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RECORDINGS OF POTENTIAL DIFFERENCE ACROSS THE PORT PATRICK - DONAGHADEE SUBMARINE CABLE (1977/78)

D PRANDLE

REPORT NO. 83

1979

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

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ABSTRACT

The flow of water through the North Channel of the Irish Sea generates a difference in electrical potential between the two sides of the Channel. This difference in potential was recorded over the period February 1977 to April 1978 by means of the Port Patrick - Donaghadee submarine cable. An analysis was made of both the tidal component and the residual component of this signal. The variability in the longer term residual flows through the channel are examined with particular reference to the effect of wind forcing.

1. INTRODUCTION

The cable measurements described in this report represent a continuation of earlier recordings made by Bowden and Hughes (1961), Hughes (1969) and Prandle and Harrison (1975). In recent years there has been considerable interest in the movement of radio-active material discharged into the Irish Sea from the reprocessing plant at Windscale. Flow data from the North Channel cable should be of value in studying this movement. The present results cover a period of 15 months and constitute the first phase in a programme of continuous monitoring of the cable.

A digital data logger is located at the Port Patrick end of the cable, this logger records the difference in potential between the two ends of the cable at ten minute intervals. Some filtering and editing of these data are then carried out to produce a continuous record of hourly values. The resulting time series may then be sub-divided into a tidal component and a residual component. Analyses of each of these components are described in the following sections.

2. TIDAL ANALYSIS

The hourly voltages were divided into 15 sets each of 29 days duration starting on 4 February 1977 and ending on 11 April 1978 (the last set involved an overlap of 3 days). A tidal analysis of each of these data sets was carried out using the standard "TIFA" programme developed at IOS Bidston. The separation of the close frequency constituents was based on the relationships determined for the vertical tide at Port Patrick. Table 1 shows a summary of the values obtained for the principal constituents together with corresponding values found by (1) Bowden and Hughes (1961) and (2) Prandle and Harrison (1975). The results for Bowden and Hughes refer to 29 days of data over the period 12 July to 9 August 1955. The results for Prandle and Harrison represent the mean of three periods each of 29 days duration taken between 19 January and 15 April 1974. The present results represent the mean of the fifteen data sets described previously. The discrepancies between the three values shown in Table 1 for the amplitude of the principal M_2 constituent may be related to the seasonal variation which results from changes in the conductivity of both the sea water and of the bed sediments (Hughes 1969). Thus the maximum value of 575 mV was obtained in summer, the minimum of 502 mV in winter while a value of 559 was found for the complete year. Figure 1 shows the annual variation in this constituent calculated from the present results. The minimum value shown, i.e. 541 mV for May 1977, is clearly not as low as the value found in 1974, presumably water temperature and salinity reached more extreme values during this earlier period.

Table 1 shows that while the values for the major semi-diurnal constituents are reasonably consistent over the three analyses, there is significant variability between the results for constituents in other frequency bands.

3. RESIDUAL VOLTAGES

The voltage recorded on the cable, $E(t)$, may be expressed as follows :

$$E(t) = E_0 + c_1 U_T(t) + c_2 U_R(t) + E_1(t) \qquad (1)$$

where E_0 is a constant "back e.m.f." associated with electrode potentials,

$U_T(t)$ is the tidal flow,

$U_R(t)$ the residual flow,

$E_1(t)$ is electromagnetic noise

and C_1 and C_2 are calibration factors relating voltage to flow.

The electromagnetic noise $E_1(t)$ is partially removed in the initial editing and filtering, however some of this component remains and is largely responsible for the corruption of the diurnal tidal constituents. Tidal filtering was used to remove the tidal components (species 1,2,3,4 and 6) from the recorded voltage, the effectiveness of this filtering may be seen from the spectral analysis of the residual component shown in Figure 2. The filtered time series, $< E(t) >$, may be written as :

$$< E(t) > = E_0 + c_2 U_R(t) \qquad (2)$$

(i) Wind forcing

It seems reasonable to represent the wind-induced flow through the North Channel, $U_W(t)$, by an expression of the form :

$$U_W(t+\Delta t) = A\, W^2(t) \cos(\theta(t) - \alpha) \qquad (3)$$

where $W(t)$ and $\theta(t)$ are respectively the wind speed and direction at time t ,

A is a coefficient,

α is the direction from which the wind is most effective in producing flow in the Channel,

Δt is the time delay between the wind forcing and the resulting flow.

Over the 15 month duration of the cable recordings, wind data were obtained, at six hourly intervals, from the meteorological station at Ronaldsway, Isle of Man, (Figure 3). By correlating the filtered time series $<E(t)>$ with the expression (3) and using a least squares fitting technique the following result was found

$$< E(t) > \quad = \quad -24.7 \; - .56 \; W^2(t) \cos(\theta(t) - 320^\circ) \qquad \text{mV} \tag{4}$$

Positive values of $<E(t)>$ here signify flow towards the north with $\theta(t)$ being the angle relative to N from which the wind is blowing. Over the entire period of 15 months a correlation coefficient of 0.62 was calculated for this formula, the correlation showed little sensitivity to changes in either α or Δt. However a value of $\Delta t = 2h$ was found to produce the maximum correlation - in agreement with an earlier result found by Bowden and Hughes (1961).

In an earlier study, Prandle and Harrison (1975) obtained a correlation of $r = 0.67$ for the expression

$$< E(t) > \quad = \quad 125 \; - .65 \; W^2(t) \cos(\theta(t) - 324^\circ) \qquad \text{mV} \tag{5}$$

for 3 months of data. While Bowden and Hughes (1961) obtained a correlation of $r = 0.83$ for the formula

$$< E(t) > \quad = \quad 152 \; - .68 \; W^2(t) \cos(\theta(t) - 334^\circ 30') \qquad \text{mV} \tag{6}$$

over a 7 day period.

In an attempt to distinguish between the effects of winds from different directions the wind data were sub-divided into two sections, one representing winds in the region from NE clockwise through to SW or approximately from the south easterly direction and the second representing winds from the remaining north westerly sector.

For winds from the south easterly direction a correlation coefficient of 0.65 was calculated for the formula

$$< E(t) > \quad = \quad -26.1 \; - .65 \; W^2(t) \cos(\theta(t) - 315^\circ) \tag{7}$$

Whereas for winds from the north westerly direction a correlation coefficient of 0.49 was calculated for the formula

$$< E(t) > \quad = \quad -28.4 \; - .47 \; W^2(t) \cos(\theta(t) - 320^\circ) \tag{8}$$

These results suggest that winds from the south easterly direction are more effective in forcing water out of the Irish Sea (through the North Channel) than in the reverse situation when winds from the north west force water into the region. However, these latter results may possibly be affected by any sheltering of the anemometer at Ronaldsway.

Figure 1 shows the effect of wind forcing averaged over 15 consecutive monthly periods. The complete time series for the wind-induced component (as derived from (4) is shown in Figure 4 together with the time series $< E(t) >$. The mean value, taken over the whole 15 month period, of the voltage associated with wind forcing is 0.36 mV, assuming a calibration factor of 1 mV = 0.135 cms^{-1} (following section) this is equivalent to a northerly flow of 0.05 cms^{-1}.

Two distinct features emerge from the comparison of the two time series shown in Figure 4. While most of the major fluctuations in the residual voltage coincide with periods of strong wind forcing, the residual voltage includes pronounced low frequency and high frequency energy not evident in the time series for wind forcing.

The disparity in the high frequency component is essentially a consequence of the data sampling intervals used for the two time series. The wind driven component was calculated from wind data recorded at six hourly intervals and linear interpolation was used to derive hourly values. The residual voltage was initially reduced to hourly values, tidal filtering then removed certain energy bands as demonstrated in Figure 2. In addition, for the purposes of correlating the two time series all of the energy in frequencies greater than quarter-diurnal was removed from the residual voltage signal. Thus the high frequency component shown in the figure corresponds with the significant residual component in the frequency bands between semi-diurnal and quarter-diurnal shown in Figure 2.

The low frequency component of residual voltage is of the order of days. This component is not the result of longer period tides. It may be some electromagnetic phenomenon which effectively varies E_0 over such periods. It may also reflect the existence of residual flows due to other forcing (e.g. density gradients, atmospheric pressure gradients, disturbances propagating from external regions) or due to less direct wind forcing effects.

(ii) Other residual components

Two major difficulties arise in interpreting the recorded cable voltages, the first is to establish the value of E_0 and the second to estimate the calibration constants. It is reasonable to assume that the calibration coefficient for residual flows is equivalent to that for tidal flows for which Bowden and Hughes

(1961) obtained the value

$$C = 1/0.135 \quad mV/cm\,s^{-1} \tag{9}$$

The value of E_0 for the North Channel cable has not been reliably determined. For the present recordings the mean voltage E(t) over the 15 month period was -27 mV whereas Bowden and Hughes obtained a mean voltage of 22 mV over the period of their recordings. From a study of the salinity budget, Bowden (1950) calculated an annual mean flow of 0.35 cms^{-1} northwards through the North Channel. Using this latter figure together with the calibration factor given by (9), the value of E(t) = -27 mV would suggest a value of E_0 = -30 mV whereas the value of E(t) = 22 mV would give E_0 = 19 mV. At present, the uncertainty in these estimates for E_0 undermine the usefulness of the calculated values of mean wind-induced flow or net residual flow. Over the next few years a more definitive value for E_0 may be derived by using results from both proposed current meter measurements and from continuing model studies.

Nonetheless the time variations in the residual components remain of interest. Figure 1 shows the monthly mean variations in the total residual (E), the wind driven residual (W) and in the non-wind driven residual (Q). The latter quantity has a well-defined seasonal variation with a maximum value in the winter months and a minimum in September. No clear observational evidence exists against which this seasonal variability might be compared.

4. CONCLUSIONS

Voltages recorded on the North Channel telephone cable provide useful information on the longer period flows in this region. Much of the variability in these flows can be related to wind forcing. However there remains a significant component that cannot yet be readily accounted for. With the increasing interest in this region, it should be possible in the near future to determine what proportion of this unaccounted residual has a physical basis and what proportion is due to electromagnetic effects.

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Const	AMPLITUDE			S.D. of (3)	PHASE			S.D. of (3)
	(1)	(2)	(3)		(1)	(2)	(3)	
O_1	9	8	12	4	155	118	126	48
K_1	6	19	17	7	205	327	236	81
N_2	130	98	108	9	13	14	14	4
M_2	575	502	559	13	42	43	42	1
L_2		16	22	7		103	86	24
S_2	209	172	197	9	81	79	78	2
MN_4		6	7	2		314	332	47
M_4	15	8	10	3	339	347	340	26
MS_4	10	7	7	2	354	19	10	24
	millivolts				Degrees			

Table 1. Tidal analyses of cable recordings; (1) Bowden and Hughes (1961), (2) Prandle and Harrison (1975) and (3) present data (mean results from 15 data sets each of 29 days duration).

LIST OF FIGURES

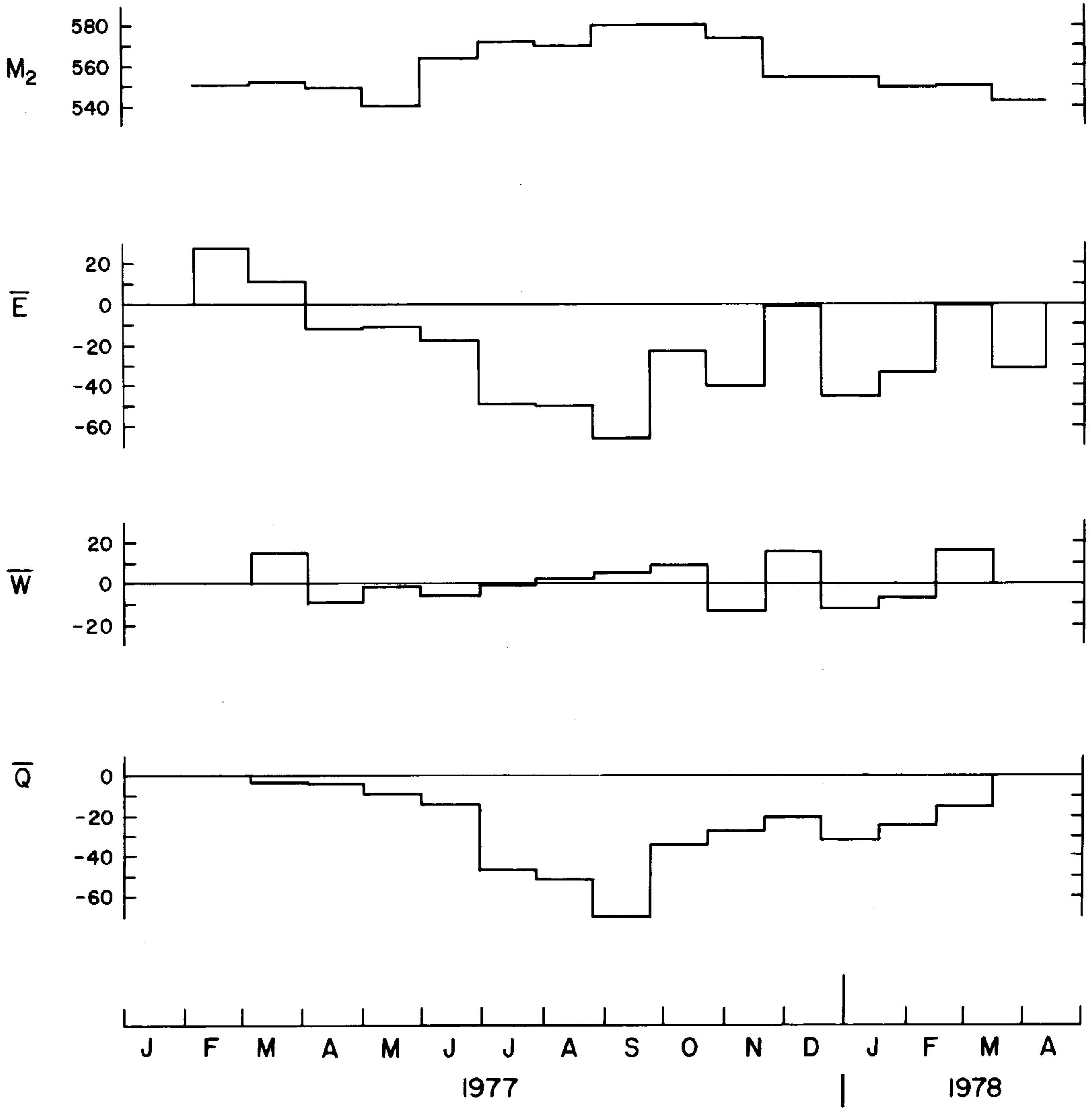
M_2
580
560
540
$\overline{E}$
20
0
-20
-40
-60
$\overline{W}$
20
0
-20
$\overline{Q}$
0
-20
-40
-60
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
1977
1978

Figure I

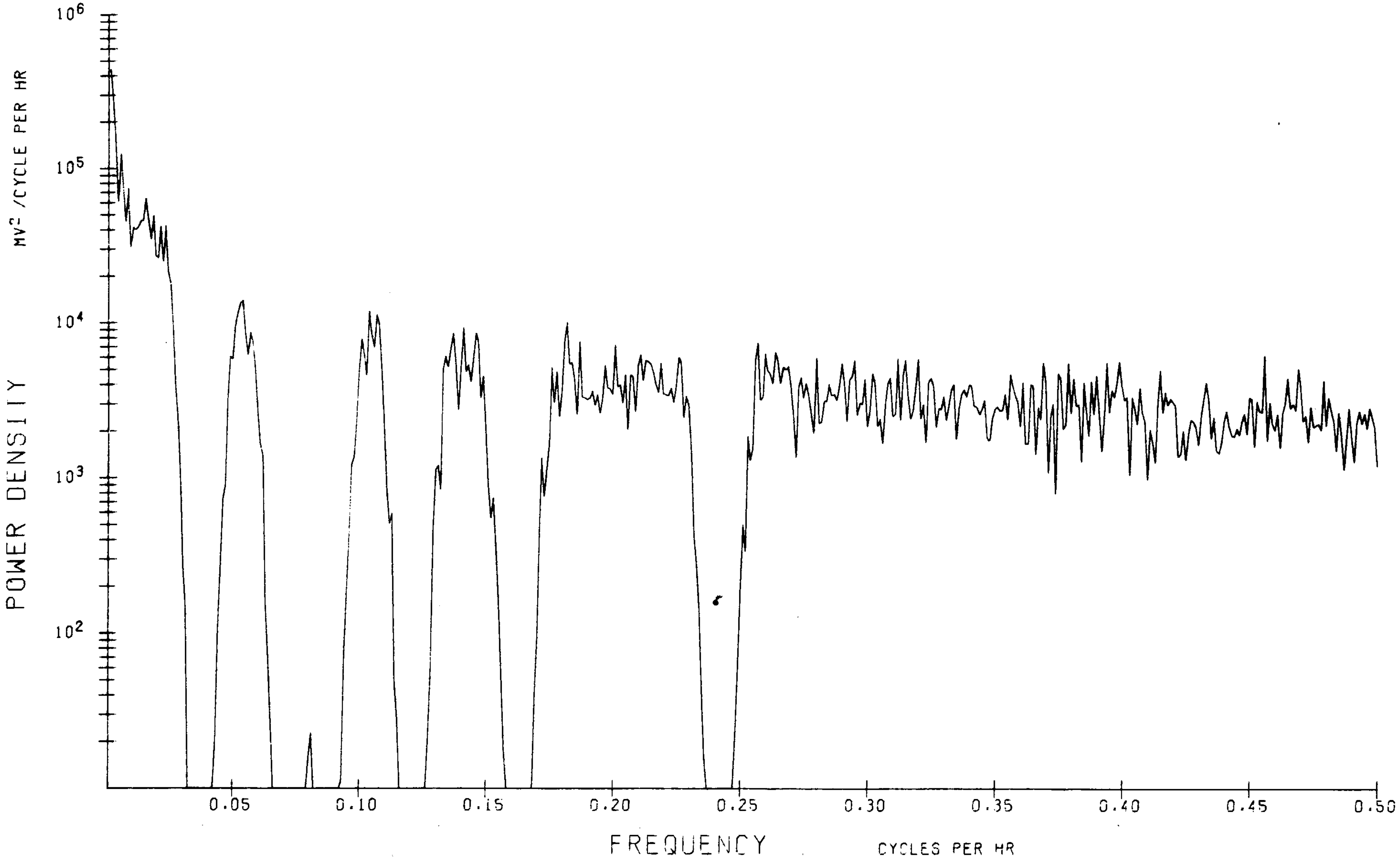
10^6
10^5
10^4
10^3
10^2
MV² /CYCLE PER HR
POWER DENSITY
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
FREQUENCY
CYCLES PER HR

Figure 2

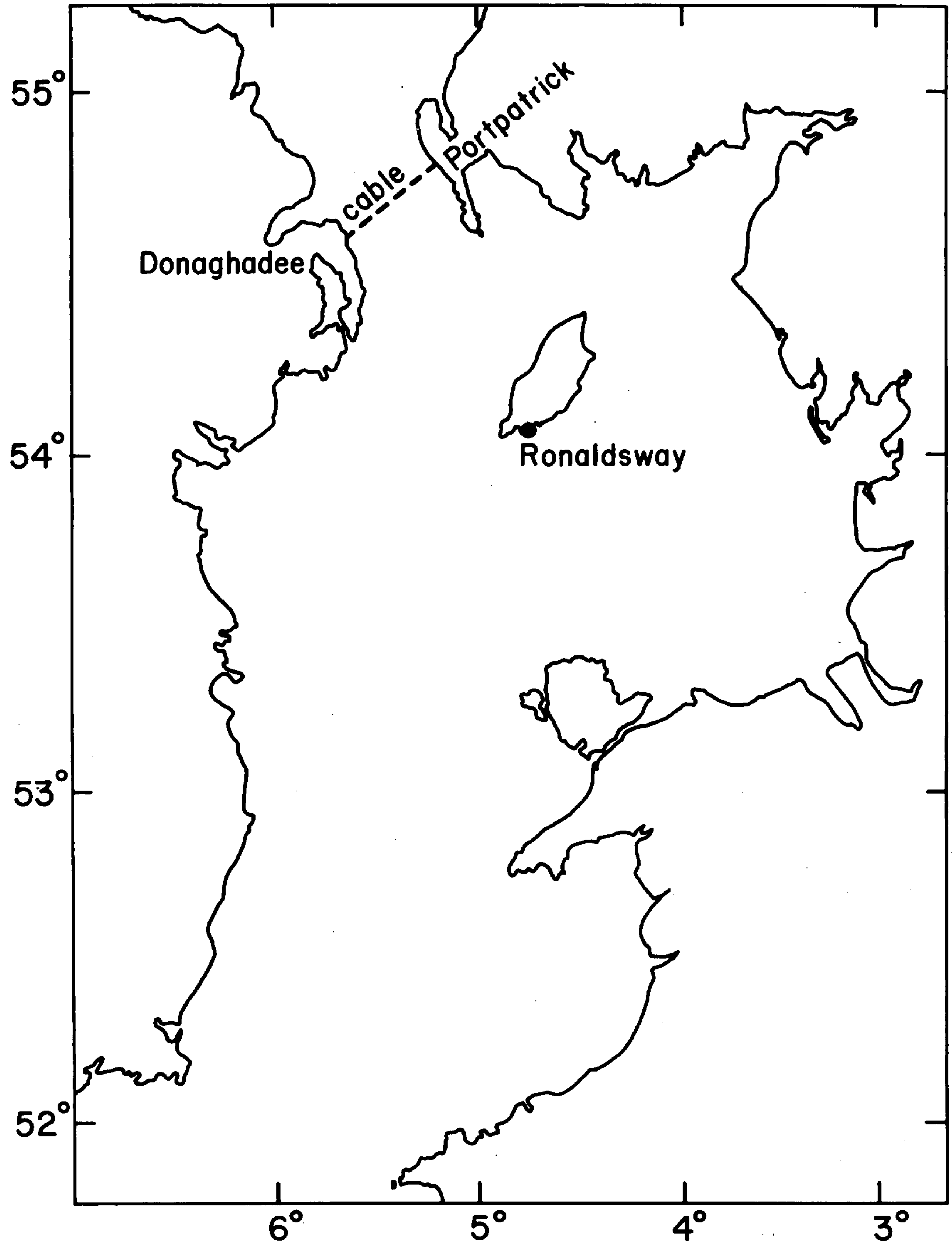

Figure 3

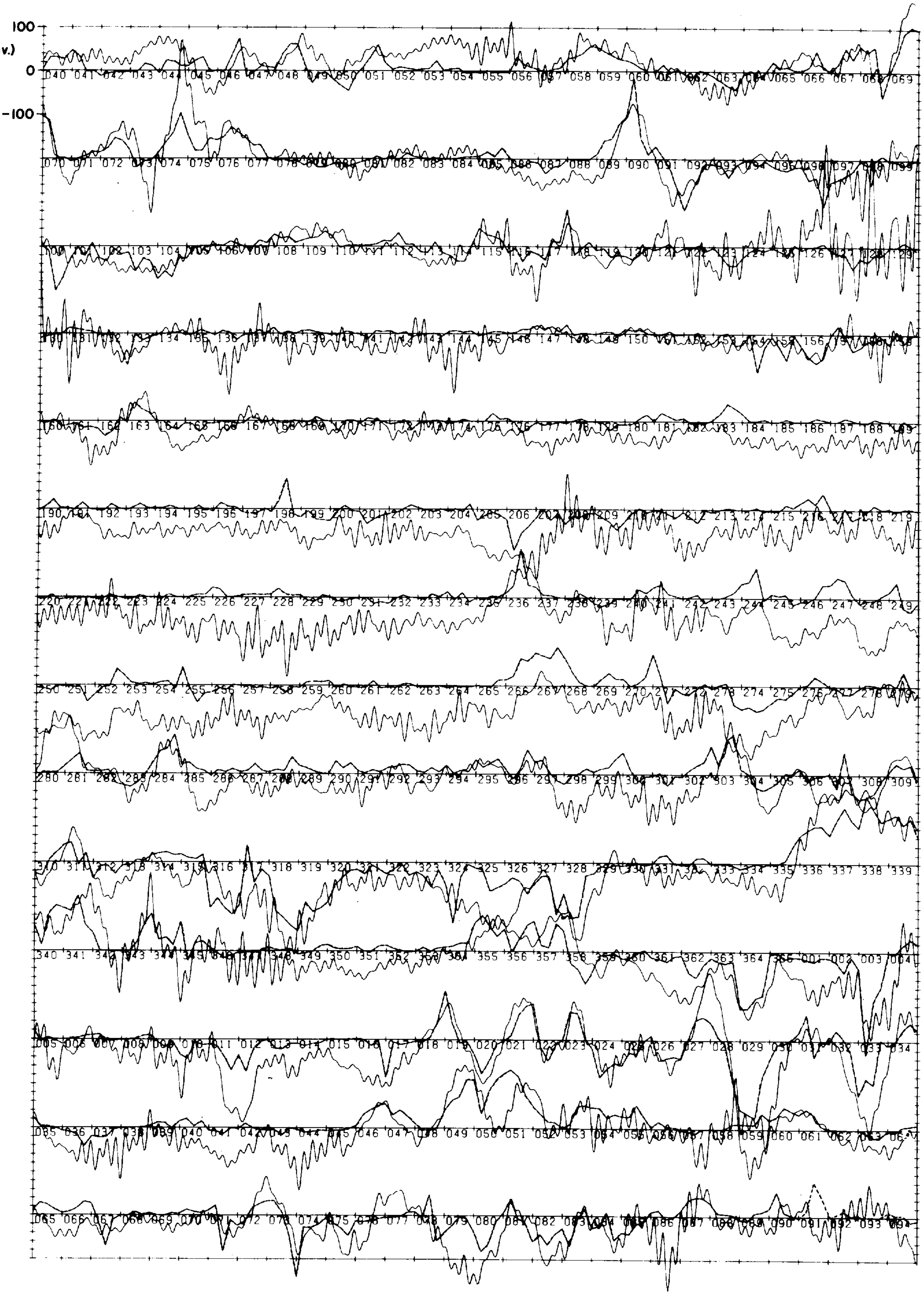

Figure 4