a general northwesterly-southeasterly direction, and has a least width of about one-eighth mile and a least depth of 4 fathoms in mid-channel. Current observations in Neva Strait were taken at station 42 in Whitestone Narrows. The position of this station is plotted on Figure 38 and the results of the observations are given in Table 44. A series of 59 slack-water observations was obtained at station 42 and the times referred to high and low waters at Sitka. The time relations given for this station in the table were determined as explained for station 35 in Killisnoo Harbor. The observations show that slack waters occur very near the times of high and low water. The values for duration of flood and ebb show that the ebb or northwesterly stream flows on the average half an hour longer than the flood. This difference seems to indicate a northwesterly nontidal set.

Following are statements based on a descriptive report accompanying the observations for station 42. At Whitestone Narrows the slack waters normally occur near the times of high and low water, but the time is much influenced by the direction of the wind, a northwesterly wind increasing the duration of the flood and decreasing that of the ebb, whereas a southeasterly wind has the reverse effect. The current has a velocity at strength of 2 to 3 knots during spring tides and an average velocity at strength of 1 to 2 knots.

Klag Bay is one of the arms of Khaz Bay and connects with it through Elbow Passage. Current station 43, in Elbow Passage is plotted on Figure 39 and the results derived from 25 days of slack-water observations are given in Table 44. A comparison of the times of slack water with the times of local tide shows that on the average the slack waters follow the high and low waters by slightly more than an hour. It will be noted that the observed flood current runs nearly half an hour longer than the ebb. A very strong ebb current has been reported in the western part of Elbow Passage and it seems likely that at station 43 the greater duration of the flood stream is compensated for by a greater velocity of the ebb stream. Since Elbow Passage serves as the only outlet for Klag Bay and adjacent lakes and glaciers, a permanent westerly current due to drainage would be expected through the passage.

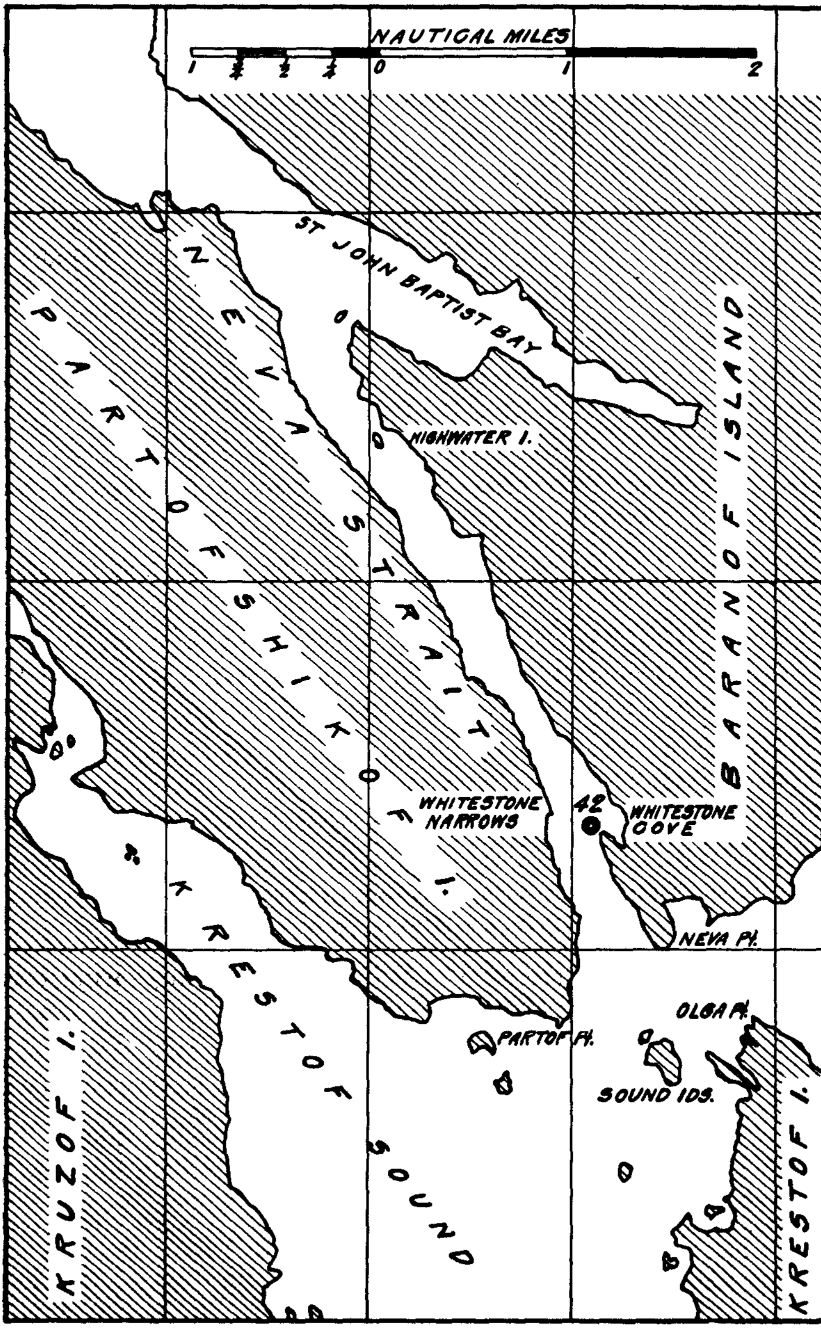

FIG. 38.—Current station, Neva Strait

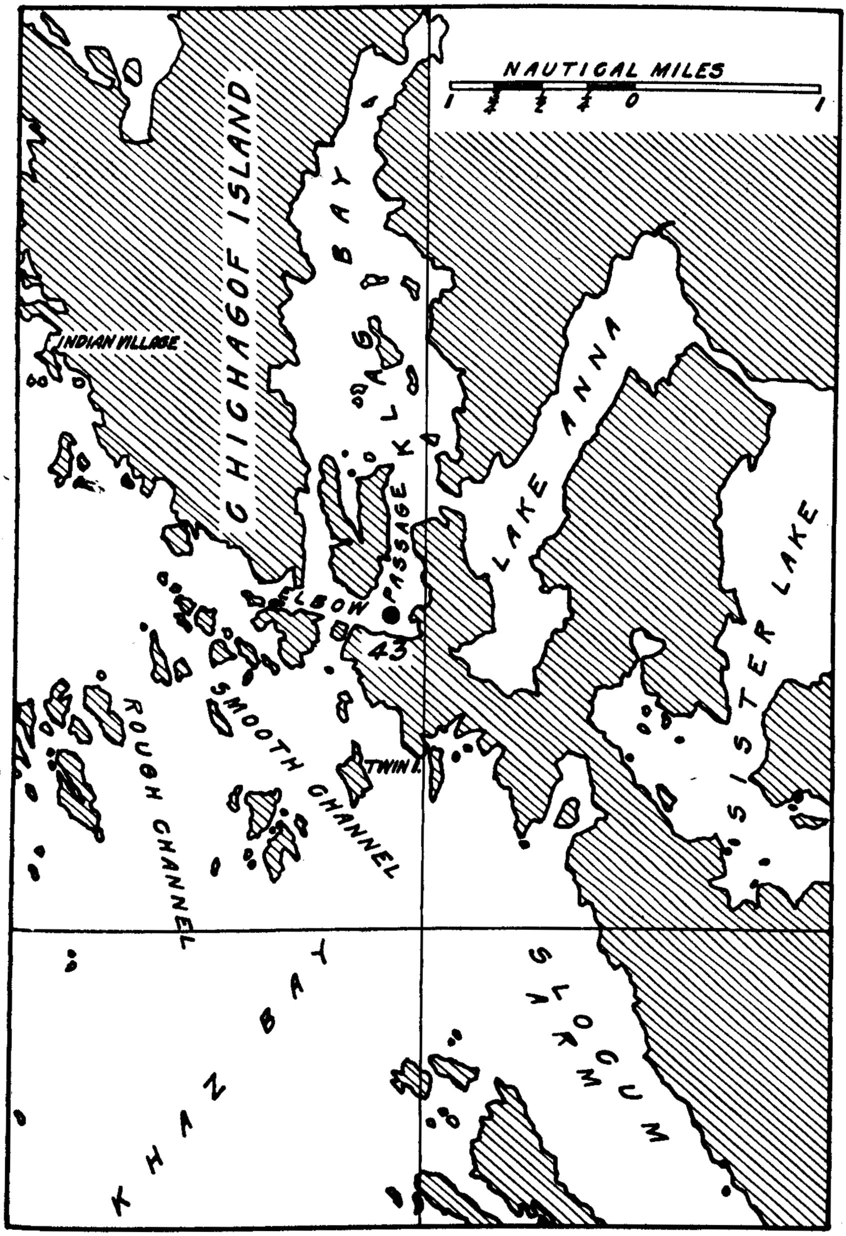

FIG. 89.—Current station, Klag Bay

11. THE CURRENT IN ICY STRAIT AND CROSS SOUND

Icy Strait and Cross Sound form a continuous passage having a total length of approximately 60 nautical miles and an average width of about 7 miles. This passage separates Chichagof Island from the mainland and extends in a general westerly direction from the junction of Chatham Strait and Lynn Canal to the sea.

The results derived from current observations taken at four stations in this passage are given in Table 47 and the stations are plotted on Figure 40. At stations 44 and 47, 2½ days of velocity observations were secured at depths of 7, 20, 50, and 80 feet. At stations 45 and 46 the times of slack water were observed for periods of 3 days and 24 days, respectively.

An investigation of the tides of this region shows that the tide is practically simultaneous throughout Cross Sound and Icy Strait, and that the average range of tide increases with approximate uniformity from about 8 feet in the western portion of Cross Sound to 13 feet at the eastern end of Icy Strait. It has been shown that a tidal condition of this sort produces hydraulic differences in head which reach their maximum at the times of high and low water, and that the resulting currents attain their strength near these times. It is found, however, by comparing the current at station 44 with the tide that the strengths of current occur midway between the times of high and low water at which times there is no hydraulic difference in the water level. It appears, therefore, that in Icy Strait and Cross Sound as in Sumner Strait the hydraulic current-producing force has a negligible effect and that the current is due to a stationary-wave type of tidal movement.

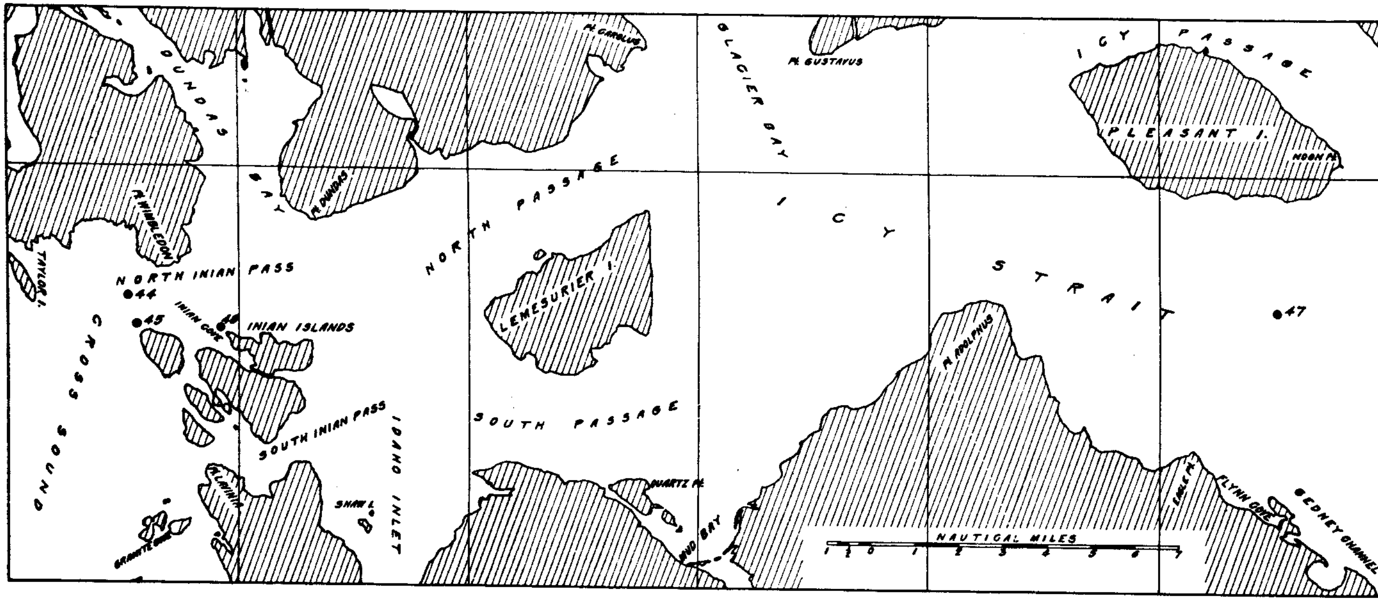

FIG. 40.—Current stations, Icy Strait and Cross Sound

TABLE 47.—*Current data, Icy Strait, Lynn Canal, and connecting passages*

[Referred to time of current at Sergius Narrows]

Station No.	Location	Date	Party of—	Observation with—	Depth	Slack before flood	Flood strength: Time	Flood strength: Direction	Flood strength: Velocity	Flood duration	Slack before ebb	Ebb strength: Time	Ebb strength: Direction	Ebb strength: Velocity	Ebb duration	Length of observations
					Feet	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Hours*	*Hours*	*True*	*Knots*	*Hours*	*Days*
44	North Inian Pass	July, 1925	L. M. Zeskind	Pole	7	3.12	2.82	N. 74° E.	3.04	4.12	1.32	1.93	S. 80° W.	5.16	8.30	2½
		Do	do	Meter	20	3.12	2.82		3.52	4.32	1.52				8.10	2½
		Do	do	do	50	2.86	2.78		3.54	4.62	1.56				7.80	2½
		Do	do	do	80	2.78	2.70		3.60	4.72	1.58				7.70	2½
45	¼ mile off North Inian Light.	August, 1925	do			2.45				5.12	1.65				7.30	3
46	North of Inian Cove	July–August, 1925	do			.85				5.28	.21				7.14	24
47	Icy Strait, 3 miles south of Pleasant Island.	July, 1925	do	Pole	7		1.94		.04			1.38	N. 66° W.	1.20		2½
		Do	do	Meter	20		1.90		.07			1.44		1.05		2½
		Do	do	do	50	1.62	1.62		.62	5.16	.86	.88		.64	7.26	2½
		Do	do	do	80	.38	.76		.81	5.42	−.12	.56		.71	7.00	2½
48	Saginaw Channel, off Barlow Point.	October, 1925	F. B. T. Siems	Pole		3.15	2.05	S. 28° E.	1.03	4.62	1.85	2.90	N. 30° W.	1.38	7.80	1
49	Saginaw Channel, off Barlow Islands.	July, 1925	L. M. Zeskind	do	14	3.00	1.85		.37	3.52	.60	2.65	N. 22° W.	1.82	8.90	1
		Do	do	Meter	20	3.10	2.50		.51	3.92	1.10	3.80		1.96	8.50	1
		Do	do	do	50	2.65	2.15		.87	4.92	1.65	2.40		1.32	7.50	1
		Do	do	do	80	2.30	2.15		1.13	5.27	1.65	2.30		.78	7.15	1
51	Favorite Channel, between Shelter and Aaron Islands.	do	do	Pole	14	4.80	4.00	S. 12° W.	.75	5.37	4.25	6.45	N. 28° W.	.65	7.05	1
		Do	do	Meter	20	4.85	4.00		.70	5.22	4.15	6.50		.65	7.20	1
		Do	do	do	50	5.50	3.90		.35	4.37	3.95	7.00		.35	8.05	1
		Do	do	do	80	5.40	4.00		.39	5.12	4.60	6.60		.24	7.30	1
52	Lynn Canal, 1½ miles northwest of Vanderbilt Reef.	do	do	Pole	14	5.15	4.36	N. 20° W.	.15	3.87	3.10	3.42	S. 29° E.	.77	8.55	2
		Do	do	Meter	20	5.12	4.26		.30	3.82	3.02	3.85		.71	8.60	2
		Do	do	do	50	5.18	4.46		.42	4.64	3.90	4.47		.41	7.78	2
		Do	do	do	66	3.95	3.75		.40	5.37	3.40	3.60		.30	7.05	1

From a study of the currents in the various passages of southeast Alaska it seems reasonable to infer that alternating differences in water level at two ends of a tidal passage produce currents of the hydraulic type only when the passage or a portion of it is narrow or restricted in its nature. In the broader waterways it appears that wave movements are the controlling factors in current production, the hydraulic effects being masked or obliterated by these movements.

Referring to Table 47 it will be noted that at station 45, which is about one-fourth mile offshore and in relatively deep water, the slacks occur on the average 0.2 hour earlier than at station 44 in midstream. At station 46, which is close to shore in shoal water and well away from the main part of the stream, the slacks occur about 1.7 hours earlier than at station 44. In general a similar condition is found wherever current observations cover a cross section of a stream or passage, a given phase of the current occurring earlier near the shore or in shallow water than in mid-channel. This phenomenon seems to be due to the combined effect of friction and inertia. The inertia of the large mass of water in midstream tends to resist any force acting to change its rate or direction of motion, whereas the relatively small mass of the shallow water near shore having less inertia responds more quickly to forces acting to change its velocity or direction. It is apparent that the force of friction near the shore tends to advance the time of slack water by its retarding effect on the motion of the water. In the case of strengths of current this retarding effect acts to decrease the acceleration as soon as the force producing the flow has passed its maximum, whereas in the center of the stream, where the force of friction is less, acceleration continues longer and the strength consequently occurs later than near the shore.

At station 47 the observed strengths of current occur about three-fourths of an hour earlier than at station 44, and as would be expected from its location in a broader part of the strait the velocities are much smaller than at station 44. The values given in the table for the velocities and durations of the flood and ebb streams show that the ebb attains a greater velocity and runs considerably longer than the flood at each of the stations. The permanent westerly current indicated by these values had during the periods covered by the observations a velocity of about 1.1 knots at station 44 and 0.6 knot at station 47. At the latter station a practically continuous ebb current was observed at the 7-foot depth, but as in the case of similar stations in Tongass Narrows and Sumner Strait the observations were taken near the times of neap tide, and when corrected for range of tide a positive mean value for strength of flood was obtained. It is therefore inferred that a continuous westerly current occurs at station 47 during neap tides and a reversing current with a small flood velocity at other times.

At stations 44 and 47 the results show that the current occurs earlier at the lower depths than near the surface. They also show an increase in the duration of the flood stream and a corresponding decrease in the duration of ebb as the bottom is approached. At station 47 a flood current was actually observed at the 50 and 80 foot depths when the current was ebbing continuously at the surface. An increase in the velocity of flood and a decrease in the velocity of ebb with increasing depth is also noted at these two stations.

Tidal harmonic constants for Hooniah together with nonharmonic values derived from the few current observations available have been used in the determination of harmonic constants for the current in North Inian Pass. These harmonic constants are used for predicting the times of slack water and the times and velocities of strength of current for each day in the year. Such predictions for North Inian Pass are included in the Pacific Coast Current Tables beginning with the issue for the year 1927.

12. CURRENTS IN LYNN CANAL AND VICINITY

Lynn Canal extends from the junction of Chatham and Icy Straits in a north-northwesterly direction for a distance of about 55 nautical miles. It has a width of from 3 to 7 miles and connects with the northerly end of Stephens Passage through Favorite and Saginaw Channels. Two current stations have been occupied in each of these channels and one in Lynn Canal. Data derived from the observations are included in Table 47 and the stations are plotted on Figure 41.

The currents observed at these stations were comparatively weak and were irregular with respect to the tide, which is practically simultaneous throughout the vicinity of Favorite and Saginaw Channels. At station 48, where the observed current was more regular than at the other stations, the strengths occurred about 2½ hours before the times of high and low water. The results given for stations 48 and 49 show in general a greater velocity for the ebb or northerly stream than for the flood. Velocities given for station 51 show no marked difference between flood and ebb. At all three stations, however, the ebb stream runs much longer than the flood, and a permanent set of the current from Stephens Passage into Lynn Canal is thus indicated. At station 49 the velocity and duration of the flood stream show an increase and the velocity and duration of the ebb a decrease with increasing depth. At station 51 the velocities and durations for the different depths are irregular and show practically no progressive change with increasing depth. A half day of observations at station 50 showed an irregular current with a velocity varying from 0.0 to 0.8 knot.

The results for station 52 indicate conditions similar to those existing at station 49, the values for duration and velocity of flood and ebb showing a permanent ebb current. There is also shown an increase in the velocity and duration of the flood stream and a decrease in the velocity and duration of the ebb stream with increasing depth. At this station the permanent southerly set of the current is doubtless due to fresh water run-off. Since the current velocities are small at all of these stations, the effect of meteorological changes is relatively great and the irregularities noted are doubtless due to such disturbances.

13. NONTIDAL CURRENTS IN SOUTHEAST ALASKA

Apart from the case of rivers where continuous discharges of fresh water occur, there is often a permanent nontidal current setting always in the same direction through an inland waterway. In some passages currents of this sort are of sufficient strength to over-

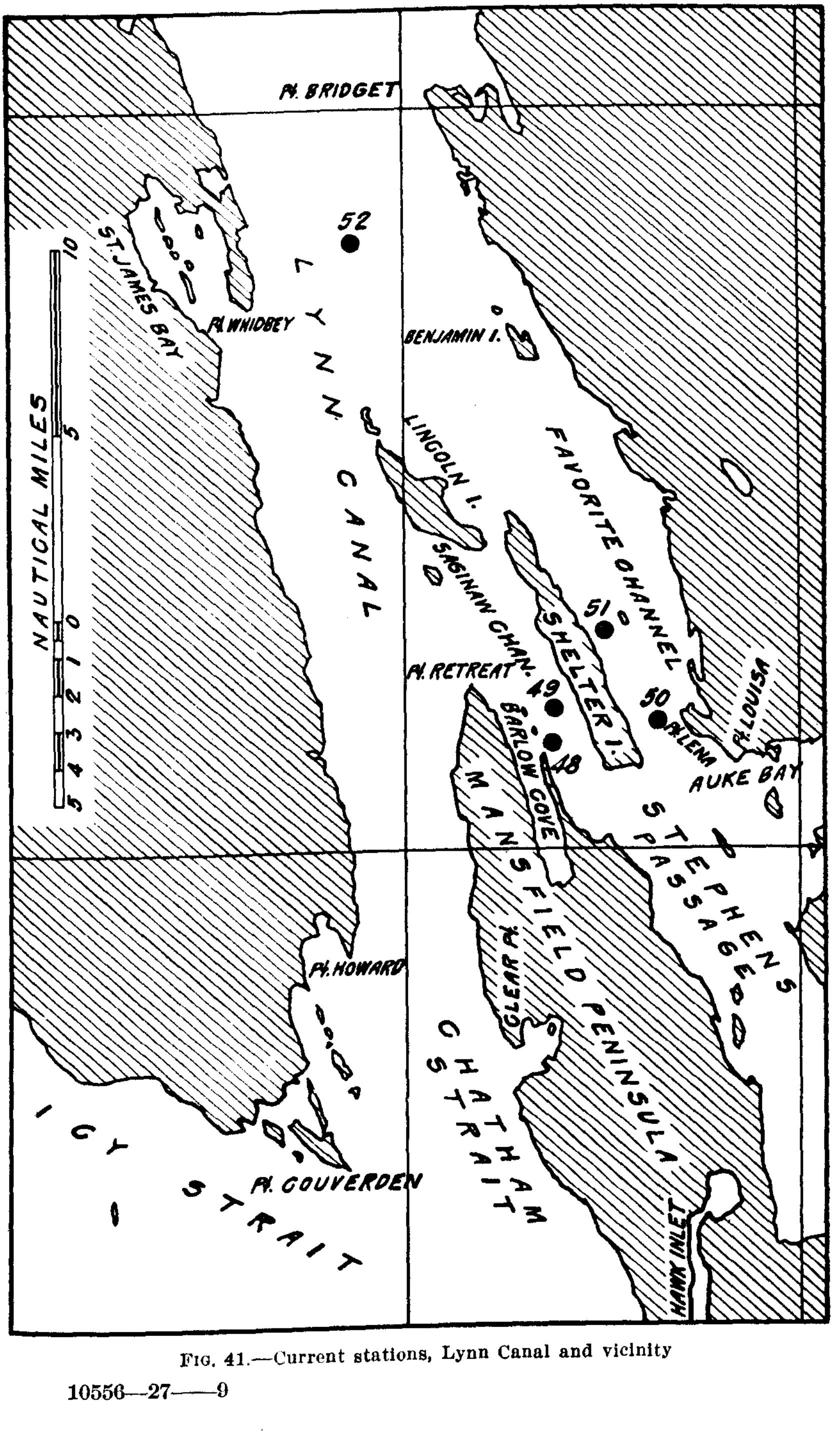

FIG. 41.—Current stations, Lynn Canal and vicinity

come completely the tidal current, and the result is a one-way current. The effect of the tidal current in this case is to alternately increase and decrease the velocity of the one-way current, the velocity being a maximum when the tidal current acts in conjunction with the permanent current and a minimum when it acts in a reverse direction.

Good examples of nontidal currents in tidal waterways are found in some of the passages of southeast Alaska. Many of these passages extend in a northwesterly-southeasterly direction, and the set of the nontidal current is in general northwesterly. The effect of this permanent northwesterly set of the current was noted in the year 1889 by Capt. H. H. Lloyd, a pilot of the Pacific Coast Steamship Co., in the drift of a spar buoy from Wrangell Narrows to a point near the western end of Icy Strait. The observed positions of the buoy on May 29, July 22, and August 23, respectively, as well as the probable route followed are shown in Figure 42. The shortest distance by water between the first and last observed positions is approximately 180 nautical miles, but the route indicated in the figure covers a distance of about 235 miles. The longer route is considered the one more likely to have been followed for two reasons. First, the results of different series of current observations in Wrangell Narrows indicate a permanent southerly set of the current in this passage, which set is a notable exception to the general northwesterly drift. A floating body in Wrangell Narrows would therefore be expected to float in a southerly direction into Sumner Strait. Here observations show there is a pronounced westerly nontidal set which would cause the buoy to follow the path indicated in Figure 42.

The se ond consideration is based on a comparison of the times required for the buoy to drift from the first to the second, and from the second to the third observed positions. In passing from the first to the second position the buoy would have traveled a distance of 95 miles by the short route through Frederick Sound or 150 miles by the long route through Sumner Strait. The distance was covered in 54 days. This was at an average of 0.07 knot by the short path or 0.12 knot if the longer path were followed. The buoy traveled from the second observed position to the third, a distance of 85 miles in 32 days. This was at the rate of 0.11 knot which compares more favorably with the rate of 0.12 knot for the long route between the first and second positions than with the rate of 0.07 knot for the shorter route.

Values for the velocities and directions of the nontidal currents have been computed for each station in southeast Alaska where the observations covered a period of time sufficient for this purpose. Since the observed current velocity is a combination of the tidal and nontidal velocities it is necessary to separate the two in order to obtain the nontidal velocity. This becomes a simple process when it is considered that the nontidal current acts always in the same direction whereas the tidal current reverses, the observed current velocity being the sum of the two velocities in one direction, and their difference in the reverse direction. The nontidal current velocity is, therefore, one-half the difference between the velocities observed at the times of current strength for the two opposite directions, and its direction is the direction of the greater velocity.

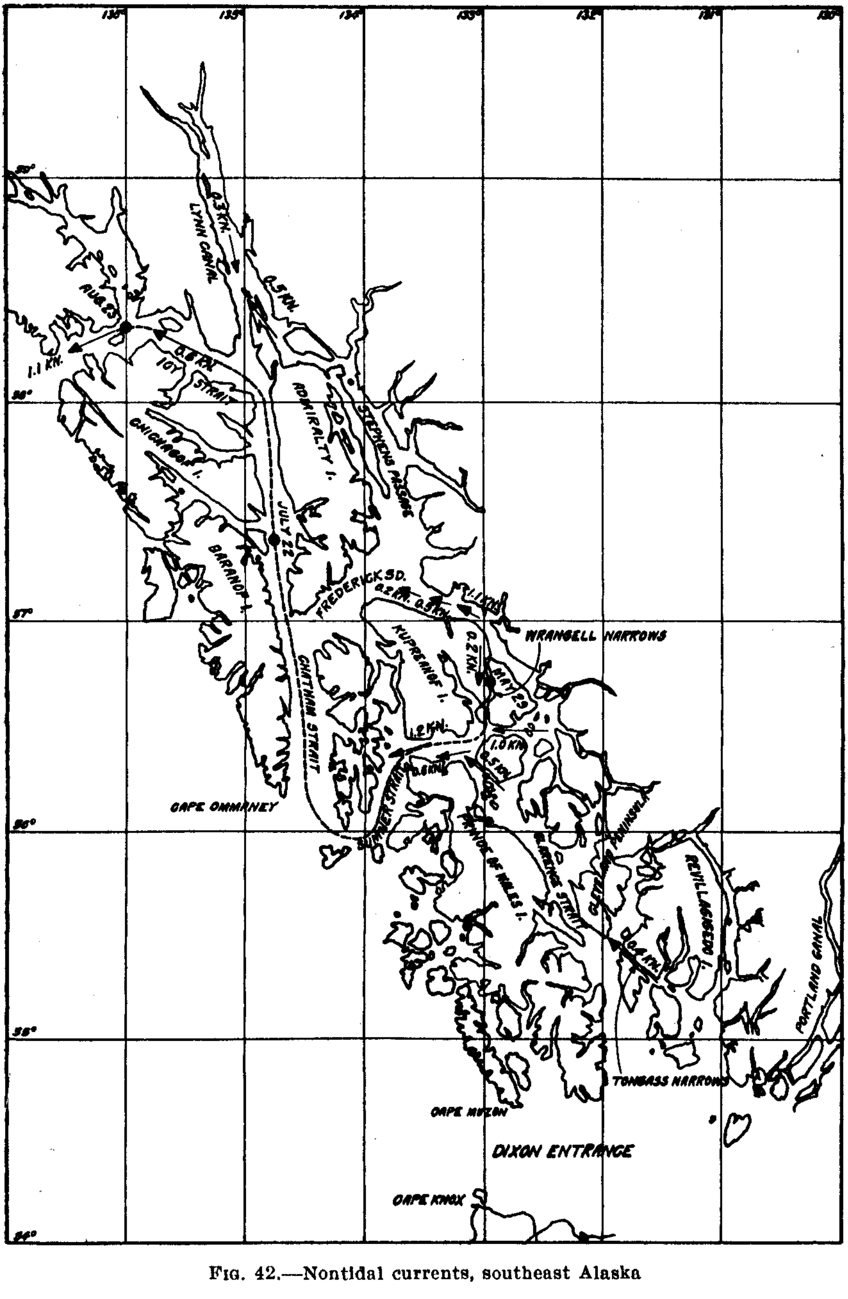

FIG. 42.—Nontidal currents, southeast Alaska

In Figure 42 the nontidal currents are indicated by arrows pointing in the direction the current is flowing together with numbers giving to the nearest tenth of a knot the velocities derived from observations as explained above. Several days of observations have been obtained in each passage where a nontidal current is indicated on the figure. Where two or more series of observations are represented by a single arrow the velocity given is an approximate average of the velocities derived from the different series, consideration being given to the length of each series.

The velocities given in the figure are based on observations taken near the surface of the water, and represent in most cases the average nontidal current for the first 14 feet below the surface. At some of the stations subsurface observations were made at various depths and these show that the nontidal current flows at all depths, there being in general a slight increase in velocity below the surface followed by a pronounced dercease as the bottom is approached. A typical case is that of station 9 in Sumner Strait, where a nontidal velocity of 1.2 knots was encountered at the 7-foot depth, 1.3 knots at the 20-foot depth, 0.8 knot at the 50-foot depth, and 0.4 knot at the 80-foot depth. The total depth of water at this station was approximately 100 feet. Referring to the drift of the buoy already discussed, it will be noted that nontidal current velocities of from 0.6 knot to more than a knot prevail in the probable path of the buoy in Sumner and Icy Straits. Unfortunately no current observations are at hand for Chatham Strait, but the nontidal current here must be appreciable since a large part of the route traversed by the buoy lies in this passage.

At two stations where current observations were made in the eastern half of Frederick Sound the nontidal current had considerably more strength than the tidal current, and the result was a continuous northwesterly flow. A similar condition prevailed at stations in Icy Strait, Sumner Strait, and Tongass Narrows. It happened, however, that observations in these three waterways were taken at times of neap tides, at which times the tidal currents are below their average in strength. Moreover, the velocities of the observed currents in these passages became quite small at the times corresponding to the opposing strengths of tidal current. It is reasonable to infer, therefore, that in Icy Strait, Sumner Strait, and Tongass Narrows the condition of continuous flow prevails during only part of the month, the current reversing at times of spring tides. In the eastern end of Frederick Sound, however, during average tides a westerly current of from 0.2 to 0.4 knot was observed at times of strength of flood of the tidal current. It seems reasonable to infer that here the nontidal set is the controlling factor at all times and that the current flows throughout the month in the direction of this set.

It will be noted that the nontidal velocities are greater in the narrower parts of the passages than in the wider portions. This is to be expected, since a continuous current necessitates the flow of a given quantity of water through all parts of the passage, and therefore the more constricted the passage the greater must be the velocity of the flow.

While the current observations taken in southeast Alaska cover comparatively short periods of time at most of the current stations, and the stations themselves are few and in most cases widely separated, the results obtained consistently indicate a general northwesterly nontidal set through the inland passages of this region.

In seeking a cause for this northwesterly set of the current we find that the Kuroshiwo or Japan current flows east across the Pacific in about latitude 45° north. Striking the North American coast the stream divides, the larger portion turning in a southerly direction, while the smaller portion turning north, produces an inshore current along the coasts of British Columbia and southern Alaska. It is apparently this inshore current, driven into the inland passages by the prevailing westerly ocean winds of this latitude, that produces the permanent northwesterly set of the current in the waterways of southeast Alaska.

APPENDIX

GENERAL CHARACTERISTICS OF TIDES AND CURRENTS

[Reprinted from United States Coast and Geodetic Survey Special Publication No. 111]

I. TIDES, GENERAL CHARACTERISTICS

DEFINITIONS

The tide is the name given to the alternate rising and falling of the level of the sea which at most places occurs twice daily. The striking feature of the tide is its intimate relation to the movement of the moon. High water and low water at any given place follow the moon's meridian passage by a very nearly constant interval, and since the moon in its apparent movement around the earth crosses a given meridian, on the average, 50 minutes later each day, the tide at most places likewise comes later each day by 50 minutes, on the average. The tidal day, like the lunar day, therefore, has an average lengh of 24 hours and 50 minutes.

With respect to the tide, the " moon's meridian passage " has a special significance. It refers not only to the instant when the moon is directly above the meridian, but also to the instant when the moon is directly below the meridian, or 180° distant in longitude. In this sense there are two meridian passages in a tidal day, and they are distinguished by being referred to as the upper and lower meridian passages or upper and lower transits.

The interval between the moon's meridian passage (upper or lower) and the following high water is known as the " high water lunitidal interval." Likewise the interval between the moon's meridian passage and the following low water is known as the " low water lunitidal interval." For short they are called, respectively, high water interval and low water interval and abbreviated as follows: HWI and LWI.

In its rising and falling the tide is accompanied by a horizontal forward and backward movement of the water, called the tidal current. The two movements—the vertical rise and fall of the tide and the horizontal forward and backward movement of the tidal current—are intimately related, forming parts of the same phenomenon brought about by the tidal forces of sun and moon.

It is necessary, however, to distinguish clearly between tide and tidal current, for the relation between them is not a simple one nor is it everywhere the same. At one place a strong current may accompany a tide having a very moderate rise and fall while at another place a like rise and fall may be accompanied by a very weak current. Furthermore, the time relations between current and tide vary widely from place to place. For the sake of clearness, therefore, tide should be used to designate the vertical movement of the water and tidal current the horizontal movement.

It is convenient to have a single term to designate the whole phenomenon which includes tides and tidal currents. Uufortunately no such distinct term exists. For years, however, " the tide " or " the tides," or even " flood and ebb," have been used in this general sense, and usually no confusion arises from this usage, since the context indicates the sense intended; but the use of the term tide to denote the horizontal movement of the water is confusing and is to be discouraged.

With respect to the rise and fall of the water due to the tide, high water and low water have precise meanings. They refer not so much to the height of the water as to the phase of the tide. High water is the maximum height reached by each rising tide and low water the minimum height reached by each falling tide.

It is important to note that it is not the absolute height of the water which is in question, for it is not at all infrequent at many places to have the low water of one day higher than the high water of another day. Whatever the height of the water, when the rise of the tide ceases and the fall is to begin, the tide is at high water; and when the fall of the tide ceases and the rise is to begin, the tide is at low water. The abbreviations HW and LW are frequently used to designate high and low water, respectively.

In its rising and falling the tide does not move at a uniform rate. From low water the tide begins rising, very slowly at first, but at a constantly increasing rate for about three hours, when the rate of rise is a maximum. The rise then continues at a constantly decreasing rate for the following three hours, when high water is reached and the rise ceases. The falling tide behaves in a similar manner, the rate of fall being least immediately after high water, but increasing constantly for about three hours, when it is at a maximum, and then decreasing for a period of three hours till low water is reached.

The rate of rise and fall and other characteristics of the tide may best be studied by representing the rise and fall graphically. This may be done by reading the height of the tide at regular intervals on a fixed vertical staff graduated to feet and tenths and plotting these heights to a suitable scale on cross-section paper and drawing a smooth curve through these points. A more convenient method is to make use of an automatic tide gauge by means of which the rise and fall of the tide is recorded on a sheet of paper as a continuous curve drawn to a suitable scale. Figure A shows a tide curve for Fort Hamilton, N. Y., for July 4, 1922.

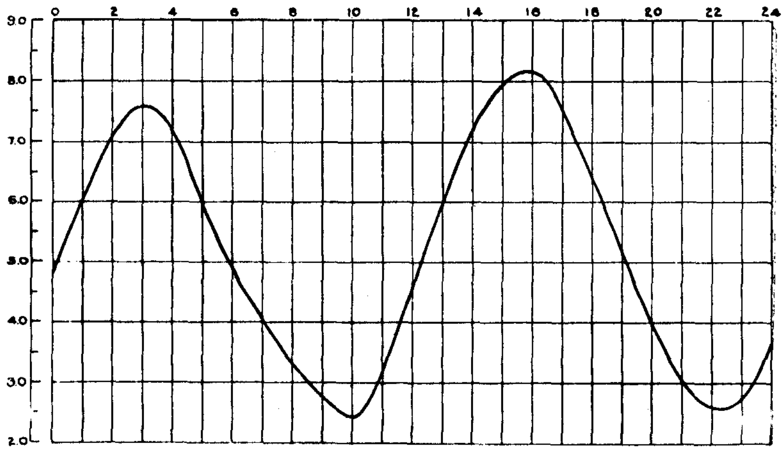

FIG. A.—Tide curve for Fort Hamilton, N. Y., July 4, 1922

In Figure A the figures from 0 to 24, increasing from left to right, represent the hours of the day beginning with midnight. Numbering the hours consecutively to 24 eliminates all uncertainty as to whether morning or afternoon is meant and has the further advantage of great convenience in computation. The figures on the left, increasing upward from 2.0 to 9.0, represent the height of the tide in feet as referred to a fixed vertical staff. The tide curve presents the well-known form of the sine or cosine curve.

The difference in height between a high water and a preceding or following low water is known as the "range of tide" or "range." The average difference in the heights of high and low water at any given place is called the mean range.

THE TIDE-PRODUCING FORCES

The intensity with which the sun (or moon) attracts a particle of matter on the earth varies inversely as the square of the distance. For the solid earth as a whole the distance is obviously to be measured from the center of the earth, since that is the center of mass of the whole body. But the waters of the earth, which may be considered as lying on the surface of the earth, are on the one side of the earth nearer to the heavenly bodies and on the other side farther away than the center of the earth. The attraction of sun or moon for the waters of the ocean is thus different in intensity from the attraction for the solid earth as a whole, and these differences of attraction give rise to the forces that cause the ocean waters to move relative to the solid earth and bring about the tides. These forces are called the tide-producing forces.

The mathematical development of these forces shows that the tide-producing force of a heavenly body varies directly as its mass and inversely as the cube of its distance from the earth. The sun has a mass about 26,000,000 times as great as that of the moon; but it is 389 times as far away from the earth. Its tide-producing force is therefore to that of the moon as 26,000,000 is to $(389)^3$, or somewhat less than one-half.

When the relative motions of the earth, moon, and sun are introduced into the equations of the tide-producing forces, it is found that the tide-producing forces of both sun and moon group themselves into three classes: (*a*) Those having a period of approximately half a day, known as the semidiurnal forces; (*b*) those having a period of approximately one day, known as diurnal forces; (*c*) those having a period of half a month or more, known as long-period forces.

The distribution of the tidal forces over the earth, takes place in a regular manner, varying with the latitude. But the response of the various seas to these forces is very profoundly modified by terrestrial features. As a result we find the tides, as they actually occur, differing markedly at various places, but apparently with no regard to latitude.

The principal tide-producing forces are the semidiurnal forces. These forces go through two complete cycles in a tidal day, and it is because of the predominance of these semidaily forces that there are at most places two complete tidal cycles, and therefore two high and two low waters in a tidal day.

VARIATIONS IN RANGE

The range of the tide at any given place is not constant but varies from day to day; indeed, it is exceptional to find consecutive ranges equal. Obviously changing meteorological conditions will find reflection in variations of range, but the principal variations are due to astronomic causes, being brought about by variations in the position of the moon relative to earth and sun.

At times of new moon and full moon the tidal forces of moon and sun are acting in the same direction. High water then rises higher and low water falls lower than usual, so that the range of the tide at such times is greater than the average. The tides at such times are called "spring tides" and the range of the tide is then known as the "spring range."

When the moon is in its first and third quarters, the tidal forces of sun and moon are opposed and the tide does not rise as high nor fall as low as the average. At such times the tides are called "neap tides" and the range of the tide then is known as the "neap range."

It is to be noted, however, that at most places there is a lag of a day or two between the occurrence of spring or neap tides and the corresponding phases of the moon; that is, spring tides do not occur on the days of full and new moon, but a day or two later. Likewise neap tides follow the moon's first and third quarters after an interval of a day or two. This lag in the response of the tide is known as the "age of phase inequality" or "phase age" and is generally ascribed to the effects of friction.

The varying distance of the moon from the earth likewise affects the range of the tide. In its movement around the earth the moon describes an ellipse in a period of approximately 27½ days. When the moon is in perigee, or nearest the earth, its tide-producing power is increased, resulting in an increased rise and fall of the tide. These tides are known as "perigean tides," and the range at such times is called the "perigean range." When the moon is farthest from the earth, its tide-producing power is diminished, the tides at such times exhibiting a decreased rise and fall. These tides are called "apogean tides" and the corresponding range the "apogean range."

In the response to the moon's change in position from perigee to apogee, it is found that, like the responses in the case of spring and neap tides, there is a lag in the occurrence of perigean and apogean tides. The greatest rise and fall does not come on the day when the moon is in perigee, but a day or two later. Likewise, the least rise and fall does not occur on the day of the moon's apogee, but a day or two later. This interval varies somewhat from place to place, and in some regions it may have a negative value. This lag is known as the "age of parallax inequality" or "parallax age."

The moon does not move in the plane of the Equator, but in an orbit making an angle with that plane of approximately 23½°. During the month, therefore, the moon's declination is constantly changing, and this change in the position of the moon produces a variation in the consecutive ranges of the tide. When the moon is on or close to the Equator—that is, when its declination is small—consecutive ranges do not differ much, morning and afternoon tides being very much alike. As the declination increases the difference in consecutive ranges increases, morning and afternoon tides beginning to show decided differences, and at the times of the moon's maximum semimonthly declination these differences are very nearly at a maximum. But, like the response to changes in the moon's phase and parallax, there is a lag in the response to the change in declination, this lag being known as the "age of diurnal inequality" or "diurnal age." Like the phase and parallax ages, the diurnal age varies from place to place, being generally about one day, but in some places it may have a negative value.

When the moon is on or close to the Equator and the difference between morning and afternoon tides small, the tides are known as "equatorial tides." At the times of the moon's maximum semimonthly declination, when the differences between morning and afternoon tides are at a maximum, the tides are called "tropic tides," since the moon is then near one of the Tropics.

The three variations in the range of the tide noted above are exhibited by the tide the world over, but not everywhere to the same degree. In many regions the variation from neaps to springs is the principal variation; in certain regions it is the variation from apogee to perigee that is the principal variation; and in other regions it is the variation from equatorial to tropic tides that is the predominant variation.

The month of the moon's phases (the synodical month) is approximately 29½ days in length; the month of the moon's distance (the anomalistic month) is approximately 27½ days in length; the month of the moon's declination (the tropic month) is approximately 27⅓ days in length. It follows, therefore, that very considerable variation in the range of the tide occurs during a year due to the changing relations of the three variations to each other.

DIURNAL INEQUALITY

The difference between morning and afternoon tides due to the declination of the moon is known as diurnal inequality, and where the diurnal inequality is considerable the rise and fall of the tide is affected to a very marked degree both in time and in height. Figure B represents graphically the differences in the tide at San Francisco on October 18 and 24, 1922. On the former date the moon was over the Equator, while on the latter date the moon was at its maximum south declination for the month. The upper diagram thus represents the equatorial tide for San Francisco, while the lower diagram represents the tropic tide.

It will be noted that on October 18 the morning and afternoon tides show very close resemblance. In both cases the rise from low water to high water and the fall from high water to low water took place in approximately six hours. The heights to which the two high waters attained were very nearly the same, and likewise the depressions of the two low waters.

On October 24, when the moon attained its extreme declination for the fortnight, tropic tides occurred. The characteristics of the rise and fall of the tide on that day differ markedly from those on the 18th, when equatorial tides occurred, these differences pertaining both to the time and the height. Instead of an approximately equal duration of rise and of fall of six hours, both morning and afternoon, as was the case on the 18th, we now have the morning rise occupying less time than the afternoon rise and the morning fall more time than the evening fall. Even more striking are the differences in extent of rise and fall of morning and afternoon tides. The tide curve shows that there was a difference of a foot in the two high waters of the 24th and a difference of almost 3 feet in the low waters.

Definite names have been given to each of the two high and two low waters of a tidal day. Of the high waters, the higher is called the "higher high water" and the lower the "lower high water." Likewise, of the two low waters of any tidal day the lower is called "lower low water" and the higher "higher low water."

The diurnal inequality may be related directly to the ratio of the tides brought about, respectively, by the diurnal and semidiurnal tide-producing forces. Those bodies of water which offer relatively little response to the diurnal forces will exhibit but little diurnal inequality, while those bodies which offer relatively considerable response to these diurnal forces will exhibit considerable diurnal inequality. On the Atlantic coast of the United States there is relatively little diurnal inequality, while on the Pacific coast there is considerable inequality.

It is obvious that with increasing diurnal inequality the lower high water and higher low water tend to become equal and merge. When this occurs there is but one high and one low water in a tidal day instead of two. This occurs frequently at Galveston, Tex., and at a number of other places.

TYPES OF TIDE

From place to place the characteristics of the rise and fall of the tide generally differ in one or more respects; but according to the predominating features the various kinds of tide may be grouped under three types, namely

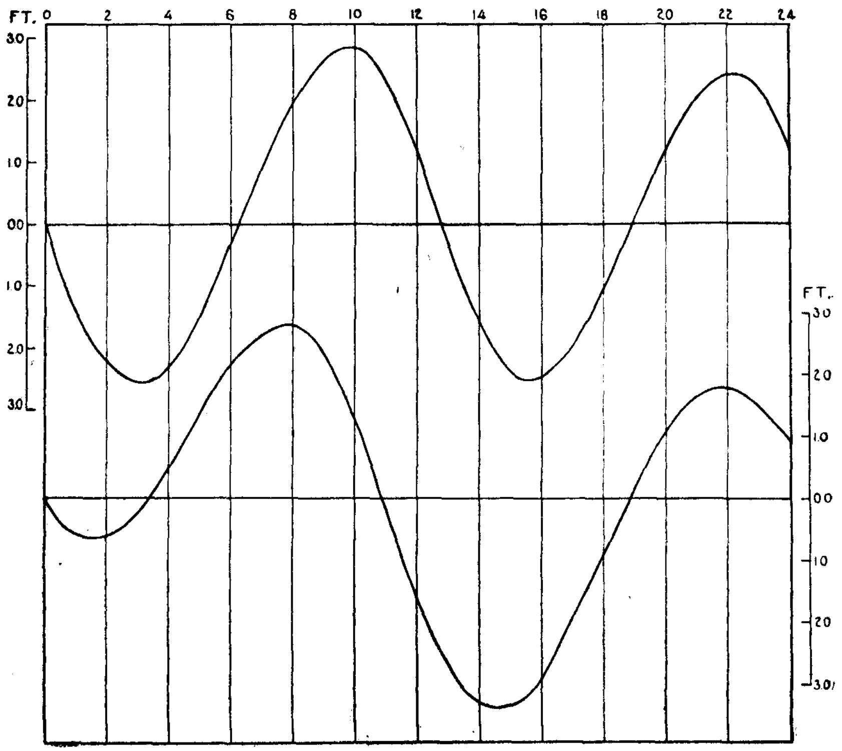

FIG. B.—Tide curves, San Francisco, Calif., October 18 and 24, 1922

semidiurnal, diurnal, and mixed. Instead of semidiurnal and diurnal the terms semidaily and daily are frequently used.

The semidiurnal type of tide is one in which two high and two low waters occur each tidal day with but little diurnal inequality; that is, morning and afternoon tides resemble each other closely. Figure A may be taken as representing this type of tide, and this is the type found on the Atlantic coast of the United States.

In the diurnal type of tide but one high and one low water occur in a tidal day. Do-Son, French Indo-China, may be cited as a place where the tide is always of the daily type, but it is to be noted that there are not many such places. When the moon's declination is zero the diurnal tidal forces tend to vanish, and there are generally two high and two low waters during the day at such times. Galveston, Tex., and Manila, P. I., may be mentioned as ports at which the tide is frequently diurnal, while St. Michael, Alaska, may be cited as a port at which the tide is largely diurnal.

The mixed type of tide is one in which two high and two low waters occur during the tidal day but which exhibits marked diurnal inequality. Several forms may occur under this type. In one form the diurnal inequality is exhibited principally by the high waters; in another form it is the low waters which exhibit the greater inequality; or the diurnal inequality may be features of both high waters and low waters.

It is to be noted that when the tide at any given place is assigned to any particular type, it refers to the characteristics of the predominating tide at that place. At the time of the moon's maximum semimonthly declination the semidiurnal type exhibits more or less diurnal inequality and thus approaches the mixed type; and when the moon is on or near the Equator the diurnal inequality of the mixed type is at a minimum, the tide at such times resembling the semidiurnal type. It is the characteristics of the predominating tide that determine the type of tide at any given place. With the aid of harmonic constants the type of tide may be defined by definite ratios of the semidiurnal to the diurnal constituents.

Type of tide is intimately associated with diurnal inequality, and hence depends on the relation of the semidiurnal to the diurnal tides; and it is the variation in this relation that makes possible the various forms of the mixed type of tide.

HARMONIC CONSTANTS

Since the tide is periodic in character, it may be regarded as the resultant of a number of simple harmonic movements. In other words, if h be the height of the tide, reckoned from sea level, then for any time t, we may write $h=A\cos(at+\alpha)+B\cos(bt+\beta)+\ldots$ In the above formula each term represents a constituent of the tide which is defined by its amplitude or semirange, A, B, etc., by an angular speed, a, b, etc., and by an angle of constant value, α, β, etc., which determines the relation of time of maximum height to the time of beginning of observation.

We may also regard the matter from another viewpoint and suppose the moon and sun as *tide-producing bodies* to be replaced by a number of hypothetical tide-producing bodies, each of which moves around the earth in the plane of the Equator in a circular orbit with the earth as center. With the further assumption that each of these hypothetical tide-producing bodies gives rise to a simple tide, the high water of which occurs a certain number of hours after its upper meridian passage and the low water the same number of hours after its lower meridian passage, the oscillation produced by each of these simple tides may be written in the form $h=A\cos(at+\alpha)$ as above. The great advantage of so regarding the tide is that it permits the complicated movements of sun and moon relative to the earth to be replaced by a number of simple movements.

Each of the simple tides into which the tide of nature is resolved is called a component tide, or simply a component. The amplitudes or semiranges of the component tides, together with the angles which determine the relation of the high water of each of these component tides to some definite time origin and which are known as the epochs, constitute the harmonic constants.

The periods of revolution of the hypothetical tidal bodies or the speeds of the various component tides are computed from astronomical data and depend only on the relative movements of sun, moon, and earth. These periods being independent of local conditions are therefore the same for all places on the surface of the earth; what remains to be determined for the various simple constituent tides is their epochs and amplitudes which vary from place to place according to the type, time, and range of the tide. The mathematical process by which these epochs and amplitudes are disentangled from tidal observations is known as the harmonic analysis.

The number of simple constituent tides is theoretically large, but most of them are of such small magnitude that they may for all practical purposes be disregarded. In the prediction of tides it is necessary to take account of 20 to 30, but the characteristics of the tide at any place may be determined easily from the 5 principal ones.

It is obvious that the principal lunar tidal component will be one which gives two high and two low waters in a tidal day of 24 hours and 50 minutes, or more exactly in 24.84 hours. Its speed per solar hour, therefore, is $\frac{2\times360^\circ}{24.84}=28^\circ.98$ This component has been given the symbol M_2. Likewise, the principal solar tidal component is one that gives two high and two low waters in a solar day of 24 hours. Its angular speed per hour is therefore $\frac{2\times 360^\circ}{24}=30^\circ.00$. The symbol for this principal solar component is S_2.

Since the moon's distance from the earth is not constant, being less than the average at perigee and greater at apogee, the period from one perigee to another being on the average 27.55 days, we must introduce another hypothetical tidal body, so that at perigee its high water will correspond with the M_2 high water, and at apogee its low water will correspond with the M_2 high water. In other words, the tidal component which is to take account of the moon's perigean movement must, in a period of 13.78 days, lose 180° on M_2, or at the rate of $\frac{180^\circ}{13.78}=13^\circ.06$ per day. Its hourly speed, therefore, is $28^\circ.98-\frac{13^\circ.06}{24}=28^\circ.44$. This component has been given the symbol N_2.

The moon's change in declination is taken account of by two components denoted by the symbols K_1 and O_1. The speeds of these are determined by the following considerations: The average period from one maximum declination to another is a half tropic month, or 13.66 days. The speeds of these two components should, therefore, be such that when the moon is at its maximum declination they shall both be at a maximum, and when the moon is on the Equator they shall neutralize each other; that is, in a period of 13.66 days K_1 shall gain on O_1 one full revolution. The difference in their hourly speeds, therefore, is $\frac{360^\circ}{24\times 13.66}=1^\circ.098$. The mean of the speeds of these two components must be that of the apparent diurnal movement of the moon about the earth, or $\frac{360^\circ}{24.84}=14^\circ.49$. The speeds are therefore derived from the equations $\frac{K_1+O_1}{2}=14^\circ.49$ and $K_1-O_1=1^\circ.098$, from which $K_1=15^\circ.04$ and $O_1=13^\circ.94$.

It is customary to designate the amplitude of any component by the symbol of the component and the epoch by the symbol with a degree mark added. Thus M_2 stands for the amplitude of the M_2 tide and M°_2 for the epoch of this tide. The five components enumerated above are the principal ones. Between 20 and 30 components permit the prediction of the time and height of the tide at any given place with considerable precision.

From the harmonic constants the characteristics of the tide at any place can be very readily determined.[1] The five principal constants alone permit the approximate determination of the tidal characteristics very easily. Thus, approximately, the mean range is $2M_2$, spring range $2(M_2+S_2)$, neap range $2(M_2-S_2)$, perigean range $2(M_2+N_2)$, apogean range $2\ (M_2-N_2)$, diurnal inequality at time of tropic tides $2(K_1+O_1)$, high water lunitidal interval $\frac{M_2{}^\circ}{28.98}$. The various ages of the tide can likewise be readily determined. Approximately, the ages in hours are: Phase age, $S_2{}^\circ-M_2{}^\circ$; parallax age, $2(M_2{}^\circ-N_2{}^\circ)$; diurnal age, $K_1{}^\circ-O_1{}^\circ$. The type of tide, too, may be determined from the harmonic constants through the ratio $\frac{K_1+O_1}{M_2+S_2}$. Where this ratio is less than 0.25, the tide is of the semidiurnal type; where the ratio is between 0.25 and 1.25, the tide is of the mixed type; and where the ratio is over 1.25, the tide is of the diurnal type.

The periods of the various component tides, like the periods of the tide-producing forces, group themselves into three classes. The tides in the first class have periods of approximately half a day and are known as semidiurnal tides; the periods of the tides in the second class are approximately one day, and these tides are known as diurnal tides; the tides in the third class have periods of half a month or more and are known as long-period tides. In shallow waters, due to the effects of decreased depth, the tides are modified and another class of simple tides is introduced having periods of less than half a day, and these are known as shallow-water tides.

The class to which any component tide belongs is generally indicated by the subscript used in the notation for the component tides, the subscript giving the number of periods in a day. With long-period tides generally no subscript is used; with semidiurnal tides the subscript is 2; with diurnal tides the subscript

[1] See R. A. Harris, Manual of Tides, Part III (United States Coast and Geodetic Survey Report for 1894, Appendix 7).

is 1, and with shallow-water tides the subscript is 3, 4, or more. Thus Sa represents a solar annual component, P_1 a solar diurnal component, M_2 a lunar semidiurnal component, S_4 a solar shallow-water component with a period of one-quarter of a day, and M_6 a lunar shallow-water component with a period of one-sixth of a day.

TIDAL DATUM PLANES

Tidal planes of reference form the basis of all rational datum planes used in practical or scientific work. The advantage of the datum plane based on tidal determination lies not only in simplicity of definition, but also in the fact that it may be recovered at any time, even though all bench-mark connections be lost.

The principal tidal plane is that of mean sea level, which may be defined as the plane about which the tide oscillates, or as the surface the sea would assume when undisturbed by the rise and fall of the tide. At any given place this plane may be determined by deriving the mean height of the tide. This is perhaps best done by adding the hourly heights of the tide over a period of a year or more and deriving the mean hourly height. It is to be noted that in such a determination the mean sea level is not freed from the effects of prevailing wind, atmospheric pressure, and other meteorological conditions.

The plane of mean sea level must be carefully distinguished from the plane of half-tide level or, as it is frequently called, mean-tide level. This latter plane is one determined as the half sum of the high and low waters. It is therefore the plane that lies halfway between the planes of mean low water and mean high water. The plane of half-tide level does not, at most places on the open coast, differ by more than about a tenth of a foot from the plane of mean seal level, and where this difference is known the plane of mean sea level may be determined from that of half-tide level. Like all of the tidal planes, the plane of half-tide level should be determined by observations covering a period of a year or more.

For many purposes the plane of mean low water is important. This plane at any given place is determined as the average of all the low waters during a period of a year or more. Where the diurnal inequality in the low waters is small, as on the Atlantic coast of the United States, this plane is frequently spoken of as the "low-water plane" or "the plane of low water"; but strictly it should be called the plane of mean low water.

Where the tides exhibit considerable diurnal inequality in the low waters, as on the Pacific coast of the United States, the lower low waters may fall considerably below the plane of mean low water. In such places the plane of mean lower low water is preferable for most purposes. This plane is determined as the average of all the lower low waters over a period of a year or more. Where the tide is frequently diurnal, the single low water of the day is taken as the lower low water.

The plane of mean high water is determined as the average of all the high waters over a period of a year or more. Where the diurnal inequality in the high waters is small, this plane is frequently spoken of as "the plane of high water" or "the high-water plane." This usage may on occasion lead to confusion, and the denomination of this plane as the plane of mean high water is therefore preferable.

In localities of considerable diurnal inequality in the high waters the higher high waters frequently rise considerably above the plane of mean high water. A higher plane is therefore of importance for many purposes, and the plane of higher high water is preferred. This plane is determined as the average of all the higher high waters for a period of a year or more. Where the tide is frequently diurnal, the single high water of the day is taken as the higher high water.

The tidal planes described above are the principal ones and the ones most generally used. Other planes, however, are sometimes used. Where a very low plane is desired, the plane of mean spring low water is sometimes used, its name indicating that it is determined as the mean of the low waters occurring at spring tides. Another plane sometimes used, which is of interest because based on harmonic constants, is known as the harmonic tide plane and for any given place is determined as $M_2+S_2+K_1+O_1$ below mean sea level.

MEAN VALUES

Since the rise and fall of the tide varies from day to day, chiefly in accordance with the changing positions of sun and moon relative to the earth, any tidal quantities determined directly from a short series of tidal observations must be corrected to a mean value. The principal variations are those connected with the moon's phase, parallax, and declination, the periods of which are approximately 29½ days, 27½ days, and 27⅓ days, respectively.

In a period of 29 days, therefore, the phase variation will have almost completed a full cycle while the other variations will have gone through a full cycle and but very little more. Hence, for tidal quantities varying largely with the phase variation, tidal observations covering 29 days, or multiples, constitute a satisfactory period for determining these quantities. Such are the lunitidal intervals, the mean range, mean high water, and mean low water. For quantities varying largely with the declination of the moon, as, for example, higher high water and lower low water, 27 days, or multiples, constitute the more satisfactory period.

As will be seen in the detailed discussion of the tides at Fort Hamilton, the values determined from two different 29-day or 27-day periods may differ very considerably. This is due to the fact that these periods are not exact synodic periods for the different variations, and to the further fact that variations having periods greater than a month are not taken into account. Furthermore, meteorological conditions, which change from month to month, leave their impress on the tides. For accurate results the direct determination of the tidal datum planes and other tidal quantities should be based on a series of observations that cover a period of a year or preferably three years. Values derived from shorter series must be corrected to a mean value.

Two methods may be employed for correcting the results of short series to a mean value. One method makes use of tabular values, determined both from theory and observation, for correcting for the different variations. The other method makes use of direct comparison with simultaneous observations at some near-by port for which mean values have been determined from a series of considerable length.

II. TIDAL CURRENTS, GENERAL CHARACTERISTICS

DEFINITIONS

Tidal currents are the horizontal movements of the water that accompany the rising and falling of the tide. The horizontal movement of the tidal current and the vertical movement of the tide are intimately related parts of the same phenomenon brought about by the tide-producing forces of sun and moon. Tidal currents, like the tides, are therefore periodic.

It is the periodicity of the tidal current that chiefly distinguishes it from other kinds of currents, which are known by the general name of nontidal currents. These latter currents are brought about by causes that are independent of the tides, such as winds, fresh-water run-off, and differences in density and temperature. Currents of this class do not exhibit the periodicity of tidal currents.

Tidal and nontidal currents occur together in the open sea and in inshore tidal waters, the actual currents experienced at any point being the resultant of the two classes of currents. In some places tidal currents predominate and in others nontidal currents predominate. Tidal currents generally attain considerable velocity in narrow entrances to bays, in constricted parts of rivers, and in passages from one body of water to another. Along the coast and farther offshore tidal currents are generally of moderate velocity; and in the open sea, calculation based on the theory of wave motion, gives a tidal current of less than one-tenth of a knot.

RECTILINEAR TIDAL CURRENTS

In the entrance to a bay or river and, in general, where a restricted width occurs, the tidal current is of the rectilinear or reversing type; that is, the flood current runs in one direction for a period of about six hours and the ebb current for a like period in the opposite direction. The flood current is the one that sets inland or upstream and the ebb current the one that sets seaward or downstream. The change from flood to ebb gives rise to a period of slack water during which the velocity of the current is zero. An example of this type of current is shown in Figure C, which represents the velocity and direction of the current as observed in the Hudson River off Fort Washington on July 22, 1922.

In Figure C the upper curve represents the velocity of the current in knots, flood being plotted above the axis of X and ebb below the axis. The velocity curve represents approximately the form of the cosine curve. The maximum velocity of the flood current is called the strength of flood and the maximum ebb velocity the strength of ebb. The knot is the unit generally used for measuring the velocity of tidal currents and represents a velocity of 1 nautical mile per hour. Knots may be converted into statute miles per hour by multiplying by 1.15, or into feet per second by multiplying by 1.69.

The lower curve of Figure C is the direction curve of the current, the direction being given in degrees, north being 0°, east 90°, south 180°, and west 270°. The directions are magnetic and represent the direction of the current as derived from hourly observations. During the period of flood the direction curve shows that the current was running practically in the same direction all the time, making an abrupt shift of about 180° to the opposite direction during the period of slack water. For the ebb period the direction curve likewise shows

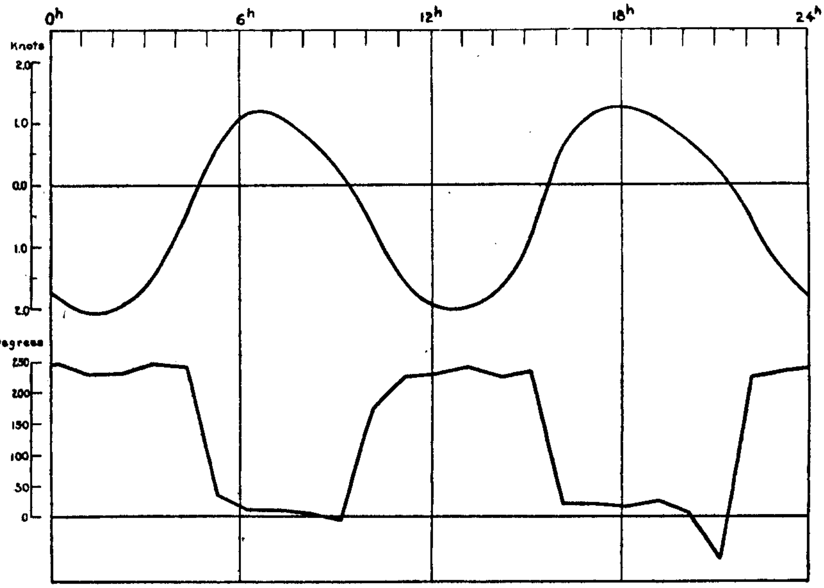

FIG. C.—Velocity and direction curves for the current, Hudson River, July 22, 1922

the current to have been running in approximately the same direction with an abrupt change of about 180° during slack.

ROTARY TIDAL CURRENTS

Offshore the tidal currents are generally not of the rectilinear or reversing type. Instead of flowing in the same general direction during the entire period of the flood and in the opposite direction during the ebb, the tidal currents offshore change direction continually. Such currents are therefore called rotary currents. An example of this type of current is shown in Figure D, which represents the velocity and direction of the current at the beginning of each hour of the afternoon on September 24, 1919, at Nantucket Shoals Light Vessel, stationed off the coast of Massachusetts.

The current is seen to have changed its direction at each hourly observation, the rotation being in the direction of movement of the hands of a clock, or from north to south by way of east, then to north again by way of west. In a period of about 12 hours it is seen that the current has veered completely round the compass.

It will be noted that the ends of the radii vectores, representing the velocities and directions of the current at the beginning of each hour, define a somewhat irregular ellipse. If a number of observations are averaged, eliminating accidental errors and temporary meteorological disturbances, the regularity of the curve is considerably increased. The average period of the cycle is, from a considerable number of observations, found to be 12^h 25^m. In other words, the current day, like the tidal day, is 24^h 50^m in length.

A characteristic feature of the rotary current is the absence of slack water. Although the current generally varies from hour to hour, this variation from

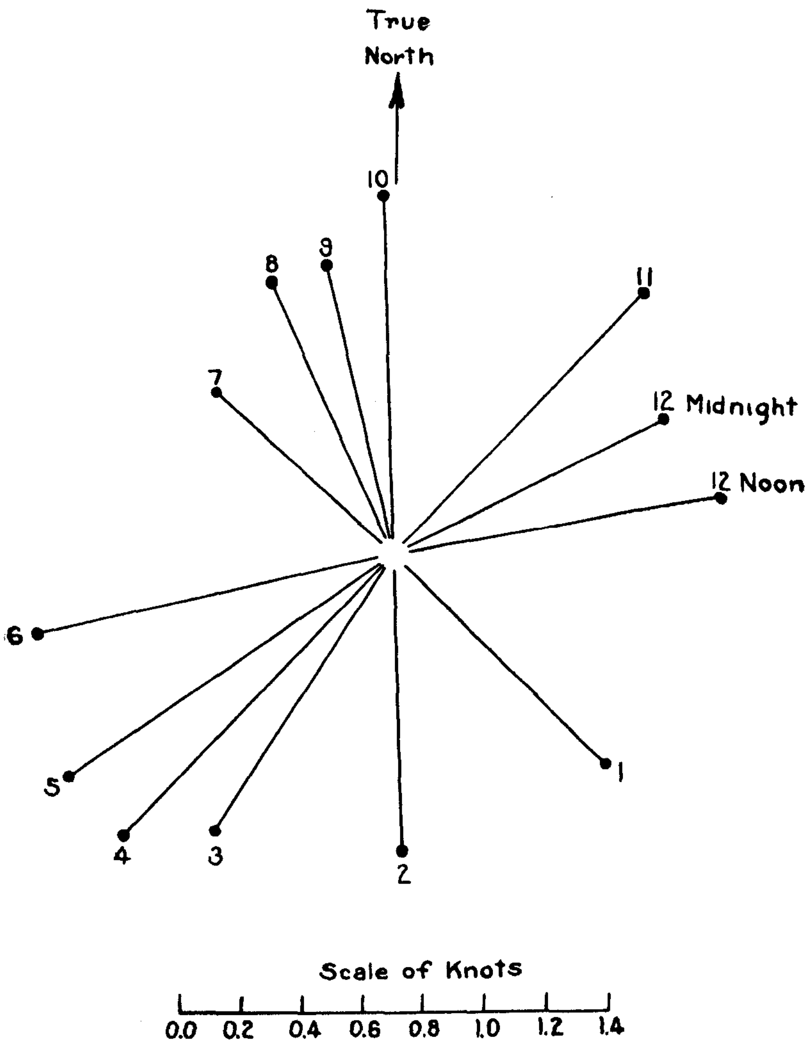

FIG. D.—Rotary current, Nantucket Shoals Light Vessel, afternoon of September 24, 1919

greatest current to least current and back again to greatest current does not give rise to a period of slack water. When the velocity of the rotary tidal current is least, it is known as the minimum current, and when it is greatest it is known as the maximum current. The minimum and maximum velocities of the rotary current are thus related to each other in the same way as slack and strength of the rectilinear current, a minimum velocity following a maximum velocity by an interval of about three hours and being followed in turn by another maximum after a further interval of three hours.

VARIATIONS IN STRENGTH OF CURRENT

Tidal currents exhibit changes in the strength of the current that correspond closely with the changes in range exhibited by tides. The strongest currents come with the spring tides of full and new moon and the weakest currents with the neap tides of the moon's first and third quarters. Likewise, perigean tides are accompanied by strong currents and apogean tides by weak currents; and when the moon has considerable variation, the currents, like the tides, are characterized by diurnal inequality.

As related to the moon's changing phases, the variation in the strength of the current from day to day is approximately proportional to the corresponding change in the range of the tide. The moon's changing distance likewise brings about changes in the velocity of the strength of the current which is approximately proportional to the corresponding change in the range of the tide; but in regard to the moon's changing declination, tide and current do not respond alike, the diurnal variation in the tide at any place being generally greater than the diurnal variation in the current.

The relations subsisting between the changes in the velocity of the current at any given place and the range of the tide at that place may be derived from general considerations of a theoretical nature. Variations in the current that involve semidiurnal components will approximate corresponding changes in the range of the tide; but for variations involving diurnal components the variation in the current is about half that in the tide.

RELATION OF TIME OF CURRENT TO TIME OF TIDE

In simple wave motion the times of slack and strength of current bear a constant and simple relation to the times of high and low waters. In a progressive wave the time of slack water comes, theoretically, exactly midway between high and low water and the time of strength at high and low water; in a stationary wave slack comes at the times of high and low water, while the strength of current comes midway between high and low water.

The progressive-wave movement and the stationary-wave movement are the two principal types of tidal movements. A progressive wave is one whose crest advances, so that in any body of water that sustains this type of tidal movement the times of high and low water progress from one end to the other. A stationary wave is one that oscillates about an axis, high water occurring over the whole area on one side of this axis at the same instant that low water occurs over the whole area on the other side of the axis.

The tidal movements of coastal waters are rarely of simple wave form: nevertheless, it is very convenient in the study of currents to refer the times of current to the times of tide. And where the diurnal inequality in the tide is small, as is the case on the Atlantic coast, the relation between the time of current and the time of tide is very nearly constant. This is brought out in Figure E, which represents the tidal and current curves in New York Harbor for October 9, 1919, the current curve being the dashed-line curve, representing the velocities of the current at a station in Upper Bay, and the tide curve being the full-line curve, representing the rise and fall of the tide at Fort Hamilton, on the eastern shore of the Narrows.

The diagrams of Figure E were drawn by plotting the heights of the tide and the velocities of the current to the same time scale and to such velocity and height scales as will make the maximum ordinates of the two curves approximately equal. The time axis or axis of X represents the line of zero velocity for the currents and of mean sea level for the tide, the velocity of the current being plotted in accordance with the scale of knots on the left, while the height of the tide reckoned from mean sea level was plotted in accordance with the scale in feet on the right.

From Figure E it is seen that the corresponding features of the tide and current in New York Harbor bear a very nearly constant time relation to each other, and this constancy in time relation of tides and currents is characteristic of tidal waters in which the diurnal inequality is small. This permits the times of slack and of strength of current to be referred to the times of high and low water. Thus, from Figure E we find strength of ebb occurred about 0.6 hour after the time of low water, both morning and afternoon; slack before flood occurred 2.2 hours before high water; strength of flood 0.4 hour after high water; slack before ebb 3.0 hours before low water. In this connection, however, it is to be noted that the time relations between the various phases of tide and current are subject to the disturbing effects of wind and weather.

Apart from the disturbing effect of nontidal agencies, the time relations between tide and current are subject to variation in regions where the tide exhibits considerable diurnal inequality; as for example, on the Pacific coast of the United States. This variation is due to the fact, previously mentioned, that the diurnal inequality in the current at any given place is, in general, only about half as great as that in the tide. This brings about differences in the corresponding features of tide and current as between morning and afternoon.

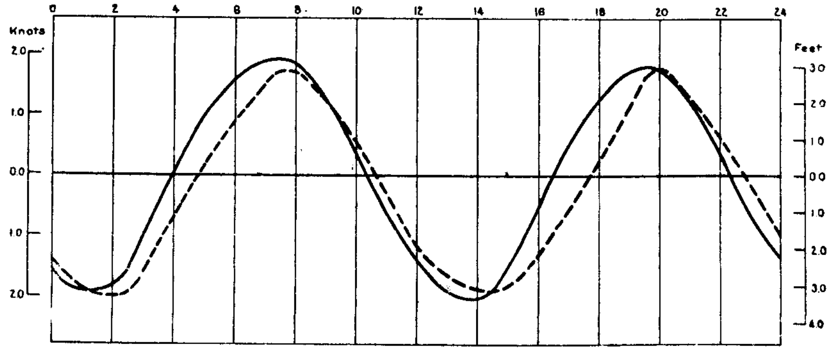

FIG. E.—Tide and current curves, New York Harbor, October 9, 1919

However, in such cases it is frequently possible to refer the current at a given place to the tide at some other place with comparable diurnal inequality.

EFFECT OF NONTIDAL CURRENT

The tidal current is subject to the disturbing influence of nontidal currents which affect the regularity of its occurrence as regards time, velocity, and direction. In the case of the rectilinear current the effect of a steady nontidal current is, in general, to make both the periods and the velocities of flood and ebb unequal and to change the times of slack water but to leave unchanged the times of flood and ebb strengths. This is evident from a consideration of Figure F, which represents a simple rectilinear tidal current, the time axis of which is the line *AB*, flood velocities being plotted above the line and ebb velocities below.

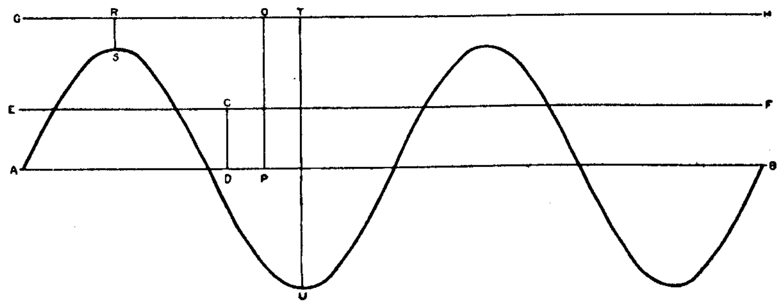

FIG. F.—Effect of nontidal current on tidal current

When unaffected by nontidal currents, the periods of flood and ebb are, in general, equal as represented in the diagram, and slack water occurs regularly three hours and six minutes after the times of flood and ebb strengths. But if we assume a steady nontidal current introduced which has, in the direction of the tidal current, a velocity component represented by the line *CD*, it is evident that the strength of ebb will be increased by an amount equal to *CD*, while the flood strength will be decreased by the same amount. The current conditions may now be completely represented by drawing, as a new axis, the line *EF* parallel to *AB* and distant from it the length of *CD*.

Obviously, if the velocity of the nontidal current exceeds that of the tidal current at the time of strength, the tidal current will be completely masked and the resultant current will set at all times in the direction of the nontidal current. Thus, if in Figure F the line *OP* represents the velocity component of the nontidal current in the direction of the tidal current, the new axis for measuring the velocity of the combined current at any time will be the line *GO* and the current will be flowing at all times in the ebb direction. There will be no slack waters; but at periods 6 hours 12 minutes apart there will occur minimum and maximum velocities represented, respectively, by the lines *RS* and *TU*.

In so far as the effect of the nontidal current on the direction of the tidal current is concerned, it is only necessary to remark that the resultant current will set in a direction which at any time is the resultant of the tidal and nontidal currents at that time. This resultant direction and also the resultant velocity may be determined either graphically by the parallelogram of velocities or by the usual trigonometric computations.

VELOCITY OF TIDAL CURRENTS AND PROGRESSION OF THE TIDE

In the tidal movement of the water it is necessary to distinguish clearly between the velocity of the current and the progression or rate of advance of the tide. In the former case reference is made to the actual speed of a moving particle, while in the latter case the reference is to the rate of advance of the tide phase or the velocity of propagation of wave motion, which generally is many times greater than the velocity of the current.

It is to be noted that there is no necessary relationship between the velocity of the tidal current at any place and the rate of advance of the tide at that place. In other words, if the rate of advance of the tide is known we can not from that alone infer the velocity of the current, nor vice versa. The rate of advance of the tide in any given body of water depends on the type of tidal movement. In a progressive wave the tide moves approximately in accordance with the formula $r=\sqrt{gd}$ in which r is the rate of advance of the tide, g the acceleration of gravity, and d the depth of the waterway. In stationary-wave movement, since high or low water occurs at very nearly the same time over a considerable area, the rate of advance is theoretically very great; but actually there is always some progression present, and this reduces the theoretical velocity considerably.

The velocity of the current, or the actual speed with which the particles of water are moving past any fixed point, depends on the volume of water that must pass the given point and the cross-section of the channel at that point. The velocity of the current is thus independent of the rate of advance of the tide.

DISTANCE TRAVELED BY A PARTICLE IN A TIDAL CYCLE

In a rectilinear current the distance traveled by the water particles or by any object floating in the water is obviously equal to the product of the time by the average velocity during this interval of time. To determine the average velocity of the tidal current for any desired interval several methods may be used.

If the curve of the tidal current has been plotted, the average velocity may be derived as the mean of a number of measurements of the velocity made at frequent intervals on the curve; as, for example, every 10 or 15 minutes. From the current curve the average velocity may also be determined by deriving the mean ordinate of the curve by use of the planimeter. For a full tidal cycle of flood or ebb, however, since the current curve generally approximates the cosine curve, the simplest method consists in making use of the well-known ratio of the mean ordinate of the cosine curve to the maximum ordinate which is $2 \div \pi$, or 0.6366.

The latter method has another advantage in that the velocity of the tidal current is almost invariably specified by its velocity at the time of strength, which corresponds to the maximum ordinate of the cosine curve; hence, the average velocity of the tidal current for a flood or ebb cycle is given immediately as the product of the strength of the current by 0.6366. And though this method is only approximate, since the curve of the current may deviate more or less from the cosine curve, in general the results will be sufficiently accurate for all practical purposes. For a normal flood or ebb period of 6.2 hours the distance a tidal current with a velocity at strength of 1 knot will carry a floating object is, in nautical miles, $0.6366 \times 6.2 = 3.95$, or 24,000 feet.

DURATION OF SLACK

In the change of direction of flow from flood to ebb, and vice versa, the tidal current goes through a period of slack water or zero velocity. Obviously, this period of slack is but momentary, and graphically it is represented by the instant when the current curve cuts the zero line of velocities. For a brief period each side of slack water, however, the current is very weak, and in ordinary usage "slack water" denotes not only the instant of zero velocity but also the period of weak current. The question is therefore frequently raised: How long does slack water last?

To give slack water in its ordinary usage a definite meaning, we may define it to be the period during which the velocity of the current is less than one-tenth of a knot. Velocities less than one-tenth of a knot may generally be disregarded for practical purposes, and such velocities are, moreover, difficult to measure either with float or with current meter. For any given current it is now a simple matter to determine the duration of slack water, the current curve furnishing a ready means for this determination.

In general, regarding the current curve as approximately a sine or cosine curve, the duration of slack water is a function of the strength of current—the stronger the current the less the duration of slack—and from the equation of the sine curve we may easily compute the duration of slack water for currents of various strengths. For the normal flood or ebb cycle of 6^h 12.6^m we may write the equation of the current curve $y=A \sin 0.4831t$, in which A is the velocity of the current in knots at time of strength, 0.4831 the angular velocity in degrees per minute, and t is the time in minutes from the instant of zero velocity. Setting $y=0.1$ and solving for t (this value of t giving half the duration of slack) we get for the duration of slack the following values: For a current with a strength of 1 knot, slack water is 24 minutes; for currents of 2 knots strength, 12 minutes; 3 knots, 8 minutes; 4 knots, 6 minutes; 5 knots, 5 minutes; 6 knots, 4 minutes; 8 knots, 3 minutes; 10 knots, 2⅓ minutes.

HARMONIC CONSTANTS

The tidal current, like the tide, may be regarded as the resultant of a number of simple harmonic movements, each of the form $y=A \cos (at+\alpha)$: hence, tidal currents may be analyzed in a manner analagous to that used in tides and the harmonic current constants derived. These constants permit the characteristics of the currents to be determined in the same manner as the tidal harmonic constants and they may also be used in the prediction of the times of slack and the times and velocities of the strength of current.

It can easily be shown that in coastal or inland tidal waters the amplitudes of the various current components are related to each other, not as the amplitudes of the corresponding tidal components, but as these latter multiplied by their respective speeds; that is, in any given harbor, if we denote the various components of the current by primes and of the tide by double primes, we have

$$M'_2 : S'_2 : N'_2 : K'_1 : O'_1 = m_2M''_2 : s_2S''_2 : n_2N''_2 : k_1K''_1 : o_1O''_1$$

where the small italic letters represent, respectively, the angular speed of the corresponding components. This shows at once that the diurnal inequality in the currents should be approximately half that in the tide.

MEAN VALUES

In the nonharmonic analysis of current observations it is customary to refer the times of slack and strength of current to the times of high and low water of the tide at some suitable place, generally near by. In this method of analysis the time of current determined is in effect reduced to approximate mean value, since the changes in the tidal current from day to day may be taken to approximate the corresponding changes in the tide; but the velocity of the current as determined from a short series of observations must be reduced to a mean value.

In the ordinary tidal movement of the progressive or stationary wave types the change in the strength of the current from day to day may be taken approximately the same as the variation in the range of the tide. Hence, the velocity of the current from a short series of observations may be corrected to a mean value by multiplying by a factor equal to the reciprocal of the range of the tide for the same period divided by the mean range of the tide. It is to be noted that in this method of reducing to a mean value, any nontidal currents must first be eliminated and the factor applied to the tidal current alone. This may be done by taking the strengths of the tidal current as the half sum of the flood and ebb strengths for the period in question.

In some places the current, while exhibiting the characteristic features of the tidal current, is in reality a hydraulic current due to differences in head at the ends of a straight connecting two independent tidal bodies of water. East River and Harlem River in New York Harbor and Seymour Narrows in British Columbia are examples of such straits, and the currents sweeping through these waterways are not tidal currents in the true sense, but hydraulic currents. The velocities of such currents vary as the square root of the head, and hence in reducing the velocities of such currents to a mean value the factor to be used is the square root of the factor used for ordinary tidal currents.

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