FISHERIES RESEARCH BOARD
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MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No.

513

Title

Internal Waves in Georgia Strait

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1953

PACIFIC OCEANOGRAPHIC GROUP

Nanaimo, B.C.

INTERNAL WAVES IN GEORGIA STRAIT

by

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File N 7-19-2

April 1, 1953

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Introduction

Aerial photographs taken as part of an oceanographic survey of Georgia Strait waters adjacent to the City of Vancouver have revealed wave patterns of considerable size. One pattern, represented by Fig. 1, shows a procession of great bands in striking contrast. Another group, farther to the northwest and shown by Fig. 2, appears to consist of surface waves with crest to crest lengths as great as 3000 feet.

Geography and Oceanography of the Region

The Strait of Georgia, 120 nautical miles long by about 15 miles wide, is the main body of water separating Vancouver Island from the mainland (Fig. 3). It is connected to the ocean by narrower channels and inter-island passes leading to the Strait of Juan de Fuca in the south and Johnstone Strait in the north. In spite of its land-locked position,

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[1] This survey was part of a study, in 1950, of the oceanographic phase of the Vancouver sewerage problem undertaken jointly by the National Research Council of Canada, the Fisheries Research Board of Canada, the Pacific Oceanographic Group of the Canadian Joint Committee on Oceanography, and the Institute of Oceanography of the University of British Columbia, in the interests of the Vancouver and Districts Joint Sewerage and Drainage Board. Mr. Shand, now with Defence Research Board of Canada at Victoria, was employed by the Fisheries Research Board while the investigation was being made.

the flood and ebb of seawater through these passages permit a maximum tidal range of about 16 feet. Figure 4 illustrates typical curves for tropic and equatorial tides together with corresponding tidal currents in one of the connecting channels. In the region where these curves apply, the flood is generally toward the northwest and the ebb toward the southeast (Tide Tables, 1950).

The discharge of the Fraser River dominates southern Georgia Strait especially in late spring and early summer. During this season muddy fresh water in great volume fans out over clearer denser seawater yielding a distinctly stratified structure. The effect of the river on salinity distribution is illustrated for one particular period by Fig. 5. As a rule when river flow is high, an upper brackish layer about 10 feet deep (S °/oo = 2 to 20) is separated from a lower seawater layer (S °/oo = 28 to 30) by a transition zone about 10 to 30 feet thick. This structure is maintained by river discharge which continually replaces the upper layer and by tidal currents which tend to replace the seawater.

Muddy water contrasts sharply with seawater and shows up lighter on photographs so that the degree of muddiness affords an approximate measure of the extent and direction of flow of fresh water. This property was utilized to investigate the movements of river discharge during varying stages of tide by a series of air photographs.

Aerial Photography

A total of 1500 aerial photographs were taken in the vicinity of the Fraser River on two days, June 1 and June 10, 1950. Series of tri-camera overlapping views were obtained at two-hour intervals from 0600 to 1800 hours on June 1, during the fall and rise of a tropic tide, and similarly on June 10 during an equatorial tide cycle. The principal line of flight is indicated in Fig. 3 and predicted tidal heights and currents are plotted in Fig. 4. Wind on both occasions was generally northwest at 10 to 20 mph but tended to be stronger on June 1. Both days were clear. River flow increased from 202,000 to 227,000 cubic feet per second between the two dates.[1] These surveys resulted in remarkable series of photographs showing successive positions of clouds of muddy Fraser River water in Georgia Strait. Four photographs have been selected as samples from among many which show prominent wave patterns.

Distinguishing Features of Large Wave Patterns

A study of the complete sequence of photographs yielded the following information which may aid in determining the nature and source of the prominent wave formations.

1. In all photographs muddy water appeared lighter in tone than seawater.[2]
2. Wave patterns were most pronounced in the two general regions represented by Figs. 1 and 2 where they seemed to occur simultaneously but independently.

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[1] These values were measured at Hope, B.C., two days before the respective dates on which photographs were taken. They represent about 80 percent of discharge at the river mouth.

[2] Portions of photographs which show sunlight directly reflected from the water were of necessity discarded in this analysis.

3. These large waves are recorded in most photographs taken during periods of flood tide, but are absent in all taken during ebb tide periods. Observations of the presence or absence of similar wave forms on other days indicate that this is a normal and not a particular phenomenon.
4. Where groups of large wave forms have been photographed or observed, each has in general been preceded by a group having wavelengths one-third to one-half as great as those in the most prominent series. A significant feature which applies to these adjacent groups is that both appear to have begun abruptly with full amplitude and wavelength.
5. Although the intensity of sunlight and the schedule of flights were similar on both dates, more numerous and distinct wave formations were recorded during the tropic tide series on June 1 than during the equatorial series on June 10.
6. Well defined wave patterns travelled in the same general direction as the flood tide. Some of them were simple wave trains (Figs. 2 and 7) while others showed interference patterns indicative of multiple sources, refraction or reflection (Figs. 1 and 6).
7. Measurements on the rate of progression of the wave group of Fig. 2, which could be recognized in successive camera surveys, showed a speed of about one and a half knots. From this value some unknown velocity of tidal set, perhaps half a knot, must almost certainly be subtracted.
8. Alternate wide and narrow bands are the most prominent

features which define the wave forms. Of these two, the narrow bands are most striking because they exhibit a line of sharp tone contrast along their length. In Fig. 2 these give the appearance of impressive amplitude but in Fig. 1 the effect of wave height is less pronounced although contrasts are quite as sharp.

9. Narrow bands in the central foreground of Fig. 1 are predominantly dark but elsewhere in the photograph they are lighter than surrounding water.

10. Foam lines, indicative of pronounced convergence, may be associated with narrow bands as they are in Fig. 7, a vertical view.

11. Surface waves generated by a consistent wind velocity were of the order of 80 feet from crest to crest. These were constant in magnitude and direction over the whole area and appeared to be unaltered in traversing regions dominated by the large wave forms.

12. Close examination of the foreground of Fig. 1 revealed what appear to be smaller surface waves which extend normal to the narrow bands. Similar waves are shown in greater detail by the enlarged vertical view of Fig. 6 in which they average about 15 feet from crest to crest and appear to be unrelated to wind direction.

An Interpretation of Surface Contrasts

The great waves of Fig. 2 show the characteristic forms of light and shadow by which surface waves are normally perceived. If waves of this length had existed with even one foot of amplitude, they should have been recorded by the tide gauge near Point Atkinson. If they were of lesser amplitude, it is most unlikely that they could have been photographed with such definition over a large area, especially in the presence of other higher surface waves. Because they lack evidence of appreciable height and because their length and speed do not correspond to those of surface waves, some other explanation must be sought not only for their presence but also for the property which permits them to be photographed.

One possible cause of contrasting reflectivity could be regular variations in mud content of surface water. In all photographs muddy water appears lighter in tone than clear water, yet narrow bands in the central foreground of Fig. 1 appear dark while in other parts of the picture they appear lighter than surrounding water. Gradations in mud content are therefore not the cause of the reflectivity contrasts by which these large banded patterns are made visible.

The presence of small waves in the vicinity of narrow bands indicates that some disturbing force other than direct wind action prevails in this region. Disturbance of the water surface could occur along lines of convergence where waves, especially small ones, should be noticeably shortened and heightened. [1] The presence of foam lines along some narrow bands as in Fig. 7 suggests strongly that these mark lines of convergence. If this were true, then the area between narrow bands should be characterized by diverging water and should be relatively

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[1] One frequently observes that small wind waves in the vicinity of tide lines, which by their accumulation of driftwood or seaweed mark convergence, are characterized by a shortness and steepness quite unlike surrounding waves.

free of the small waves which contribute to surface roughness.[1] Depending on the relative angles of sun and camera, a roughened water surface may appear lighter or darker than an adjacent smooth area. Consider, for example, the familiar "cat's paws" formed when turbulent air is blown across a water surface forming capillary wind waves which may appear distinctly dark or may glitter brightly in the sun. The gradations of light and shadow which define these banded patterns are believed to result from variations in the height, length or shape of waves too small to be recognized in the photographs.

This interpretation of light and shaded areas and of the significance of the narrow bands is substantiated by observations from shipboard of regularly banded patterns under comparable wind conditions. Patterns observed consisted of elongated regions of short, choppy waves as much as three feet in height alternating with slicks.

Considering this evidence, it appears reasonable that the narrow bands recorded by the camera are regions of intense surface roughness resulting from converging water.

Banded Patterns and Related Internal Waves

If surface water converges and diverges along regularly recurring lines, then water below the surface must exhibit complementary horizontal and vertical components of flow. According to Sverdrup et al (p. 588) this situation would exist if internal waves were present.

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[1] Where water has an upward component of velocity, as it has on the windward side of a ship which is adrift, the resulting slick effectively inhibits the formation of small wind waves.

Suppose that a definite structure be assumed in order to make a first approximation of the speed of internal waves if they existed. Let an abrupt boundary separate an upper layer of water 10 feet thick from a lower layer 1000 feet thick and let their densities be 1.00 and 1.02 respectively. Substituting these values into a formula for the approximate velocity of internal waves (Sverdrup et al pp. 586-7) yields about 1.5 knot, a speed of the same order as that which has been measured. Thus the presence of internal waves is strongly indicated.

Probable Cause of Internal Waves

Observations from shipboard left the impression that considerable energy must be supplied to a regularly banded pattern in order to maintain the turbulence apparent at the surface. Wind may build up a uniform system of gravity waves over the entire area and perhaps part of this wave energy is expended in the form of visible turbulence, but in order to initiate a train of internal waves it is reasonable to look for some disturbing force and continuing source of energy supplied at the density boundary. The cyclic occurrence of large wave forms points to tide, in particular the flood tide entering from the southern passages, as the most important cause.

Energy is available in the hydraulic head of the Fraser River and in the rise and fall of tide. Utilization of a part of this energy in disturbing the density boundary may occur in one of the following ways.

Tully (1952) has described the mechanics of a river discharging into the sea. He has shown that river discharge assumes the form of an expanding cloud of brackish water, or upper zone, which overrides a lower zone of denser seawater. Fresh water proceeding seaward has a relative velocity component opposite in direction to that of the deep water and thereby sets up a shear between the zones. A flooding tide which, because of its greater density, intrudes under the upper zone should similarly introduce shear between the water layers. This shear results in the formation of an intermediate or boundary zone characterized by considerable mixing. When the tide is flooding, the "front" of the fresh water cloud is marked by a line of convergence where surface waters, both fresh and salt, are carried downward into the boundary zone. Large turbulences which result in the violent displacement of water from one density medium to another may introduce vertical motion to the interface between density layers and thus initiate a train of internal waves. In southern Georgia Strait tidal currents can flood through connecting channels at velocities of several knots. Surface convergences[1] resulting from these streams take the form of violent tide rips which are prevalent in this area.

In the region being considered, shoals or sills usually occur between adjacent islands. The effect of abrupt changes in bottom configuration is to introduce vertical components of velocity into a passing stream. Such vertical displacement of stratified water may initiate a regular undulation of the density boundary. Similarly, the horizontal constriction of a stratified stream is likely to result in some vertical displacement of the density boundary which also may continue in a downstream direction.

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1. Convergences referred to here involve a transfer of water from the surface to appreciable depths. Those associated with internal wave motion may not necessarily be accompanied by an actual downwelling of surface water.

One or more of these disturbing features may be responsible for instituting the wave patterns observed although the mechanism has not been determined.

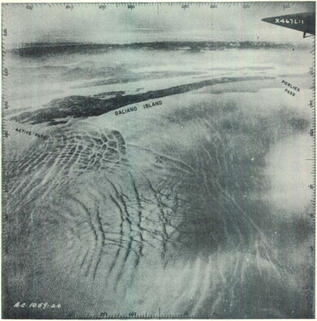
Current velocities accompanying a tropic tide should be expected to produce large wave patterns over a greater proportion of a tidal cycle than would currents associated with an equatorial tide. This may account for the higher incidence of prominent wave patterns observed during the high tidal range of June 1 than during the lesser range of June 10.

Probable Sources of Internal Waves

The largest wave patterns have appeared prominently in two regions, one between Galiano Island and the mainland, the other east of Gabriola Island. Present information does not permit exact definition of points or regions of origin but it appears likely that they are in the vicinity of channels such as Rosario Strait, Boundary Pass, Active Pass and Porlier Pass which bound the southern part of Georgia Strait.

References

1. Tide Tables for the Pacific Coast of Canada, Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, King's Printer, 1950.
2. Data Record, Fraser River Estuary Project, 1950, Joint Committee on Oceanography, Pacific Oceanographic Group, Nanaimo, B.C., 1951.
3. The Oceans, Sverdrup, Johnson and Fleming, New York, Prentice-Hall, 1946.
4. Notes on the Behaviour of Fresh Water Entering the Sea, John P. Tully, Seventh Pacific Science Congress, New Zealand, III, 267-289, 1949. Wellington, 1952.



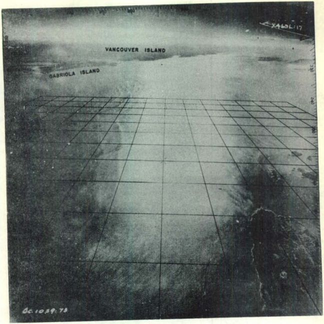
B.C. Government Air Photograph

Figure 1

GEORGIA STRAIT LOOKING WESTWARD TOWARD GALIANO ISLAND
FROM THE SOUTHERN EXTREMITY OF THE LINE OF FLIGHT

1435 June 1, 1950

The boundary at the surface of a fresh water front shows clearly this side of Porlier Pass.



B.C. Government Air Photograph

Figure 2

GEORGIA STRAIT LOOKING WESTWARD FROM THE
NORTHERN EXTREMITY OF THE LINE OF FLIGHT

1618 June 1, 1950

The grid divides the foreground
area into square miles.

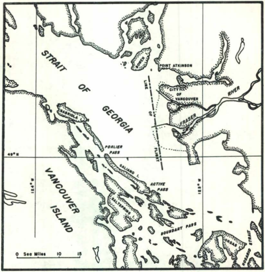


Figure 3

SOUTHERN GEORGIA STRAIT

The line of flight for air photography is shown in its relation to the Fraser River and surrounding islands.

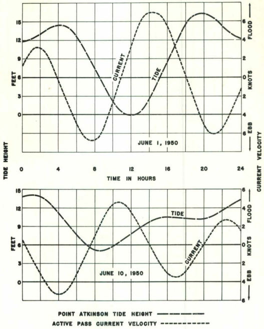


Figure 4

TIDE HEIGHT AT POINT ATKINSON WITH CORRESPONDING TIDAL CURRENTS AT ACTIVE PASS

June 1 and 10, 1950

(From Tide Tables for the Pacific Coast of Canada, 1950)

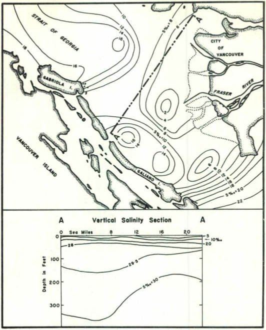
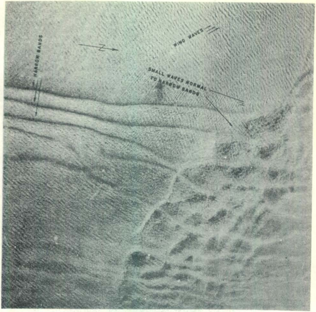


Figure 5

SALINITY CONTOURS AT 6 FOOT DEPTH IN SOUTHERN GEORGIA STRAIT, June 19-26, 1950

Salinity stratification is shown in section. (From data being studied by Mr. M. Waldichuk, Pacific Oceanographic Group, Nanaimo.)



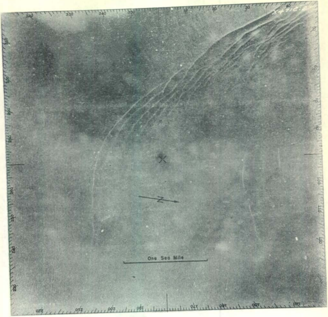
B.C. Government Air Photograph

Figure 6

ENLARGED VERTICAL PHOTOGRAPH OBTAINED
AT SOUTHERN END OF LINE OF FLIGHT

1210 June 10, 1950

Small waves which extend normal to the narrow bands may be distinguished from the larger wind waves. The area shown is one square nautical mile.



B.C. Government Air Photograph

Figure 7

VERTICAL PHOTOGRAPH TAKEN FROM
SOUTHERN END OF LINE OF FLIGHT

1809 June 1, 1950

Foam lines are shown extending from
the ends of the narrow bands.