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DEPARTMENT OF NATIONAL DEFENCE
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DREO REPORT NO. 713
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A SIMPLE MODEL FOR THE NEAR-SURFACE CURRENTS IN ROBESON CHANNEL

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PROJECT NO.
97-67-05

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PUBLISHED MAY 1975
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75-101

ABSTRACT

A simple, qualitative model is proposed to explain some of the prominent features in the near-surface current observations in Robeson Channel reported previously. The current profile associated with Kelvin waves in a homogeneous body of water in a channel is extended to a layered channel with sharp discontinuity in density. Initially only one interface at about 50 m is assumed to explain the near-surface current pattern. In addition to disrupting the vertical continuity of the transverse current, the interface is also assumed to respond to the transverse oscillations of the sea surface created by the tide moving in and out of the channel, thereby affecting the speed distribution of the lateral current. The characteristics of the resulting velocity distributions, both vertically and laterally across the channel, are shown to exhibit the observed near-surface velocity profile qualitatively. The two oscillations of periods $\tau_1 \simeq 8.2$ and $\tau_2 \simeq 6.1$ hours, which are apparent in the spectra of the longitudinal and transverse components of the observed current velocities, are re-examined. These are conjectured to originate from the oscillations of two interfaces, one at a depth of about 50 m and another at about 150 m. It is shown that the initially one-dimensional oscillations with periods very different from τ_1 and τ_2 can be modified by the Coriolis force to give rise to two-dimensional oscillations with periods close to τ_1 and τ_2. Some suggestions on future measurements are made to further verify the model.

RÉSUMÉ

L'auteur propose un modèle simple et qualitatif pour expliquer certaines particularités relevées dans les observations faites dans les courants superficiels du chenal Robeson, observations qui ont fait l'objet d'un rapport antérieur. A partir du profil de courant associé aux ondes de Kelvin, valable pour un chenal contenant une masse d'eau homogène, on établit un profil valable pour un chenal stratifié présentant des changements brusques de densité. Pour commencer, on explique la circulation des courants superficiels en considérant une seule surface de séparation à environ 50 mètres. Le rôle de la surface de séparation n'est pas seulement de rompre la continuité verticale du courant transversal, mais aussi de se prêter aux oscillations transversales de la surface de la mer créées dans le chenal par les marées et d'affecter ainsi la distribution des vitesses latéraux du courant. On montre que le schéma résultant de distribution des vitesses, tant verticalement que transversalement, s'accorde qualitativement avec le profil des vitesses superficielles observées. Après le réexamen des deux oscillations de période $\tau_1 \simeq 8.2$ et $\tau_2 \simeq 6.1$ heures, visibles dans le spectre des composantes longitudinale et transversale des vitesses observées, l'auteur suppose qu'elles proviennent des oscillations de deux surfaces de séparation situées à une profondeur de 50 mètres environ pour l'une et de 150 mètres environ pour l'autre. Il montre que la force de Coriolis peut transformer les oscillations originellement unidimensionnelles, de période très différente de τ_1 et de τ_2, en oscillations bidimensionnelles de période proche de τ_1 et de τ_2. L'auteur propose finalement quelques idées applicables aux mesures futures et visant à vérifier plus complètement le modèle.

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INTRODUCTION

In this report, a qualitative model for the current in a channel is proposed to explain some of the features in the near-surface current observations in Robeson Channel reported previously by Chow (1).#

Robeson Channel is the northeastern section of a larger body of water collectively known as Nares Strait, which connects Baffin Bay in the southeast to Lincoln Sea in the northeast (Figures 1 and 2). Two series of current observations had been made in the springs of 1971 and 1972. In this report, only the near-surface currents to a depth of 75 m obtained in 1971 will be examined, the status of the data from the later operation being in need of further clarification because of problems with the meters on the Greenland side of the channel.

Near-surface current observations described in (1) were made at three stations in a cross section of Robeson Channel by suspending current meters from the fast ice (see Figure 2 for the locations of the three stations). Seven meters were deployed at the three stations. Station I and Station III each had only one meter at a common depth of 50 m. The remaining five meters were installed at Station II at depths of 2.25, 7.25, 20, 50 and 75 m below the ice. The prominent features of the observed current velocity field can be summarized as follows:

(1) The current velocities, apparently separated into two layers, rotate in opposite directions, with the velocity vector in the top layer (depth D from 0 to 50 m) rotating counterclockwise and that in a lower layer (D > 50 m) rotating clockwise (Figure 3).

(2) The axial currents at different depths and at different locations across the channel are in phase and this component of the current increases to the left of the longitudinal flow* in the ebb and flood of the tidal current. The transverse currents from 50 m upward exhibit similar behaviours but the increase in speed to the left is not as pronounced (Figure 4).**

(3) The amplitude of oscillation of the transverse component of the current first diminishes with depth in the top layer and then suddenly increases in magnitude with a phase shift at the depth of 75 m (Figure 5(a)).

Reference 1 will be referred to as (1) hereafter

* With respect to an observer looking in the opposite direction of the longitudinal flow.

** Note that the positive direction for the transverse current has been reversed from that of Reference (1).

(4) The transverse component of the current at 50 and 75 m appears to have twice the number of oscillations as does the same component at lesser depths (Figure 5(b)).

(5) The progressive vector constructed from the velocities measured at 50 m at Station III contained a greater number of complicated current loops (Figure 6) than the other progressive vectors.

(6) In addition to the usual tidal oscillations, the spectrum for each of the longitudinal and transverse components of the current exhibits two oscillations, apparently of non-tidal origin, with periods $\tau_1 \simeq 8.2$ and $\tau_2 \simeq 6.1$ hours. The amplitudes of these oscillations are comparable to those at the major tidal frequencies. Moreover, at each location in the cross section of the channel, the normalized (as well as the unnormalized) power densities for the transverse components at τ_1 and τ_2 are greater than those of the longitudinal component (Figure 7).

From the discontinuous behaviour of the observed transverse current, a boundary layer seems to exist near the depth of 50 m. The overall current pattern seems to be that associated with the Kelvin-type oscillations in a channel and a complete solution of the problem would require the consideration of Kelvin waves in a multi-layered channel (2). This will not be attempted in this report. Instead, results from combining simple Kelvin waves (3,4,5) with the natural oscillations of internal boundary layers from density stratification (6) are discussed qualitatively. For the simple model to be useful, it must account at least qualitatively for the enumerated characteristics of the current velocity.

For the purpose of discussing the pattern of the near-surface current, one boundary layer is sufficient. The need for more than one boundary layer arises in the discussion of the internal waves and the additional layer will be introduced in the model when these waves are dealt with.

The effect of the ice cover on the current is completely ignored in the present treatment. This is perhaps justified since only the qualitative features of the currents are being considered.

A QUALITATIVE MODEL FOR THE CURRENT PATTERN IN A TWO-LAYERED CHANNEL

SIMPLE KELVIN WAVES

Consider a hypothetical channel in the Northern Hemisphere and, without loss of generality, let the longitudinal axis of the channel be in a north-south direction. Longitudinal currents of tidal origin will be assumed to exist in the channel. In analogy to the current characteristics described in (1), a weak constant current in the channel will be assumed to flow from the north to the south, otherwise referred to as in the "down-channel" direction. The simple case in which there is only one species of water in the channel will be discussed first.

If a longitudinal current due to one of the many tidal oscillations is first considered to be flowing in one direction, say, from north to south, then the effect of the Coriolis force is such that water is piled up towards the west shore (the left shore for an observer facing the opposite direction to the longitudinal flow) thus creating a sea surface sloping downward from west to east (left to right). The resulting current flow in the channel is given by that associated with the Kelvin-type waves.

The most elementary Kelvin waves apparently exist in a uniform channel of constant depth and they are characterized by the absence of a transverse current. This absence of lateral current can be realized when the Coriolis force is exactly balanced by the transverse slope of the sea surface. The longitudinal current and the height of the sea surface, however, decrease exponentially from the west to the east shore (left to right shore). The spatial rate of the exponential decay is determined by the depth of the channel and the Coriolis parameter.

For channels of more complicated cross section, analytic solutions for the Kelvin waves are possible only in special cases (see Reference 4). However, some general characteristics of the current common to them do emerge. Typically, the longitudinal and the transverse current components have distributions of the form shown in Figure 8. The transverse component usually lags the longitudinal component by a quarter of the period. These velocity components are highly asymmetric with respect to the mid-section of the channel. The longitudinal component attains a maximum somewhere on the west (left) half of the channel and vanishes at the two shorelines. More importantly, the transverse component is no longer zero everywhere in the cross section. In addition to exhibiting the same general pattern as the longitudinal current, it changes its sign before vanishing at the east (right) shore.

Now if the tidal current reverses its direction so that the longitudinal current flows from the south to the north, the previous reference to "right" and "left" remains unchanged but "east" and "west" must be interchanged.

The simple Kelvin waves without lateral current are clearly inappropriate for Robeson Channel since fairly strong transverse currents appeared in the measured data. Furthermore, the exponential behaviour of the longitudinal current across the channel is inadmissible since, in reality, this component must vanish at the two shorelines. More relevantly, the observed longitudinal and transverse components of the current across Robeson Channel seem to conform to the shape of the speed distribution for the longitudinal component in Figure 8 during the ebb and flood of the strong semi-diurnal tidal oscillations. Neither of the maxima in the two current components shown in Figure 8 was actually observed and the existence of these maxima would not have been realized unless the three stations at which the data in (1) were recorded were situated in some very special positions in the cross section (see Figure 8).

Although the simple Kelvin waves without transverse current component in a channel are not suitable for Robeson Channel, they do offer a simple means for estimating the difference in the water levels between the opposite shores. From the exact balance of the Coriolis force and the transverse slope of the sea surface, this difference in the water level is approximately 4.5 cm across the channel for every increment of 10 cm/sec in the longitudinal current.

RESPONSE OF AN INTERFACE TO THE SLOPING SEA SURFACE

The additional effect on the transverse current due to the boundary layer in the water will now be considered.

The existence of a boundary layer near the depth of 50 m in Robeson Channel can be easily seen from an examination of the water density curve. A typical water density curve obtained near the observation site during the period of the current measurements reported is shown in Figure 9. This figure shows that there are basically two water masses present, Arctic surface water above 50 m and Atlantic bottom water below 200 m, separated by a relatively thick mixing layer. An abrupt change in the water density occurs near the 50-meter depth, providing an interface between the surface water and the mixing zone.

It is well known, both theoretically and experimentally, that surface wind stress on a two-layered water basin causes the water to pile up against the leeward shore thereby giving rise to a sloping surface with an accompanying tilting of the interface in the opposite direction. (See, for instance, Reference 5). Thus the sloping of the sea surface due to the piling of water to the left shore by the Coriolis force will cause this interface to incline in the opposite direction for hydrodynamic equilibrium and, because of the small difference in density between the two water masses, this tilting of the interface can be considerable for a small difference in surface water levels across the channel. The resulting transverse flow caused by the inclining interface may resemble the pattern illustrated in Figure 10(a). The magnitude of the transverse current in each layer is constant and a sign change occurs at the interface. Consequently the transverse currents are in opposite directions on the two sides of the interface. As the slope of the sea surface reverses itself due to the reversal of the longitudinal flow, the tilt of the interface follows this change with the result that the transverse current in each layer reverses its direction. The resulting flow pattern across the channel will be represented by Figure 10(b).

QUALITATIVE CURRENT PROFILE IN A TWO-LAYER CHANNEL

So far, the simple Kelvin waves and the transverse current in a two-layered system have been pictured to occur independently of each other with the exception of the tilting of the interface to follow the changing surface slope. Now, let the Kelvin waves and the oscillations of the interface occur simultaneously and, in the light of the current observations in (1), consider the overall near-surface current pattern in a cross section of the channel. The longitudinal current would be expected to maintain its speed distribution across the channel as in Figure 8, but because of the interface, the vertical distribution of the transverse current must be interrupted at this level of discontinuity. Above the interface, the transverse current at a given depth has a distribution across the channel as in Figure 8. Below the interface, a reversal in direction for this component of the current takes place. Figure 10 may still be used to summarize the transverse current by visualizing that the current at any depth, instead of being a constant, varies in a manner similar to that shown in Figure 8.

In the remainder of this section, it will be shown that the first five characteristics of the near-surface currents enumerated in the Introduction follow from the simple qualitative two-layered model.

From the water density measurements, it has been shown that an interface does in fact exist at about the 50-meter depth. Now assume that, for any one of the tidal components, a down-channel flow is accompanied by a transverse current towards Greenland above the interface (i.e., the transverse current is flowing to the (right). Consider the superposition of this transverse component to the axial current due to the ebb and flood of one of the tidal oscillations. It is now easy to see the current velocity rotating in a counter-clockwise direction above 50 m and decreasing to a smaller or zero rotation in the immediate neighbourhood of the interface. The reversal to a clockwise rotation below the interface follows since the transverse current is exactly out of phase with that above the interface (Figure 3).

Figure 9 has further implications for the current profile. In order to compare the current pattern of the generalized channel to the observed currents in Robeson Channel, consider observations of the current in the cross section of the channel at locations denoted by A, B, C, D_1, D_2, D_3, and E in Figure 11.* D_1, D_2 and D_3 are locations of approximately the same depth and are near the interface.

* The left and right shores in Figure 11 now represent Ellesmere Island and Greenland, respectively, and a longitudinal current out of the page corresponds to a flow from the Lincoln Sea through Robeson Channel to Baffin Bay.

Now, if the distribution of the current speed is as shown in Figure 8, the amplitude of the current, longitudinal as well as transverse, at two different locations at the same depth (for instance, any two of D_1, D_2 and D_3 in Figure 11) must alternately be greater and lesser than the other for two consecutive halves of a complete cycle for any one of the tidal components. This is illustrated by Figure 4.

Figure 11 implies that the amplitude of the transverse current must decrease as the discontinuity layer is approached from above and finally reverses its direction below the interface. Results of current measurements in (1) at A, B, C, D_2 and E confirmed this pattern (Figure 5(a)).

Suppose that D_1, D_2, D_3 and E are sufficiently near the interface that the interface moves through these locations during a complete oscillation. Then the transverse current at these locations would show a double reversal of its direction in comparison to the transverse current in a position away from the interface (for instance, at A). These multiple oscillations were observed during the weaker of two consecutive semi-diurnal tidal oscillations (Figure 5(b)).

It was shown in (1) that there was a weak, constant axial flow of water from the Lincoln Sea with an even weaker cross-channel current towards Greenland. Consequently a situation in which the interface, on the average, inclines upward towards Greenland as illustrated in Figure 11 exists. Now, because of its proximity to the interface, the current at D_3 would be affected more by the interface than at D_1 or D_2, two other locations at a depth of 50 m. This is perhaps the reason for the confusing current loops recorded at a depth of 50 m at the station closest to Greenland (Figure 6).

INTERNAL WAVES

The last characteristics enumerated for the near-surface current in the Introduction, two fairly strong oscillations with periods $\tau_1 \simeq 8.2$ and $\tau_2 \simeq 6.1$ hours, remain to be accounted for. Several reasons were given in (1) to rule out the possibility of the tidal origin for these oscillations. These arguments will be repeated here. From Figure 7, the typical ratios between the the normalized power densities for the transverse and longitudinal currents are approximately 9.4 and 6.6 at τ_1 and τ_2, respectively. Thus the transverse oscillation at each of τ_1 and τ_2 is stronger than that of the longitudinal oscillation, an unlikely consequence if these were of tidal origin. More importantly, to the same degree of resolution as the power spectra in Figure 7, the power spectrum of the water level which was measured at Lincoln Bay (see Figure 2) during the period of the current observations, showed no significant oscillations at these frequencies.

In addition to responding to the tidal oscillations by inclining across the channel, an interface can also have its own natural modes of oscillation. Since the difference between the densities of the water species separated by an interface is usually very small, these natural modes can easily be excited by the tidal oscillations. It is conjectured that the oscillations with periods $\tau_1 \simeq 8.2$ and $\tau_2 \simeq 6.1$ hours are periods of the natural modes of the interfaces separating different water species being excited by the tides.

It is clear that the oscillation at τ_2 is not a higher harmonic of that at τ_1 since the ratio τ_1/τ_2 is not close to an integer. They could be independent fundamental modes arising from oscillations of either one interface separating two different water masses in a channel with two distinct cross sections or from the oscillations of two interfaces separating three water masses.

With one interface, the presence of τ_1 and τ_2 could be the consequence of the superposition of two natural modes from the two different cross sections of the channel nearby, τ_1 being the period of the normal mode for the wider northwestern section and τ_2 for the narrower southwestern section of Robeson Channel. If this is indeed the case, then the weakening of the oscillation at τ_1 and the strengthening of that at τ_2 should have been observed in the 1972 current measurements carried out in a cross section of the Channel near Wrangel Bay about 15 km down-channel from Lincoln Bay (see Figure 2). Such relative changes in the power densities at the two frequencies were not seen and we are thus led to consider the possibility of two interfaces in the Channel.

The presence of another interface, of course, will change the simple current pattern of the channel represented by Figure 10. It necessitates the addition of another layer of transverse current. This modification to Figure 10(a) can be made by including, below the two existing layers, an interface tilted upward to the left together with a current flowing to the right. Similar modification to Figure 10(b) is obvious. Other than the existence of the two modes of oscillation for the internal waves, the overall near-surface current pattern is not changed and the deep current need not be of concern at the present.

Let the densities and equilibrium thicknesses of the three layers be ρ_1, ρ_2, ρ_3 and h_1, h_2, h_3, respectively, with Medium 1 being the lightest top layer and Medium 3 being the densest bottom layer (Figure 12). According to Mortimer (5), there are three normal modes of oscillation. One of these is that of a surface wave across the channel with period of the order of 20 minutes.* The other two modes of immediate interest are of periods given by

$$T'_k = \frac{2L}{\sqrt{-gH_k}} , \qquad k = 1,2 \tag{1}$$

* There is evidence for these waves being observed in the current measurements from ice floes in the summer of 1974.

where L is the width of the channel and g the acceleration due to gravity. H_k are the two solutions of the quadratic equation

$$(h_1 + h_2 + h_3)H^2 - h_1h_2h_3 \left(\frac{\rho_2 - \rho_3}{h_1\rho_3} + \frac{\rho_1 - \rho_3}{h_2\rho_3} + \frac{\rho_1 - \rho_2}{h_3\rho_2}\right) H$$

$$+ h_1h_2h_3\left(\frac{\rho_1 - \rho_2}{\rho_2}\right)\left(\frac{\rho_2 - \rho_3}{\rho_3}\right) = 0. \tag{2}$$

In analogy to a surface wave, H_k in Equation (1) can be interpretted as the effective depths for the two internal waves. For a channel of width $L \simeq 20$ km (at the depths of the interfaces) with layer thicknesses 50, 100 and 450 m and $\Delta\rho/\rho \simeq (\rho_2 - \rho_1)/\rho_3 \simeq (\rho_3 - \rho_2)/\rho_3 \simeq 10^{-3}$, the periods are approximately $T_1' \simeq 20.9$ hours and $T_2' \simeq 10.0$ hours.

These values of T_1' and T_2' for the periods of oscillations are in poor agreement with τ_1 and τ_2. Furthermore, even if they are close to τ_1 and τ_2, only the transverse oscillations will result. The oscillations along the channel axis at these frequencies remain to be explained. For the free oscillations of a single interface with period T', two dimensional motion can result from the influence of the Coriolis force on the original unidirectional oscillations, giving rise to the so-called "internal inertia waves" (7,8). The period of oscillation becomes

$$T = (1/T'^2 + 1/T_0^2)^{-\frac{1}{2}} \tag{3}$$

where T_0 is the inertial period which, in hours, is given by

$$T_0 = 12/\sin\phi$$

with the latitude ϕ. Now each of the two oscillations at T_1' and T_2' is influenced by the Coriolis force in the same manner, giving rise to longitudinal in additional to transverse oscillation with the new periods

$$T_k = (1/T_k'^2 + 1/T_0^2)^{-\frac{1}{2}}, \qquad k = 1, 2 \tag{4}$$

At the latitude of Robeson Channel, these periods are approximately $T_1 \simeq 10.5$ hours and $T_2 \simeq 7.7$ hours. Thus, the Coriolis force not only changes the original transverse oscillation to motions in two dimensions but also modifies the periods to better approximate the measured τ_1 and τ_2.

The frequencies of the higher harmonics of the two original normal modes are given by

$$T'_{k,j} = T'_k/j; \qquad k = 1, 2 \text{ and } j = 1, 2, 3, \ldots \tag{5}$$

where j = 1 corresponds to the fundamental frequencies. Under the influence of the Coriolis force, these become

$$T_{k,j} = (1/T'^2_{k,j} + 1/T_0^2)^{-\frac{1}{2}}; \qquad k = 1,2 \text{ and } j = 1, 2, 3, \ldots \qquad (6)$$

Therefore τ_α in Figure 7 is a higher harmonic of τ_1. However, τ_β is not a higher harmonic of τ_2 for it does not satisfy Equation (6) for $k = 2$, and $j = 2$.

DISCUSSION

The current pattern emerging from the simple qualitative model obtained by combining Kelvin-type waves with free oscillations of internal interfaces seems to conform qualitatively to the observed characteristics of the near-surface currents in Robeson Channel enumerated in the Introduction. The behaviour of each component of the current approximately agreed with Figure 8 with important exceptions: The dramatic change of the current speed across the channel as illustrated was not observed. Moreover, it was not possible to determine the existence of a region for the reversal in direction in the transverse current because of the limited area in the cross section of the channel over which current observations were made. The existence of longitudinal and transverse oscillations with periods near $\tau_1 = 8.2$ and $\tau_2 = 6.1$ hours has been reasonably explained, starting with only transverse oscillations with periods quite different from τ_1 and τ_2. This was done by incorporating the influence of the Coriolis force with the unidirectional motion. In addition to modifying the motions to two-dimentional oscillations, the Coriolis force also changed the periods to within reasonable agreement with the observed τ_1 and τ_2 for parameters typical of Robeson Channel.

There are several observations which may be made to further verify the simple model. All these involve simultaneous observation of more than one parameter at one location or the same parameter at different places. These are measurements of: water level (tide) on opposite sides of the channel; current across the channel at a minimum of four stations with one or more meters at each station at the same depths to detect the maximum speeds in both components as well as the reversal of direction in the transverse component; and water densities at the interfaces.

The measurement of the water level on opposite sides of the channel should detect the sloping of the sea surface. A very rough estimate of the difference in water levels with parameters typical of Robeson Channel was about 4.5 cm for every 10 cm/sec of longitudinal current. While this order-of-magnitude estimate may not be appropriate because of the assumptions it was based on, the reversal of the water level difference could certainly be detected during the ebb and flood of the tide. In such measurements, a channel-like environment is desirable and so deployment of tide gauges at the mouth of the channel, where the wave front of the tide may arrive at the two gauges at different times, should be avoided.

Opportunity to carry out extensive current observation in Robeson Channel may not arise again. However, in the future, in a channel-like environment it is desirable to have four stations rather than three across a channel to detect the distribution of the current speeds. This arrangement is advantageous even if knowledge of the current at one level in one of the other stations is sacrificed to provide just one meter for the extra station. Of course this meter must be placed at a depth common to meters at the other stations for meaningful comparison.

To determine if the water in a channel oscillates as if there were two interfaces, the density of the water should be monitored at the suspected levels of sharp discontinuity. If there are two interfaces, the fluctuation of the density at the two levels will be opposite to each other with the density increasing at one location while a decrease takes place at the other. In the event that a second interface at a deeper level oscillating out of phase with the one at about 50 m is absent, the wave with period τ_2 may have to be re-attributed to a tidal origin. The possibility of τ_2 being of tidal origin is even more convincing when, instead of the ratio between the normalized power densities of the transverse to the longitudinal currents, the ratio of the un-normalized power densities at τ_2 is examined. This latter ratio is perhaps more appropriate for determining whether a given oscillation is an internal oscillation or not since it is not subject to large distortion due to the contribution from the strong static component to the normalization. This ratio ranges from unity to about 3 with one value of 0.3 at a depth of 20 m at Station 2.

In this report, discussion has been carried out as if each one of the tidal oscillations and the internal waves could be observed separately, free from mutual interference. In reality, all tidal components and internal waves as well as other disturbances occur simultaneously. Fortunately, most of the characteristics of the current were seen because of the strong semi-diurnal tidal component, The intensity of this component is such that the dominant features are not obscured by the simultaneous occurrence of other components. To study any one of these components in detail, each of the longitudinal and transverse currents as well as the water level should be analysed by harmonic analysis (9) in conjunction with the spectral analysis to obtain the individual frequency components for further examination. Unless these analyses are carried out, the previously described difference in the water level across the channel may remain obscured and hidden under the many disturbances and noise. From the result of these analyses on the near-surface currents, the sense of rotation of each individual component should be clearly seen. In particular, each of the tidal oscillation should be clockwise or counterclockwise depending on the depth (below or above the interface) whereas the sense of rotation of those oscillations with periods τ_1 and τ_2 should be strictly clockwise.

The mixing of the many oscillations is, no doubt, why the phase difference between the transverse and the longitudinal components as well as between the transverse components across the interface is so poorly illustrated. The transverse current at 75 m in Figure 5(a) is hardly exactly out of phase with the others. Nor was the lag of the transverse to the longitudinal current by a quarter of a period well demonstrated in (1). Presumably, a better illustration of the time lag can be obtained when individual component from harmonic analysis can be examined.

Finally, consider the possibility of reflection of the Kelvin waves. In (1), it was noted that the longitudinal currents everywhere at the three stations were almost in phase with each other and they led the water level by 2 to 2.4 hours (nearly a quarter of the semi-diurnal tidal period). Thus the tidal waves coming into the channel are like standing waves. This is reasonable since the tides coming into Nares Strait from Lincoln Sea in the north and Baffin Bay in the south must meet somewhere in the Strait (Figure 1).* The location where the two meet may act like a rigidly reflecting wall and hence the standing wave characteristics for the tidal waves. Now, this same "rigid wall" must also reflect the Kelvin waves thereby giving rise to rotating cells with stationary centers (amphidromic points) distributed along the Strait. The longitudinal currents examined in (1) show no tendency to rotate. In fact, they behave as if the waves are propagating. This could be because all three 1971 stations were situated to one side of the vortex. In principle, the 1972 current observations could have resolved this question as the locations of the stations were better chosen. Unfortunately, because of problems with the meters on the Greenland side of the channel, the status of the data produced by them has still to be clarified.

* A very special requirement would be imposed on the geometry of the Strait for the tide to appear as if it propagates right through.

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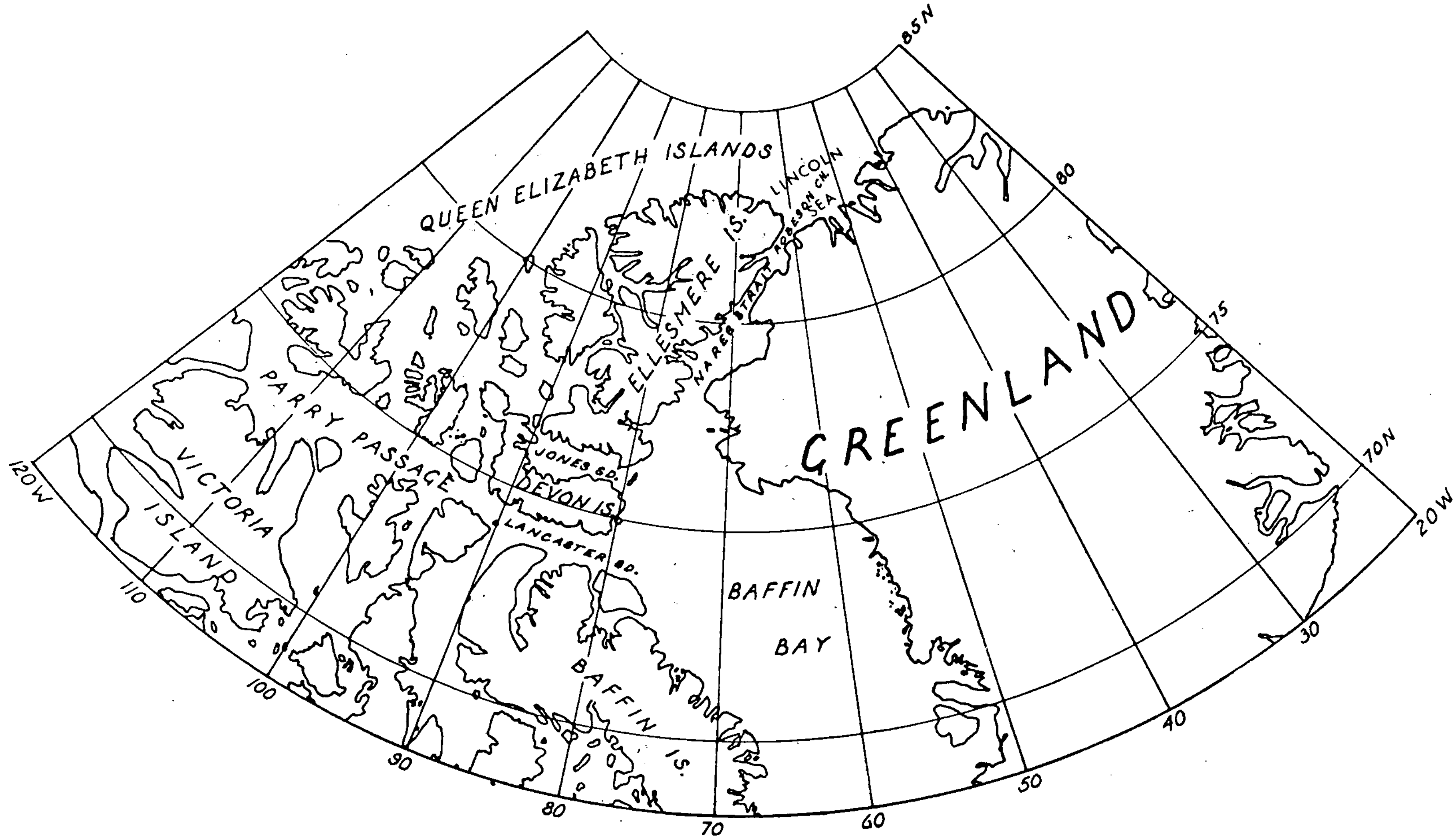

Fig. 1 Part of the Canadian Arctic and Greenland.

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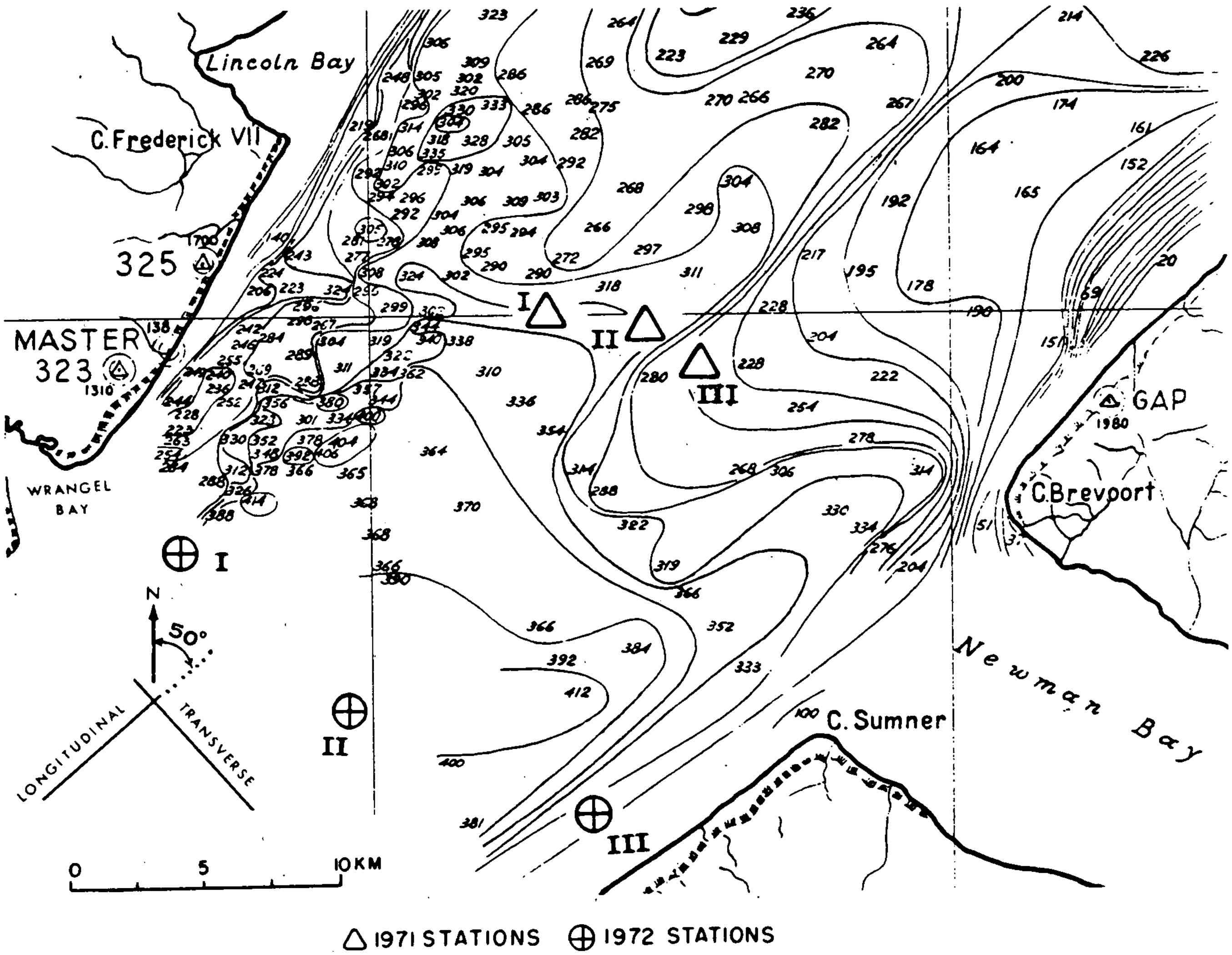

Fig. 2 *A detailed map of Robeson Channel region with stations of 1971 and 1972 spring operations indicated. The longitudinal and transverse channel axes are illustrated at the lower left corner. (Water depths in fathoms).*

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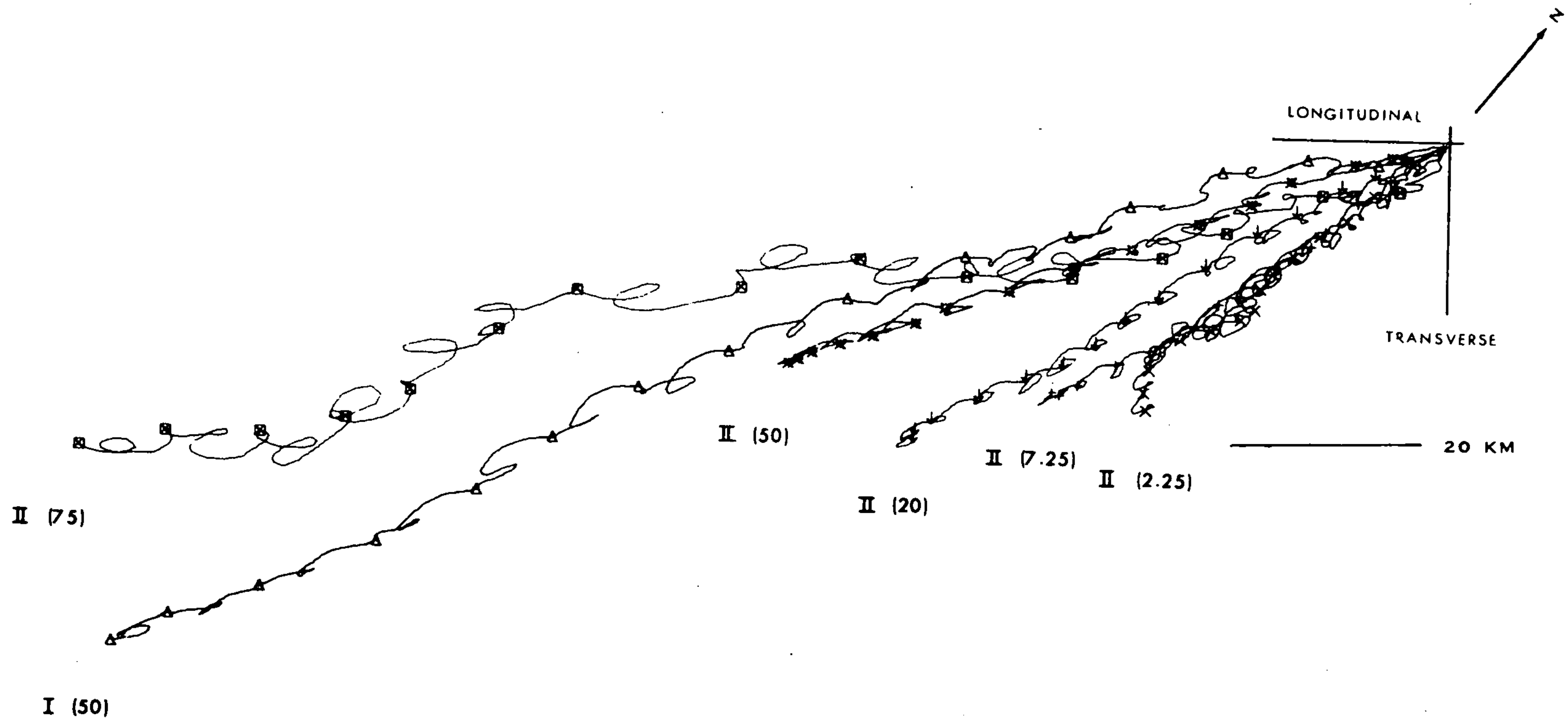

Fig. 3 Progressive vectors constructed from current velocities at Stations I and II for the period May 4 to May 18, 1971 exhibiting opposite rotations across 50 m layer. Numbers in brackets denote depths.

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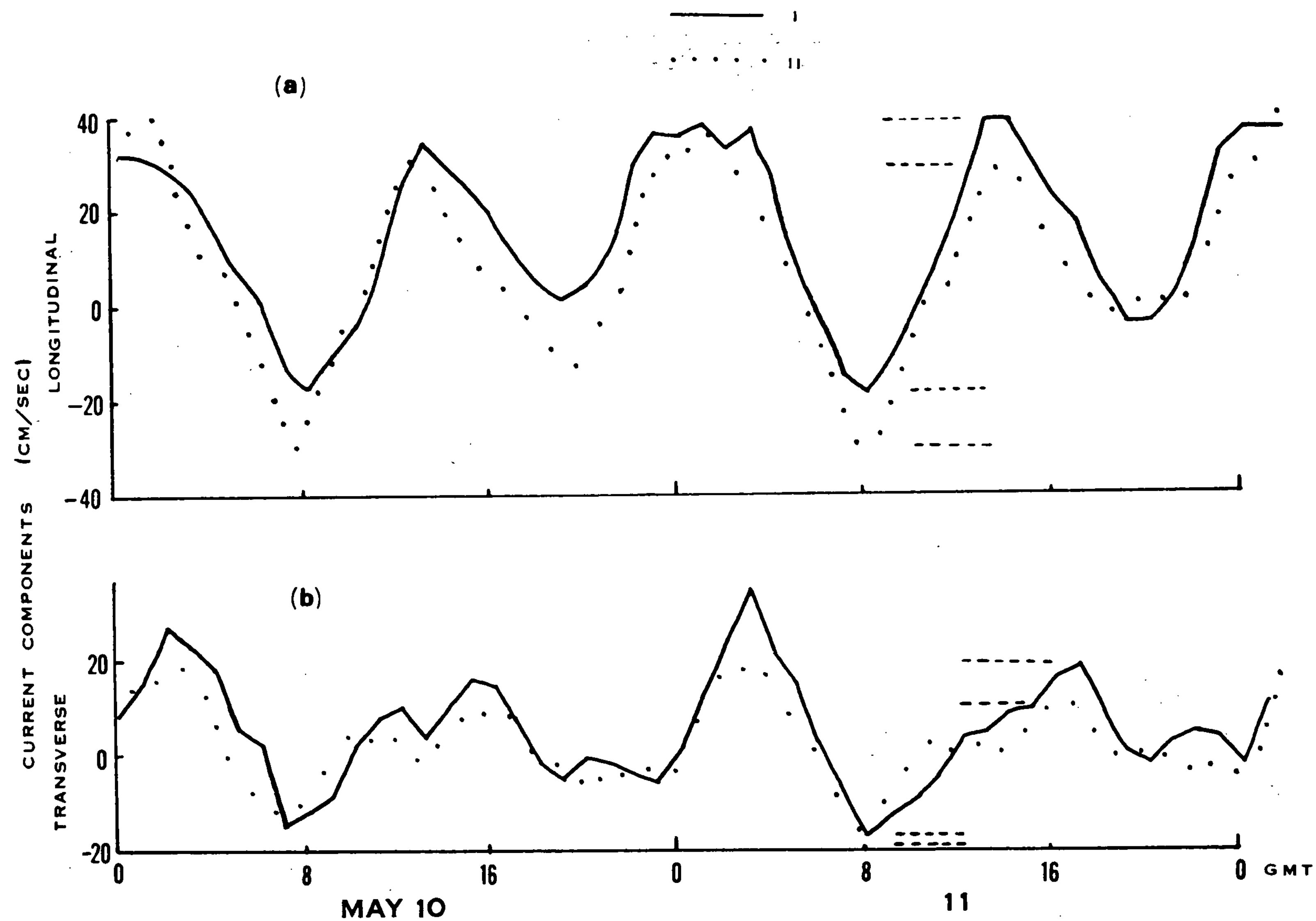

Fig. 4 Longitudinal (a) and transverse (b) currents at 50 m depth at Stations I and II showing the increase of the current speeds to the left of an observer looking in the opposite direction of the longitudinal flow.

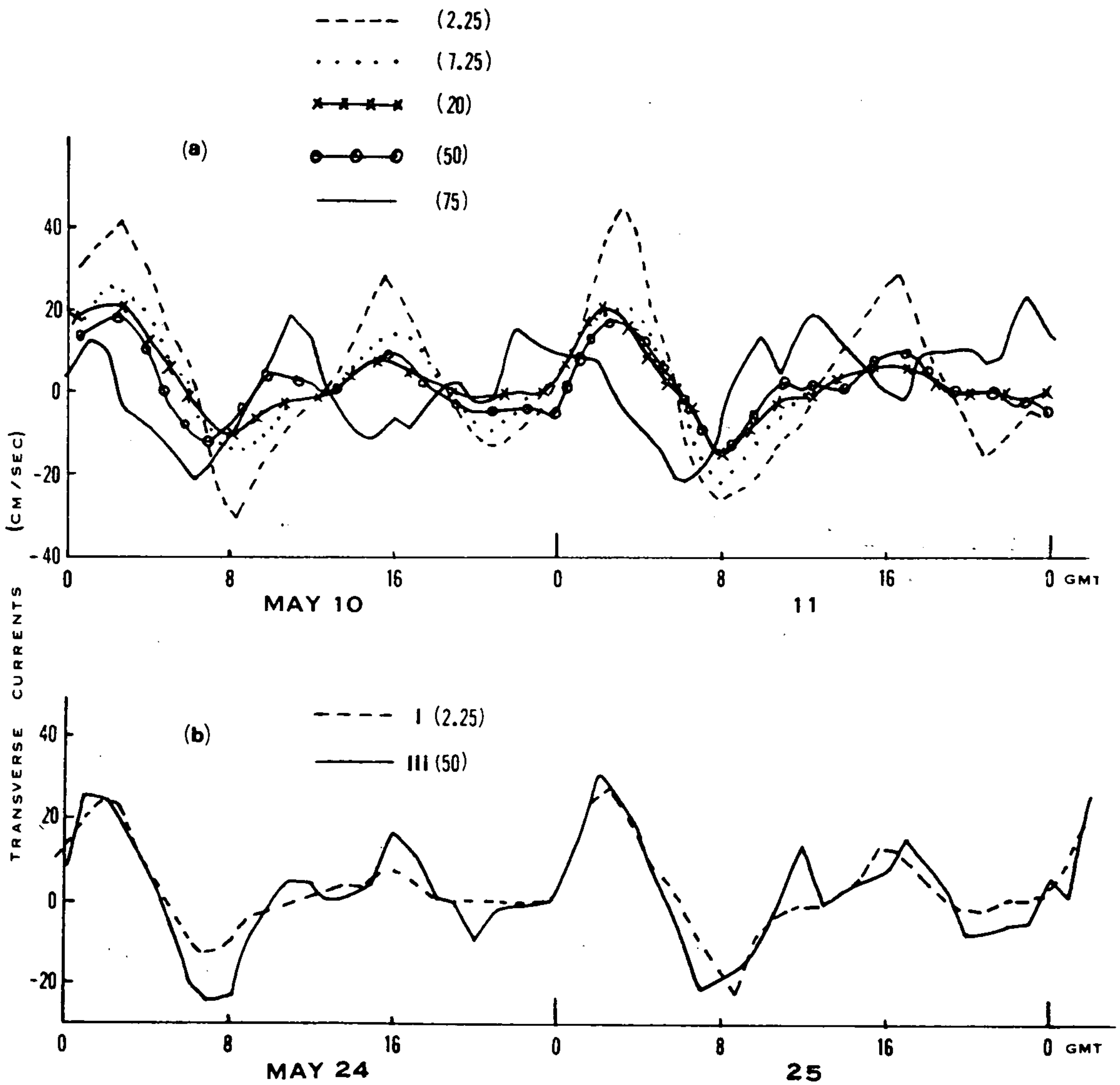

Fig. 5 *Transverse currents at Station II (a) and at Stations I and III (b). (a) shows the decreasing amplitude of oscillation with increasing depth to 50 m and the phase shift at 75 m. (b) illustrates the multiple oscillations at 50 m depth during the weaker semi-diurnal oscillations.*

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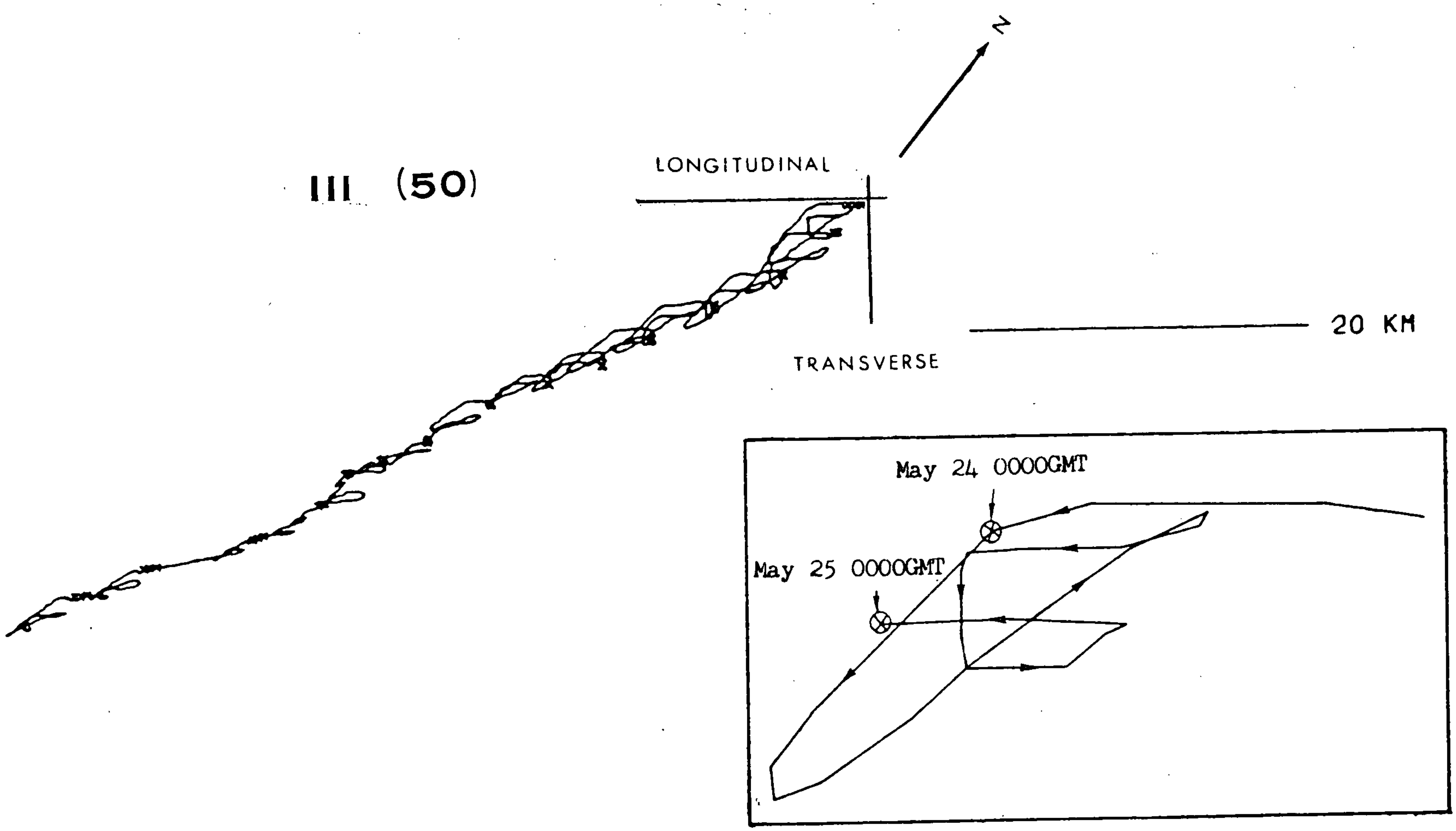

Fig. 6 *Complicate progressive vector for Station III at 50 m for the period May 23 2110 GMT to June 7 1930 GMT (sampling time 20 minutes). Consecutive marks on trajectory denote 24 hours. Inset, plotted from hourly velocity readings, shows beginning of trajectory in detail.*

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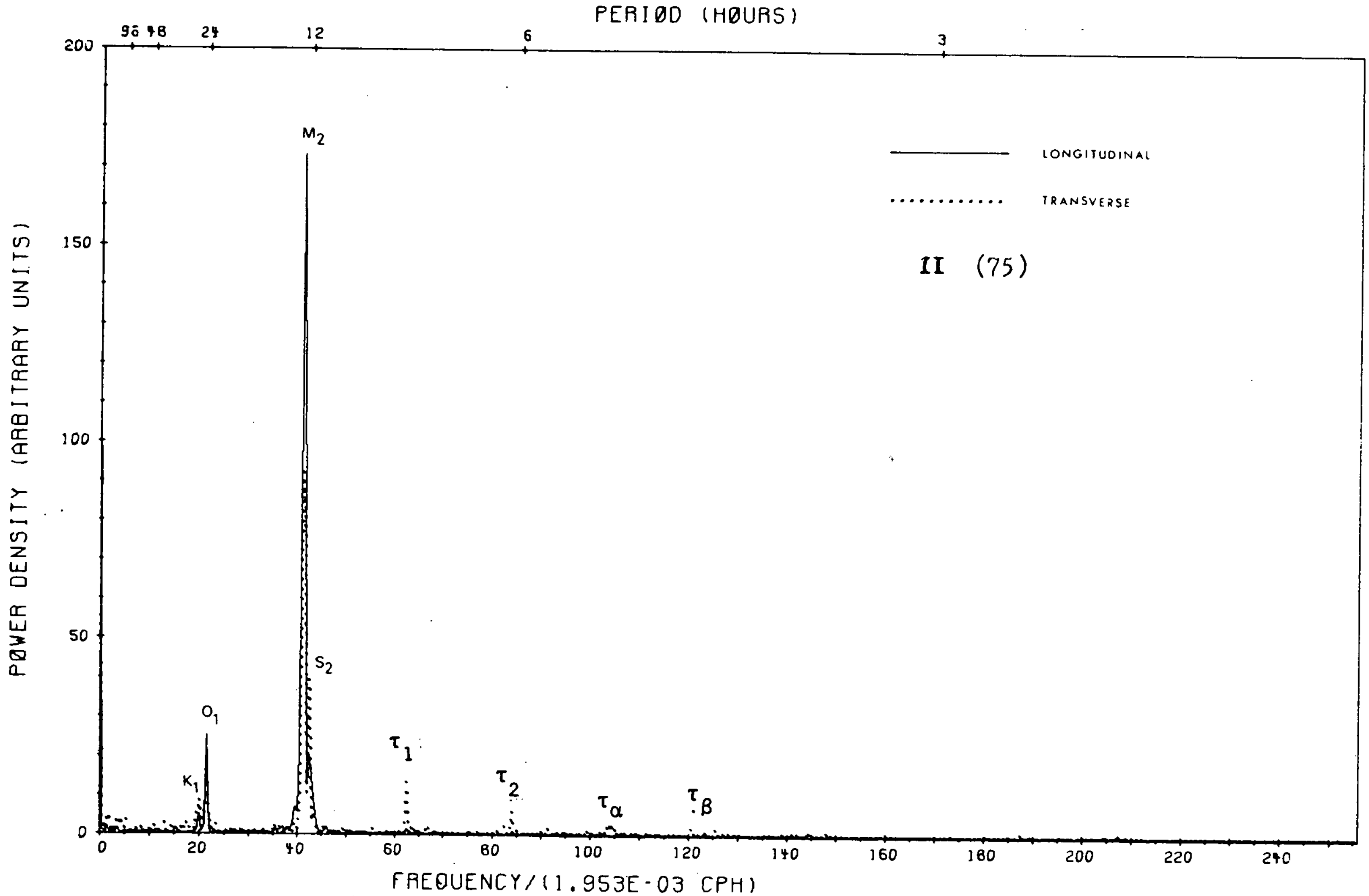

Fig. 7 *Typical normalized power spectra for the longitudinal and transverse currents. K_1, O_1 and M_2, S_2 are diurnal and semi-diurnal components.*

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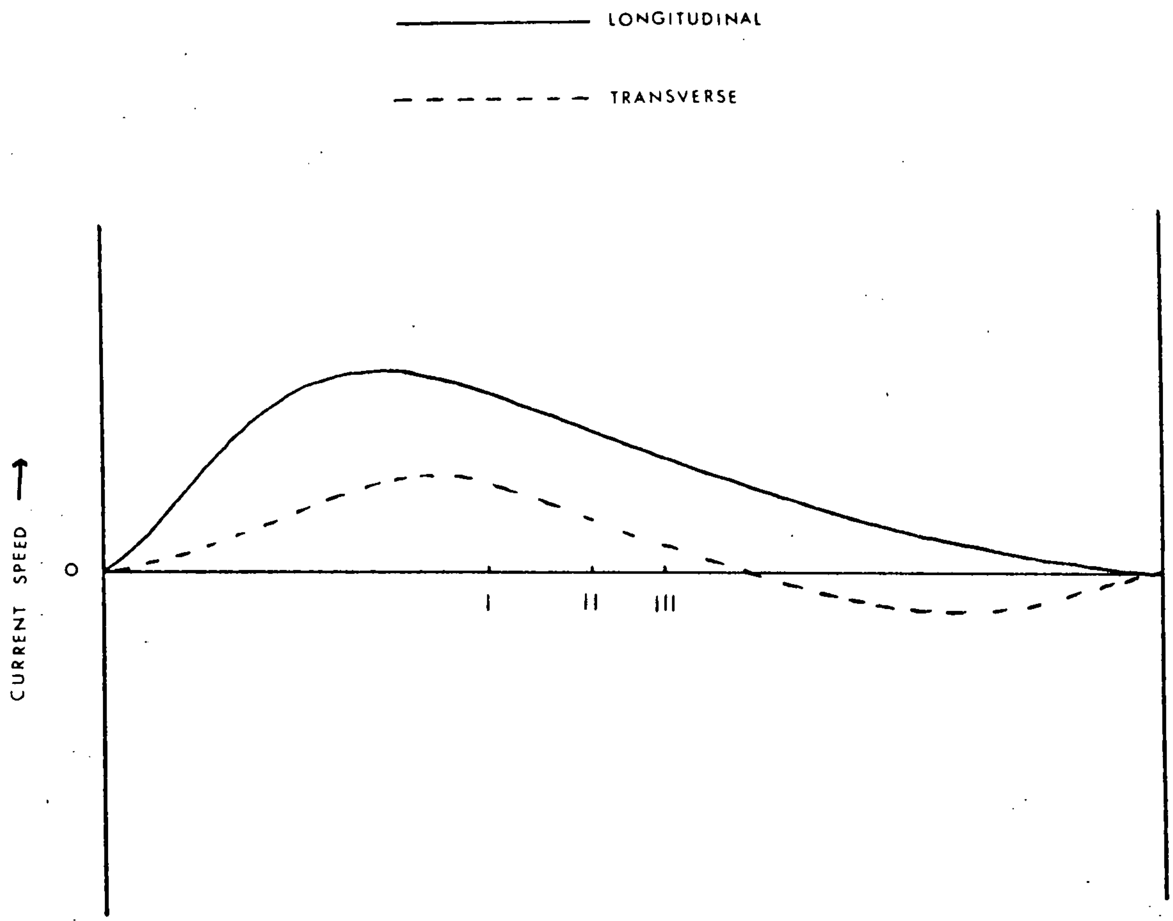


Fig. 8 *Distributions of longitudinal and transverse current speeds across the channel, looking in direction opposite to that of the longitudinal flow. A positve transverse current flows to the right. (I, II and III indicate the approximate locations for the 1971 observations, looking in the northeast direction.)*

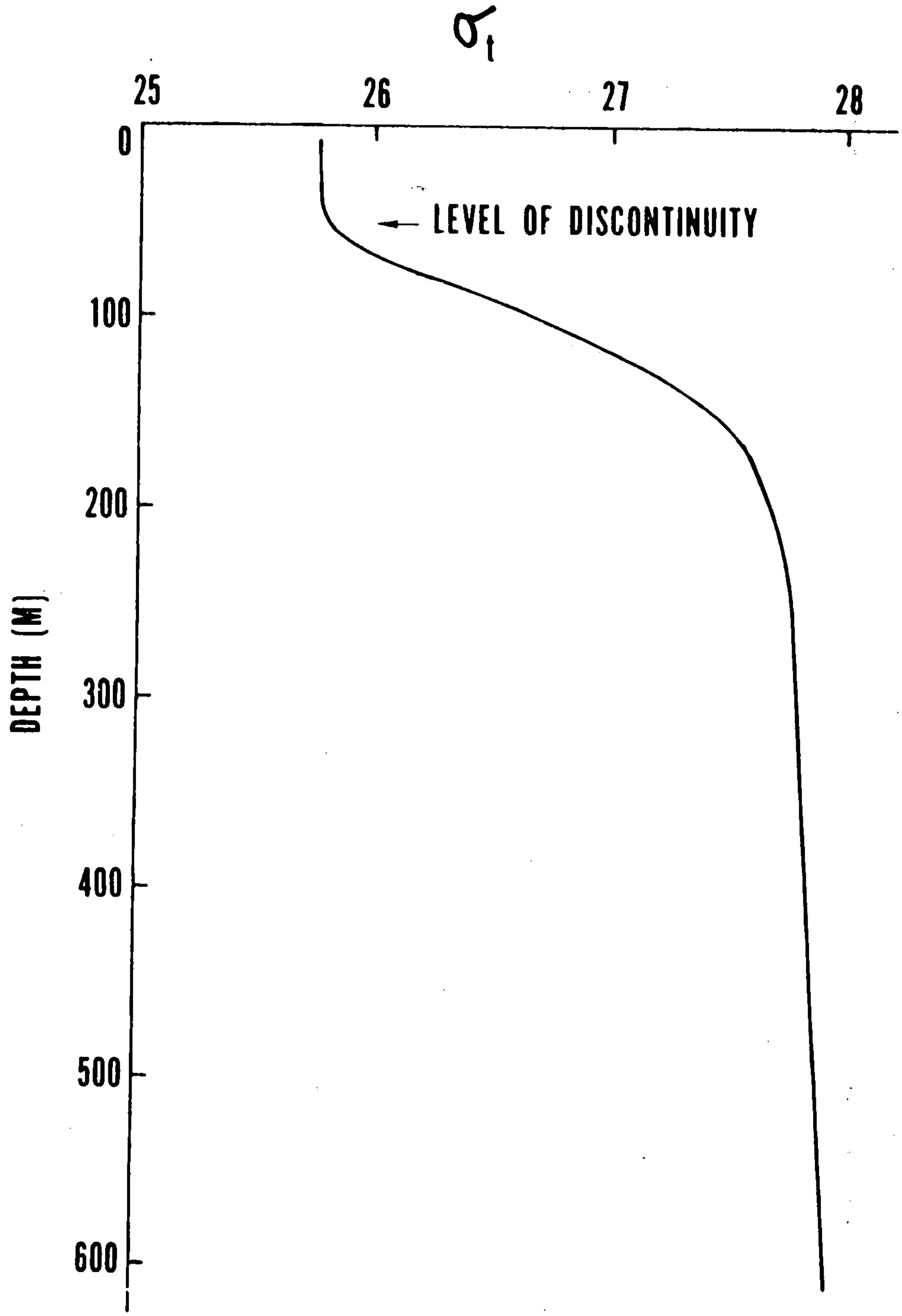
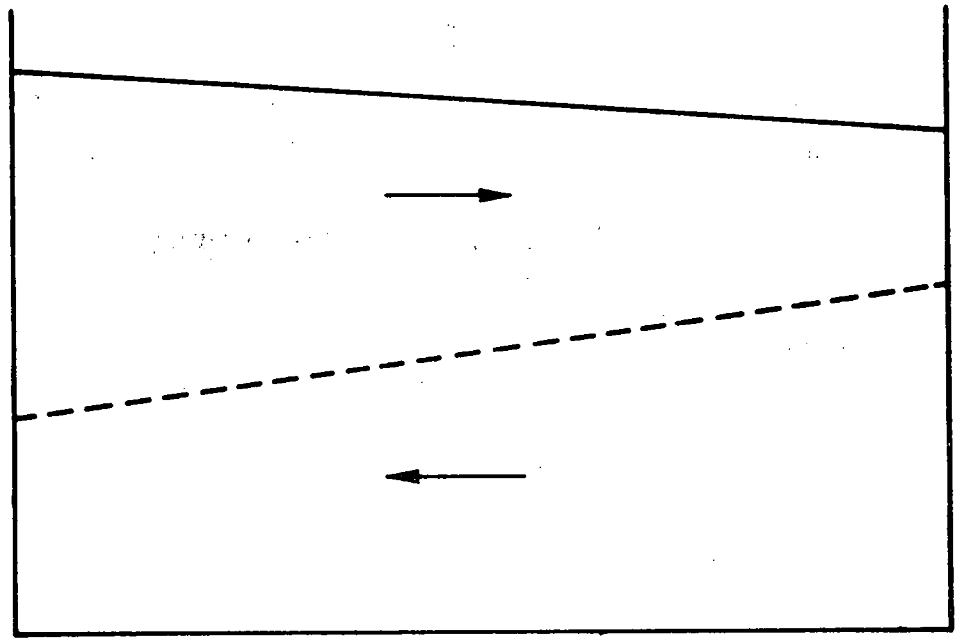


Fig. 9 Typical σ_t *from Robeson Channel during the period of current observations in 1971.*

(a)



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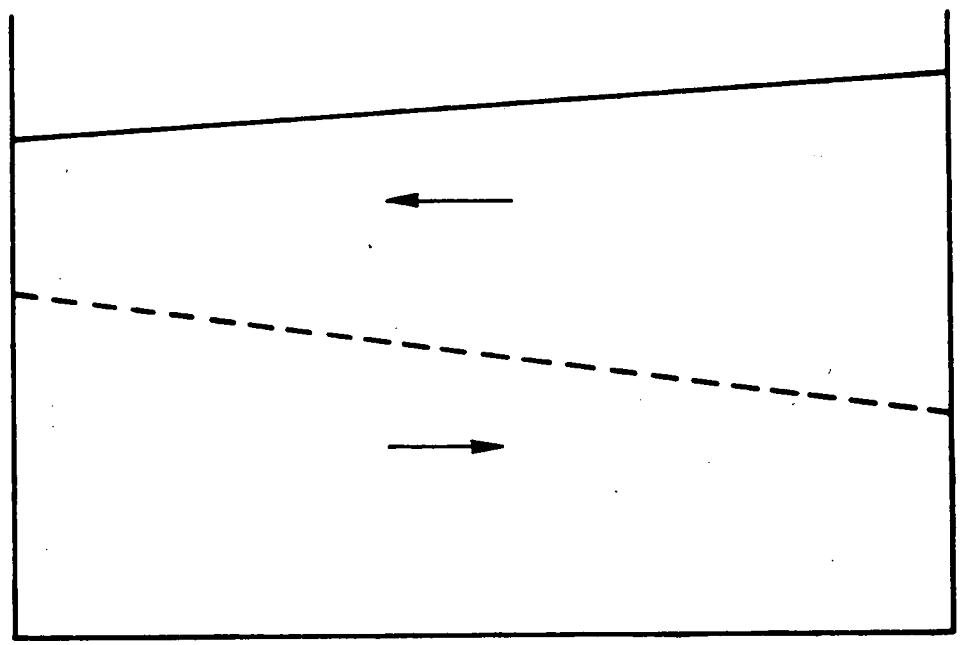

Fig. 10 Configurations of sea surface (solid line) and interface (dashed line) across channel for longitudinal current flowing out of page (a) and into the page (b). Arrows denote transverse current above and below interface.

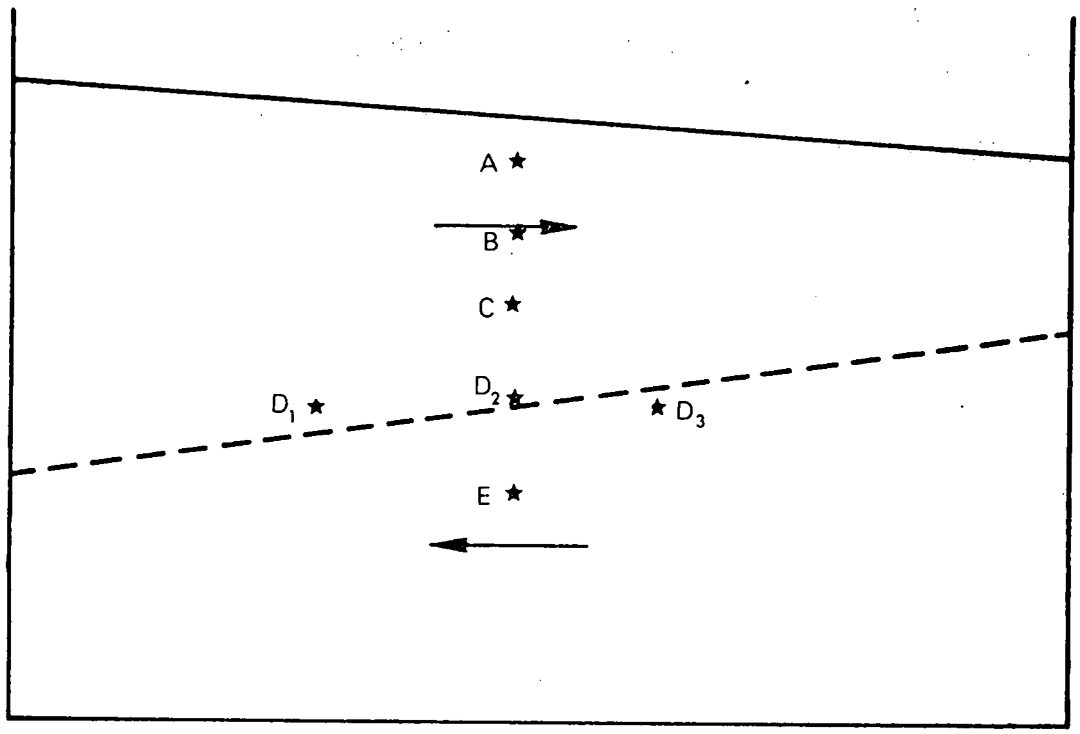

Fig. 11 As Figure 10(a). A, B, C, D_1, D_2, D_3 and E represent locations of current observations. Left and right shores correspond to Ellesmere Island and Greenland, respectively.

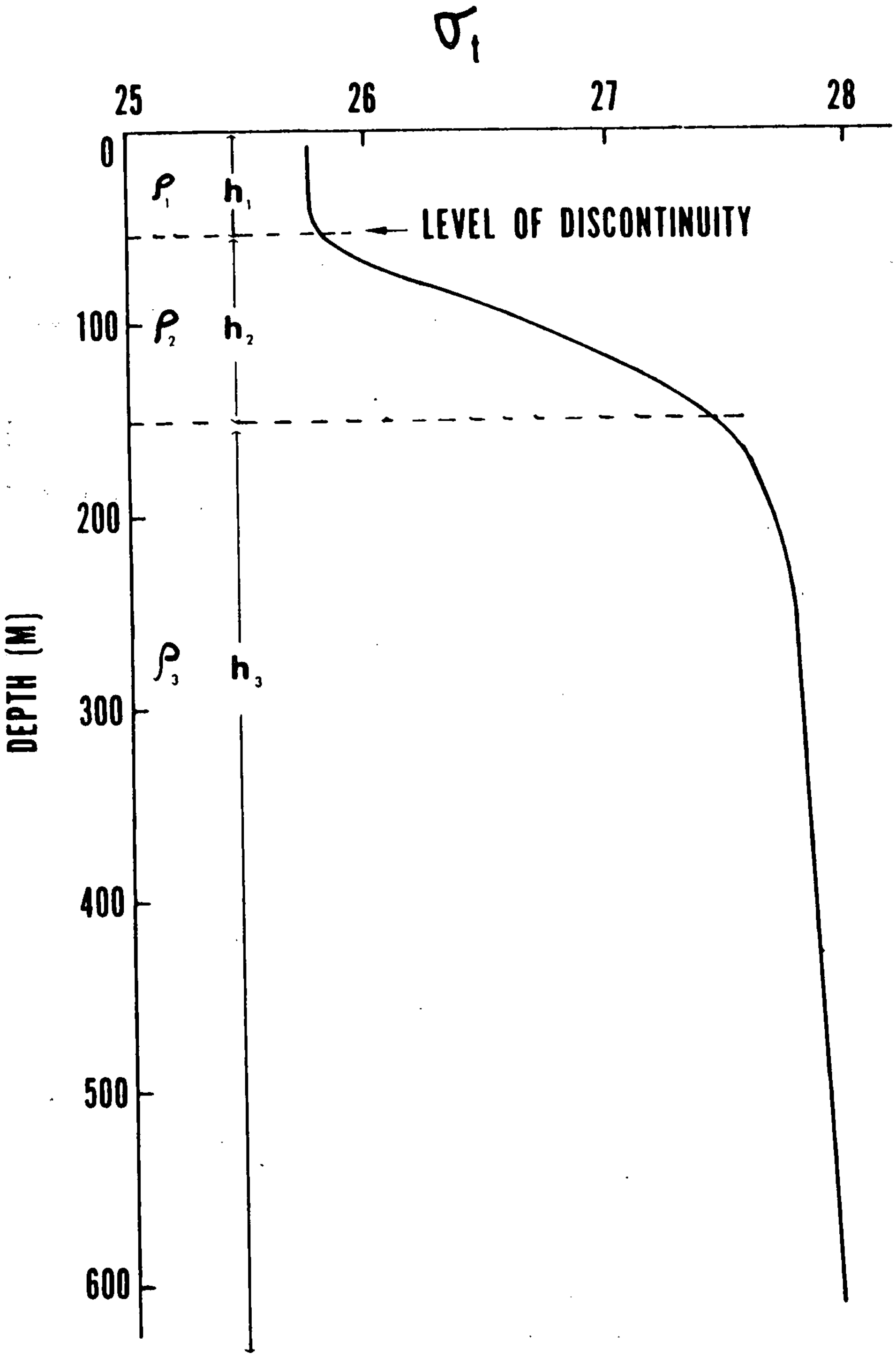

Fig. 12 Water in Robeson Channel visualized as a hypothetical three-layered system.

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1. ORIGINATING ACTIVITY

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National Defence Headquarters, Ottawa, Ontario

2a. DOCUMENT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
N/A

3. DOCUMENT TITLE

A Simple Model for the Near-Surface Currents in Robeson Channel

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
DREO report

5. AUTHOR(S) (Last name, first name, middle initial)

Chow, R.K.

6. DOCUMENT DATE
March 1975.

7a. TOTAL NO. OF PAGES
27

7b. NO. OF REFS
9.

8a. PROJECT OR GRANT NO.

97-67-05

9a. ORIGINATOR'S DOCUMENT NUMBER(S)

713

8b. CONTRACT NO.

9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10. DISTRIBUTION STATEMENT

Unlimited

11. SUPPLEMENTARY NOTES

12. SPONSORING ACTIVITY

13. ABSTRACT unclassified

A simple, qualitative model is proposed to explain some of the prominent features in the near-surface current observations in Robeson Channel reported previously. The current profile associated with Kelvin waves in a homogeneous body of water in a channel is extended to a layered channel with sharp discontinuity in density. Initially only one interface at about 50 m is assumed to explain the near-surface current pattern. In addition to disrupting the vertical continuity of the transverse current, the interface is also assumed to respond to the transverse oscillations of the sea surface created by the tide moving in and out of the channel, thereby affecting the speed distribution of the lateral current. The characteristics of the resulting velocity distributions, both vertically and laterally across the channel, are shown to exhibit the observed near-surface velocity profile qualitatively. The two oscillations of periods $\tau_1 \simeq 8.2$ and $\tau_2 \simeq 6.1$ hours, which are apparent in the spectra of the longitudinal and transverse components of the observed current velocities, are re-examined. These are conjectured to originate from the oscillations of two interfaces, one at a depth of about 50 m and another at about 150 m. It is shown that the initially one-dimensional transverse oscillations with periods very different from τ_1 and τ_2 can be modified by the Coriolis force to give rise to two-dimensional oscillations with periods close to τ_1 and τ_2. Some suggestions on future measurements are made to further verify the model.

DSIS
72-508

KEY WORDS

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Near-Surface Currents
Kelvin Waves
Multi-Layered Channel
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PROJECT NO: 97-67-05

TITLE: A Simple Model for the Near-Surface Currents in Robeson Channel

AUTHOR: R.K. Chow

DATED: May 1975

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