Chapter 12. Johnstone Strait Region

The complex system of waterways that extends seaward from the northern end of the Strait of Georgia provides access to some of the most spectacular scenery on the British Columbia coast. Snow-capped mountain peaks, cascading waterfalls, steep-sided channels, and surging tidal narrows contribute to a stark ruggedness (Fig. 12.1). Settlements are few and far between, but wildlife is abundant, and it is not uncommon to see a pod of killer whales or a school of porpoises moving easily through the chilly waters. The large numbers of killer whales that frequently gather in Robson Bight, at the western end of Johnstone Strait, create an impressive sight, unequalled in few areas of the coast.

FIG. 12.1. Aerial view of Johnstone Strait near Kelsey Bay, May 1977. View toward mainland side of channel. (Photo by author.)

Background

Formation of the narrow channels along the northeast coast of Vancouver Island dates back to the ice ages, when glaciers carved their way into the arc of igneous rocks that extends across the northern end of the Georgia Depression. Figure 12.2 shows that Johnstone Strait and Discovery Passage presently constitute the main route through the maze of islands that characterize this portion of the coastline. To the northwest of Johnstone Strait, the seaway broadens into Queen Charlotte Strait, a relatively shallow basin that marks the beginning of the coastal lowlands of the Hecate Depression, and then continues through a group of shoal-infested channels into Queen Charlotte Sound.

Queen Charlotte Strait, Johnstone Strait, and Discovery Passage, together with the interconnecting channels, make up a major part of the navigable "inside passage" that separates Vancouver Island from the mainland coasts of British Columbia and Washington State. Johnstone Strait accounts for nearly 20% of the length of this passage, and closely ranks with the Strait of Georgia and Juan de Fuca Strait in importance to the marine environment. Experience has demonstrated, for example, that the channels of the Johnstone Strait region form a key link in the migration route of Pacific salmon. Indicative of this importance is the fact that typically 10–20% of Fraser River sockeye salmon that return to the coast every 4 yr enter the river via Johnstone Strait rather than Juan de Fuca Strait. In certain years of the 4-yr cycle, this "diversion" of salmon through the northern passages is close to half the returning run. In 1978, for example, approximately 57% of the run chose this route rather than Juan de Fuca Strait, and in 1980 there was a record diversion of 70%.

Because the three main channels carry most of the water that flows between the Pacific Ocean and the northern end of the Strait of Georgia, they further influence the physical oceanographic structure of the inside passage and adjoining fiords. The central portion of Johnstone Strait is particularly relevant in this respect, for the simple reason that all such exchanges of water must pass between its shores. The protected nature of the channels has a distinct advantage to marine traffic. Tugboats, bulk carriers, cruise ships, freighters, and pleasure craft are common sights in these waters, and a large percentage of each type of vessel fly the U.S. flag.

Captain George Vancouver was the first European to recognize the importance of these channels to navigation and many modern place names originate with his charting of this region in the summer of 1792. Discovery Passage is named after his command vessel HMS *Discovery* (310 t, 134 crew). Johnstone Strait and Broughton Strait were named personally by Vancouver in honor of James Johnstone and William Broughton, Master and Lieutenant Commander, respectively, of his accompanying consort HMS *Chatham*. Spanish commanders Valdes and Galiano sailed through this region within a few days of Vancouver and, although most of their designated place names are not used on present day charts, their two vessels *Sutil* and *Mexicana* are remembered in the names of Sutil Channel (near Cape Mudge), and in Sutil Point and Mexicana Point on Goletas Channel, which extends seaward from Queen Charlotte Strait. The way in which Helmcken Island, just east of Kelsey Bay, received its name gives an insight into the difficulties early mariners encountered when navigating the rapid and complex currents in Johnstone Strait. Helmcken, who was a medical officer with the Hudson's Bay Company, and later speaker of the Provincial Legislature, spent part of his early career sailing the coast. "In the year 1850 I was on board the company's steamer *Beaver* going to Fort Rupert, and we were passing along Johnstone Strait against a flood tide. As this island was approached, which stands in the middle of the channel, the tide rapidly increased in strength, owing to the island in the way, till the *Beaver* had extremely hard work to make any headway, the vessel sheering about in the swirling current. I asked the Captain the name of the island near which we were struggling along. Captain

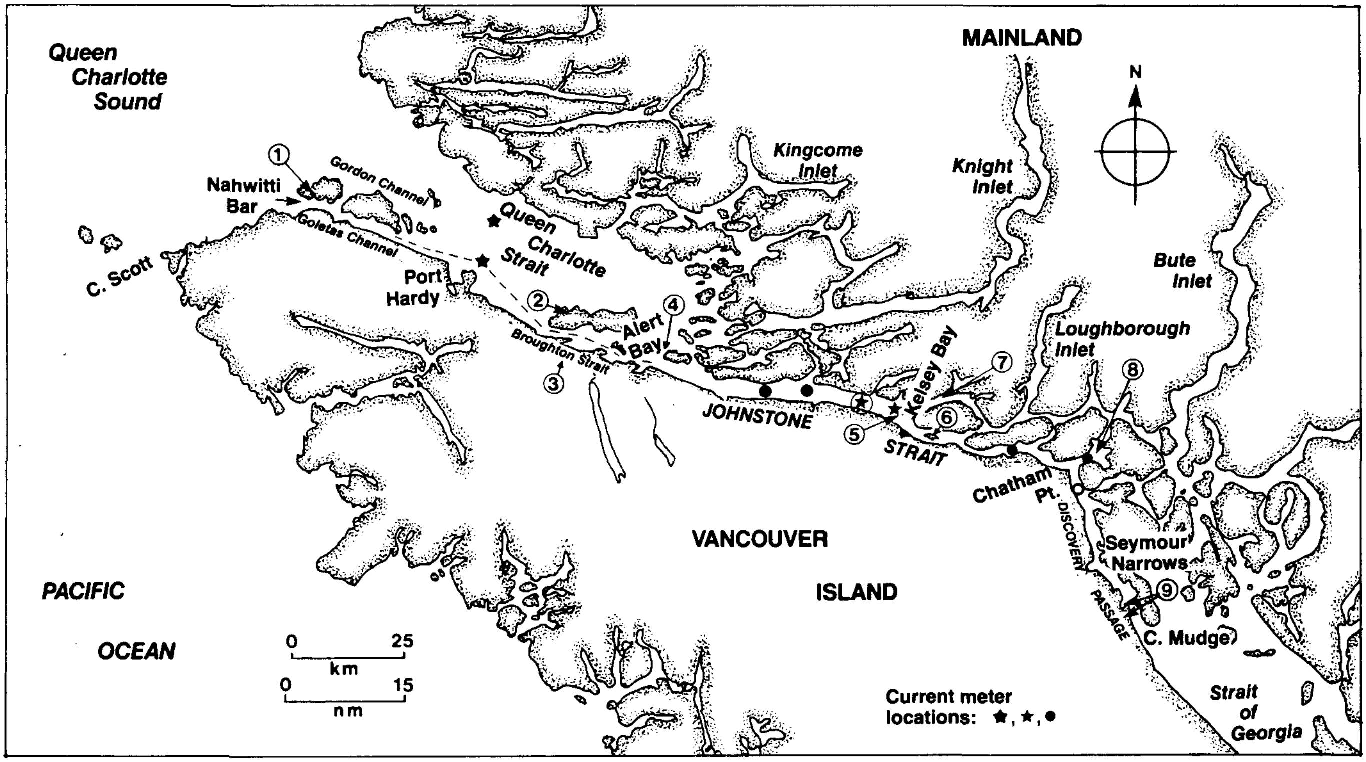

FIG. 12.2. Map of Johnstone Strait region: 1, Bull Harbour; 2, Malcolm Island; 3, Port McNeill; 4, Weynton Passage; 5, Hardwicke and Yorke Islands; 6, Helmcken Island; 7, Sunderland Channel; 8, Nodales Channel; 9, Duncan Bay and Campbell River area. Broken line in Queen Charlotte Strait gives sounding line for bottom profiles, Fig. 12.6, 12.7.

Dodd replied, 'It has no name, but I will call it after you, doctor, for it is like you, always in opposition.' The island has since been known by my name." (Walbran 1971). Dodd's comment on the current in Race Passage has undoubtedly been echoed by many skippers who have tried to stem the 3 m/s (6 kn) currents that surge through the narrows.

Bathymetry and Water Propeties

Although the three main channels of the Johnstone Strait region are part of a continuous seaway, Queen Charlotte Strait has significantly different bathymetry and oceanographic characteristics from Johnstone Strait and Discovery Passage.

Johnstone Strait–Discovery Passage

Johnstone Strait and Discovery Passage are the narrowest of the major channels that make up the navigable inside passage of coastal British Columbia. Between Alert Bay and Kelsey Bay the channel is only about 3.5–4.5 km wide, and from Kelsey Bay to Seymour Narrows its width rarely exceeds 2.5 km. These two channels also contain some of the deepest basins of the inshore waters. Figure 12.3 shows that depths within the western half of Johnstone Strait increase regularly from 70 m over the partial sill off Kelsey Bay to nearly 500 m near the entrance to Broughton Strait. By comparison, the maximum observed depth in the Strait of Georgia is 420 m and in Juan de Fuca Strait a shallow 275 m. Only in some adjoining inlets, such as Knight and Bute, are deeper basins found. Within Discovery Passage and the more constricted eastern half of Johnstone Strait, the bottom is characterized by a highly irregular profile with numerous sills and shoals. Maximum depths in this region are around 250 m.

The large depths and narrow widths are indicative of the steep-sided channels of the region, where safe overnight anchorages are somewhat at a premium. On the other hand, lure fishing can be quite productive, provided the angler takes advantage of the numerous shoals and nearshore underwater shelves and avoids the deeper water that often exists right to the shoreline. Even when doing oceanography at night under strong lights directed onto the surface, there is rarely any sign of life in the dark green mid-channel waters of Johnstone Strait.

As the region is characterized by rapid tidal streams, constricted passages, and numerous shallow sills, the water is in almost constant agitation from top to bottom and never has the oportunity to settle into strongly stratified layers that typify water in inlets and the Strait of Georgia. Therefore, water temperatures increase very slightly inward along Johnstone Strait and Discovery Passage and remain low throughout the year (Fig. 12.3). At the height of summer heating in late July, for example, temperatures of the surface water are usually colder than 10°C, which is appreciably colder than the contemporary values of over 20°C in the central portion of the Strait of Georgia. Even the oceanic surface waters of Queen Charlotte Sound are warmer in summer than those in Johnstone Strait. (This cold surface water is a principal reason for the common occurrence of summer fogs in the area.) Particularly vigorous tidal mixing occurs

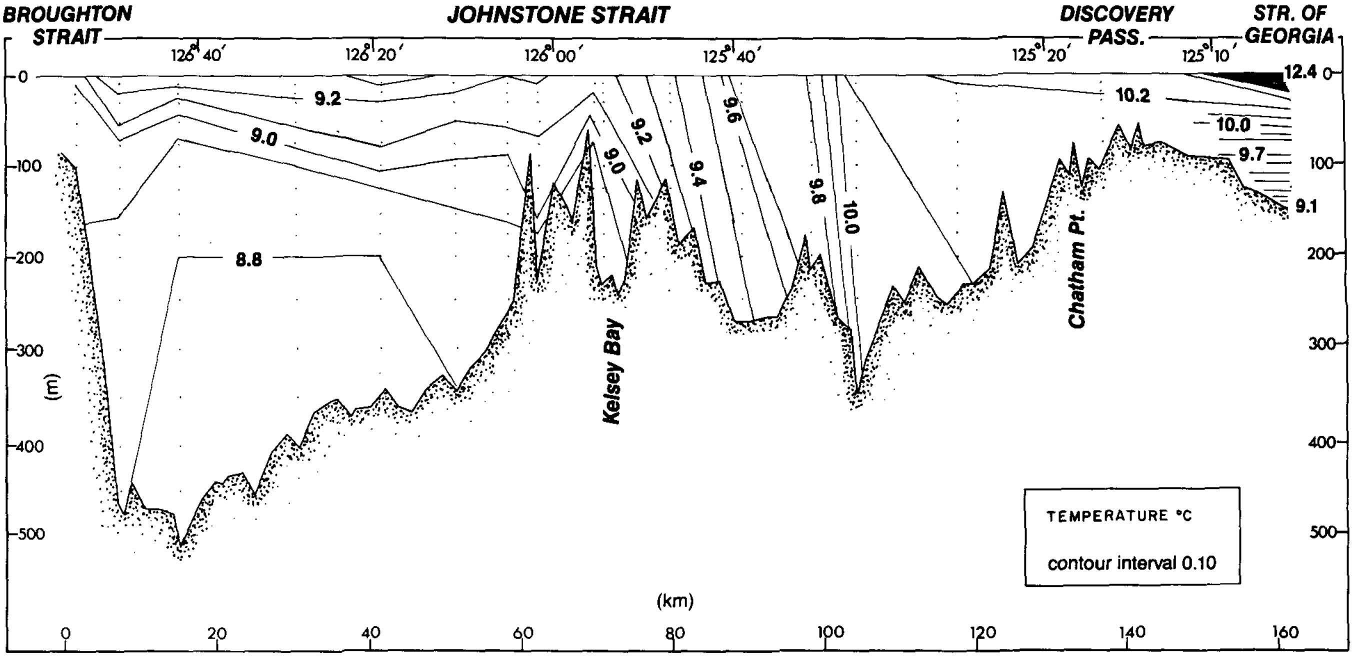

FIG. 12.3. Temperature distribution along mid-channel in Discovery Passage and Johnstone Strait, September 1977. (Note highly structured surface waters in Strait of Georgia in Fig. 12.3–12.5.) (From Thomson et al. 1980)

throughout the year in such areas as Seymour Narrows, Race Passage, and Weynton Passage.

During winter and spring, the waters of Johnstone Strait and Discovery Passage become uniformly cold from top to bottom. Maximum temperatures during these seasons are typically around 7°C and the along-channel variation becomes almost indiscernible. A similar situation exists below 30 m in summer. Just how cold this water can be was made clear to the scientists and crew of a research vessel during a recent May oceanographic survey, when, in the early light of a calm day, they watched helplessly as a large timber wolf died from hypothermia halfway through an attempted swim across Johnstone Strait.

The nearly uniform salinity of the waters within Johnstone Strait and Discovery Passage also reflect the vigorous tidal mixing that takes place over the sills and in the narrow passes (Fig. 12.4). Unlike temperature distribution, however, there is at all times a discernible in-

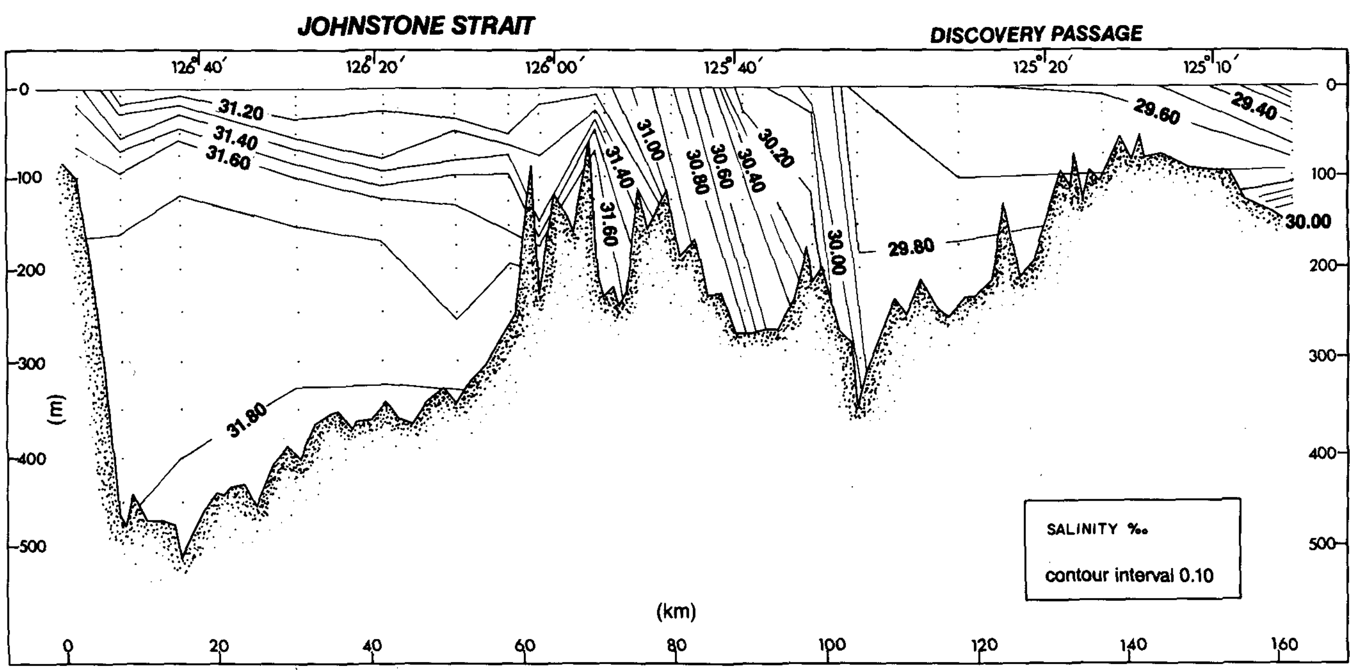

FIG. 12.4. Salinity distributions along mid-channel in Discovery Passage and Johnstone Strait, September 1977. (From Thomson et al. 1980)

crease in saltiness seaward along the channels and a weak but permanent increase in salinity with depth. In Johnstone Strait, salinities increase from a surface minimum of 30‰ to a near bottom maximum of 32‰, and in Discovery Passage the corresponding range is about 26–31‰. Typically, the salinity distributions, and to a lesser extent those of temperature, are similar to other estuarine-type environments on the coast. In the present case, relatively cold, salty Pacific Ocean water continually works its way inward below depths of about 100 m in the two channels while relatively warm, low-salinity water, derived largely from runoff from the Fraser River and the Homathko River in Bute Inlet, makes its way seaward in the top 100 m. Although the fraction of Fraser River runoff that moves seaward via the northern seaway becomes highly diluted by the time it reaches the Pacific Ocean off the northern end of Vancouver Island, it possibly retains enough of its "aroma" that Fraser River salmon, returning southward along the Alaska–British Columbia coast after 4 yr roaming the sea, are able to "smell" their way home to the river mouth.

A striking indication of the well-mixed nature of the waters in Johnstone Strait and Discovery Passage is the uniformity of dissolved oxygen values observed from top to bottom throughout the year (Fig. 12.5). At the seaward end of Johnstone Strait, near-bottom values may even exceed those close to the surface as negatively buoyant flood streams that surge southward from Weynton Passage carry aerated surface waters to the very depths of the basin. Because of this, benthic (bottom) organisms within the two channels never suffer the devastating effects of low oxygen supply that so often plague their counterparts in some of the silled basins and fiords along the coast. Like a metaphorical oceanic wind, the strong bottom currents constantly blow freshly oxygenated water over the floor of the channels to encourage a proliferation of marine life. It was no surprise when, during a recent detailed sampling of the sediments in the western basin of Johnstone Strait, a compacted muddy bottom teeming with worms, brittle stars, crabs, sea urchins, and clams was discovered.

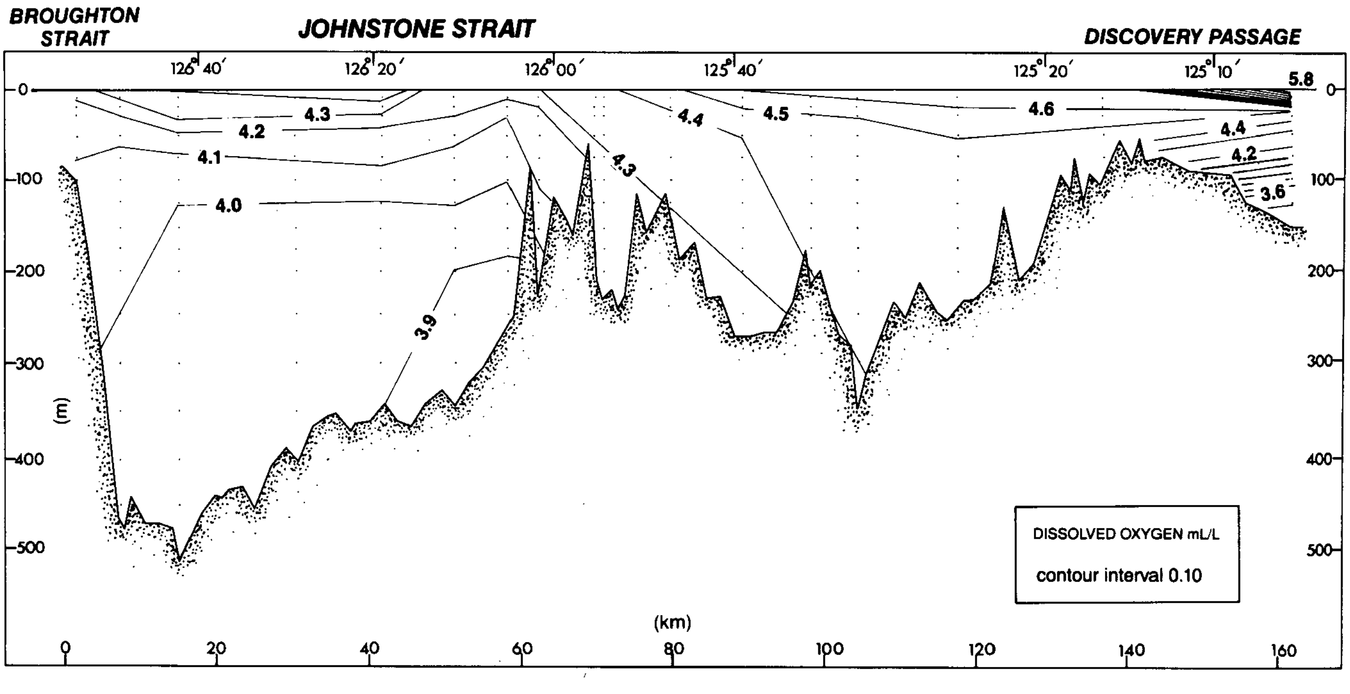

Fig. 12.5. Dissolved oxygen distribution along mid-channel in Discovery Passage and Johnstone Strait, September 1977. (mL/L = millilitres dissolved oxygen per litre of water.) (From Thomson et al. 1980)

Queen Charlotte Strait

At the seaward end of Johnstone Strait, the floor of the channel rises abruptly to form the 90-km long, shallow, island-strewn basin of Queen Charlotte Strait (Fig. 12.2). The steep-sided walls so characteristic of the narrow seaway to the east are replaced by a broken, shoal-infested coastline adjoining a comparatively low land relief. Shoals and drying rocks are especially numerous within the broad seaward entrance that flanks the mainland shore and within Broughton Strait to the south of Malcolm Island.

The width of the main basin of Queen Charlotte Strait widens from around 13 km at its eastern extremity to more than 26 km at midlength, then narrows to less than 15 km at the seaward approach. Greatest depths within the basin are associated with the narrow, eastward-shoaling trough that extends along Goletas Channel to George Passage north of Malcolm Island. Goletas Channel, with its narrow regular geometry, steep-sided shoreline, depths in excess of 350 m, and shallow entrance sill (Nahwitti Bar), bears a closer physical resemblance to Johnstone Strait than to adjacent Queen Charlotte Strait.

Queen Charlotte Strait is a meeting place for the nearly homogeneous waters that move seaward through the inside passage and the more highly stratified oceanic waters that move inland from Queen Charlotte Sound. Because of this, the temperature and salinity distributions within the basin have slightly more structure than in Johnstone Strait, although the difference really only becomes pronounced in summer. From late fall to early spring, water temperatures generally range around 7–10°C near the surface and about 7–8°C at depth, accompanied by a slight warming trend from east to west (Fig. 12.6). During summer, near surface temperatures

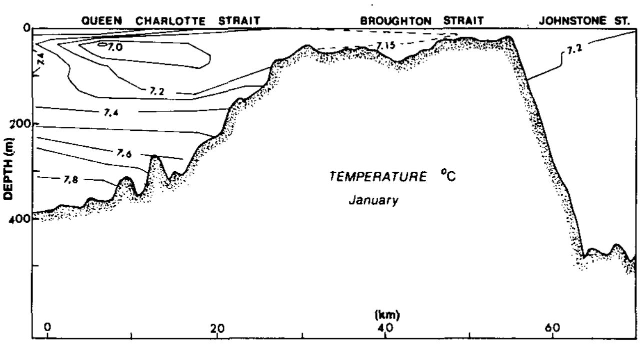

FIG. 12.6. Temperature distribution along southern side Johnstone, Broughton, and Queen Charlotte straits, January 1978. (See broken line Fig. 12.2 for location.) (From Thomson et al. 1980)

rise above 10°C as local runoff covers portions of the Strait with a thin blanket of brackish water capable of retaining a greater proportion of solar heating. Within the more protected embayments along the northern side of the basin, surface temperatures can be expected to exceed 15°C during hot, windless days.

Salinities in Queen Charlotte Strait typically range from 31 to 33‰ throughout the year (Fig. 12.7). As in

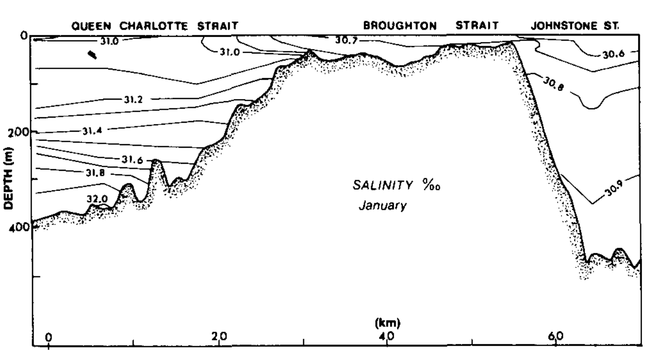

FIG. 12.7 Salinity distribution along southern side Johnstone, Broughton and Queen Charlotte straits, January 1978. (See broken line Fig. 12.2 for locations.) (From Thomson et al. 1980)

Juan de Fuca Strait, surface salinities are lowest in December and January (a result of a maximum in local precipitation) and highest around October after the end of the snow melt period. In deeper water, maximum salinities occur in summer when the combined influence of northwest winds off the coast and a well-established estuarine circulation associated with river runoff induce salty oceanic water outside the entrance sills to spill into the basin. This process all but ceases by late fall with the onset of southeast winds and weakened estuarine flow, and salinities in the deeper portions of the basin gradually decrease to a midwinter low.

Dissolved oxygen values within Queen Charlotte Strait tend to be higher at the surface but lower at the bottom than in Johnstone Strait. There are two main reasons for this: tidal currents are less intense so the more highly oxygenated surface waters are less able to mix with the deeper waters; and dense, low-oxygen oceanic water over the continental shelf can flow to the bottom of the basin. For the most part, however, values remain above 3 mL/L, enough to support most marine animals without any undue hardship.

Winds

The prevailing winds over the waters of the Johnstone Strait region are linked to the large-scale pressure systems of the eastern Pacific Ocean and, guided by the mountainous terrain, blow predominantly in along-channel directions. Only where extensive interconnecting basins from the mainland side open into these passageways do winds sometimes blow from other directions, for example, at the trifurcation area formed by Johnstone Strait, Discovery Passage, and Nodales Channel. The influence of such cross-channel winds dies out quickly a short distance into the main channels; the wind's major effect is to generate rips where it opposes the surface currents.

Within Johnstone and Queen Charlotte straits, prevailing winds are westerly in summer and easterly in winter (Table 12.1). These are funneled into northerly and southerly prevailing winds, respectively, in Discovery Passage. Polar outbreaks from the mainland interior that move down some of the larger fiords such as Knight Inlet, Kingcome Inlet, and Loughborough Inlet can lead to gale force winds over limited areas within the region but, in general, strong winds along the main channels are associated with the passage of frontal systems. During summer, there is a distinct sea-breeze effect in Johnstone and Queen Charlotte straits as rising air over the heated mainland coast draws cooler marine air inland. On clear sunny days, these westerly winds build in strength beginning in the late morning and, combined with the prevailing air flow, can lead to wind speeds of 15 m/s (30 kn) by late afternoon; the western portion of Johnstone Strait appears to be especially susceptible to these winds, the eastern portion less so. The sea breeze dies out just before dusk and is replaced by a considerably weaker land breeze from the east, whose influence is mostly confined to the more exposed waters of Queen Charlotte Strait.

Waves

Wave heights in Johnstone Strait and Discovery Passage are limited by the fetch of the wind and by the narrow, winding nature of the channels. It is unlikely, for example, that waves generated at one end of an along-strait fetch will be able to reach the far end of the channel before running ashore on either side. Even over the longest wind fetch of 65 km in the western portion of

TABLE 12.1. Winds at Chatham Point, Johnstone Strait (*top*). Percentage occurrence of winds from 8 directions for each month, from February 1960 to March 1973. Winds at Bull Harbour, Goletas Channel (*bottom*) from November 1964 to February 1973. (From Sailing Directions British Columbia Coast, Vol. 1, 1976)

		MONTH											
		J	F	M	A	M	J	J	A	S	O	N	D
DIRECTION	N	6	3	3	1	1	1	0	1	1	2	4	5
	NE	28	19	20	14	7	5	3	6	9	16	23	26
	E	18	21	18	13	9	7	5	8	11	18	22	19
	SE	18	19	16	21	15	13	10	10	13	22	17	17
	S	1	1	1	1	1	1	1	0	1	1	1	1
	SW	9	12	16	13	20	22	25	27	21	15	11	10
	W	11	14	16	22	32	34	42	36	32	16	12	12
	NW	6	7	8	12	12	15	14	9	9	5	7	8
	Calm	3	4	2	3	3	2	1	2	3	5	3	2
Mean speed	(m/s)	3.8	3.4	3.9	4.1	4.4	4.9	5.5	4.4	3.8	3.4	3.4	3.9
	(kn)	7.4	6.5	7.6	8.0	8.5	9.6	10.8	8.5	7.4	6.6	6.7	7.6
DIRECTION	N	4	2	5	4	5	4	3	4	3	4	3	4
	NE	4	3	3	2	4	3	2	3	3	3	2	3
	E	7	6	4	3	4	3	2	3	6	5	5	5
	SE	47	49	49	35	19	14	9	19	33	50	57	52
	S	10	11	12	13	11	6	8	8	8	8	11	10
	SW	11	10	6	7	7	9	10	9	6	5	5	9
	W	1	2	2	3	9	10	12	10	6	2	1	1
	NW	12	11	16	28	33	34	37	20	16	14	12	13
	Calm	4	6	3	5	8	17	17	24	19	9	4	3
Mean speed	(m/s)	3.8	3.1	3.4	3.1	2.4	1.9	1.6	1.2	1.7	2.8	3.4	3.9
	(kn)	7.4	6.0	6.6	6.0	4.7	3.6	3.0	2.3	3.3	5.5	6.7	7.6

Johnstone Strait, much of the wave energy generated by westerly or easterly winds will be lost to breakers at the shoreline. Because waves produced in the remaining shorter basins will suffer similar fates, long, rolling seas and swell never have the opportunity to develop.

Heights of wind-generated waves within Queen Charlotte Strait are also limited by a fully exposed fetch of only 65 km. For a given wind speed and duration, however, seas will become somewhat higher and have longer periods than those in Johnstone Strait, due to the greater width of the channel. The low, eastward-propagating swells commonly found in Queen Charlotte Strait are for the most part highly attenuated remnants of larger oceanic swell from Queen Charlotte Sound that have negotiated the shoals and passages of Goletas and Gordon channels. When they enter the Strait, these waves undergo a further gradual reduction in height as they move inland. Although no direct measurements have been made of waves in this region, maximum seas will be consistently lower than the 3- to 4-m seas observed at Roberts Bank in the more extensive Strait of Georgia (Chapter 10).

Based solely on the above criteria, it could be assumed that waves in Johnstone Strait and Discovery Passage are insignificant and worthy of little comment. Unfortunately, the presence of strong surface currents in these two channels partially makes up for the short fetches and twisting coastlines, as they contribute to the formation of a short, steep chop more than a metre or two high when winds rise above 10 m/s (20 kn). Because surface ebb currents in these two channels are considerably stronger than surface flood currents, the largest seas for a specified wind speed and duration will develop for winds from the west in Johnstone Strait and from the north in Discovery Passage, in the region north of Seymour Narrows. South of Seymour Narrows, on the other hand, largest wave heights will occur on the flood during periods of strong southeasterly winds in the Strait of Georgia as current-amplified seas and swell propagate into the passage. Especially choppy rip currents are set up near points of land and at entrances to most of the passes that lead into Johnstone Strait, when winds oppose the surface currents. Winds from the east in Johnstone Strait, however, typically will be associated with less choppy seas as they blow in the direction of the average surface flow; in Discovery Passage a similar condition holds for southerly winds.

The short, steep, whitecapping seas that cover the two channels during moderate to strong northwest winds have little effect on larger vessels; onboard the 62.5-m CSS *Parizeau*, for instance, the motion is a gentle roll at worst even during winds in excess of 15 m/s. Although smaller vessels are much more affected by these waves and light displacement pleasure craft pitch and roll awkwardly in the steep seas, heavy displacement tugs or trollers of comparable length cut through the waves with considerably greater ease.

In Queen Charlotte Strait, where surface currents are weaker and the ebb bias less pronounced, amplification of wind-generated waves by opposing currents is not generally an important factor. Only over shoals and in the neighborhood of prominences do rip conditions frequently develop. Nahwitti Bar at the western end of Goletas Channel is particularly well known for its high waves. Sea and swell that cross the 2.5-km wide, 15-m deep sill from Queen Charlotte Sound are amplified by the combined effect of the shoaling bathymetry and the opposing tidal currents. In heavy weather with westerly winds, the sea breaks over the bar and it becomes dangerous to cross in any vessel.

Tides

As in Juan de Fuca Strait, the mixed-type tide that propagates inland from the Pacific Ocean north of Vancouver Island undergoes considerable modification as it makes its way toward the Strait of Georgia. Tides in the vicinity of Alert Bay and Port McNeil, for example, are mostly semidiurnal throughout the month and only take on a truly mixed-type nature around the time of the moon's maximum declination north or south of the equator (Fig. 12.8). In this particular region, therefore, the semidiurnal part of the tide associated with the moon's gravitational pull predominates over the diurnal part associated with changes in the moon's declination. As the tide progresses southeastward, the semidiurnal contribution diminishes in analogy with tides in Juan de Fuca Strait. By the time it reaches Yorke Island (where there are remains of World War II gun emplacements and bunkers) the tide has become mixed, mainly semidiurnal as semidiurnal and diurnal effects begin to become of equal importance.

Near Chatham Point at the eastern end of Johnstone Strait, the contribution from the semidiurnal tide has dropped to 0.7 of the Alert Bay value, whereas that from the diurnal tide has increased by a factor of 1.3. In the vicinity of Duncan Bay, the diurnal contribution becomes sufficiently great that the tide has a diurnal nature and roughly 12 days each month there is only 1 stand of high and 1 stand of low water each day. This state is especially

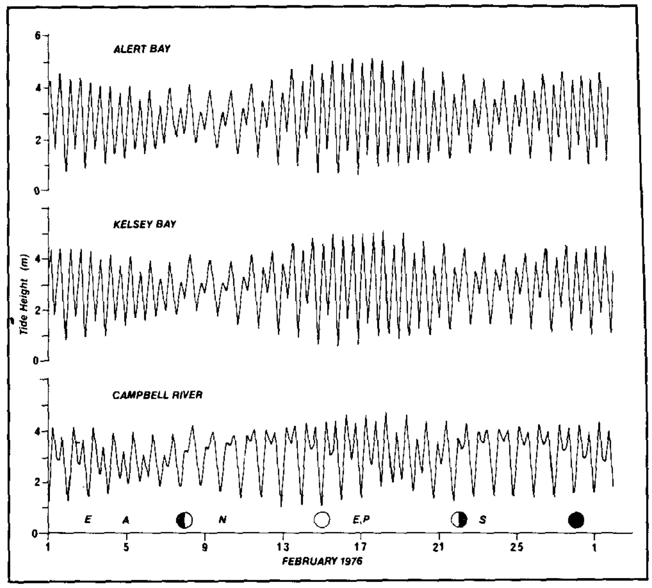

FIG. 12.8. Tide heights over 1 mo at three locations from Broughton Strait to Discovery Passage. Campbell River at southern end Discovery Passage. Times of lunar phases shown; moon on equator (E), maximum north (N) and south (S) declination, and apogee (A) and perigee (P). (Courtesy A. Douglas.)

well established when the moon is furthest north or south of the equator, so the moon's declinational effect is most pronounced. South of this area, past Campbell River and into the Strait of Georgia, the tide switches back to mixed, mainly semidiurnal.

The change in character of the tide along the channels is further accompanied by a change in tidal sequence. From Cape Scott to Seymour Narrows this sequence is invariably Higher High Water, Lower Low Water, Lower High Water, Higher Low Water. However, south of the Narrows, this sequence is more complicated. For most of the month, the sequence is Higher High Water, Higher Low Water, Lower High Water, Lower Low Water, but for a few days each month just prior to the moon's maximum declination the sequence is identical to that between Cape Scott and the Narrows. Therefore, only a relatively small low tide is expected to follow the highest tide of the day, except just after the moon has crossed the equator, when Higher High Water will be followed by Lower Low Water. The times when this occurs can be determined from the back cover of any ***Canadian Tide and Current Tables*** for B.C. waters.

The southward propagation of the tides to the Strait of Georgia can be followed by measurements made at various locations throughout the area. The basic information for this purpose is in Table 12.2 where, in addition to the time it takes Higher High Water and Lower Low Water to travel from Cape Scott to a particular location, the mean and extreme tidal ranges for each location have also been listed. For all practical purposes, the along channel propagation for Higher High Water and Lower Low Water is the same and, for illustrative purposes, discussion is confined to Higher High Water alone.

The first thing to notice in Table 12.2 is that the northward propagating tide along the west coast of Van-

TABLE 12.2. Propagation rates for Higher High Water (HHW) and Lower Low Water (LLW) relative to Cape Scott, plus tidal ranges. (Minus sign at Tofino means tides occur earlier than at Cape Scott.) Tidal ranges for extreme spring and extreme neap tides, respectively. South of Seymour Narrows times quoted are for Lower High Water. (Courtesy W. Rapatz)

Location	Travel time from Cape Scott (*min*)		Tidal Range (*m*)	
	HHW	LLW	Spring	Neap
Cape Scott	0	0	4.7	3.0
Tofino	−7	−9	4.1	2.7
Port Hardy	+21	+18	5.6	3.6
Alert Bay	+34	+36	5.5	3.5
Yorke Island	+53	+63	5.3	3.4
Kelsey Bay	+66	+71	5.4	3.4
Chatham Point	+101	+128	4.8	2.9
Seymour Narrows	+149	+270	5.1	3.0
Campbell River	+240	+270	4.6	2.9

couver Island takes about 7 min to cover the 260 km from Tofino to Cape Scott for an average speed of 2230 km/h. Once the tide turns the corner at Cape Scott it requires over 20 min to travel 75 km to Port Hardy in Queen Charlotte Strait, for a speed of 225 km/h, and another 13 min to reach Alert Bay 37 km to the southeast at the reduced speed of 170 km/h. In addition, the tidal range reaches its peak at Port Hardy and then decreases along the channel.

The sluggish nature of the tide after it rounds Cape Scott is, of course, due to the narrowness of the passes and the greatly diminished water depth; tides can move faster in deep water than in shallow water. The latter feature is suggested by the fact that it takes a few minutes longer for Lower Low Water to cover the same distances in Table 12.2 than Higher High Water. After it enters Johnstone Strait, the tide becomes even more sluggish and requires more than 30 min to reach Kelsey Bay, just over 75 km to the east, and an additional 35 min to reach Chatham Point, only 37 km from Kelsey Bay. Respective speeds over these two distances are 150 km/h and 63 km/h. Throughout the journey along Johnstone Strait the tide also decreases in range. This, in part, results from the tide spreading into the various corners of the complex region and from a loss of energy due to friction and mixing processes. At Seymour Narrows, a complicated exchange of water takes place with the result that Higher High Water on the northern side of the Narrows becomes Lower High Water on the southern side of the Narrows. Moreover, both High Water and Low Water are delayed by approximately 2 h at the Narrows. South of Cape Mudge at the northern end of the Strait of Georgia, the diminished southward moving tide then meets the northward moving tide to produce a system of weak and variable currents.

In Fig. 12.8 the tides have been plotted over a month at three locations (Alert Bay, Kelsey Bay, and Campbell River) to show the biweekly variation of the tidal range. Note the reduction in range from one location to the next, the biweekly modification of the diurnal inequality, and the difference in the form of the tidal curves between Campbell River and the more northerly locations.

Currents

Despite its importance to many aspects of the marine environment of southwestern British Columbia, the Johnstone Strait region has only recently received special attention from oceanographers. As a consequence, the assumption must be made that current measurements from a few strategic locations within the major channels can be used to imply the overall flow structure, even though recent measurements have clearly demonstrated the limited applicability of such an assumption, especially where the channel is curved or where shallow sills are present. The symbols in Fig. 12.2 mark the locations of current meter moorings used to study the circulation in the Johnstone Strait region. Current observations from the two starred locations in Johnstone and Queen Charlotte straits will be considered in some detail. In the former case, particular attention will be paid to the circled station because in this region of the channel the mainland coast lies directly opposite the coast of Vancouver Island and, therefore, is the section through which all east–west water exchange must take place.

Johnstone Strait–Discovery Passage

These two channels are characterized by swift and rectilinear tidal currents. In the vicinity of shallow sills and constricted narrows, surface currents are accelerated even further, and take on a turbulent jetlike nature, generally associated with quasi-permanent tidelines that delineate rapid cross-stream changes in speed and direction of the set. Tidelines are especially well defined at the seaward extremity of Johnstone Strait, in the vicinity of Kelsey Bay, and south of Seymour Narrows. Many authors of oceanographic books have referred to Seymour Narrows as an illustration of the maximum strength attainable by tidal currents in the world ocean and to demonstrate their hazard to navigation.

Figure 12.9b–d illustrates the kinds of flow variability at various depths near mid-channel in Johnstone Strait and Discovery Passage; Fig. 12.9a shows the corresponding sea-level variations within the region. Flood currents in Johnstone Strait are toward the east (measured upward in each figure) and ebb currents are toward the west (measured downward in each figure). In Discovery Passage, floods are toward the south and ebbs toward the north. An analysis of these currents indicates they can be separated into three distinct components.

1) Tidal streams associated with the astronomical tide which change speed and direction in a regular manner throughout the day.

2) Estuarine currents driven by freshwater runoff and induced along-channel density gradients which are essentially steady over periods of days.

3) Wind currents confined to the upper layer of the water column which only become important during times of moderate to strong winds.

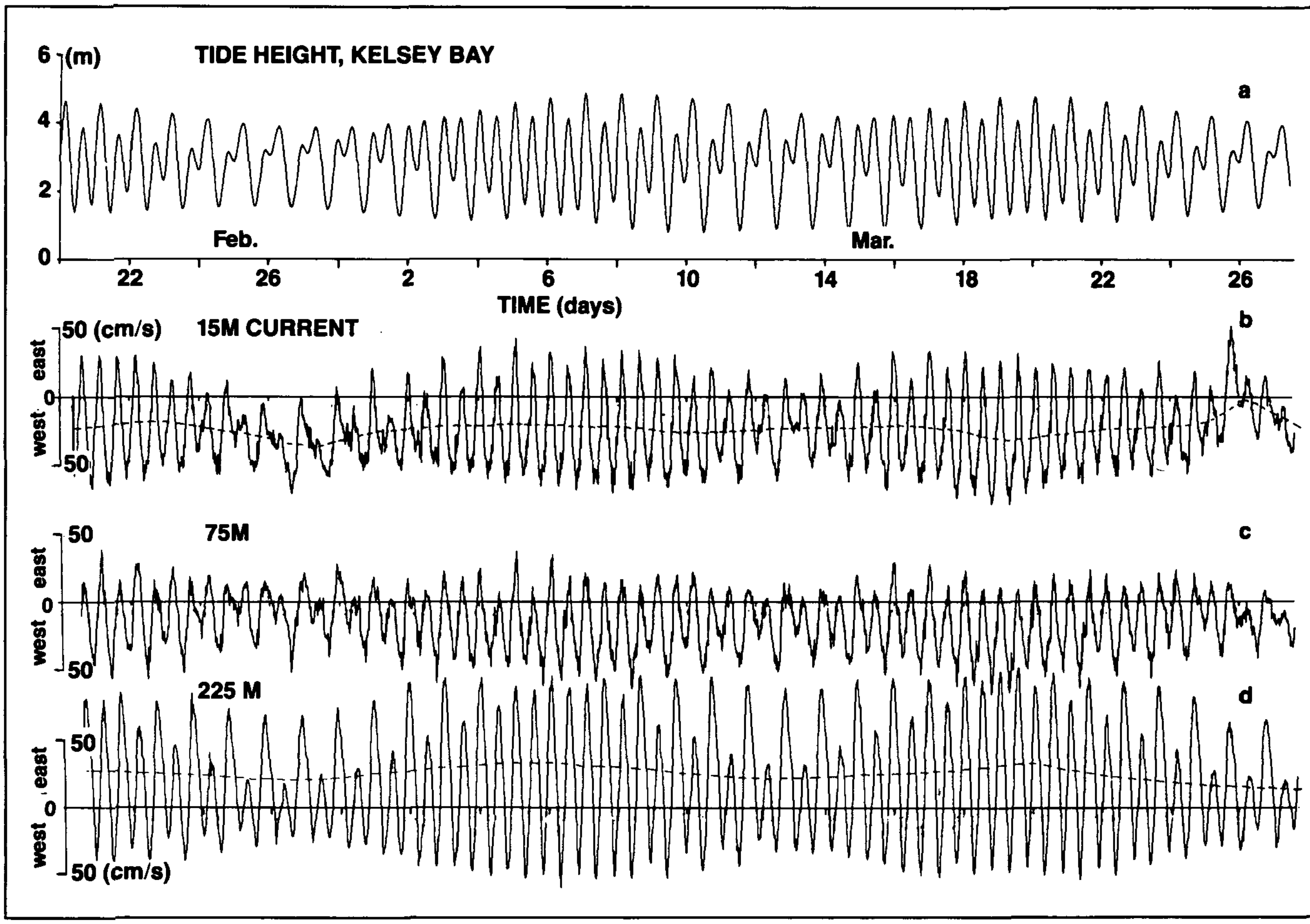

FIG. 12.9 Tides and tidal currents near Kelsey Bay February and March 1973. Tide heights (a) at Kelsey Bay compared with along-channel (east-west) component of currents (b) 15, (c) 75, and (d) 225 m deep, 10 km to west (circled star in Fig. 12.2). Speeds, cm/s; tide heights, m. Lines in (b) and (d) give strength and direction of mean (residual) flow. (From Thomson 1976).

The last two constitute the residual or nontidal current. All three components are in turn affected by the earth's rotation, channel curvature, bottom topography, and the cross-sectional area of the channel. The latter effect, for example, requires that where the width or depth of the channel decreases in the direction of flow, there is an acceleration of the along-channel current to maintain the same volume of transported water and vice-versa.

ESTUARINE CURRENTS

Estuarine currents are a slow, time-varying component of the overall flow that change speed and direction with depth in the channels. In Fig. 12.9b, d, they are represented by the gradually varying line drawn through the more rapidly changing curve for the total current composed of the tidal stream and combined wind-estuarine flow. In the estuarine component, the flow in the upper layer (Fig. 12.9b) is always westward in Johnstone Strait and northward in Discovery Passage; that is, toward the sea. In the lower layer (Fig. 12.9d), the estuarine flow is always to the east in Johnstone Strait and to the south in Discovery Passage; that is, toward the Strait of Georgia. This two-way structure is clearly illustrated in Fig. 12.10, based on current velocity measurements taken at various

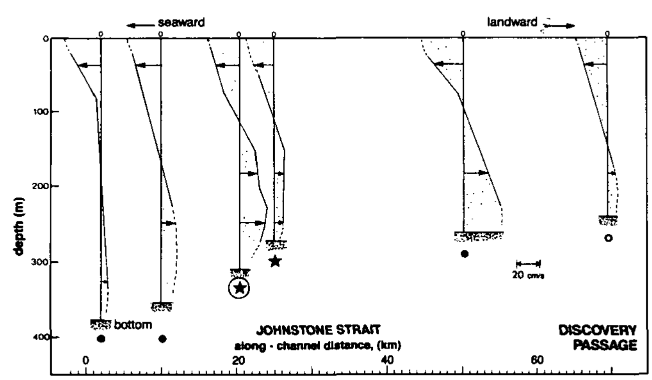

FIG. 12.10. mean flow profiles at various locations in Johnstone Strait and Discovery Passage. Symbols correspond to Fig. 12.2. Resultant currents are westward in upper layer, eastward in lower layer. Speeds obtained by measuring horizontally from vertical axis and comparing to scale.

depths along mid-channel. Above about 100 m the average flow is always seaward whereas below this depth it is invariably landward. Thus, a log on the surface of Johnstone Strait or Discovery Passage would drift progressively toward the open ocean (in the absence of persistent westerly winds) at roughly 20 cm/s (0.4 kn); a powerless submarine near the bottom, by contrast, would gradually drift toward the Strait of Georgia at an average speed of 5–10 cm/s (0.1–0.2 kn). This type of depth-dependent net drift is, of course, common to many inland seaways along the British Columbia–Washington coast (see Juan de Fuca Strait, Chapter 11). As in other coastal regions, moreover, the strength of the estuarine current in the two channels varies over periods of days, weeks, and months in response to changes in the amount of land drainage entering the system, to variations in the large-scale winds over southwestern British Columbia, and to the degree of along-channel tidal mixing but, unlike more exposed channels such as Juan de Fuca Strait, is less susceptible to direct modifications introduced via the open ocean. (Estuarine circulation is discussed more thoroughly in Chapter 2.)

Figures 12.11A, B illustrate the cross-channel structure of the estuarine current at two locations in Johnstone Strait. The flow is probably representative of Johnstone Strait and Discovery Passage as a whole, excluding Seymour Narrows, Race Passage, and Weynton Passage, where tidal jets and fronts are known to disrupt the expected flow patterns. The main feature is that, in the upper seaward flowing layer, the strongest average currents are on the mainland side of the channel whereas in the lower eastward flowing layer, the strongest currents are on the Vancouver Island side. This effect is due in part to the Coriolis effect. Also, because these particular measurements were taken where the channel has a pronounced curvature, the inertia of the water was an important factor in producing the stronger surface currents along the mainland side. The combined effect of the earth's rotation and the curvature of the channel is seen further to produce a downward tilt of the line of zero net velocity, which separates the westward outflow in the upper layer from the eastward inflow in the lower layer. The downward tilt is greater in Fig. 12.11A because of the greater channel curvature involved. Moreover, the cross-sectional area of the upper layer experiences comparatively little along-channel variation except in the narrower passes of the seaway. As a result, near-surface speeds of the estuarine component of the flow are typically around 20 cm/s (0.4 kn) throughout most of Johnstone Strait and Discovery Passage. The cross-sectional area of the lower

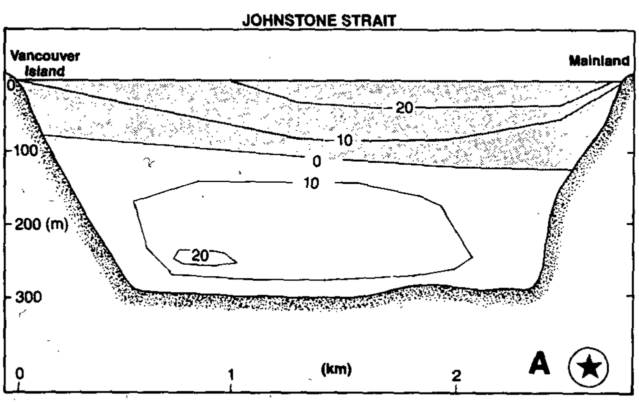

FIG. 12.11. Speed (cm/s) and direction of mean currents at two cross-channel locations in Johnstone Strait. (A) February–June 1973.

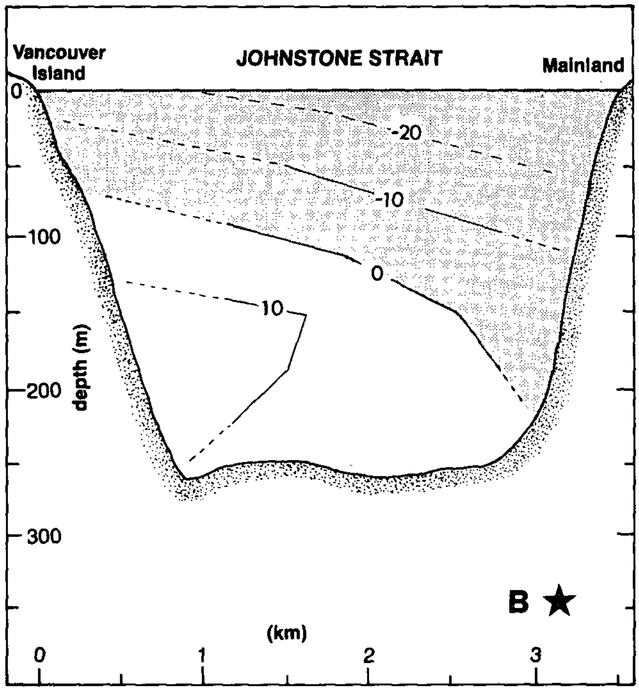

FIG. 12.11. (B) May 1978. Symbols correspond to Fig. 12.2. In shaded upper zone, net flow is westward (negative values); in lower zone, net flow is eastward (positive values). Broken lines represent less certain values of speed.

layer, on the other hand, undergoes large along-channel variations due mainly to changes in depth. This leads to the marked differences in the speed of the nontidal current at depth along the two channels (Fig. 12.10).

Recommendation A slow boat that needs more than a day to cover a particular course in Johnstone Strait or Discovery Passage should keep well to the starboard side of mid-channel. The boat will get maximum assistance from the estuarine flow when heading westward and minimum resistance from this current when heading eastward.

Residual plus Tidal Streams

The tidal stream contribution will now be discussed in relation to the estuarine current. In the absence of any surface wind drift, the sum of these two accounts for nearly all the observed current speed and variability.

Tidal streams are that part of the total current directly associated with the rise and fall of the tide; except where deflected by the bottom topography or coastline they produce no significant net drift over a period of a few tidal cycles, just as the tide produces no net change in the water depth. In reality, of course, those who make tidal predictions lump the pure tidal streams together with the residual currents to get a sort of hybrid tidal flow, a procedure that can be erroneous unless the residual current remains almost constant over many weeks and months. As the residual flow is not generally constant because of variability in the various mechanisms that produce it, current predictions are often incorrect, particularly for times of slack water.

There are a number of things to note about the combined tidal current and residual current in Fig. 12.9b. For example, the ebbs are much stronger than the floods and the maximum strength of these currents varies in a regular way over a period of 15 days in agreement with the tides. Near mid-channel, the larger of the two ebbs each day is generally over 50 cm/s (1 kn), sometimes reaching 75 cm/s (1.5 kn) during spring tides. On the other hand the larger of the two floods is always weaker than 50 cm/s whereas the weaker flood often produces nothing more than a short period of slack water near high tide. In fact, many days can pass before there is any appreciable surface flood current in Johnstone Strait and Discovery Passage. Within ½ km of either shore the speed of the net current diminishes so that at any given time nearshore speeds are about 20% weaker than those near mid-channel. Moreover, surface currents are usually weaker on the Vancouver Island side than on the mainland side.

As indicated in Fig. 12.9b, the surface ebb currents have a much longer duration than the floods; 8–10 h for ebbs compared with 2–4 h for floods. Nevertheless, near mid-channel the maximum ebbs and maximum floods always occur within ½ h of local low water and local high water, respectively, unless there is a strong wind blowing. Away from mid-channel, the times of maximum ebb or flood become increasingly delayed until at either side they occur roughly 1 h later than at mid-channel. Table 12.3 gives the times of tidal currents at various locations along Johnstone Strait and Discovery Passage based on current observations taken between 1976 and 1978.

TABLE 12.3. Delay times of ebb and flood streams within the Johnstone Strait region. Time (min) for a particular stage of flood (e.g. maximum flood) after its occurrence at western end of Queen Charlotte Strait. Time delay for a particular stage of ebb. As an example, maximum flood occurs at northern end of Discovery Passage about 160 min later than Queen Charlotte Strait.

	Queen Charlotte Strait	Johnstone Strait			Discovery Passage	
	west	west	central	east	north	Seymour Narrows
Flood	0	100	110	140	160	170
Ebb	170	70	60	30	10	0

There is another important facet of the relationship between the tide and the tidal currents in Johnstone Strait and Discovery Passage. The stronger of the two floods each tidal day is not directly associated with the higher of the two high tides, nor is the stronger of the two ebbs directly associated with the lower of the two low tides each day. A rule must be devised, based on the predicted tides, to predict (in a qualitative sense at least) whether to expect strong or weak tidal currents.

Rule for flood currents If an ensuing flood is preceded by Lower Low Water then it will be the stronger of the two floods for a particular 25-h period; if the ensuing flood is preceded by Higher Low Water, it will be the weaker of the two floods for that day. The greater the difference in height between the two low tides the greater the difference in the strength of the two floods.

Rule for ebb currents If an ensuing ebb is preceded by a Higher High Water then it will be the stronger of the two ebbs for a given 25-h period, but if the ensuing ebb is preceded by Higher Low Water then it will be the weaker of the two ebbs for that day. The greater the difference in height between these two high tides the greater the difference between the strength of the two ebbs.

There are of course exceptions to this rule but, generally speaking, the current directions and speeds are closely tied to the height of the tide 6 h earlier. The sequence of the surface currents varies but typically follows the daily pattern larger flood, larger ebb, weaker flood, weaker ebb, although there is usually only a small difference in the strength of consecutive ebbs.

Wind Currents

Winds can generate significant surface currents if the fetch and strength of the wind are sufficiently great. The long, narrow channels provided by Johnstone Strait and Discovery Passage are well suited to this type of situation.

Figure 12.12 illustrates four occasions when the record of the flow was "abnormally" disrupted. The wind data for this region show that these four periods corresponded to times of strong along-channel winds, whose average speeds exceeded 7 m/s (14 kn) for more than 24 h. The most spectacular change in the normally regular pattern of the currents occurred around March 27 when the floods were appreciably enhanced. According to the wind charts, this was the time of the strongest storm of the season and westerly winds blew up-channel at an average speed of over 10 m/s (20 kn) for over 3 days. At its height, this particular storm generated an inward wind-drift current of over 20 cm/s (0.4 kn), and if it is considered that the currents were actually measured at a depth of 15 m, the wind currents right at the surface probably had speeds of around 30 cm/s (0.6 kn) or about 3% of the average speed of the wind. (Unfortunately surface measurements cannot be made with moored instruments in this region because of the possibility of damage by ships.) A somewhat different case occurred around February 27 when the winds were down-channel (easterly). At that time, the ebb currents were strengthened by the wind, and for a period of several days there were no flood currents.

The above findings again bear out some general comments concerning the currents in Johnstone Strait and Discovery Passage. In winter, when the prevailing winds are from the southeast, the wind currents will tend to enhance the ebb currents and, therefore, reduce the strength and duration of the flood currents. This effect will occur less often in summer when the prevailing northwesterlies tend to enhance the floods and, therefore, ensure a regular daily reversal of the flow regime.

Additional Current Features

Some general features of the current pattern in these northern channels have been described. Now some particular aspects of these flows will be examined.

One of the more surprising features of the current observations so far is that there appears to be little flow through the entrances to channels that open into

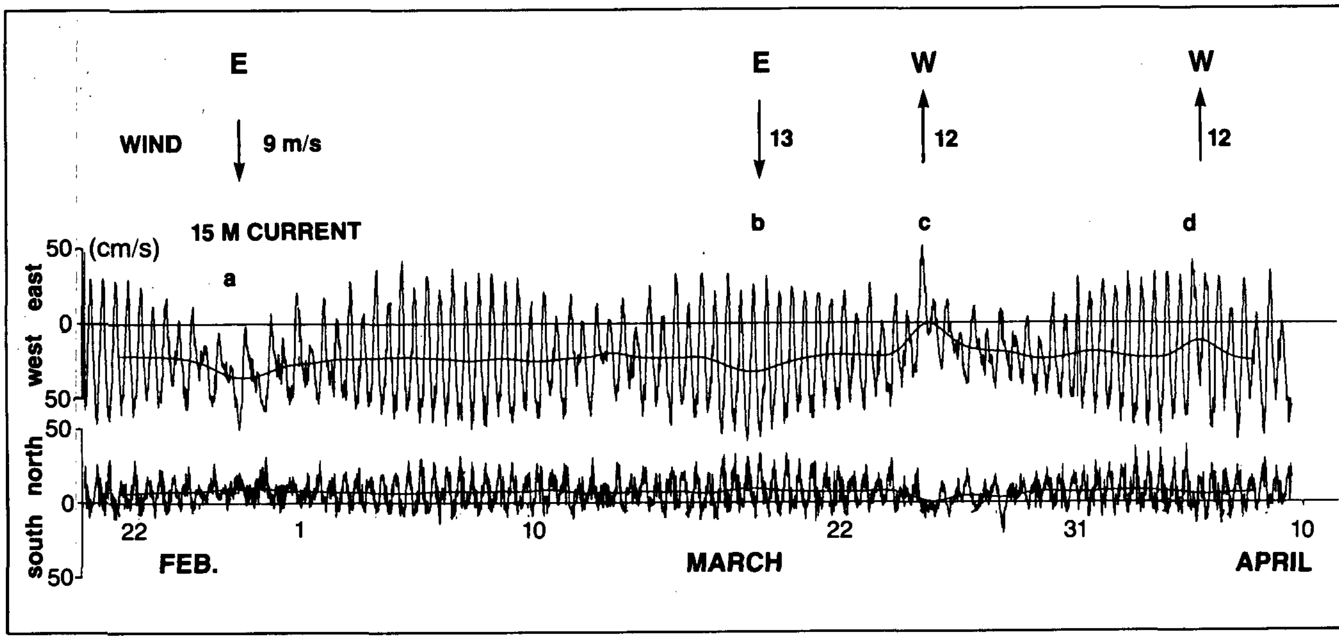

FIG. 12.12. Variations in speed and direction of currents at a depth of 15 m (50 ft) in Johnstone Strait at circled-star in Fig. 12.2. February–April 1973. Top line, along-channel currents; bottom line, weaker cross-channel currents. Flood directions are upward and ebb directions downward. Solid line through more rapidly varying ebb–flood cycles represents residual flow persistent to west and north (i.e. like persistent ebb). Residual current disrupted on four occasions (a–d) by strong winds; numbers next to arrows give wind speed (m/s). Downward arrows correspond to easterly winds, upward arrows to westerly winds.

Johnstone Strait or Discovery Passage from the mainland side. Therefore, strong currents are mostly confined to the main basins except in the very narrow tidal passes such as Yuculta and Dent rapids further inland. At the entrance to Sunderland Channel north of Kelsey Bay, for example, surface currents were almost nonexistent at a time when currents in Johnstone Strait, less than ½ km to the south on the other side of Yorke Island (Fig. 12.2), had speeds of nearly 100 cm/s (2 kn). Measurements from Nodales Channel that adjoins the northern end of Discovery Passage also reveal weak currents compared to those along the main channels to the west. Therefore, it would appear that tidal streams along Johnstone Strait and Discovery Passage prefer the larger channels and little branching of the flow takes place.

The brief current velocity measurements obtained in the 500-m deep, western end of Johnstone Strait indicate that tidal currents from Weynton Passage penetrate to the very bottom of the basin during the flood. The result is an eastward-advancing wall of water with a strong bottom jet that sweeps up-channel at maximum speeds in excess of 1.5 m/s (3 kn). A sharply defined tideline usually marks the leading edge of the flood waters that push their way into the Strait from the adjoining passages. Formation of the strong penetrative jet in this case is analogous to that of Rupert Inlet described in Chapter 3, with negatively buoyant flood streams that sink as they enter the less dense water of the Strait.

At the opposite end of the deep western basin of Johnstone Strait, it is over the shallow 70-m deep sill on the Kelsey Bay side of Race and Current Passages that some of the most vigorous tidal mixing on the coast occurs (see Fig. 12.3, 4, 5). Within the confined passages themselves, the swirling ebb and flood streams can flow at more than 3 m/s (6 kn) and there is little maneuvering room for larger vessels or tugs with a tow. These factors led to establishment of a maritime separation scheme in the vicinity of Helmcken Island, that requires traffic to proceed westbound via Current Passage and eastbound via Race Passage (Chart No. 3523). Mariners should note that the times of slack water in Race Passage are nearly simultaneous with those at Seymour Narrows, despite the 65-km separation and, therefore, are obtainable from tide tables. This correspondence also holds true for low-water slack in Current Passage but not, surprisingly, for high-water slack. For some reason (possibly the differences in inertia of the flood streams in each channel), the turn to ebb in Current Passage occurs some 75 min earlier than in Race Passage! It may be this peculiarity that accounts for the sharply defined tideline that lies in a northwest–southeast direction just west of Hardwicke Island on the ebb; waters on the northern side of the demarcation line can be ebbing westward at the same time those to the south flood eastward or flow westward at a somewhat slower rate. On the change to flood, the slow westward advance of the tideline is arrested, reverses direction, and approaches Kelsey Bay along the Vancouver Island shore. The waters behind the line are commonly distinguished by their turbulent churning motions and by an accompanying choppy sea, which breaks at the leading edge of the advancing convergence zone. Eventually, the tideline enters the two passages where it is swept away during the change to flood.

Perhaps the most interesting feature of the currents is the presence of a strong, westward-propagating internal tide in the deep western basin of the Strait. An analysis of current meter records from this basin (Thomson and Huggett 1980) indicates these long internal waves of tidal period are continually generated by the ebb–flood motions of the astronomical tide over the shallow sill immediately west of Kelsey Bay. Within 10 km of the sill, these internal tides produce depth-variable, along-channel currents with upper layer speeds of about 20 cm/s (0.4 kn), which accounts for the marked difference in the strength of the tidal flows between the top and bottom layers. Yet, despite the magnitude of these internal motions, less than 0.3% of the total energy carried eastward by the inward-propagating, astronomical tidal wave goes into their generation at the sill. The internal tides themselves undergo rapid frictional damping as they travel toward Broughton Strait, with current speeds attenuating by a factor of ⅓ within a distance of a single wavelength (25 km) from their place of origin. Half way along the 100-km channel any trace of the internal tides has all but disappeared.

Queen Charlotte Strait

Present knowledge of the flow structure in this region is based on 4 mo of velocity measurements taken at the western end of the main basin (Fig. 12.2). Essentially, the current patterns have a similar synthesis to those in Johnstone Strait — tidal streams, estuarine currents, plus wind-drift currents. Because of the considerably greater cross-sectional area of Queen Charlotte Strait, however, all but the wind-generated surface currents have appreciably lower speeds compared to Johnstone Strait.

At the shallow, more northerly location, the estuarine component of the flow was seaward to a depth of roughly 100 m, with maximum near-surface speeds of about 15 cm/s (0.3 kn). Extrapolation of the data implies that the deeper waters to the bottom at 135 m were inland but at a much slower speed, consistent with the normal kind of estuarine flow structure found throughout the inland seaways (Fig. 12.13a). The estuarine flow at the deep, more southerly location was quite different (Fig. 12.13b). In this case, the average drift was negligible to a depth of 15 m, then gave way to a comparatively strong inflow to a depth of about 250 m. The estuarine component was again weak from this depth to the bottom at 330 m. If the measurements were characteristic of Queen Charlotte Strait, it means that the lower-density surface waters that flow out of Johnstone Strait eventually make their way seaward via the northern half of the basin. In contrast, the higher density oceanic waters that eventually plunge to the deeper portions of Johnstone Strait gradually work their way eastward at middepths on the southern side of Queen Charlotte Strait. Much of this oceanic water appears to move through Goletas Channel and, based on the bathymetry of the Strait, most likely prefers to continue eastward, following the deep trough that terminates north of Malcolm Island. During the height of the snowmelt period in early summer, there is probably a strengthening of the estuarine current in the surface layer and a more definitive seaward flow over the entire breadth of the Strait.

Tidal streams in the Strait are mixed, mainly semidiurnal so the two floods and two ebbs each lunar day are generally of unequal strength. The larger daily flood and ebb typically have speeds of around 20–25 cm/s (0.4–0.5 kn) but increase to as much as 30 cm/s during large spring tides. (Stronger flows will, of course, arise over shoals and in constricted passes between islands.) Tidal ellipses are flat and oriented parallel to the axis of the basin at all depths (Fig. 12.14). Except near the shore or in the vicinity of shoals, therefore, tidal streams flood to the east-southeast and ebb to the west-northwest and there is negligible cross-channel set. When the estuarine circulation is added to these pure tidal streams, the flow structure over the northern portion of the basin resembles a somewhat weakened version of Johnstone Strait, with relatively strong ebb currents and weak flood currents in the upper

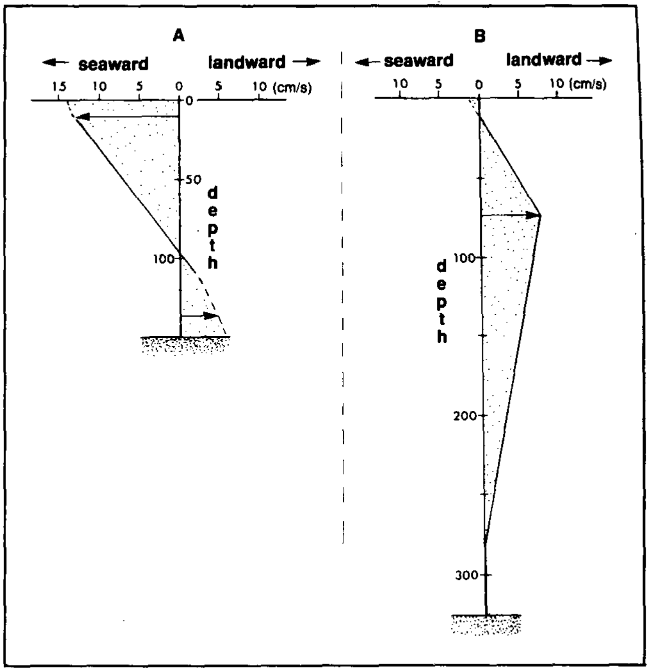

FIG. 12.13. Speed and direction of mean currents at two locations, western Queen Charlotte Strait, January–May 1977. (see Fig. 12.2 for locations.) (A) northern side; (B) southern side. Net flow generally seaward (westward) on northern side and landward (eastward) on southern side.

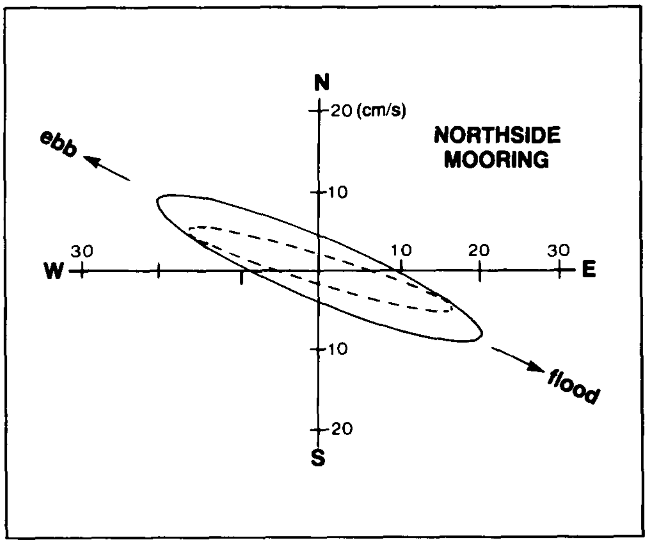

FIG. 12.14. Ellipses for semidiurnal tidal currents at two depths, northside mooring location, Queen Charlotte Strait. Solid line for 15 m depth; broken line for 75 m depth. Speeds cm/s, and currents rotate clockwise around ellipses (see Rotary Currents, Chapter 3).

100 m and the reverse situation at depth (Fig. 12.15a). Except during summer months, on the other hand, surface currents over the southern half of the basin possess little of this ebb bias (Fig. 12.15b).

Wind-generated surface drift in open oceanic basins like Queen Charlotte Strait was discussed in Chapter 4, 10. The only additional comment to make here is that the prevailing northwesterlies in summer tend to produce drift currents that partially counter the net seaward flow in the upper layer. During moderate to strong winds, flood currents become of comparable strength and duration to the ebb currents. The opposite effect develops in winter under the prevailing southeasterlies and, as in Johnstone Strait, there may be periods of a day or so when floods are weak or nonexistent. Further details on the currents in Queen Charlotte Strait await future oceanographic studies.

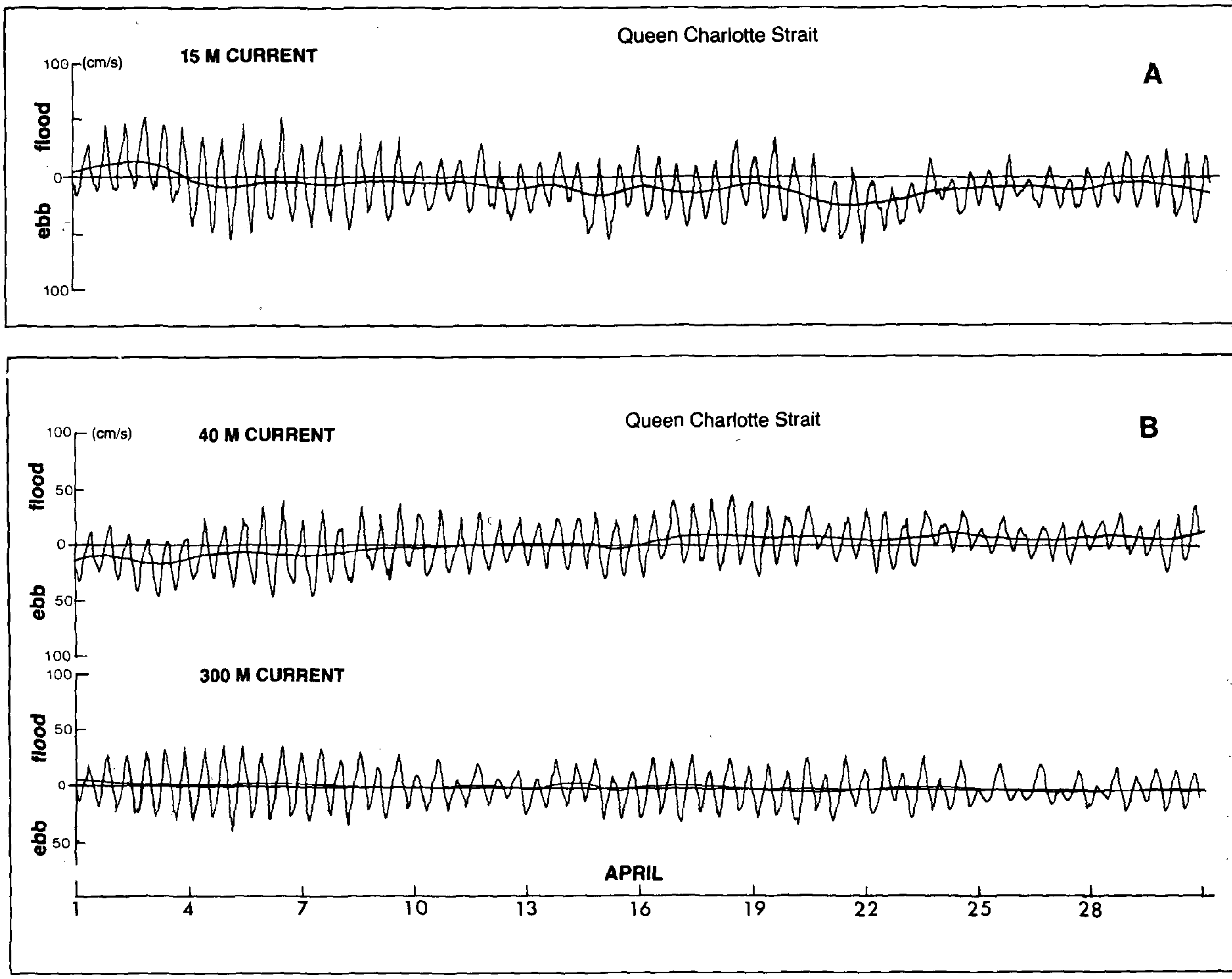

FIG. 12.15. Along-channel currents at western end Queen Charlotte Strait, April 1977 (A) northside, at depth of 15 m, (B) southside, at 40 and 300 m. Smooth line through more rapidly varying tidal currents represents residual flow.