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CANADIAN ARCTIC TIDE MEASUREMENT TECHNIQUES AND RESULTS

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ABSTRACT

About 10 years ago the Canadian Hydrographic Service recognized the need for a planned approach to completing tide and current surveys of the Canadian Arctic Archipelago in order to meet the requirements of marine shipping and construction industries as well as the needs of environmental studies related to resource development. Therefore, a program of tidal surveys was begun which has resulted in a data base of tidal records covering most of the Archipelago. In this paper the problems faced by tidal surveyors and others working in the harsh Arctic environment are described and the variety of equipment and techniques developed for short, medium and long-term deployments are reported. The tidal characteristics throughout the Archipelago, determined primarily from these surveys, are briefly summarized.

It was also recognized that there would be a need for real time tidal data by engineers, surveyors and mariners. Since the existing permanent tide gauges in the Arctic do not have this capability, a project was started in the early 1980's to develop and construct a new permanent gauging system. The first of these gauges was constructed during the summer of 1985 and is described.

INTRODUCTION

The Canadian Arctic Archipelago shown in Figure 1 is a large group of islands north of the mainland of Canada bounded on the west by the Beaufort Sea, on the north by the Arctic Ocean and on the east by Davis Strait, Baffin Bay and Greenland and split through the middle by Parry Channel which constitutes most of the famous North West Passage. The tides in the channels of the Archipelago

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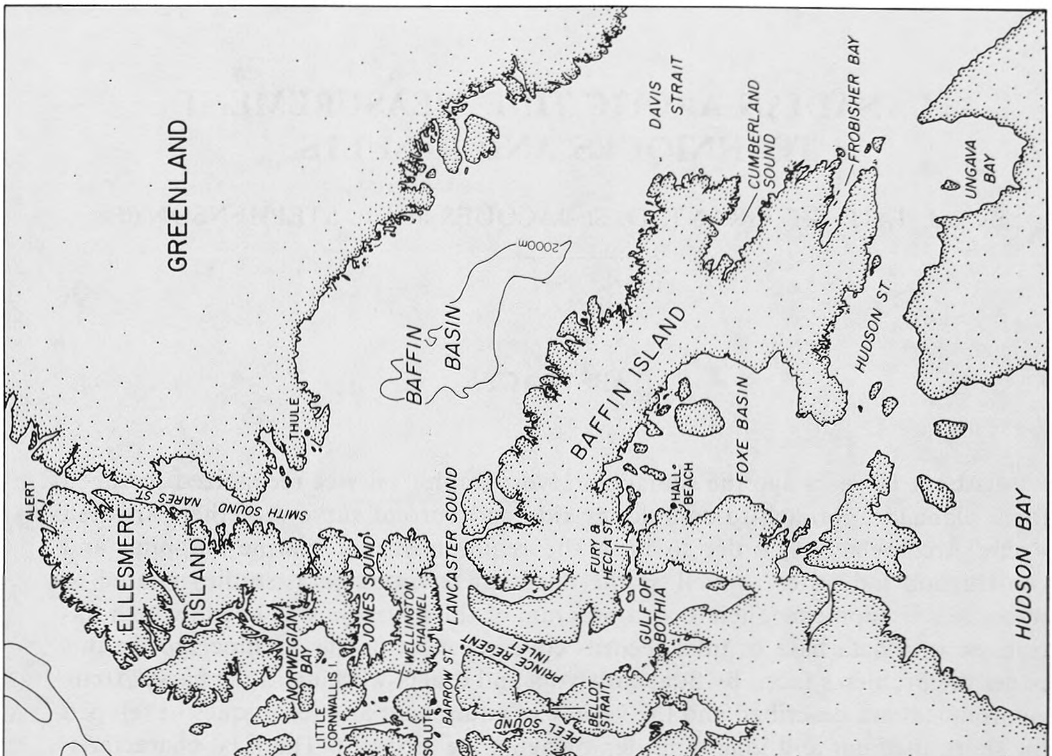

FIG. 1. — Canadian Arctic Archipelago.

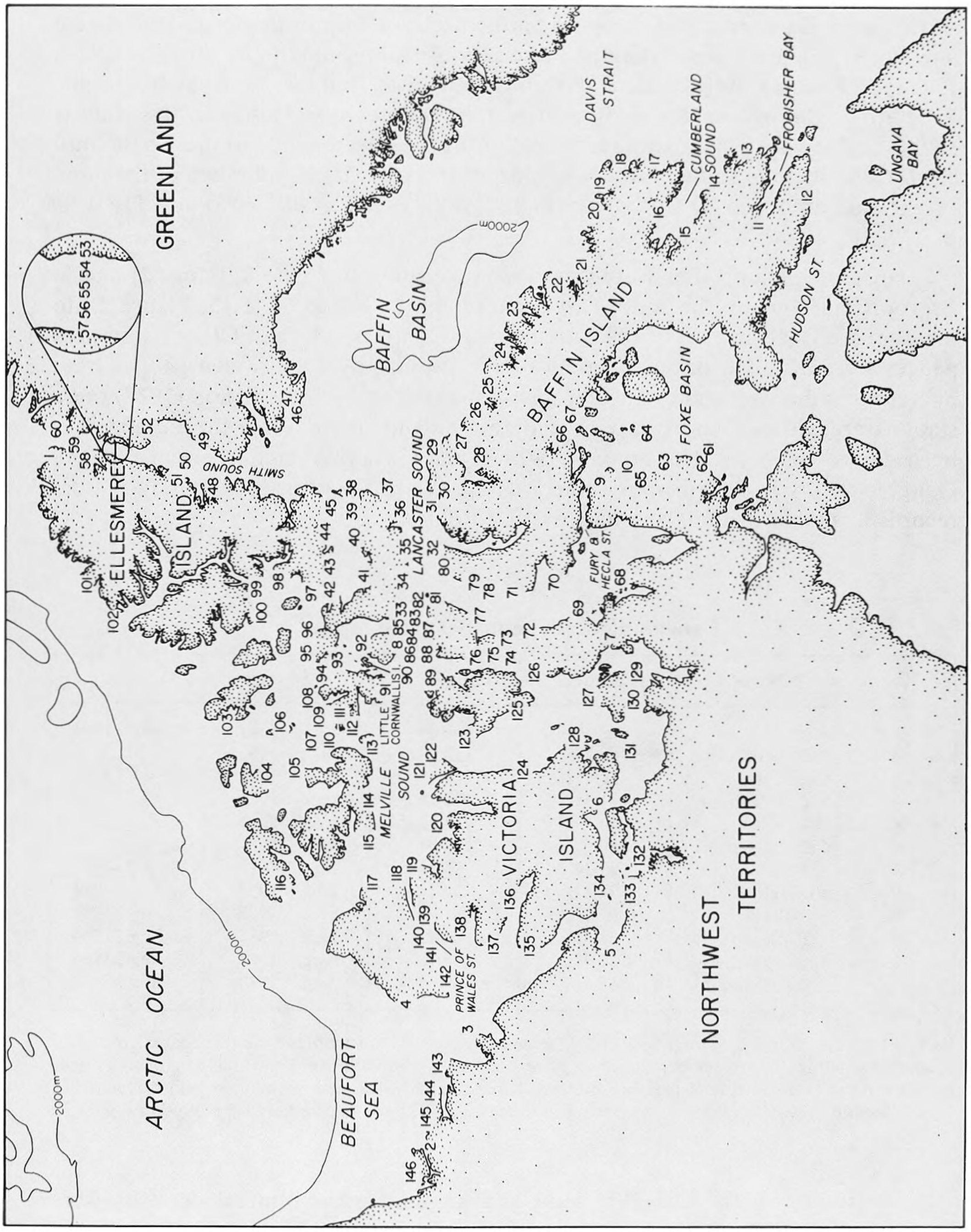

FIG. 2. — Locations of tide and current measurement sites during the past 10 years. Tables 1 and 2 give the names, positions, dates and lengths of the records collected.

consist of combinations of the Atlantic Ocean tide propagating westward through the Labrador Sea and Baffin Bay and the tide of the Arctic Ocean propagating eastward.

The earliest tidal observations made in the Arctic were those of the explorers of this land. Data from Port Leopold on the north-east tip of Somerset Island near site No. 81, Figure 2, date from the search for Sir John Franklin by Sir James Ross in 1848. Records were collected during scientific, military and hydrographic expeditions throughout the early part of the 20th century. However, this data is sparse and few systematic measurements of the tides were made in the Arctic until 1957. Compilations and appraisals of most of this early data and much of the more recent data are given by CORNFORD *et al.* (1982), BIRCH *et al.* (1983) and FISSEL *et al.* (1983).

In 1957 gauging sites were installed at Resolute Bay (site 8, figure 2) and at Brevoort Harbour on the south east coast of Baffin Island, (site 13, Figure 2), to measure sea levels as part of the International Geophysical Year. Other permanent gauges were installed through the 60's and 70's and by 1974 fifteen gauges were operating in the Arctic and Hudson Bay. As described by STEPHENSON (1977) these stations are difficult and costly to maintain and in recent years the number has been decreased to six. The present status of the Canadian Arctic Permanent Tide Gauge Network is described in Table 1. The network has provided the longest tidal records available in the Canadian Arctic to date.

TABLE 1

Canadian Arctic permanent tide gauges

No.	Name	Latitude	Longitude	Start	End
1.	Alert	82 30	62 20	Aug., 1961	Aug., 1984
2.	Tuktoyaktuk	69 27	133 00	July, 1952	
3.	Cape Parry	70 09	124 40	July, 1966	
4.	Sachs Harbour	71 58	125 15	Sept., 1971	
5.	Coppermine	67 49	115 05	Nov., 1972	
6.	Cambridge Bay	69 07	105 04	Aug., 1961	
7.	Spence Bay	69 32	93 31	Mar., 1970	
8.	Resolute Bay	74 41	94 54	Sept., 1957	Aug., 1984
9.	Igloolik	69 22	81 48	Sept., 1975	Sept., 1981
10.	Hall Beach	68 45	81 13	Sept., 1981	Aug., 1984
11.	Frobisher Bay	63 43	68 32	Aug., 1963	Aug., 1984
12.	Lake Harbour	62 51	69 53	Aug., 1970	Aug., 1982

Except for sites 2 and 6, which have bubbler gauges, the tidal instruments at these sites consist of submersible self recording devices that are replaced each year by divers. Site 1 and sites 8 through 11 have been temporarily discontinued pending successful completion of the new permanent gauge depicted in Figure 10. Site 12 was destroyed by an iceberg in the fall of 1982 (station numbers are plotted in Figure 2).

Beginning in the late 1960's oil and gas and other mineral deposits were discovered in the Arctic Archipelago and the Beaufort Sea. The impending increase in shipping activities to move these resources to southern markets has emphasized the need for hydrographic surveys to modern standards throughout the Arctic. To meet the requirement for vertical control for these hydrographic surveys, tidal observations have been made either concurrent with or in advance of the survey operations. However, the Canadian Hydrographic Service (CHS) also recognized the need for a planned approach to completing tide and current surveys of the whole Archipelago in order to meet the needs of marine shipping and construction industries, as well as the needs of environmental studies related to the same resource development. Therefore, about 10 years ago, a program of tidal surveys was begun which has resulted in a data base of tidal records covering most of the Archipelago. At the same time, it was apparent that there would be a need to supply real-time tidal data to users, particularly engineers working on coastal structures and mariners navigating to these sites. Since the existing permanent gauging instruments in the Arctic do not have this capability, a project was started in the early 1980s to develop and construct a new permanent gauging system.

This paper reports on the methods used and planned to be used by the CHS to collect tidal data in the Canadian Arctic. It also describes the general characteristics of the tide that propagates through the Archipelago. For details on other aspects of tidal and current surveying and tidal analysis in the CHS see FORRESTER (1983), GODIN (1972) and FOREMAN (1977).

SHORT TERM TIDAL MEASUREMENTS

The installation of tidal instruments in open water in the Arctic Archipelago during the short summer season is often hindered by moving ice floes and bergs and the uncertainty of finding open water. Therefore, the vast majority of short term tidal records (lasting one to two months) have been collected during the winter, using instruments deployed through the relatively stable ice cover. (See Table 2 and Figure 2). The start and end dates for this type of operation are dictated by the number of hours of daylight on one end and the safety of the ice for landing aircraft on the other. Suitable conditions usually occur in a two-month window between mid to late February and late April to early May, depending on latitude.

Submersible self-recording pressure gauges have been used almost exclusively for these surveys. This type of instrument can be started in a warm environment, then sealed and transported to the site for deployment with no further adjustments. This is a definite advantage in the Arctic where winter temperatures of — 40 °C are not uncommon. Even when sealed, the tide gauges are sensitive to cold temperatures and must not be allowed to sit on the ice since small amounts of moisture inside the case will condense and freeze on contacts and moving parts. The submersible gauges have the added advantage of being small enough to be easily installed through the ice.

For most of these deployments the submersible gauges are programmed to record frequency counts of a digi-quartz pressure sensor on magnetic tape every 15 or 30 minutes. Following recovery, the tapes are returned to the office and the frequency counts are translated to equivalent pressure values using the latest calibration coefficients. Since total pressure is measured, it is necessary to substract the atmospheric pressure to obtain the hydrostatic pressure. These hydrostatic pressure values are then converted to tidal heights using representative values for

TABLE 2

Permanent and temporary tidal and current measurement sites occupied by the Canadian Hydrographic Service during the past ten years. Sites marked by * are current meter sites. These sites are plotted in Figure 2.

No.	Name	Latitude	Longitude	Central Time (M/Yr)	Length (Days)
13	Brevoort I.	63 16	64 09	3/85	57
14	Lemieux I.	64 37	65 10	3/85	56
15	Kingmiksok	65 31	67 05	3/85	56
16	Pangnirtung Fiord	66 05	65 56	3/85	53
17	Anjijak I.	65 36	62 17	3/85	55
18	Cape Dyer	66 36	60 19	Flooded	
19	Padloping I.	67 12	62 26	3/85	49
20	Broughton I.	67 32	63 45	3/85	56
21	Cape Hooper	68 25	66 36	3/85	54
22	Avlitiving I.	69 31	67 08	3/85	48
23	Cape Christian	70 31	68 13	3/85	53
24	Scott Inlet	71 15	71 08	3/85	53
25	Cape Hunter	71 40	72 19	3/85	26
26	Nova Zembla I.	72 13	74 39	3/85	53
27	Albert Harbour	72 46	77 29	12/84	276
28	Pond Inlet	72 42	77 58	1/83	279
29	Cape Liverpool	73 16	80 45	3/85	52
30	Canada Point	73 38	77 56	3/85	52
31	Borden Station	72 46	77 29	4/83 2/85	87 135
32	Sargent Point	73 52	86 07	Lost	
33	Cape Ricketts	74 38	91 18	3/85	50
34	Maxwell Bay	74 39	88 51	Lost	
35	Burnett Inlet	74 29	86 09	3/85	49
36	Dundas Harbour	74 31	82 28	3/85	49
37	Cape Cockburn	74 51	79 22	3/83	61
38	Coburg I.	75 49	79 27	Lost	
39	Belcher Point	75 46	81 06	8/83	31
40	Cape Skogn	75 46	84 13	3/83	61
41	Nookap I.	75 36	87 36	3/83	61
42	Bay of Woe	76 25	89 01	3/81	46
43	Baad Fiord	76 22	86 34	3/83	19
44	Grise Fiord	76 25	83 05	3/83	61
45	King Edward Point	76 08	81 04	8/83	31
46	North Baffin Bay	76 18	70 11	8/83	23
47	Thule, Greenland	76 33	68 53	8/83	24
48	Alexander Fiord	78 55	75 31	4/85	44
49	Marshall Bay	78 56	69 25	4/85	44
50*	Kennedy Channel	79 55	69 28	Lost	
51	Scoresby Bay	79 55	71 19	4/85	47
52	Nygaard Bay	80 02	65 28	4/85	47
53	Cape Field	81 07	64 12	4/85	46
54*	Kennedy Channel	81 08	64 25	Lost	
55*	Kennedy Channel	81 11	64 50	4/85	39
56*	Kennedy Channel	81 12	65 28	4/85	39
57	Cape Defosse	81 13	65 48	4/85	47
58	Cape Murchison	81 47	64 13	4/85	49
59*	Robeson Channel	81 57	61 59	4/85	40
60	Cape Brevoort	81 58	60 14	4/85	49
61*	Cape Wilson	67 06	81 23	3/84	45
62	Cape Wilson	67 06	81 23	3/84	45
63	Cape Jermain	67 46	81 46	3/84	45
64	South Spicer I.	68 12	79 05	3/84	46
65	Roche Bay	68 24	82 09	3/84	47

TABLE 2 (cont.)

No.	Name	Latitude	Longitude	Central Time (M/Yr)	Length (Days)
66*	Steensby Inlet	69 52	78 30	3/84	42
67	Steensby Inlet	69 52	78 30	3/84	18
68	Cape Chapman	69 18	89 15	3/84	41
69	Martin Islands	70 19	91 40	3/84	41
70	Easter Cape	70 55	89 27	3/84	42
71	Cape Kater	71 58	90 04	3/84	42
72	Cape Augherston	71 29	93 17	3/84	41
73	Bellot Str. East	72 01	94 20	4/83	39
74	Bellot Str. West	71 58	95 08	4/83	39
75	False Strait	71 59	95 10	8/77	2
76	Wadsworth I.	73 26	95 41	5/79	62
77	Fury Point	72 54	91 48	4/83	42
78	McBean I.	72 38	89 38	5/79	55
79	Port Bowen	73 17	89 03	4/83	44
80	Peak Valley	73 42	87 52	4/83	44
81	Whaler Point	73 49	90 18	4/83	44
82	Burrow Strait	74 13	93 46	4/83	28
83	Burrow Strait	74 24	93 54	4/83	27
84	Burrow Strait	74 34	94 01	4/83	30
85	Assistance Bay	74 37	94 14	10/81	364
				4/82	40
86	Griffin Inlet	75 07	92 10	3/79	47
87	Gifford Point	74 10	93 37	4/82	40
88	Cape Granite	73 42	95 45	4/81	39
89	Cape Briggs	73 38	96 54	4/81	44
90	Lowther Island	74 39	97 25	4/81	47
91	Allison Bay	74 58	99 22	4/81	46
92	Stuart Bay	75 38	94 35	4/80	32
93	Pelham Bay	76 45	96 54	4/76	33
94	Hyde Parker I.	76 29	97 06	3/79	42
95	Norah Island	77 01	96 37	3/79	43
96	Bere Bay	76 57	94 10	3/81	45
97	Lands End	76 54	89 25	3/81	46
98	West of Bjorne Pen.	77 42	88 57	3/81	145
99	Hyperite Point	78 08	88 53	3/81	45
100	Cape Southwest	78 13	91 50	3/81	45
101	Cape Woods	82 16	86 48	4/83	44
102	Audhild Bay	81 32	91 09	12/82	369
				12/83	357
				11/84	372
103	Isachsen	78 47	103 32	12/83	360
				12/84	345
104	MacKenzie King I.	77 29	110 14	3/79	52
105	Vessey Hamilton I.	76 53	109 00	3/79	47
106	Lougheed I.	77 27	104 53	3/79	51
107	Cameron I. West	76 30	104 35	4/85	42
108	Seymoor I.	76 48	101 14	3/79	42
109	Cameron I. East	76 25	103 00	4/85	42
110	Cameron I. T.S.	76 19	104 02	4/85	42
111	Massey I.	76 04	102 17	4/85	42
112	Alexander I.	75 46	103 17	4/85	42
113	Byam Martin I.	75 01	104 13	3/77	33
114	Cape Bounty	74 51	109 32	3/77	34

TABLE 2 (cont.)

No.	Name	Latitude	Longitude	Central Time (M/Yr)	Length (Days)
115	Cape Dundas	74 28	113 46	4/82	105
116	Mould Bay	76 17	110 28	12/83	370
				12/84	364
117	Parker Point	73 52	116 15	4/82	107
118	Russel Point	73 29	115 08	3/79	23
119	Peel Point	73 16	115 11	5/77	18
120	Natkusiak Pen.	73 01	110 28	3/77	31
121	Stephansson I.	73 45	105 11	3/78	34
122	Stephansson I.	73 23	104 28	4/80	36
123	Minto Head	73 06	102 15	4/80	37
124	Cape Stang	71 29	104 16	4/80	36
125	Thackeray Point	71 40	99 42	4/80	31
126	Otrick I.	72 36	95 33	5/79	52
127	Cape Felix	69 56	97 58	4/80	34
128	John Halkett I.	70 01	100 48	4/80	34
129	Gjoa Haven	68 38	95 53	10/79	143
				4/80	101
130	Gladman Point	68 39	97 44	2/80	369
131	Jenny Lind I.	68 39	101 45	9/79	81
132	Bay Chimo	67 42	107 57	1/84	307
133	Hepburn I.	67 54	110 54	11/79	207
134	Johansen Bay	68 35	111 21	1/85	300
135	Bell I.	69 38	117 00	4/82	33
136	Prince Albert Sound	70 42	114 16	4/82	33
137	Holman I.	70 44	117 45	4/82	35
138	Fort Collinson	71 37	117 52	4/82	31
139	Victoria I.	72 41	118 00	3/82	41
140	Johnston Point	72 45	118 27	3/82	41
141	Jessie Harbour	72 15	120 09	4/82	33
142	De Solis Bay	72 26	121 32	4/82	36
143	Baillie Islands	70 31	128 21	8/77	48
				8/81	58
				8/82	39
144	Gillet Bay	70 09	124 40	2/84	365
145	Atkinson Point	69 57	131 28	8/81	50
				8/82	44
146	Garry I.	69 27	135 36	8/77	66
				8/81	45

water density and temperature. At remote sites barometric pressure readings are taken during deployment and recovery and are averaged to obtain a constant atmospheric pressure correction which is applied to the whole record. This approach places a limit on the accuracy of the absolute tidal heights in the order of the fluctuations in atmospheric pressure (i.e. 1 to 2 decimetres). Self-recording barometers capable of operating unattended at the extreme Arctic temperatures are presently not available. Near communities with weather stations, the barometric records are used to correct the tidal records and some improvement in accuracy is achieved.

The installation of submersible gauges is carried out by first drilling a hole approximately 30 cm in diameter through the ice using a portable gasoline-powered auger. Ice thicknesses are normally between one and three metres. Earlier moorings consisted of a weight attached to the bottom of the gauge and floats attached to the top (Fig. 3). The whole package was lowered to the bottom using a wire rope

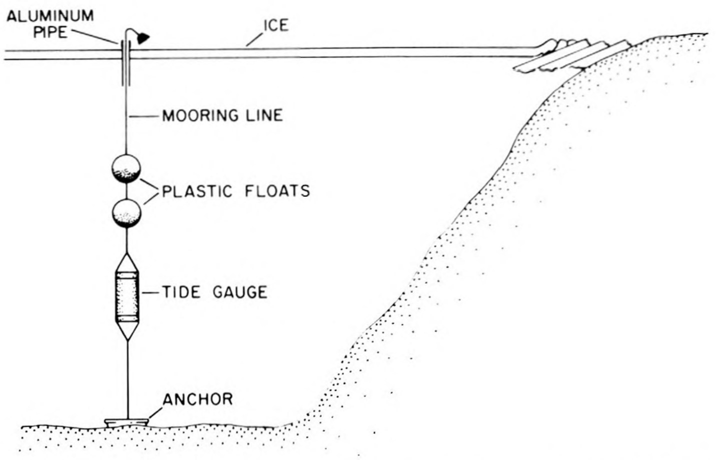

FIG. 3. — Temporary through-ice tide gauge mooring. More recent deployments dispensed with the floats and anchor.

FIG. 4. — Temporary through-ice tide gauge mooring about to be deployed. Both helicopters and fixed-wing aircraft are used during these surveys.

as illustrated in Figure 4. In more recent deployments the flotation was removed and the gauge was enclosed in a steel pipe that provided both weight and protection. Since aircraft are used during all installations, the weight of the mooring equipment is an important consideration. Therefore, yet another deployment scheme involved the use of PVC pipe and nylon rope instead of wire rope. A short length of chain was attached to the bottom of the gauge to provide extra weight and also to prevent it from rolling down steep bottom slopes. Each of these approaches has been successful, although during some of the more recent deployments the instruments settled on the bottom on end and later fell over, resulting in a datum shift of several centimetres part way through the record. After the instrument has been lowered to the bottom the rope is allowed to freeze in the hole. A certain amount of slack is left in the rope to allow for the vertical movement of the ice cover with the tide. To recover the gauge at a later date a second hole is drilled near the first one, the rope is snagged using a hooked arm (Fig. 9) and the gauge is pulled to the surface.

The selection of the site is a critical factor to the success of the deployment and recovery. The spacing of the sites must be adequate to define the tide in the study area. The ice in the area must be shorefast and smooth and thick enough to allow a fixed-wing aircraft to land. The water depth must be sufficient to avoid the risk of ice keels grounding on top of the gauge or of the ice growing in thickness and reaching the bottom. This latter situation results in the gauge being encapsulated in the ice and impossible to recover. The site must also be in good hydraulic contact with the study area. GODIN (1980) found, for example, that at "sites removed from the open ocean by shallows or in deep recesses of water bodies... ranges appear higher during open water and the time of arrival of the tide is changed".

For easy location during recovery the sites should be near prominent geographical features such as islands or small bays. This is particularly important since much of the Arctic landscape has little relief or colour under the winter snow cover. Although radio navigation systems are used, they do not always provide sufficient accuracy to pinpoint the markers which identify the sites. Experience has shown that reliance should not be placed on the marker. Even large fluorescent plywood markers or oil drums are difficult to see from the air and it is not uncommon to have them completely covered by snow or totally destroyed by polar bears.

MEDIUM AND LONG TERM DEPLOYMENTS

Early attempts to collect multi-year tidal records in the Arctic used conventional stilling wells or bubbler gauges. Since these instruments were not capable of operating unattended for extended periods, they had to be installed near communities. The locations were often not ideal from a tidal perspective and the extreme temperatures and ice conditions made them unreliable. The remoteness of the sites made them difficult and expensive to maintain. In recent years the CHS has devised a number of new techniques for collecting multi-year records using submersible water level recorders. Although many of the problems of the earlier instruments have been overcome, a number of new problems have had to be dealt with. Before recounting the various new techniques that have been used, some of these problems are discussed.

Since submersible gauges are typically capable of operating for up to 14 months, attempts to collect records of lengths longer than one year have made it necessary to redeploy a replacement gauge at exactly the same position. Unfortunately, due to the different ageing characteristics of the pressure sensors in the gauges, slight datum shifts between the two records occur, even when the replacement gauge is installed at precisely the same position as the previous instrument. This makes it difficult, although not impossible, to use these records for long term mean sea level studies.

In most areas of the Arctic the ice melts, breaks up and moves during the summer months. However, the presence of open water at a site at a particular time or even at any time during a given year is not guaranteed. When the ice is moving, icebergs and pressure ridges ground even at significant depths.

The two main modes of transportation in the Arctic are by ships and by aircraft. Shiptime is expensive and ship operations are restricted to the summer months. Even in summer their movements are limited by the sea ice and there is no guarantee that they will be able to reach a particular site. Some sites are never accessible to ships. Aircraft operations to remote sites are not feasible during the winter period of total darkness. Fixed-wing aircraft equipped with ski-wheels can land on the ice during the early spring, before break-up, but during the summer the ice is either unsafe or non-existent and the number of land based landing sites is very limited. Helicopters can be used during these periods but their range and carrying capacity is limited.

Divers have been and still are used very effectively for deploying and recovering submersible tide gauges under the Arctic ice. However, the use of divers under these circumstances introduces a number of operational constraints. The most important consideration is, of course, the safety of the diver working under the ice. The additional equipment necessary to support a diving operation is expensive both to acquire and to transport to the site. The depth of the mooring is limited and if qualified divers are not already on staff they must be hired.

To overcome these problems a number of different approaches to collecting tidal data have been used. At many sites the presence of open water along the shore during the summer months is quite common. Initially a large anchor pad with an instrument mounting bracket is placed in the water. Using suitable flotation the diver maneuvers the anchor into position away from the shore, sometimes under the permanent ice cover. Ideally the anchor is placed in a depression on the bottom so that the shallower water around the gauge prevents icebergs from drifting over it. Each year thereafter the diver returns, removes the gauge and replaces it with a new one. Although this approach has been very successful, problems do occur. For example, when the diver swam out to replace the gauge at Lake Harbour (site 12, Figure 2) in the summer of 1983, he found a 20 m wide, 5 m deep trench where the gauge should have been. An iceberg had drifted through the site the previous fall.

In areas where there is permanent ice cover or where the site is only accessible during the spring, before the ice breaks up, a slightly different approach is used. A special ice melting machine, shown in Figure 5, is used to melt a ring 75 cm in diameter through the ice. The cylinder of ice within the ring is then removed to create the required hole as illustrated in Figure 6. An anchor similar to that described above or a mooring package similar to that shown in Figure 3 is then deployed through the hole. In succeeding years a new hole is melted and the gauge is replaced by diver as shown in Figure 7. The deployment site is positioned from horizontal control points on shore and can be accurately reoccupied each year.

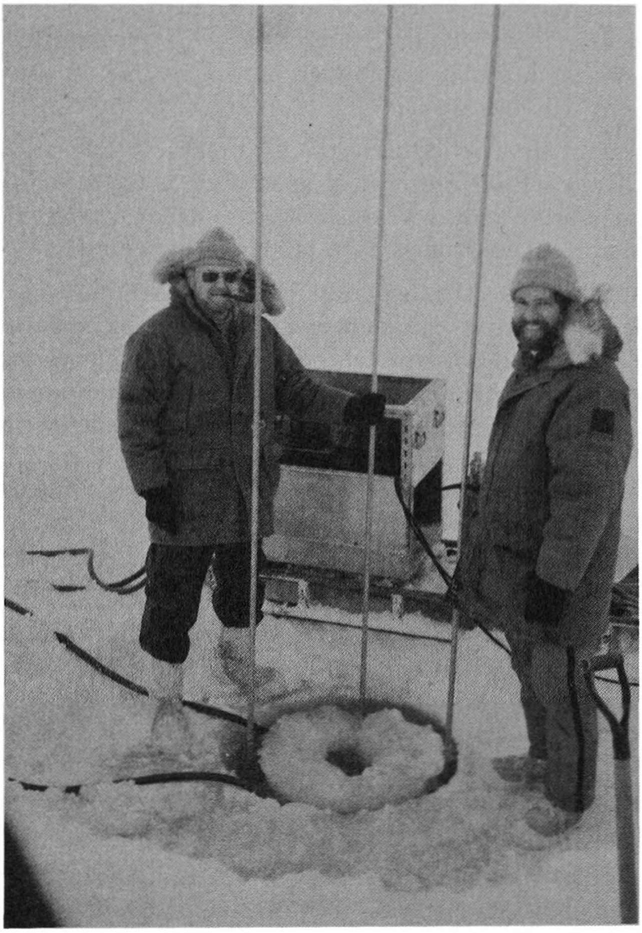

FIG. 5. — Ice hole melter in operation. Initially a 30 cm hole is drilled through the ice using a gasoline-powered auger. A 75 cm ring is then melted around the hole as shown. The hole melter consists of a circular pipe or melting ring with three rods attached for recovery. Water is heated in the furnace shown at the rear and is pumped through hoses to the melting ring.

In 1981 the CHS attempted to recover a tide gauge mooring in Barrow Strait with a Remotely Operated Vehicle (ROV). In theory, the ROV was to search for the mooring with the aid of its underwater television and attach a line to the mooring once located. The mooring was then to be acoustically released and guided to the surface for recovery. However, the ROV was unable to locate the mooring without having acoustic locating equipment installed on both the ROV and the mooring. Because of this failure and the logistic problems associated with the operation, it has not been attempted again. However, it is possible that, with more compact and more sophisticated ROVs, this may be a viable alternative in the future.

In 1982 a 5-year project was commenced to measure long term sea level variations in the Arctic Ocean at sites adjacent to the Arctic Archipelago. This project required the design of an instrument mooring package that could be deployed in areas with year-round ice cover. The mooring had to be entirely

FIG. 6. — Removing ice cylinder to create 75 cm hole. After the ring is melted through the ice a rope is used to lift the ice cylinder out of the hole. The Twin-Otter in the background is the most common type of fixed-wing aircraft used on these types of surveys.

FIG. 7. — Diver about to descend beneath the ice.

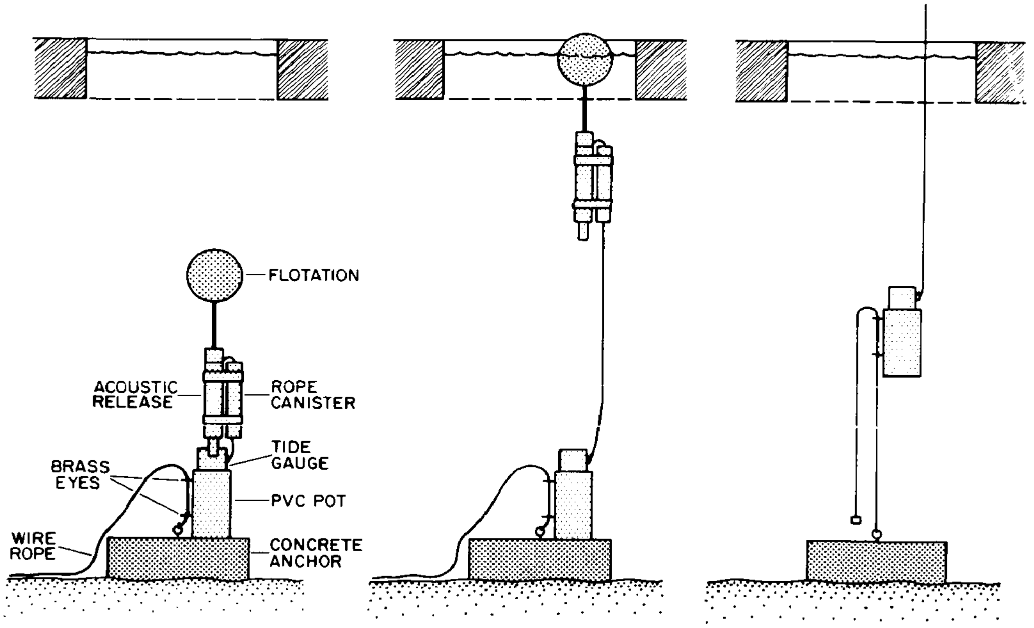

Figure 8

self-contained, with no surface attachments, and yet be configured so that the gauge could be recovered without diver support through a hole melted in the ice and then redeployed onto the mooring platform.

The requirements were met by the mooring package illustrated in Figure 8. The mooring platform is a concrete-filled drum which is lowered through a 75 cm diameter hole in the ice to the bottom using a wire rope. The wire rope is permanently attached to the drum and becomes the messenger line for guiding the instrument package to the platform. The instrument package consists of a float, an acoustic release, a rope canister, a pinger and the tide gauge. After deployment of the package the messenger line is strung out beneath the ice away from the platform, using a line of holes drilled in the ice, and is lowered to the bottom as shown in Figure 9.

For redeployment a hole is melted in the ice at the site and the acoustic release is triggered and brought to the surface by the float. If the float does not surface at the hole, it can be grappled using a hooked arm deployed beneath the ice surface. The rope from the canister is paid out as the float ascends and is used to raise the tide gauge. As the gauge is raised it pulls with it the wire messenger rope which is then used to redeploy the package.

This mooring package has been used successfully since 1982 at the three sites numbered 101, 102 and 103 on Figure 2. As a follow-up to this project it is felt that a submersible tide gauge capable of operating for up to 10 years without service, and acoustically transmitting data to the surface on a yearly basis, would provide a viable alternative to the above technique. Such an instrument is not presently available. Also, a self-contained, self-recording barometer capable of operating unattended for year-long periods at remote sites in the Arctic is not available.

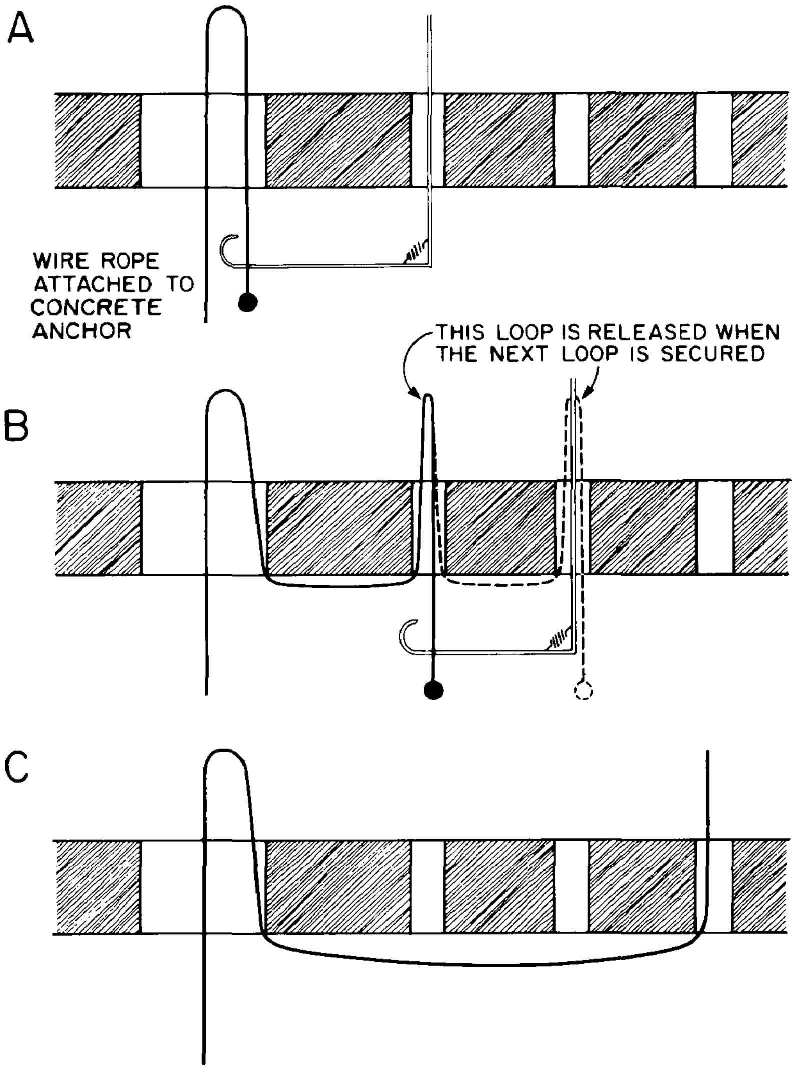

Figure 9

FIG. 8 & 9. — Long term through-ice tide gauge mooring. The concrete anchor is lowered to the bottom using a wire rope which becomes the messenger line for guiding the instrument package to the platform. The messenger line is then strung out beneath the ice away from the platform using a line of holes as illustrated in Figure 9. For redeployment a hole is created and the acoustic release triggered and brought to the surface by the float. The rope from the canister is paid out as the release ascends and is used to raise the tide gauge. As the gauge is raised it pulls with it the wire messenger rope which is then used to redeploy the package.

PERMANENT WATER LEVEL GAUGING STATIONS

A continuing need for a permanent water level gauging installation in the Arctic is foreseen, with applications expanding to include the use of real-time data by marine operators for projects related to resource development. With this in mind, a project was started to develop and construct a permanent gauging system which will be engineered for installation and operation at coastal structures built in the Arctic to transmit the data to a southern site for quality control purposes and to provide the data to local users on a real-time basis.

The design and manufacture of this system is complete in most respects (see Figure 10) and installation will take place during the summer of 1985 at Polaris Mine of Cominco Ltd. on Little Cornwallis Island (Figure 1) where a ship loading dock built of vertical sheet piles exists. The depth of water at the base of the piling is sufficient to enable the sensor to be installed approximately 7.5 m below low water.

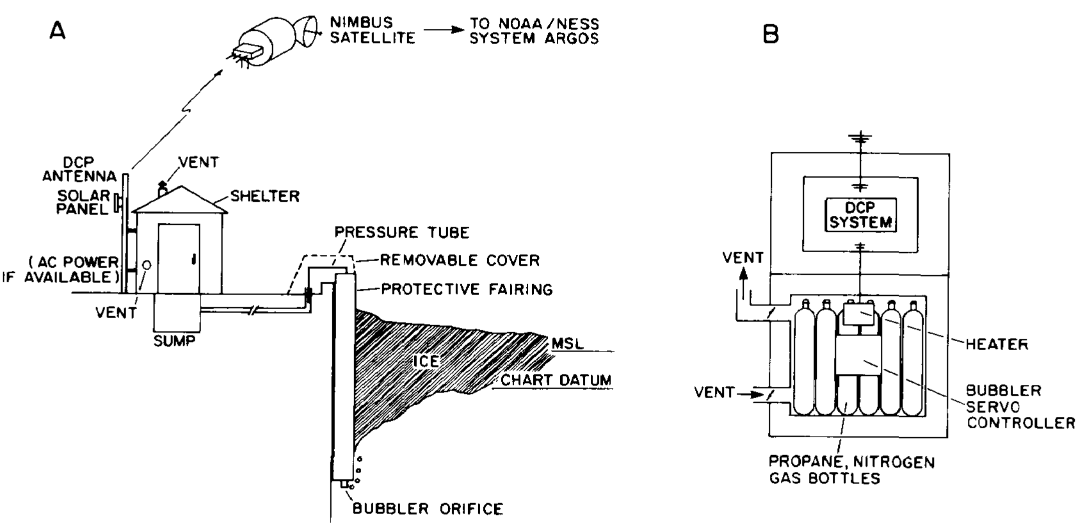

FIG. 10. — Permanent Arctic tide gauge being built at Little Cornwallis Island. See text for details.

A nitrogen gas purge system (i.e. bubbler gauge) will be used to measure the hydrostatic pressure head over the sensing orifice. A protective housing consisting of a 20 cm steel pipe behind a fairing of plate steel will be welded to the face of the dock. Within the pipe a sectional 5 cm diameter stainless steel support assembly will be installed which in turn will house the stainless steel bubbler hose. A cast bronze sensing orifice is attached to the base of the support assembly. The protective housing is a permanent installation while the support assembly, bubbler hose and orifice are designed to be installed and removed from the top of the protective housing using a small mast and chain hoist.

The pressure in the bubbler system will be measured by an electronic differential pressure sensor with atmospheric pressure compensation applied. The sampling and storage of data will be controlled by a satellite data collection platform (DCP). Data transmission will be by Service Argos. Both the pressure sensor and DCP will be housed in an enclosure located on the deck of the loading dock and insulated and heated to reduce the operational temperature range. The data will be telemetered by satellite to a southerly location to allow monitoring of the gauge performance and detection of operating problems. While the design of the bubbler system is specific to Little Cornwallis Island, the overall gauge system should prove adaptable to installation at other suitable structures in the Arctic.

TIDAL CHARACTERISTICS IN THE CANADIAN ARCTIC ARCHIPELAGO

The tides in the Canadian Arctic Archipelago, as determined to a large extent from the surveys carried out during the past decade, will now be described briefly. Much of the information has been incorporated into the various CHS publications (e.g. Tide Tables, Sailing Directions and charts). General descriptions of the tides and currents are given by DOHLER (1966), GODIN (1980) and KU (1980), and numerous papers and reports on the tides and currents in specific areas have also been published.

The tide in the channels of the Archipelago reflect the complex interaction of the Atlantic Ocean tidal signal propagating northwestward through Davis Strait and Baffin Bay and the tide of the Arctic Ocean propagating eastward. However, the Atlantic Ocean tide, with a range several times that of the Arctic Ocean, is the dominating influence throughout most of the area. The mean surface flow in the Canadian Arctic is from the Arctic Ocean toward the south and east (LEBLOND, 1980). Strong oscillating tidal currents and counter currents opposite to the general surface flow are found in many of the channels.

Baffin Bay

The tides in Baffin Bay are semi-diurnal with a range of 3.0 m in the south. They become mixed mainly semi-diurnal with a range of 2.8 m in the north at the entrance to Lancaster Sound. An M_2 amphidromic point exists near Clyde River (site 23, Figure 2) where the range is 1.4 m. The tides in the north are about 6 hours out of phase with those in the south. A Canadian Contractor Report of Hydrography and Ocean Sciences, describing the results of the 1985 deployments at sites 13 through 37 and 48 through 60, Figure 2, is now in preparation. The currents in Nares Strait are described by GODIN (1979) and FISSEL (1980).

Hudson Strait, Ungava Bay and Foxe Basin

The tides in Hudson Strait, Ungava Bay and the south and east portions of Foxe Basin are semi-diurnal in character and become mixed mainly semi-diurnal in the northern part of the basin where they are influenced by the tides from the Gulf of Boothia. The tides in Fury and Hecla Strait are mixed mainly diurnal.

The large tide range at the entrance to Hudson Strait is 7.3 m and increases as the tide propagates westward through the Strait. Dramatic increases in tidal range also occur as the tide propagates into Ungava Bay where ranges of about 14.8 m have been recorded at Lac aux Feuilles in the south west corner. No modern tidal records have been collected in this area in recent years, so it is possible that the tides may equal or even exceed those of the Bay of Fundy on Canada's east coast where the highest tides in the world of 16 m have been recorded. Tidal currents of 5 to 7 knots occur throughout Ungava Bay and the eastern entrance to Hudson Strait.

Tidal ranges along the north shore of Hudson Strait are about 20 % larger than along the south shore and increase to a maximum of 12.6 m about halfway through the Strait. Thereafter, the tidal range decreases to about 3.0 m at Nottingham Island in the west. As the tide propagates into Foxe Basin, its range continues to decrease northward along the western side of the basin to an amphidromic point located just south of Hall Beach where tides of 1.4 m occur. Ranges of 9 m have been reported in the southeast corner of Foxe Basin.

About one hour after entering the eastern end of Hudson Strait the tide has progressed to the south shore of Ungava Bay and about half way through the Strait. However, a further three hours is required for it to progress to the southern entrance of Foxe Basin. The degenerate amphidromic point at Hall Beach causes the tides in the northern half of the basin to be about 6 hours out of phase with those in the south.

For further details on the tides and other oceanographic features of Hudson Strait, Ungava Bay and Foxe Basin, see GRIFFITHS *et al.* (1981), DRINKWATER (1983), GREISMAN (1984), PRINSENBERG (1985), and CHANDLER *et al.* (1985).

Lancaster Sound, Barrow Strait and Viscount Melville Sound

Throughout Lancaster Sound and Barrow Strait the tides are mixed mainly semi-diurnal and are semi-diurnal in Viscount Melville Sound. The tide enters the eastern end of Lancaster Sound from Baffin Bay and propagates westward to Resolute in about 1 1/2 hours, to the eastern end of Viscount Melville Sound in 3 hours and to the entrance to M'Clure Strait in about 6 hours. The large tide range remains constant at about 2.8 metres throughout Lancaster Sound but decreases westward through Barrow Strait and is 2.0 metres at Resolute. The tidal range in Viscount Melville Sound varies from 1.6 m to 1.0 m along the north shore and from 1.4 m to 1.0 m along the south shore. Further details on the tides and currents in this area are given by TAIT *et al.* (1980), TODOROFF (1982), FISSEL & MARKO (1978) and LEBLOND (1980).

Jones Sound and Norwegian Bay

The tide in Jones Sound is semi-diurnal and propagates into the sound from Baffin Bay, taking about 40 minutes to progress from the eastern entrance to Cardigan Strait at the western end. The large tide range at the eastern end is 2.7 metres and increases to 3.8 metres about three quarters of the way along the sound. The range decreases thereafter and is 2.9 metres at the entrance to Cardigan Strait. Through the strait the tidal range continues to decrease and is 1.6 metre where it enters Norwegian Bay. A Canadian Data Report of Hydrography and Ocean Sciences describing the data collected at sites 37 through 47, Figure 2, is in preparation. Further details are given by BARBER & HUYER (1977).

The tide in Norwegian Bay is semi-diurnal. Most of the tidal signal enters the bay from Jones sound and traverses the bay in a northwesterly direction in about 20-30 minutes. The range of tide in Norwegian Bay also decreases to the northwest from 1.6 m to 1.0 m. (SANDILANDS *et al.*, 1985).

Sverdrup Basin

The Atlantic tide entering the Sverdrup Basin from Wellington Channel and Penny Strait is mixed mainly semi-diurnal (SANDILANDS *et al.*, 1985). It requires about an hour to travel from Barrow Strait to the Sverdrup Basin and undergoes a reduction in range from 2.6 m to 0.8 m. In the basin, the character of the tide changes from mixed mainly semi-diurnal in the east to semi-diurnal in the west as the influence of the Arctic tide becomes more significant. It takes approximately 30 minutes to traverse the basin in a westerly direction and experiences a further reduction in range to about 0.5 m.

Prince Regent Inlet and Gulf of Boothia

The character of the tide changes markedly from mixed mainly semi-diurnal to mixed mainly diurnal as it propagates southward through Prince Regent Inlet to the Gulf of Boothia. Indeed, the tide in the vicinity of Bernier Bay (site No. 70, Figure 2) is diurnal. The range of tide also increases as the tide propagates southward, particularly along the western shore, where a gradual increase from 2.7 m to 3.7 m takes place between sites 81 and 68 on Figure 2. Along the eastern shore the tidal range remains constant at about 2.2 m, except at site 70 where the strongly diurnal tide has a range of only 1.6 m. The tide propagates through Prince Regent Inlet in about one hour but takes another three hours or more to progress to the end of the Gulf of Boothia. See St. JACQUES *et al.* (1983) and SANDILANDS *et al.* (1985) for further details.

Amundsen Gulf, Coronation Gulf, Queen Maude Gulf and M'Clintock Channel

Throughout this area the tides are mixed mainly semi-diurnal except in the western portion of Coronation Gulf where the tide is diurnal. The eastern extent of this diurnal influence has not yet been fully delineated. The large tide range in M'Clintock Channel (SANDILANDS, 1985) increases from 1.2 m in the north to 1.9 m in the south and then decreases again to approximately 0.7 m where it enters Queen Maude Gulf. The large tide range throughout the remainder of this waterway from Queen Maude Gulf to the Beaufort Sea is about 0.5 m, except near the western end of Coronation Gulf where the diurnal tide has a range of about 0.3 m.

The tide in the southern Beaufort Sea and in Amundsen Gulf propagates counterclockwise about an amphidromic point situated near the southwest corner of Banks I. It propagates quickly along the coast from Alaska to a point approximately midway along the Tuktoyaktuk Peninsula where it slows significantly, reaching Sachs Harbour (site 4, Figure 2) on Banks I. about six hours later. In Amundsen Gulf the tide travels east into Dolphin and Union Strait and Prince Albert Sound and northwest into Prince of Wales Strait.

The tidal propagation patterns in the waterways between the eastern end of Amundsen Gulf and the southern end of M'Clintock Channel are complex and not yet well defined. Further field surveys are planned for these areas.

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