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Some Features of Tsunamis on the Pacific Coast of South and North America

T. S. Murty, S. O. Wigen and R. Chawla

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Preface

This paper is to be published in Spanish in the Proceedings of the Tsunami Committee XVII Meeting, Lima, Peru 20-31 Aug. 1973, under the I.U.A.A. International Association of Seismology and Physics of the Earth Interior.

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Abstract

In order to investigate the response of inlets to tsunamis, the resonance characteristics of some inlets on the coast of Chile have been deduced through simple analytical considerations. A comparison is made with the inlets of southeast Alaska, the mainland coast of British Columbia and Vancouver Island. It is shown that the general level of intensity of secondary undulations is highest for Vancouver Island inlets, and least for those of Chile and Alaska. It is also shown that tsunami forerunners are more common than is generally believed.

Résumé

Dans le but d'étudier l'interaction des tsunamis, ou raz-de-marée du Pacifique, avec les fjords qui en jalonnent la côte, l'auteur calcule à partir de considérations analytiques simples les résonances caractéristiques de quelques fjords de la côte chilienne. Il les compare ensuite avec ceux du sud-ouest de l'Alaska, de l'Ile de Vancouver et de la côte de la Colombie-Britannique. Il montre qu'en général, l'intensité des ondulations secondaires est la plus élevée dans les fjords de l'Ile de Vancouver et la plus faible dans ceux du Chili et de l'Alaska. Il établit enfin que les signes avant-coureurs d'un raz-de-marée sont beaucoup plus fréquents qu'on le croyait.

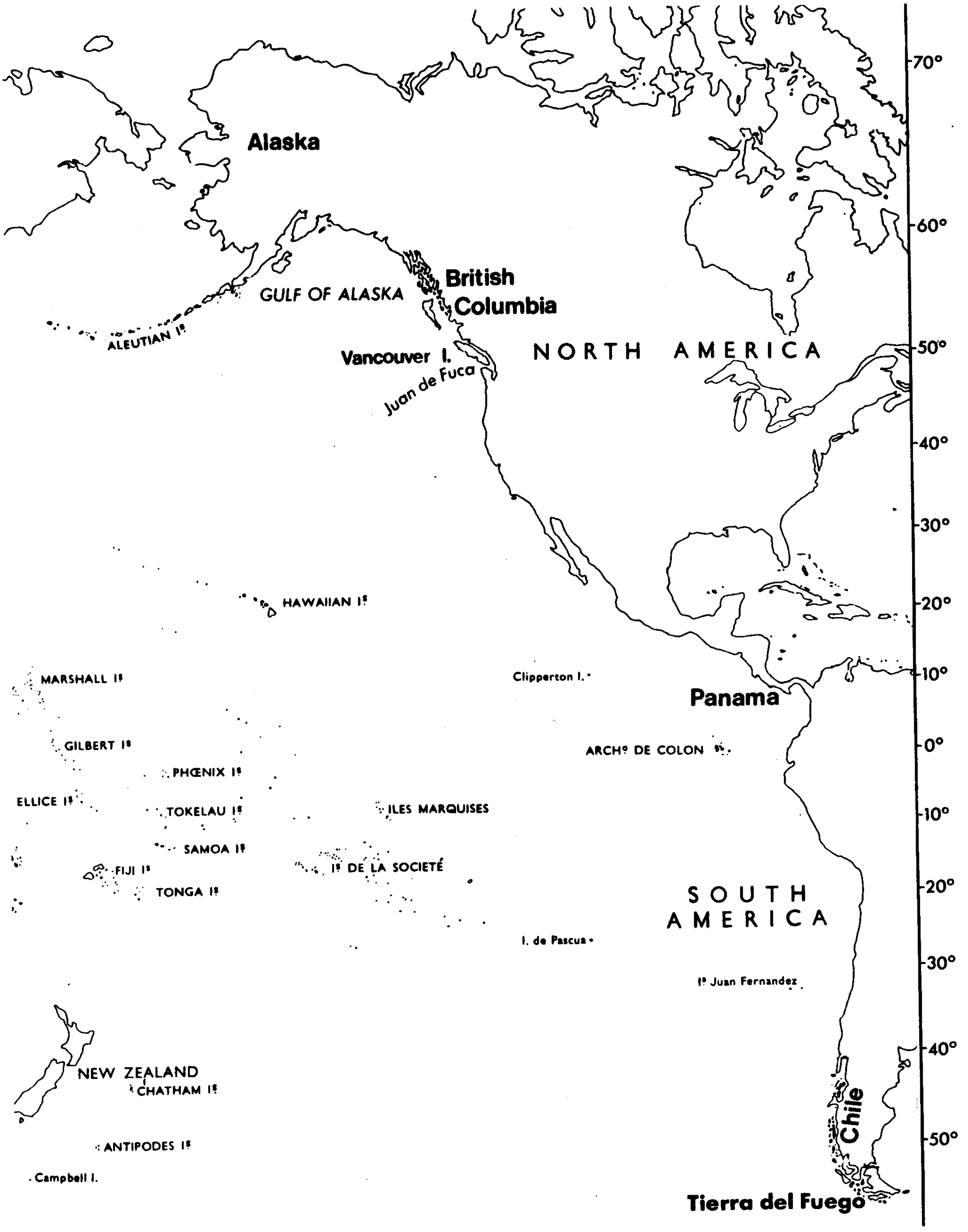


Figure 1 The Pacific coast of North and South America.

1. Introduction

The Pacific Coast of the South American continent can be conveniently visualized as two regions of widely differing characteristics (Fig. 1): from 9° N to 42° S, a distance along the coast of about 5700 kilometers, the coast line is regular with few indentations, while from 42° S to Tierra del Fuego at 56° S, a coastal distance of 1800 kilometers, the coast is penetrated by a complex system of fjords. These two regions have parallels on the Pacific coast of North America: from Panama (9° N) to Juan de Fuca Strait (48° N), a coastal distance of 7200 km, the coast line is regular, while northward to the Gulf of Alaska (59° N), a coastal distance of 1600 km, the coast is highly indented. All of these regions have been subject to severe tsunamis.

Tsunamis in the indented regions of both South and North America are modified by similar physiographic features. Inlets penetrate deeply into the coast and are connected to the open sea by complex passages between islands. Beyond the islands lies the continental shelf, averaging 32 kilometers in width off central and southern Chile, and 40 kilometers off the coast of British Columbia and southeast Alaska.

A simple examination of the available tsunami data is made in the following sections with a view to obtaining qualitative and quantitative information on a number of aspects, including resonance phenomena, secondary undulations, tsunami forerunner and initial withdrawal of water. Detailed comparisons are made between the relevant features of the inlets of the Chilean coast and those of the inlets of Alaska and British Columbia.

TABLE 1. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF CENTRAL CHILE

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
1	Estero Reloncavi	56	.225	80	2.7	20.7	194	
2	Golfo Corcovado-Golfo de Ancud	250	.175	402	42.0	6.0	82	NX
3	Estero Comau	41	.420	43	4.5	9.1	33	
4	Estero Renihue	28	.245	38	5.1	5.5	45	
5	Canal Moraleda	148	.225	210	16.7	8.9	83	R
6	Canal Jacaf	52	.340	60	3.8	13.7	69	
7	Canal Puyuguapi	100	.220	144	4.2	23.8	231	
8	Seno Aysen	70	.225	99	4.2	16.7	156	
9	Estero Quitralco	39	.125	74	3.4	11.5	260	
10	Estuario Francisco	44	.200	66	2.7	16.3	182	
11	Bahia San Quintin	32	.030	124	8.2	3.9	751	X

N New listing, not in Pickard.

R Revised dimensions from Pickard.

X Inlet where one-dimensional approximation may be invalid, because of dimensions or shape.

TABLE 2. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF CENTRAL AND SOUTHERN CHILE

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
12	Estero Steffen	24	.240	33	3.4	7.1	60	
13	Estero Mitchell	45	.265	59	2.3	19.6	144	
14	Canal Baker	112	.470	110	3.1	36.1	112	R
15	Estero Nef	37	.275	48	1.3	28.5	198	
16	Seno Iceberg	26	.125	50	1.9	13.7	310	
17	Canal Messier	154	.520	144	6.3	24.4	65	N
18	Seno Eyre	46	.310	56	4.6	10.0	58	
19	Estero Asia	85	.265	111	3.2	26.6	195	
20	Estero Peel	9	.140	16	2.9	3.1	59	
21	Estero des las Montanas	59	.225	84	2.5	23.6	221	R
22	Canal Swett	59	.445	60	2.8	21.1	71	
23	Golfo Xaultegua	46	.465	45	4.6	10.0	32	
24	Seno Otway	124	.215	180	15.0	8.3	83	
25	Paso Forward - Paso Ancho	222	.260	293	20.4	10.9	82	NX
26	Seno Almirantazgo-Bahia Inutil	200	.240	275	18.1	11.0	94	RX

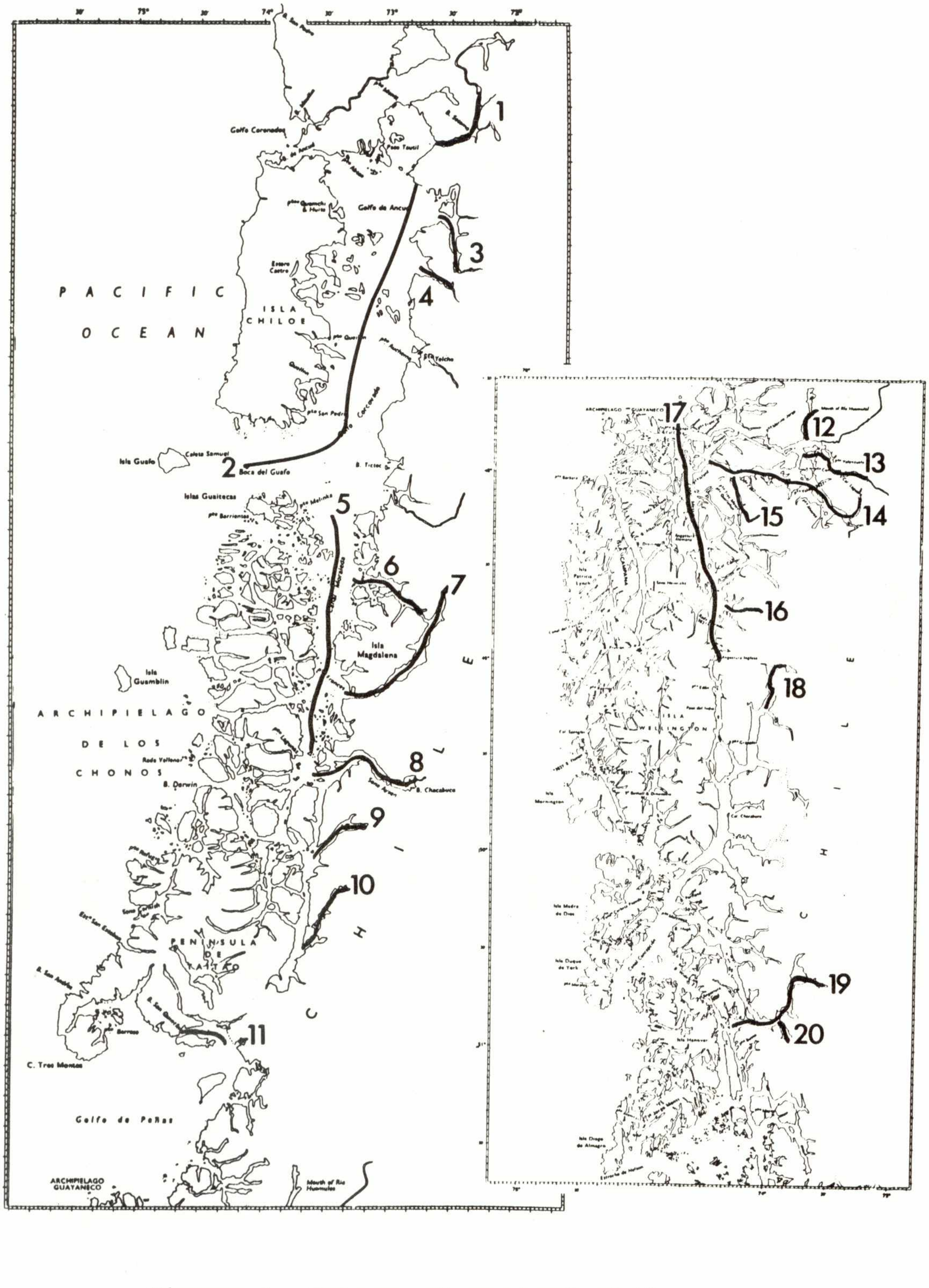


Figure 2 Inlets of central Chile.

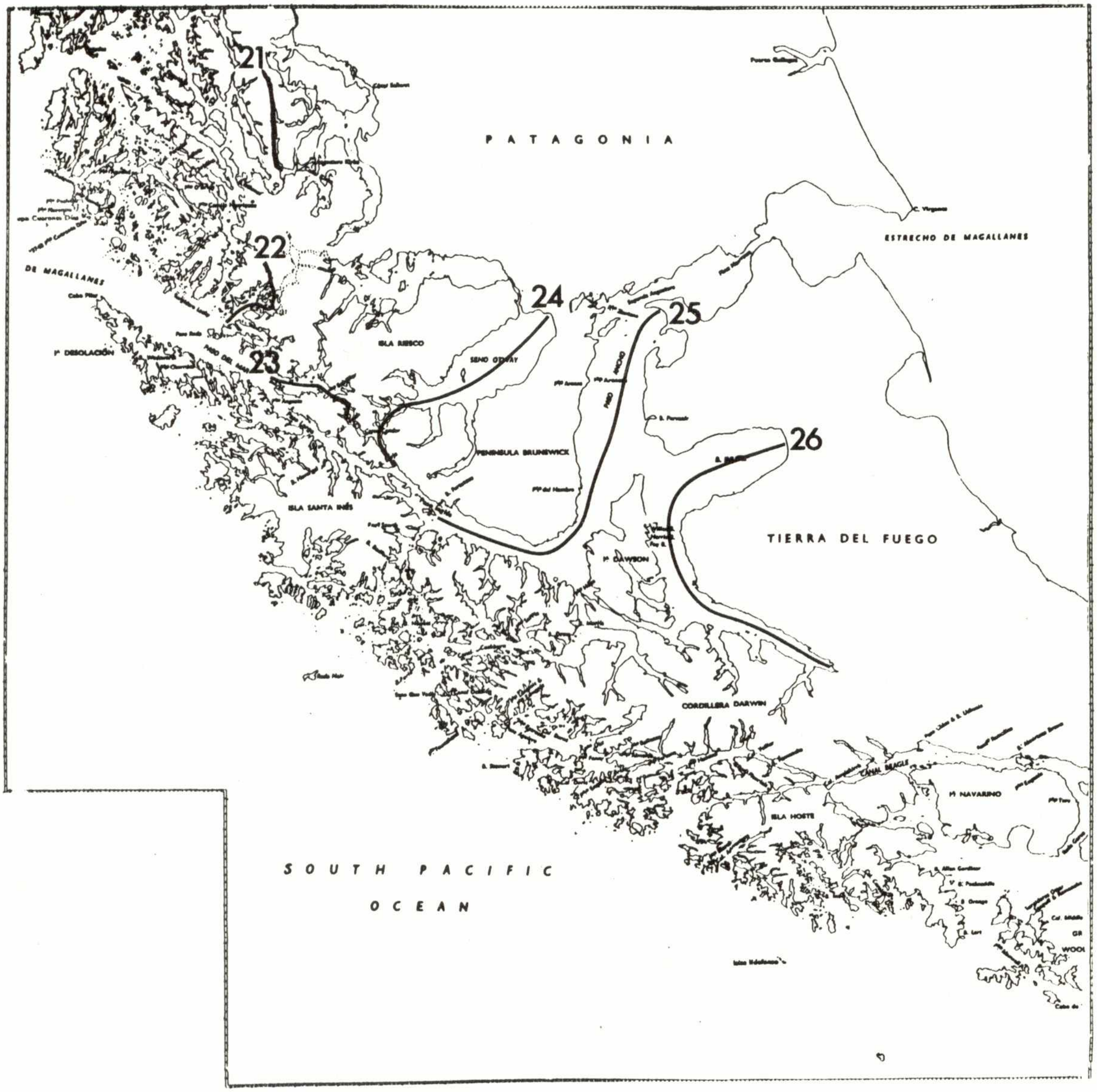


Figure 3 Inlets of southern Chile.

2. Resonance characteristics of some inlets on the Pacific coast of South and North America

Inlets of the coast of Chile whose resonance characteristics may be defined from presently available depth information are listed in table 1 (central Chile) and table 2 (southern Chile). Their locations and the sections assumed to be resonant are shown in figures 2 and 3. Unless otherwise indicated the dimensions of these inlets are those listed by Pickard (1971). The data from Pickard as well as those extracted by the writers from hydrographic charts were used to compute the period of the fundamental longitudinal mode of the inlets and to determine the possible intensity of secondary undulations; calculations were based on the lengths, mean widths and mean midinlet depths for each of these inlets. The period of the fundamental longitudinal mode of the inlets was calculated using the Merian formula (for an inlet open at the mouth and closed at the head), i.e.

$$T_1 = \frac{4L}{\sqrt{gH}} \qquad (1)$$

where T_1 is the period, L is the length of the inlet, H is the average depth of the inlet and g is gravity. The average depth of the inlet obviously would be somewhat less than the mean midinlet depth and from (1) it can be seen that use of the latter in place of the former provides a smaller estimate of the period. On the other hand, it is known that the Merian formula usually over-estimates the period. Thus, as using both, i.e. mean midinlet depth and an approximate formula, produces opposite effects, the estimates of the periods may be satisfactory.

For comparison of the characteristics of the Chilean inlets with those on the Pacific coast of North America, information on the dimensions of inlets of southeastern Alaska and northern British Columbia are listed in tables 3 and 4 and of southern British Columbia in tables 5 to 8 (also included are data on a number of inlets in Puget Sound, Washington State). Their locations are shown on corresponding figures 4 and 5. Unless otherwise indicated, the dimensions of those inlets are those listed by Pickard (1961; 1963; 1967).

All the tables list the identifications of the inlets, their length, mean (midinlet) depth, period computed from the Merian formula and the ratio of the length to width. The significance of the last column is explained in section 3 dealing with secondary undulations. It can be seen from these tables that the periods of the inlets vary from 15 minutes to 400 minutes, but predominantly they are in the range of 30 to 180 minutes (Fig. 6). The periods with which tsunamis enter from the deep ocean into coastal waters usually lie in this range and thus the resonance in coastal inlets should be considered in prediction of tsunami heights.

It can be seen from figure 6 that as far as the resonance periods are concerned, the distribution is similar for the inlets of the various regions. Thus, for understanding the resonance phenomenon, a study of one of these systems of inlets enable one to make deductions about other systems.

This similarity among the systems does not appear strongly when secondary undulation activity (see next section) is considered. Some of the inlets included in tables 1 to 8 are separated from the open ocean by passages so restricted that only minor excitation from tsunamis due to distant causes (here by distant tsunamis is meant tsunamis which originate in the Pacific Ocean) will be possible. However, those inlets are included since a tsunami response to seismic activity occurring within their region is possible. Others of the listed inlets are restricted, rather than closed at the inner end, and many have bifurcations and confluences with other passages; higher modes and more complex resonances are likely (Henry and Murty, 1972).

TABLE 3. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF ALASKA

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
27	Tarr Inlet- Glacier Bay	111	.220	159	5.6	19.8	192	
28	Muir Inlet	35	.215	51	3.5	10.0	100	
29	Lynn Canal	146	.360	164	6.6	22.1	102	R
30	Gastineau Canal	18	.040	61	1.3	13.8	1725	N
31	Taku Inlet- Stephens Passage	133	.295	165	13.0	10.2	64	
32	Tracy Arm	43	.270	56	1.8	23.9	170	
33	Endicott Arm	44	.260	58	3.3	13.3	100	
34	Frederick Sound	80	.165	133	22.2	3.6	54	R
35	Thomas Bay	20	.150	35	2.8	7.1	122	
36	Tenakee Inlet	64	.140	115	3.2	20.0	382	N
37	Peril Strait	71	.210	104	4.0	17.8	185	N
38	Sitka Sound- Silver Bay	43	.095	94	8.7	4.9	167	N X
39	Bradfield Canal- Ernest Sound	80	.310	97	5.7	14.0	81	
40	Behm Canal West- Bell Arm	72	.425	74	5.2	13.8	50	R
41	Burroughs Bay- Behm Canal East	113	.420	174	3.5	32.3	119	R

TABLE 4. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF ALASKA AND NORTHERN BRITISH COLUMBIA

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
42	Rudyerd Bay	22	.170	36	.9	24.4	348	
43	Boca de Quadra	56	.245	76	1.3	43.1	355	
44	Carroll Inlet	44	.130	82	1.6	27.5	587	N
45	George Inlet, Alaska	22	.225	31	1.4	15.7	147	N
46	Portland Canal, B.C.	115	.255	153	2.2	52.3	406	
47	Observatory Inlet-Hastings Arm	76	.385	82	2.2	34.5	144	
48	Alice Arm	19	.240	26	1.3	14.6	124	
49	Khutzeymateen Inlet	25	.120	49	1.0	25.0	601	R
50	Work Channel	54	.240	74	2.0	27.0	230	
51	Prince Rupert Inlet	19	.045	60	1.2	15.6	1634	N
52	Rennell Sound	32	.125	61	6.7	4.8	109	NX
53	Tasu Sound	15	.145	27	2.0	7.5	136	NX

TABLE 5. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF SOME INLETS OF BRITISH COLUMBIA

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
54	Douglas Channel	83	.330	97	3.5	23.7	125	
55	Kildala Arm	19	.175	31	1.5	12.7	173	
56	Gardner Canal	91	.275	117	1.9	47.9	332	R
57	Surf Inlet	22	.220	32	.9	24.4	236	
58	Laredo Inlet	39	.295	48	1.5	26.0	162	
59	Sheep Passage-Mussel Inlet	33	.275	42	1.5	22.0	153	
60	Spiller Channel	46	.255	61	1.9	24.2	188	
61	Roscoe Inlet	43	.135	79	1.1	39.1	788	
62	Cousins Inlet	12	.070	31	.8	15.0	810	N
63	Cascade Inlet	26	.250	35	1.1	23.6	189	
64	Dean Channel	111	.420	115	2.4	46.3	170	
65	Kwatna Inlet	24	.345	28	2.0	12.0	59	
66	South Bentinck Arm	37	.240	51	2.2	16.8	143	
67	Rivers Inlet	46	.295	57	3.0	15.3	95	
68	Moses Inlet	26	.200	39	.9	28.9	323	
69	Smith Inlet	33	.270	43	1.3	25.4	181	

TABLE 6. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF SOUTHERN BRITISH COLUMBIA AND PUGET SOUND

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
70	Mereworth Sound	19	.090	43	.4	47.5	1759	R
71	Belize Inlet	52	.255	69	1.1	47.3	367	
72	Nugent Sound	24	.075	59	.7	34.3	1669	
73	Seymour Inlet	67	.420	70	1.7	39.4	145	
74	Drury Inlet	22	.040	74	1.3	16.9	2112	R
75	Queen Charlotte Strait	82	.150	143	18.6	4.4	76	NX
76	Knight Inlet	130	.295	161	3.0	43.3	270	
77	Call Inlet	28	.135	51	1.5	18.7	377	
78	Loughborough Inlet	35	.190	54	1.7	20.6	249	
79	Bute Inlet	76	.510	72	3.7	20.5	56	
80	Toba Inlet	37	.390	40	2.6	14.2	58	
81	Jervis Inlet	89	.495	85	3.2	27.8	80	
82	Howe Sound	43	.225	61	7.0	6.1	57	
83	Strait of Georgia	232	.255	309	20.8	11.2	87	NX
84	Puget Sound	111	.165	184	6.0	18.5	276	N
85	Hood Canal	102	.110	207	2.5	40.8	1118	N
86	Possession Sound-Saratoga Passage	70	.090	157	3.7	18.9	700	N

TABLE 7. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF VANCOUVER ISLAND

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
87	Holberg-Rupert Inlet	44	.165	73	1.4	31.4	469	R
88	Quatsino Sound-Neroutsos Inlet	59	.150	103	2.2	26.8	461	
89	Forward Inlet	11	.030	43	1.1	10.0	1925	
90	Klaskino Inlet	11	.035	40	.7	15.7	2398	
91	Ououkinsh Inlet	14	.085	32	1.2	11.7	472	
92	Port Eliza	11	.050	33	.7	15.7	1404	
93	Espinosa Inlet	14	.215	20	1.3	10.8	108	
94	Nuchalitz Inlet	15	.025	64	1.3	11.5	2909	
95	Tahsis Inlet	29	.120	56	.9	32.2	775	R
96	Cook Channel-Tlupana Inlet	31	.150	54	1.9	16.3	281	R
97	Zuciarte Channel-Muchalat Inlet	48	.220	69	1.5	32.0	310	
98	Sydney Inlet	20	.080	48	1.3	15.4	681	
99	Shelter Inlet	19	.115	38	1.3	14.6	374	
100	Herbert Inlet	23	.100	49	2.0	11.5	364	

TABLE 8. DIMENSIONS AND PERIODS OF FUNDAMENTAL MODE AND INTENSITY OF SECONDARY UNDULATIONS OF INLETS OF VANCOUVER ISLAND

No.	Name of Inlet	L Length (Km)	H (Mean Depth) (Km)	Period (Minutes)	W (Mean Width) (Km)	L/W	$\frac{L/W}{H\sqrt{H}}$	Notes
101	Pipestem Inlet	9	.045	29	.7	12.9	1351	
102	Effingham Inlet	17	.095	37	1.2	14.2	485	
103	Alberni Inlet	69	.145	122	1.3	53.1	962	
104	Juan de Fuca Strait	154	.165	255	23.8	6.5	97	NX
105	Saanich Inlet	23	.180	37	2.5	9.2	120	N

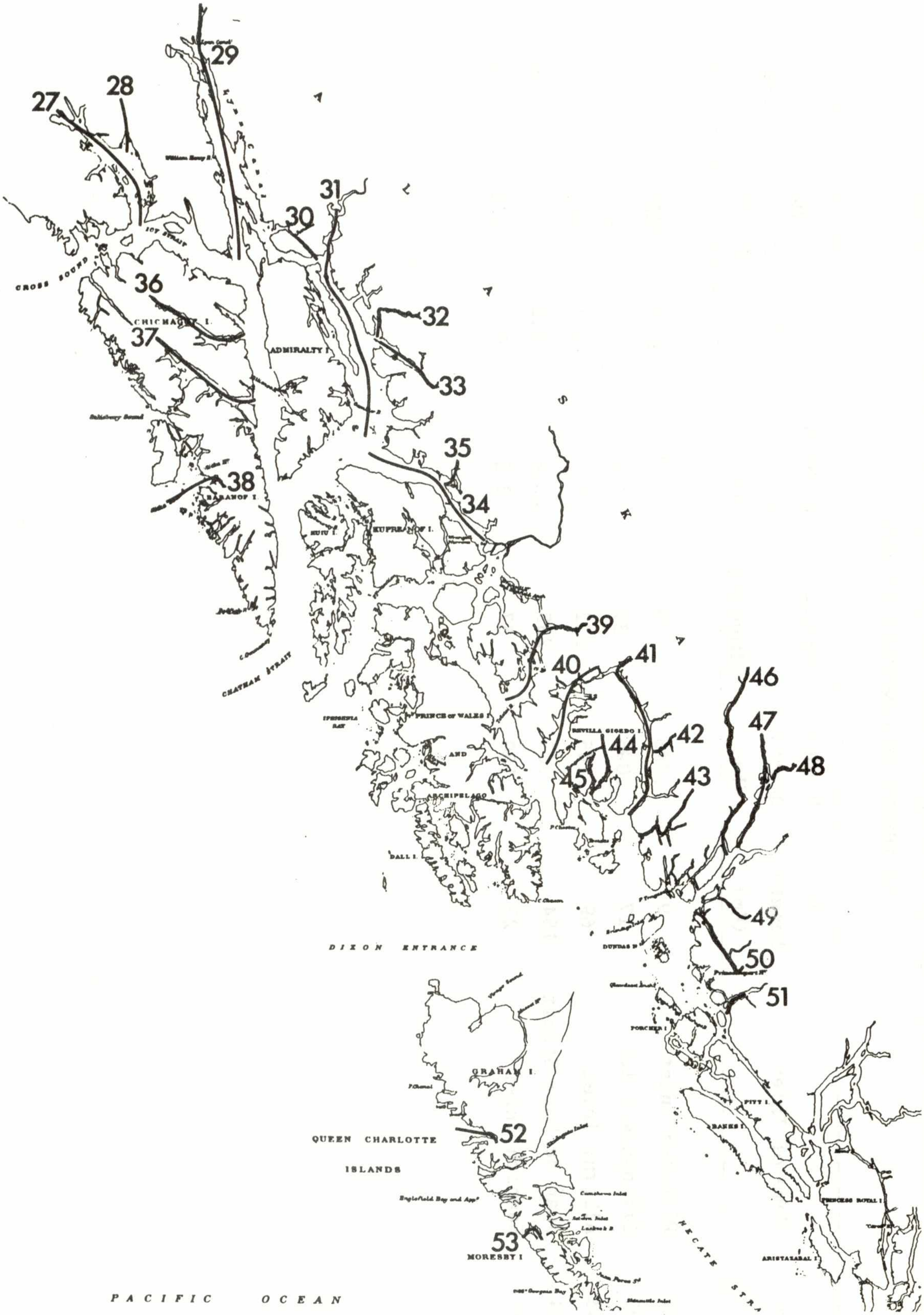


Figure 4 Inlets of southeastern Alaska and northern British Columbia.

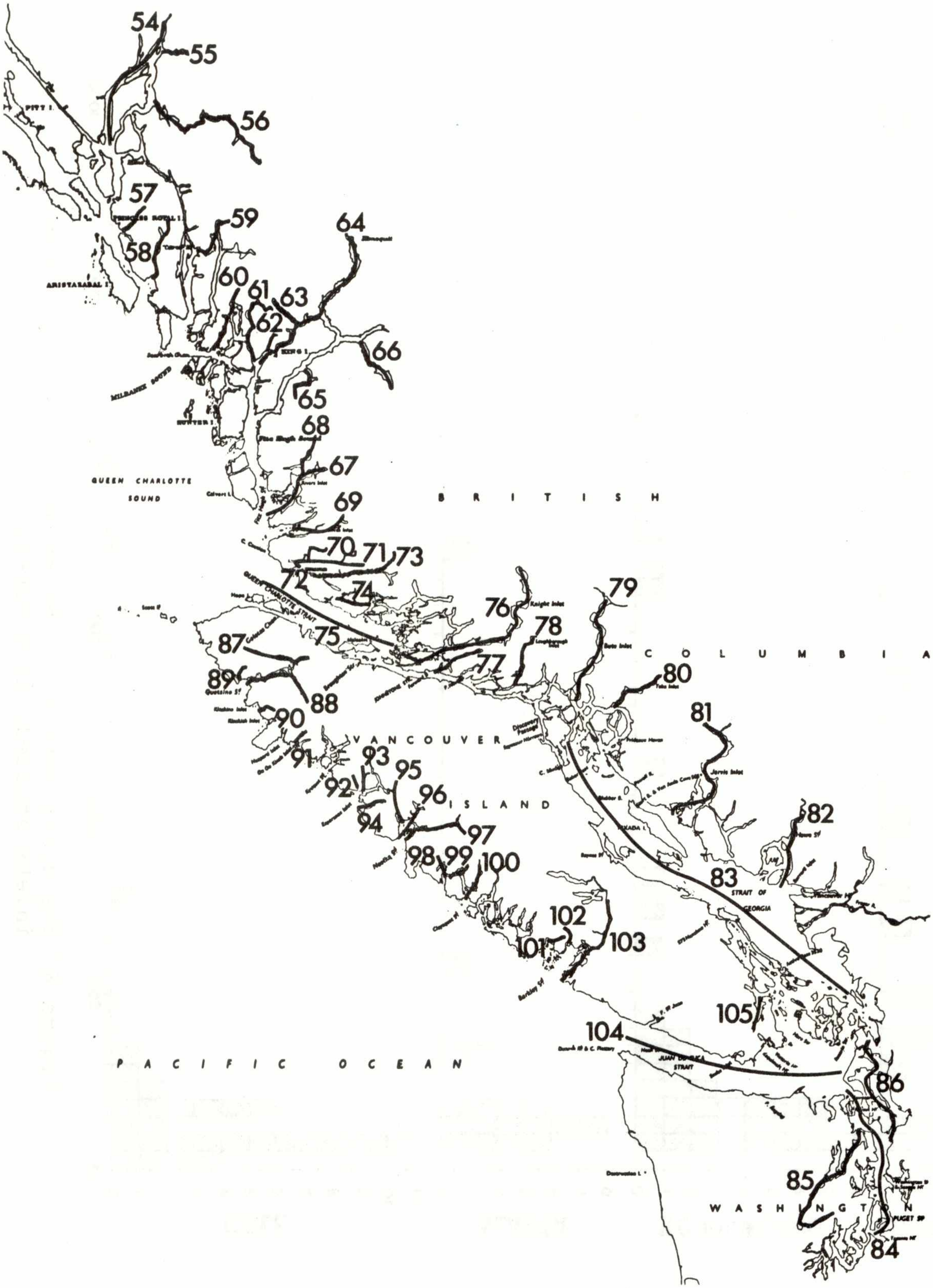


Figure 5 Inlets of the mainland of British Columbia, Puget Sound and Vancouver Island.

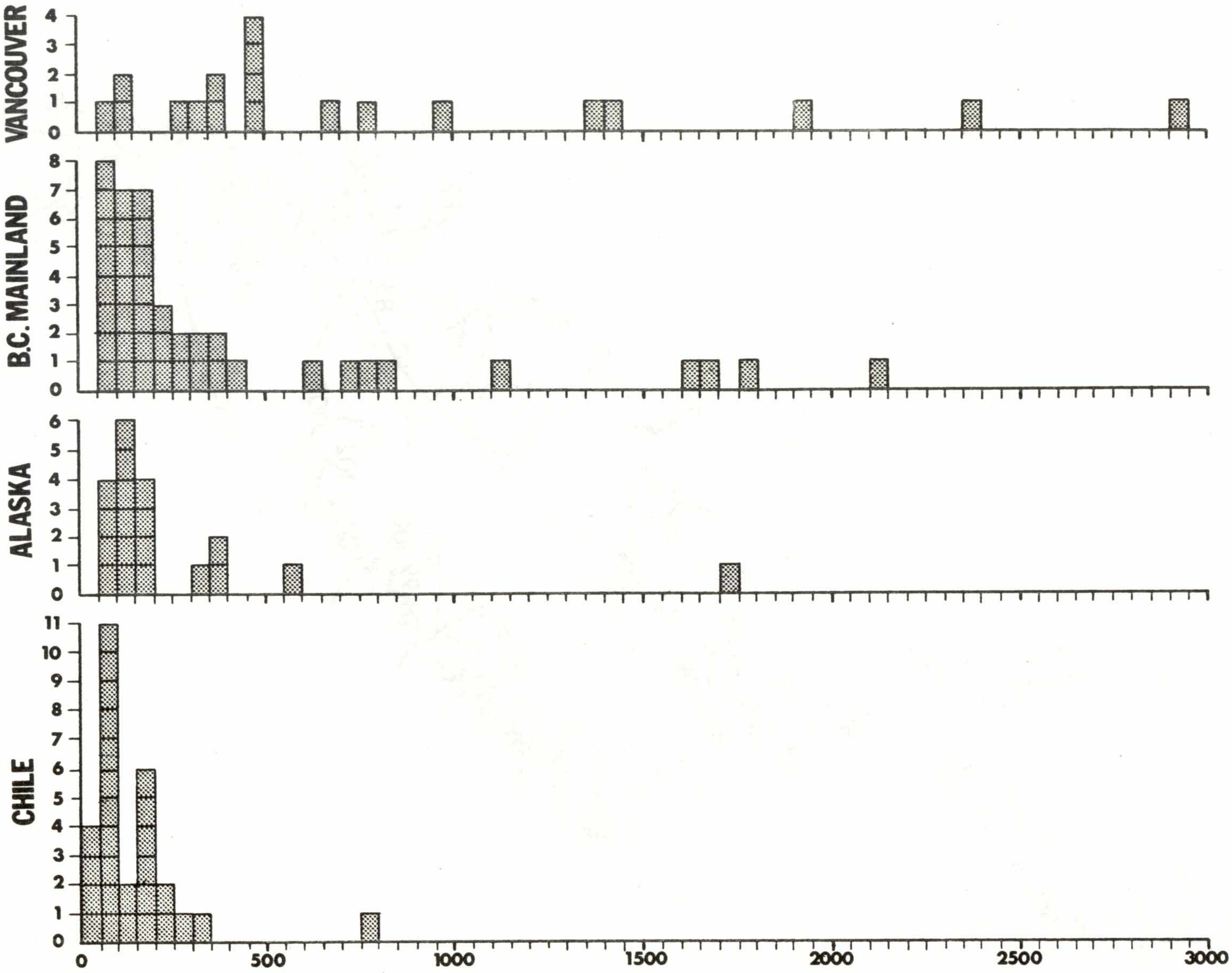


Figure 6 The distribution of the resonant periods of the inlets studied, in minutes.

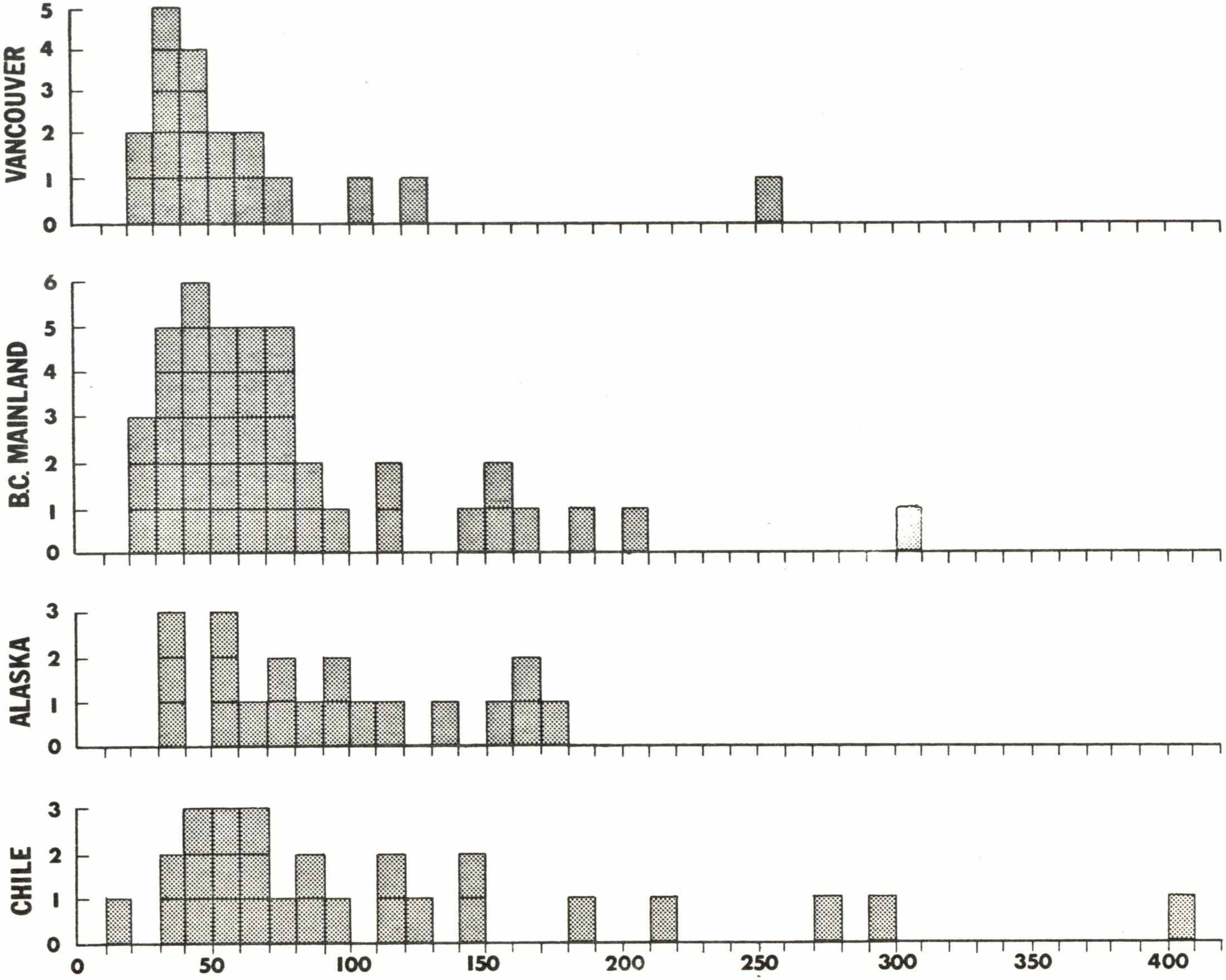


Figure 7 The distribution of the intensity of secondary undulations.

3. Secondary undulations

Nakano (1932) defined secondary undulations as the oscillations on tide gauge records that are distinct from tides. In a bay excited by a tsunami, these oscillations are essentially the normal modes of the bay. From Nakano's work it may be seen that the intensity of secondary undulations is proportional to the length L of the bay and inversely proportional to the width W and inversely proportional to $H^{3/2}$, where H is the average depth of the inlet. In the last column of tables 1 to 8 the calculated intensity of secondary undulations for each inlet is listed. This intensity value provides in a limited quantitative manner, a measure of the continued disturbance in an inlet following the main tsunami wave. For inlets receiving a similar amount of energy from a tsunami, those with a higher value for the secondary undulation should excite larger amplitudes of oscillation relative to those with a smaller value.

Figure 6 shows the histogram of the distribution of the number of inlets versus the resonant period for inlets on the coasts of Chile, Alaska, British Columbia (mainland) and Vancouver Island. Figure 7 shows a similar histogram for the intensity of secondary undulations. The distribution is somewhat similar for Chilean and Alaskan inlets and is drastically different for Vancouver Island inlets. The pattern for British Columbia mainland coast (and Puget Sound) falls between that for Vancouver Island and that of either Chile or Alaska. It may be noted that differences of this type are not obvious in figure 6.

Next, some observational evidence will be presented to show that the concept of the intensity of secondary undulations as described here is indeed relevant in natural situations. Analogue records from the 1964 Alaska earthquake tsunami were obtained for several of the Alaska, British Columbia mainland, Puget Sound and Vancouver Island inlets; these records are shown in figure 8. From these we may obtain some assessment of the validity of the secondary undulation calculations. These figures include some tsunami records from open-ended channels and from the Fraser River, which are of questionable relevance in the present context.

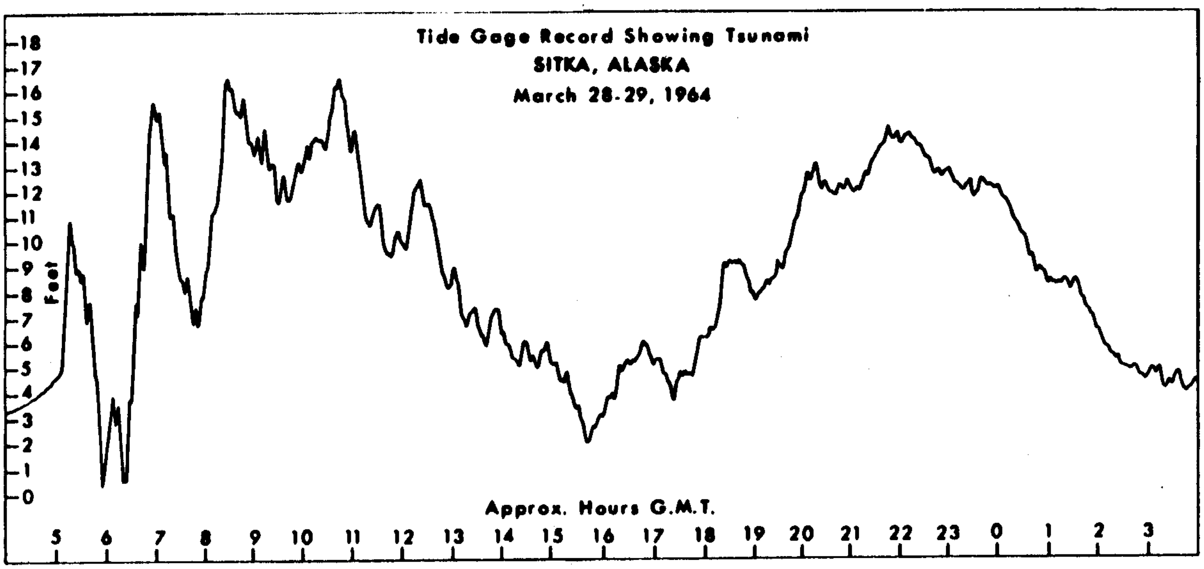
On the British Columbia coast the most sustained secondary undulation on record occurred at Port Alberni at the head of Alberni Inlet (No. 103 in the tables and figure 8e). The secondary undulation value for Alberni Inlet is 962, which falls among the top 10% of all listed values. Ocean Falls in Cousins Inlet (No. 62 and figure 8c) has a value of 810 and shows a strong secondary undulation. Prince Rupert (No. 51 and figure 8b) has a high value of 1634, but does not sustain a large secondary undulation. Tsunami energy in this case may have been dissipated in major side channels. Victoria (Fig. 8d) and Neah Bay (Fig. 8f) both sustain large secondary undulations, even though the adjacent Juan de Fuca Strait (No. 104) has a low value of 97. This discrepancy may result from the one-dimensional theory not being valid for inlets with a low length to width ratio and where, as a consequence, transverse motion is important.

From the 1960 tsunami, two sets of records are shown in figure 9. Punta Arenas in Paso Ancho (No. 25) has a secondary undulation value of 87 and is the only analogue tsunami record we had available from the Chilean inlets. In view of the large width of Paso Ancho, the one-dimensional calculation for resonance period and secondary undulation may not be valid. The other record for 1960 provides a unique intercomparison as each of four inlets received tsunami energy through the same restricted entrance. These inlets and their secondary undulation intensities are respectively:

No. 70	Mereworth Sound	1759
No. 71	Belize Inlet	367
No. 72	Nugent Sound	1669
No. 73	Seymour Inlet	145

The total energy penetrating through the tidal rapids at the entrance is small, but clearly the Mereworth Sound and Nugent Sound records have the highest levels of secondary undulation, Seymour Inlet shows little activity and Belize Inlet is intermediate. We speculate that the differences in the geometry and topography of these inlets account for the differences in the activity of secondary undulation.

Figure 8 Tsunami records observed during the event of March, 1964 at a number of stations between Alaska and Puget Sound. (a) For southeast Alaska including Sitka No. 38, (top), Juneau No. 30 (middle) and Ketchikan No. 44 and 45. (b) For Prince Rupert No. 51 (top) and Tasu No. 53. (c) For Alert Bay No. 75 (middle) and Ocean Falls No. 62 (bottom). (d) For Victoria No. 104 (top) and Point Atkinson No. 83. (e) For Port Alberni No. 103 (bottom). (f) For Neah Bay No. 104 (top) and Seattle No. 84 (bottom).


Tide Gage Record Showing Tsunami
SITKA, ALASKA
March 28-29, 1964
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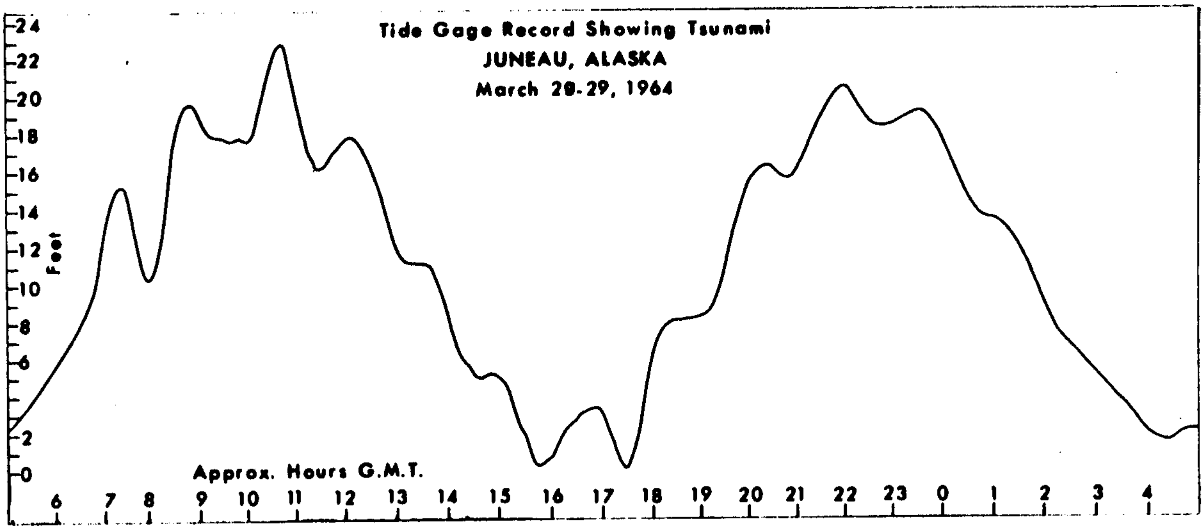
Tide Gage Record Showing Tsunami
JUNEAU, ALASKA
March 29-29, 1964
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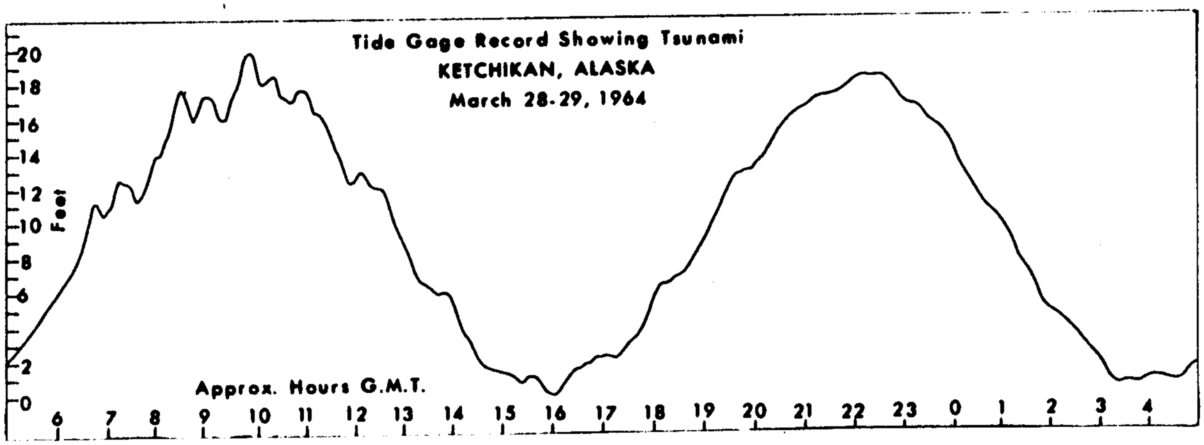
Tide Gage Record Showing Tsunami
KETCHIKAN, ALASKA
March 28-29, 1964
Feet
20
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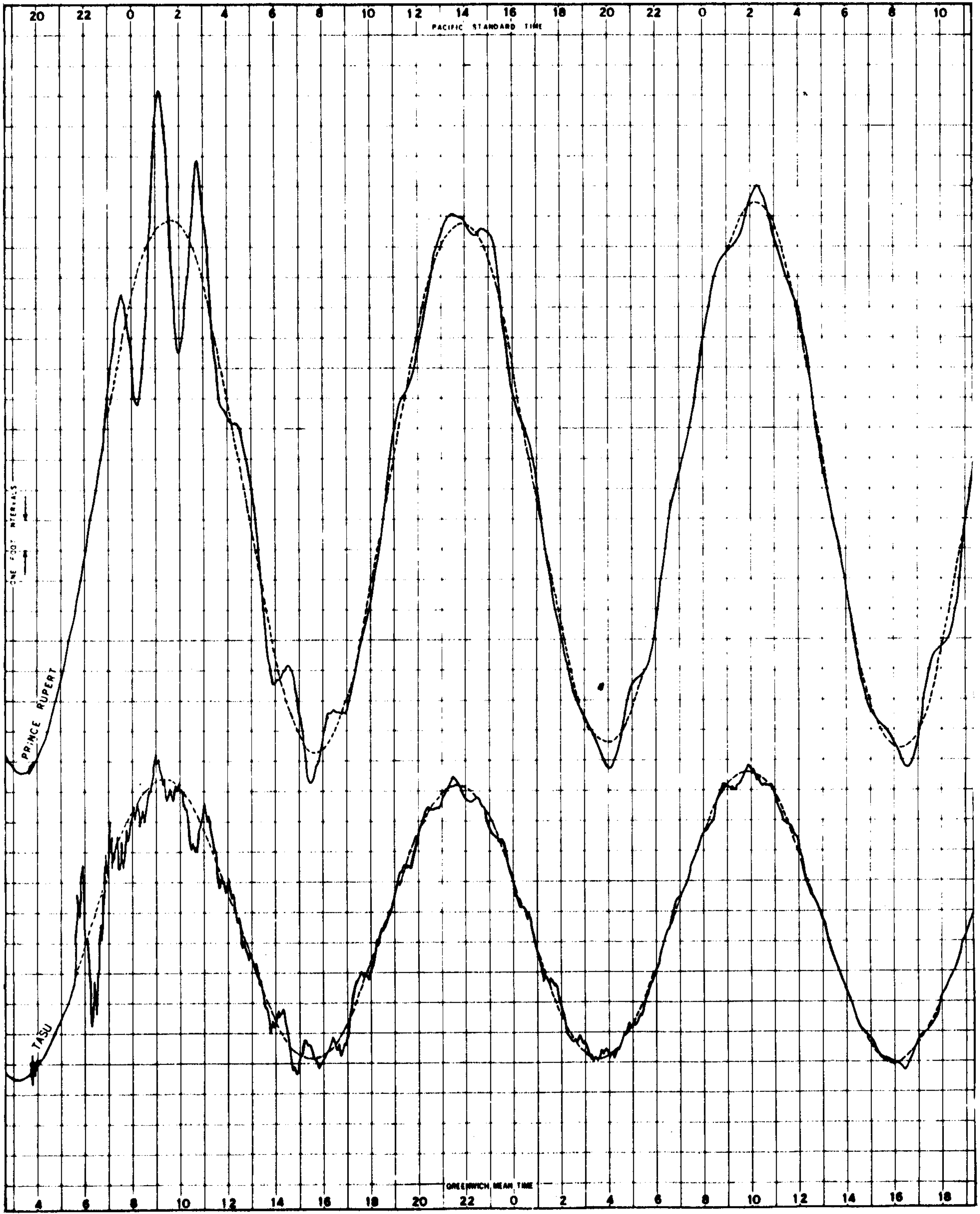
Approx. Hours G.M.T.
6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 0 1 2 3 4

TSUNAMI **WEST COAST OF CANADA** MARCH 27-29 1964



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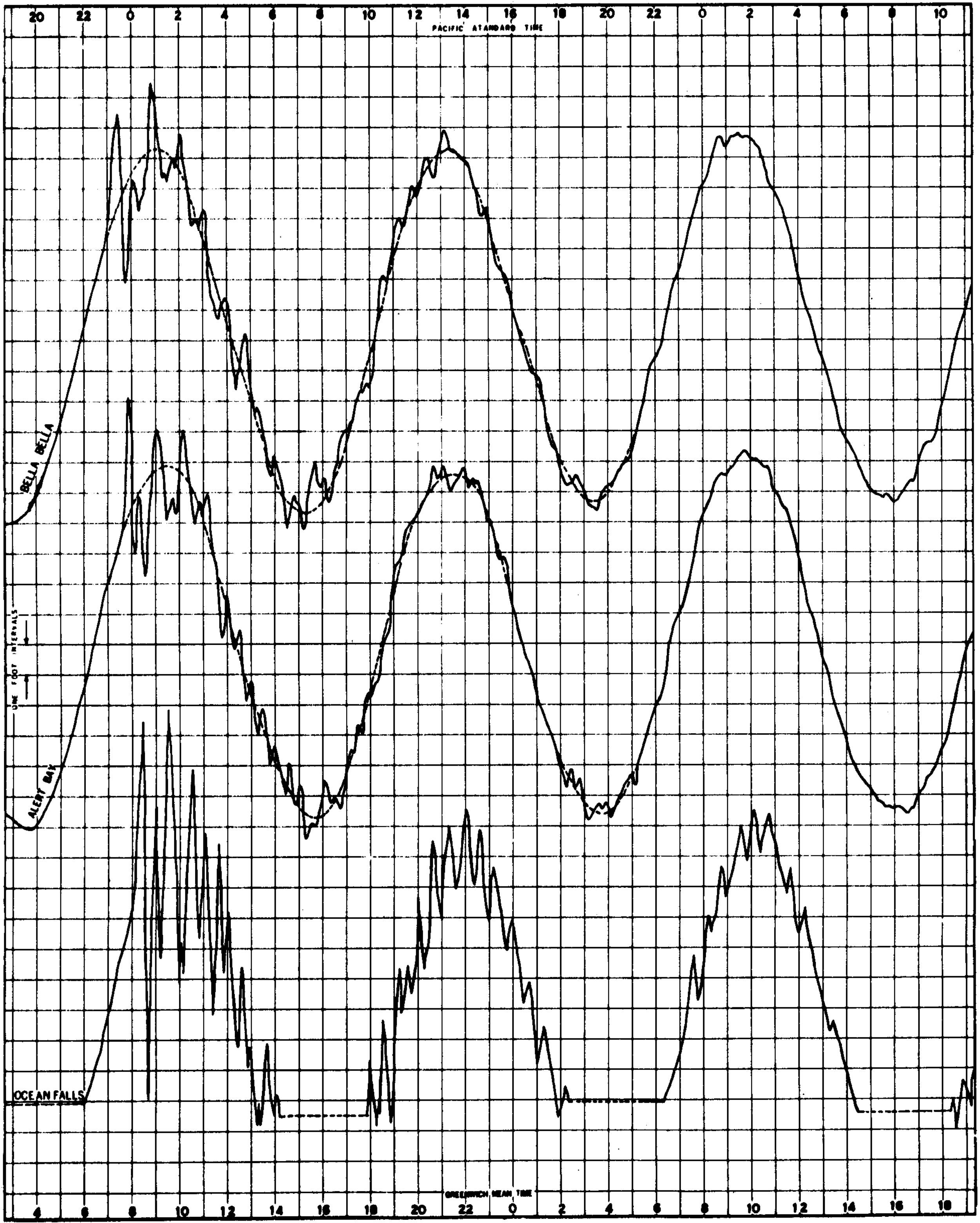
WEST COAST OF CANADA

MARCH 27-29 1964



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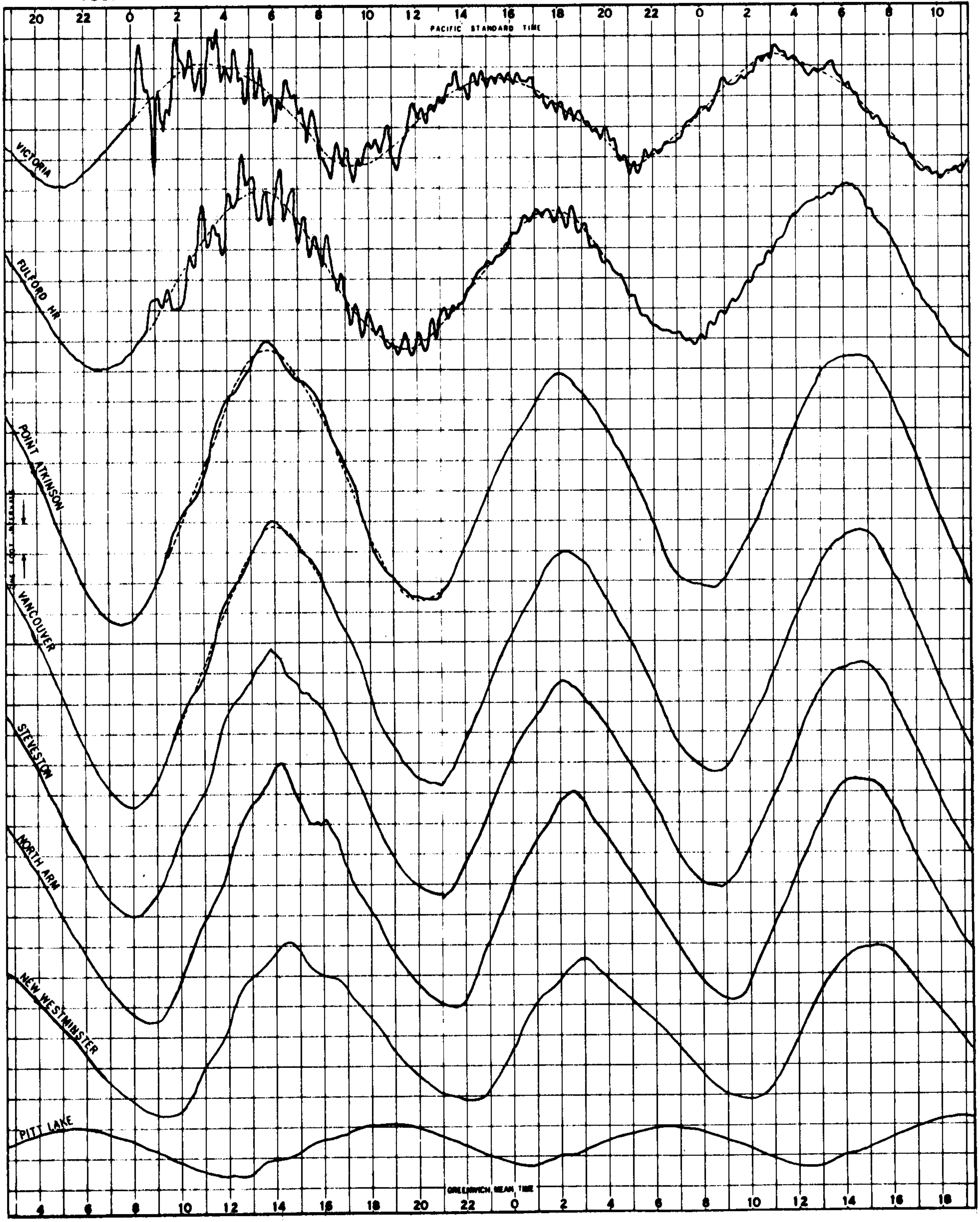
MARCH 27-29 1964



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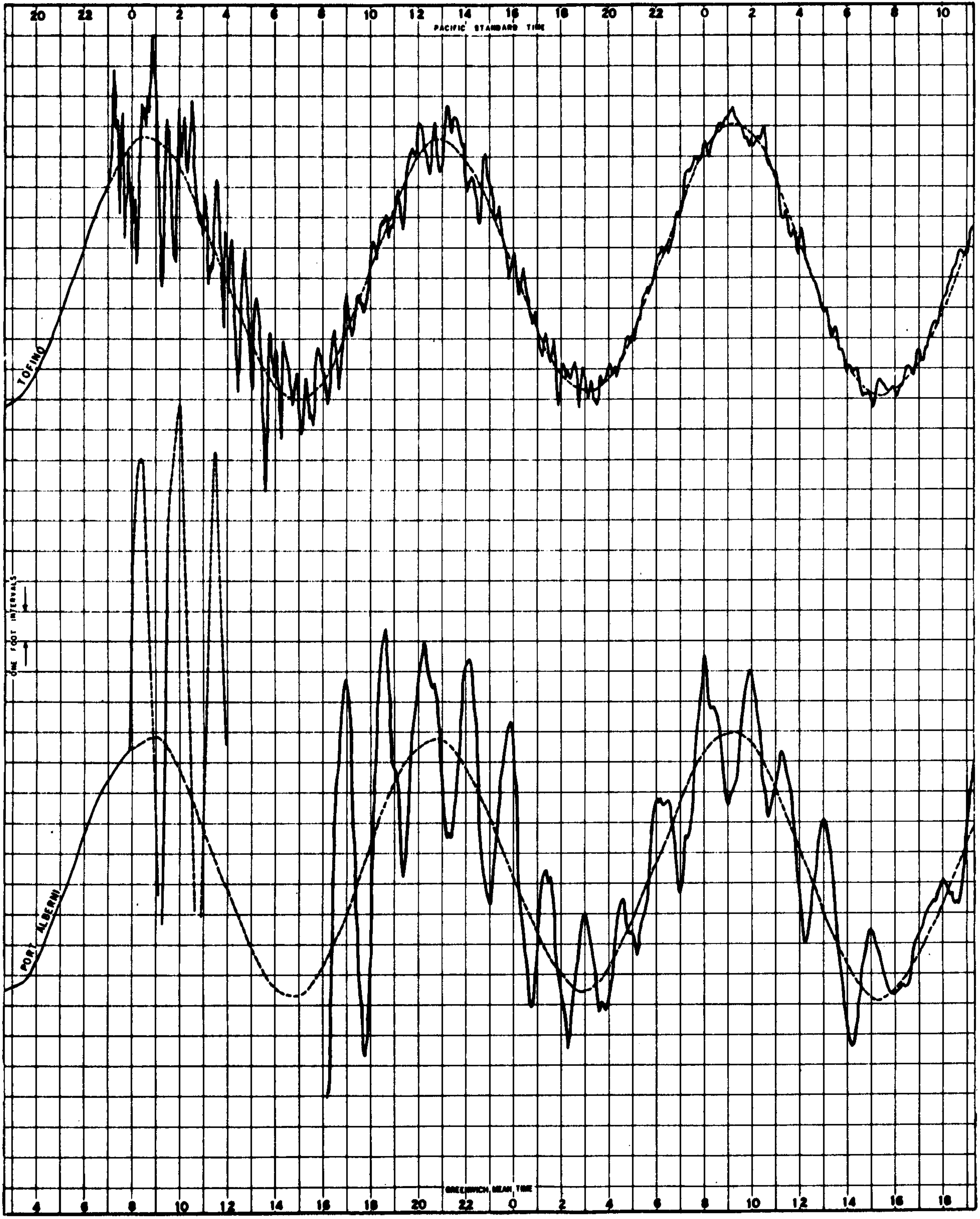
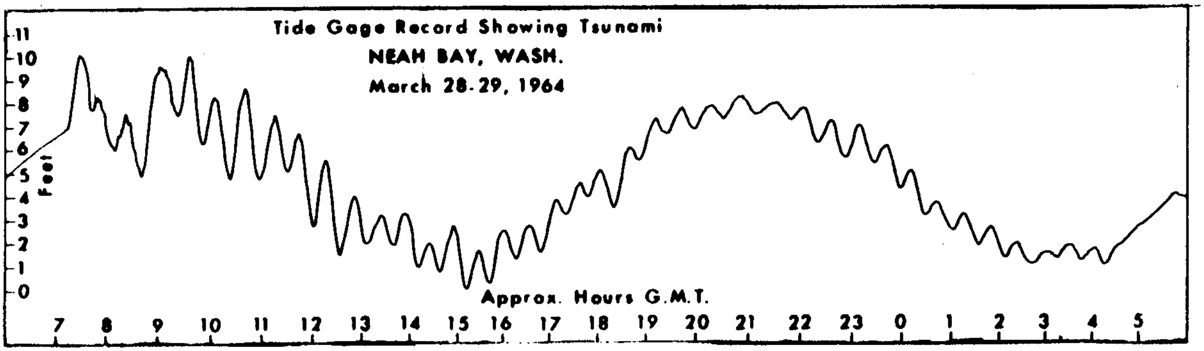
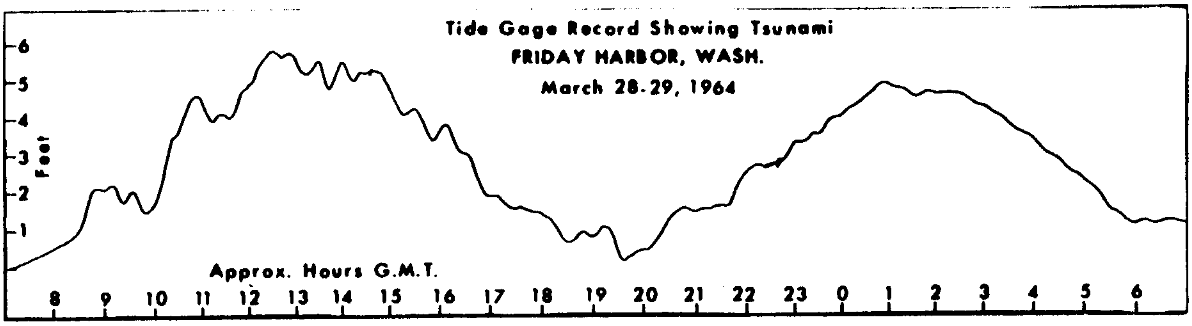
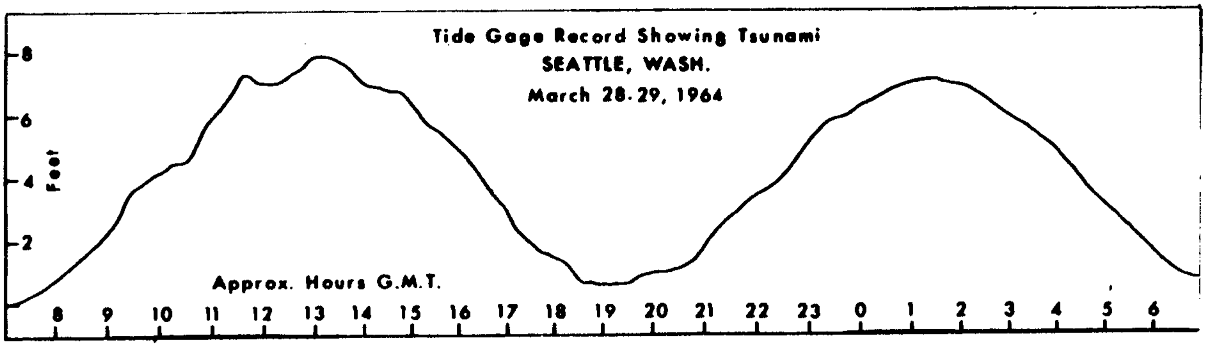
WEST COAST OF CANADA

MARCH 27-29 1964




Tide Gage Record Showing Tsunami
NEAH BAY, WASH.
March 28-29, 1964
Feet
0
1
2
3
4
5
6
7
8
9
10
11
Approx. Hours G.M.T.
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3
4
5


Tide Gage Record Showing Tsunami
FRIDAY HARBOR, WASH.
March 28-29, 1964
Feet
1
2
3
4
5
6
Approx. Hours G.M.T.
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6


Tide Gage Record Showing Tsunami
SEATTLE, WASH.
March 28-29, 1964
Feet
2
4
6
8
Approx. Hours G.M.T.
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6

4. Tsunami forerunner

Nakamura and Watanabe (1961) defined "tsunami forerunner" as a series of oscillations of the water level preceding the arrival of the main tsunami waves. Since the forerunner has periods and amplitudes less than the main tsunami wave, the forerunner could be easily distinguished. Nakamura and Watanabe stated that there is no clear indication of a tsunami forerunner in the data for either the North or South American coasts and they ascribed the absence to the oblique nature of incidence of the initial wave upon these coasts. They explained the existence of the forerunner at other places such as Japan as due to the resonance in bays which could occur before the arrival of the main tsunami wave. They remarked that no previous tsunamis on the Japanese coast showed forerunners. They also stated that the 1960 Chilean earthquake tsunami did not generate forerunners at any region other than Japan.

In an examination of Canadian and United States records for the 1960 tsunami it was noted that initial waves of lower amplitude and simple form marked the arrival of the disturbance at most ports. More complex waves of larger amplitude occurred after the first two or three crests. As in the Japanese example, this pattern was not characteristic of preceding and succeeding tsunamis. The existence of these low amplitude initial waves might be useful in determining the potential destruction of the tsunami that follows the forerunner.

5. Initial withdrawal of water

Much has been said about initial withdrawal of water before the arrival of the main tsunami waves. There are several instances of initial withdrawal and probably just as many cases of no initial withdrawal. Here we present some information on the initial withdrawal on the South American coast and it should be noted that this list (Table 9) is not a complete one due to the inaccuracies of descriptions by people not specifically trained.

TABLE 9 - INSTANCES OF INITIAL WITHDRAWAL ON THE PACIFIC COAST OF SOUTH AMERICA

No	Year	Month	Day	Remarks
1	1687	October	20	Initial withdrawal at Callao.
2	1751	May	25	Epicentre near Concepcion; duration of initial withdrawal was 7 minutes.
3	1819	April	11	Epicentre near Copiapo.
4	1859	October	5	Water level at Caldera was 14 feet below average sea level.
5	1877	May	9	At San Francisco (37° 40'S, 122° 32'W) initial withdrawal. Initial withdrawal also at Carrizal Alto (28° 5'S, 71° 10'W), Chanaral (29° 2'S, 71° 34'W) Talcahuano, Penco, Aranco.
6	1960	May	22	Initial withdrawals at Ancud Isla Mocna, Isla Guabo, Quellon, Linao, Punta Corona, Maullin, Puerto Sauvedra, Lota and Isla Juan Fernandez.

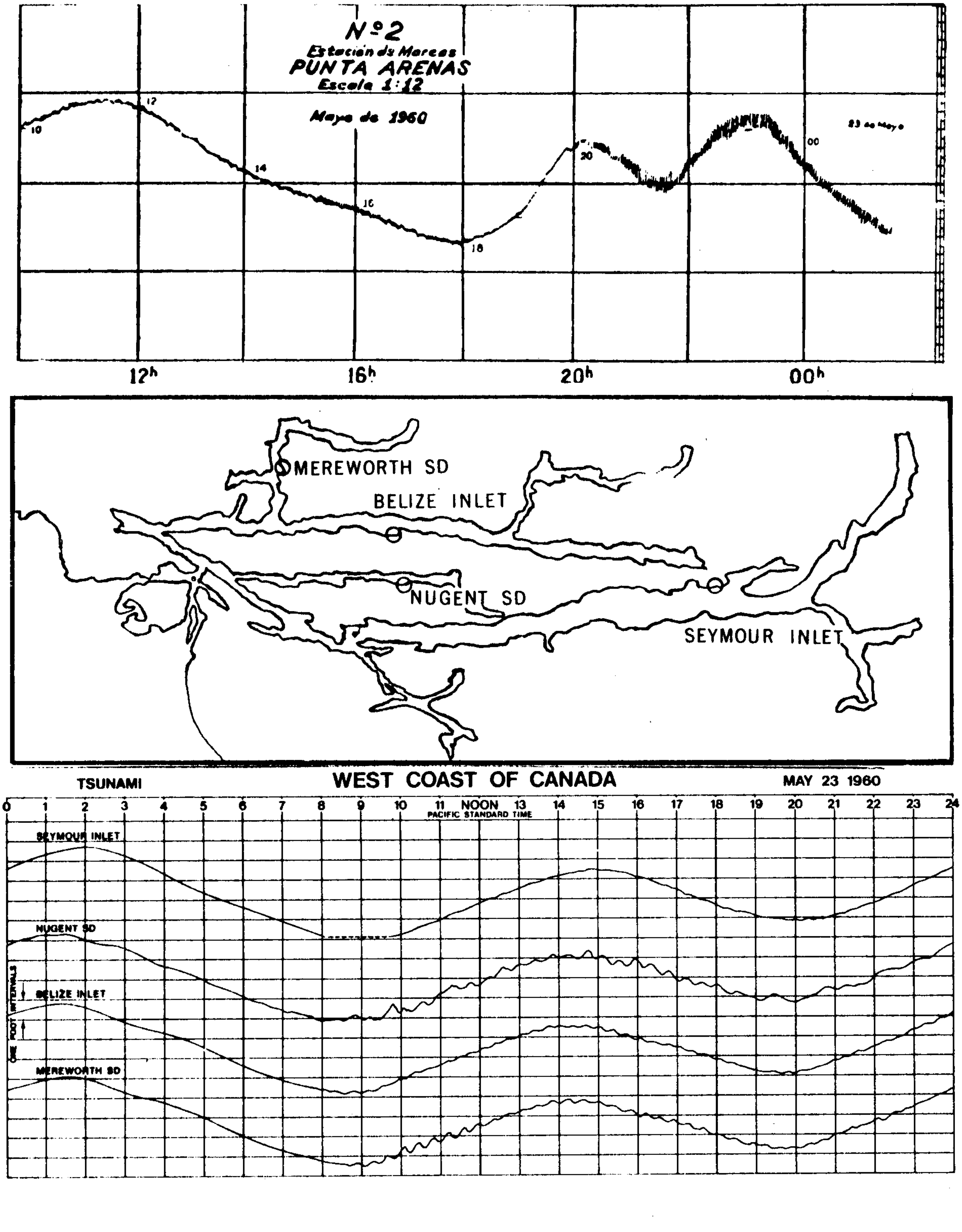


Figure 9 Tsunami records observed during the event of May 1960 at Punta Arenas No. 25 (top) and at Mereworth Sound No. 70, Belize Inlet No. 71, Nugent Sound No. 72 and Seymour Inlet No. 73 (bottom).

6. Conclusion

A comparison of the fundamental periods of the inlets of Chile with those of southeast Alaska, mainland British Columbia including Puget Sound, and Vancouver Island shows that all areas have a similar distribution of resonance periods. However, a calculation of the intensity of secondary undulations shows significant differences, with Chilean and Alaskan inlets being similar, Vancouver Island inlets being markedly greater and British Columbia mainland inlets intermediate.

A study of the response of inlets to the 1964 and 1960 tsunamis tends to confirm the validity of the secondary undulation calculation, but shows major discrepancies in inlets with side channels and inlets where the one-dimensional approximation may not be valid. The large range of intensity in secondary undulations is not obvious "a priori" in the tsunami records. Forerunners from the 1960 tsunami were recorded at stations other than in Japan. As a fundamental conclusion, the experiences in one geographical area can be translated with some modifications into another area for a greater understanding of tsunamis and for the purpose of prediction.

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