Identification of microseismic activity with sea waves

By J. Darbyshire, *Royal Naval Scientific Service*

(*Communicated by G. E. R. Deacon, F.R.S.—Received* 9 *March* 1950)

Three series of simultaneous wave and microseism records are examined. They give a clear indication that bands of microseismic waves from different sources can be distinguished by submitting seismograph records to frequency analysis. The agreement between the results of analysis and the theoretical expectation from the prevailing meteorological conditions appears to justify the assumption that microseismic waves of different periods travel independently. Under the simple meteorological conditions that have been studied, each band of microseismic activity can be identified with a band of sea waves of twice its period. The existence of this two to one ratio between the period of waves and microseisms affords some confirmation of the theory that microseisms are produced in a region of interference between similar wave trains travelling in opposite directions either near the coast or in deep water.

Sea waves and microseisms

Bernard (1941) obtained evidence which led him to believe that microseismic oscillations have periods which are half those of the sea waves which give rise to them. He reached this conclusion by comparing the microseisms recorded at Averroes near Casablanca with simultaneous observations on the waves reaching the coast. The same ratio was noticed by Deacon (1947) between microseisms recorded at Kew and sea waves recorded at Perranporth on the north coast of Cornwall. The reason for an exact relationship became apparent when Longuet-Higgins & Ursell (1948), using theoretical work on standing waves by Miche (1944), showed that the mean pressure on the sea bottom below a region of interference between trains of waves of the same period travelling in opposite directions varies with half the wave period. The mean pressure variation is a second-order effect proportional to the product of the amplitudes of the two wave trains and the square of the frequency, and unlike the pressure variation below a single train of waves, it does not vanish with depth. This result has been used by Longuet-Higgins (1950) as the basis of a new theory of microseism generation. He shows that interference between trains of waves of the same dominant period, travelling in opposite directions, causes variations in mean pressure on the sea bottom sufficiently large to account for the observed microseismic oscillations, even when the water is very deep. Such interference can occur when waves or swell are reflected from a steep coast, when waves generated in different quadrants of a fast-moving depression meet each other travelling in opposite directions, and when similar trains of swell travel in opposite directions from two storm areas.

There may, according to the theory, be some departure from the exact two to one ratio between wave and microseism periods when each wave band is of appreciable width. For a given wave height, more energy will be communicated to the sea bottom by short waves than by long waves. Resonance of the overlying water column may also favour a frequency which corresponds to a compression wave in water which is $(\frac{1}{2}n+\frac{1}{4})$ times as long as the depth, n being an integer.

Comparison of the variation in microseismic activity at Kew with changes in wave height at Perranporth (Deacon 1947) gave a clear indication that waves entering the coastal region west of the British Isles are mainly responsible for the microseismic activity at Kew, but similar work in the U.S.A. (Ramirez and Gilmore) showed that the microseismic activity recorded in observatories in the eastern states was due mainly to the presence of storms over deep water. The two generalizations can be reconciled if it is admitted that the microseismic activity at a particular observatory is due to more than one source. In the British Isles the microseismic activity is not due entirely to wave interference in the coastal region but also to interference of waves in distant regions. If the wave periods in the coastal region are appreciably different from those in the distant region, there should be two bands of microseism frequencies. The method of investigation previously used, the visual examination of records, is not sufficiently precise to distinguish weaker oscillations from one source in the presence of stronger oscillations from another source; but it should be possible to separate them by using the technique of frequency analysis. This method was applied by Barber & Ursell (1948) to sea waves. They found sufficiently close agreement between their results and those predicted from the hydrodynamical theory to justify their assumption that wave trains of different periods travel independently, the velocity potentials being additive.* In this paper, it is proposed to make a similar assumption that microseismic waves travel independently, and its validity will be tested by the agreement which is found between theory and the results of analysis.

The microseism records were converted by the use of a photo-electric curve-following machine, described by Tucker & Collins (1947, 1949), into a form suitable for analysis on the machine described by Barber, Ursell, Darbyshire & Tucker (1946). This involved the magnification of each microseism record about twenty-five times. This magnification may introduce spurious fluctuations in the final record which may be partly responsible for the background of Fourier peaks at the long-period end of the periodograms, but examination of analyses of records taken at successive times shows that within the frequency range covered by the microseisms, the envelope of the microseismic waves stands out sufficiently above the background to give a reasonable indication of the main frequencies present. The height of the envelope affords a measure of the amplitude of the microseisms; the energy in any period interval will be proportional to the sum of the squares of the peaks on the periodogram within that interval.

Three examples are presented in which a single depression over the Atlantic Ocean was producing large waves at a time when the wave activity in the coastal region was small and of different period. The seismograph records were routine recordings taken at Kew Observatory with the Galitzin vertical seismograph. Simultaneous wave records were obtained from Perranporth for the first two examples and from Pendeen for the third. The waves were measured by pressure recorders laid on the sea bed, the instrument at Perranporth lying at a depth of 45 ft. and that at Pendeen at 100 ft. The frequency-response curve of the Kew Galitzin vertical seismograph is nearly uniform

* The method has been criticized by Seiwell & Wadsworth (1949) and Seiwell (1949) but their criticisms are answered by Barber and Ursell (1948).

between 6 and 13 sec. In comparing the mean periods of the bands of waves and microseisms, some account must be taken of the effect of tidal streams on the wave period as measured by a stationary instrument. Barber & Ursell (1948) and Barber (1949) have shown that the recorded period can vary by as much as 1 sec. on either side of the true period because the tidal stream changes direction relative to the

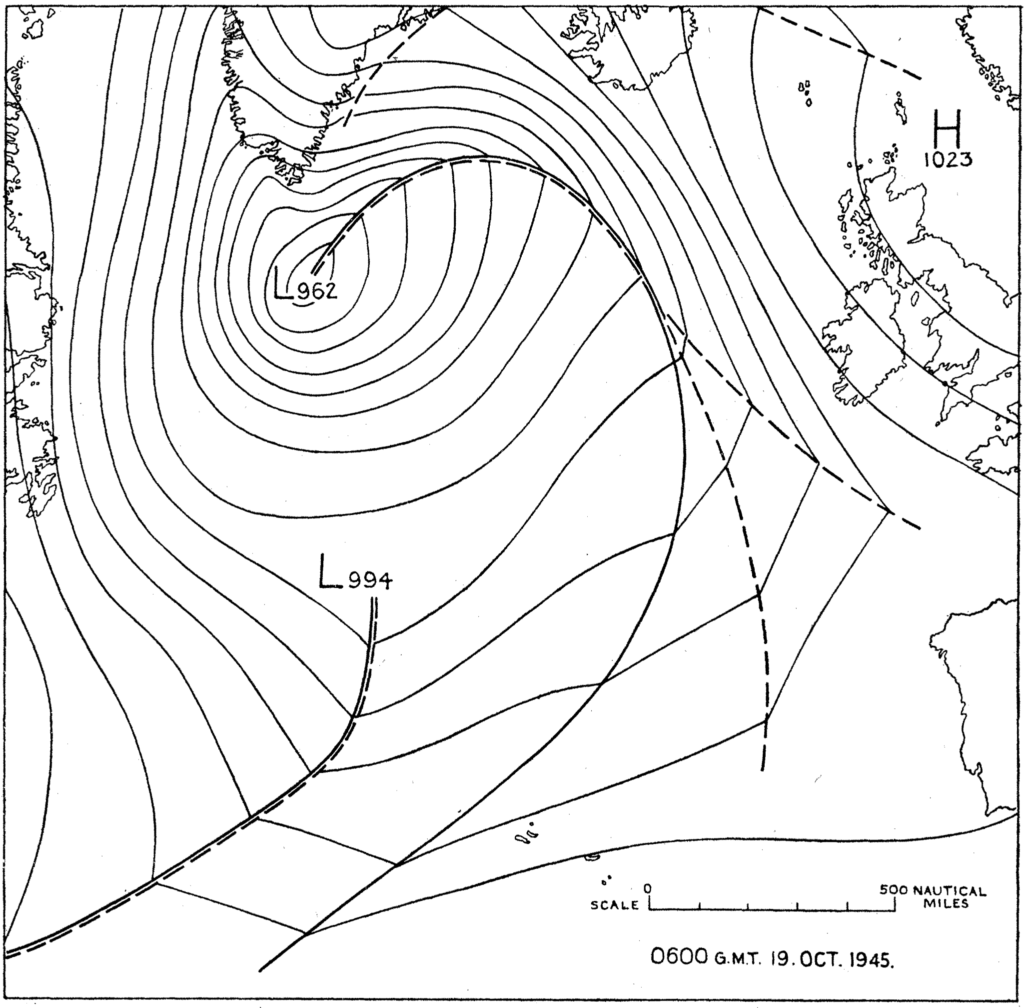

FIGURE 1. Meteorological chart of the North Atlantic Ocean, 19 October 1945.

direction of wave propagation. The change of stream gives rise to a semi-diurnal oscillation of approximately 1 sec. amplitude superimposed on the general trend of a wave band from long to short periods. The wave band is usually wide enough to include waves of the same period among the incident and reflected waves, and it is presumably these which produce the microseisms; if so, the periods of the microseisms should not be affected by variations in tidal streams, and it is to be expected that the trend of the upper and lower limits of the wave band from record to record should therefore be more regular for microseisms than for waves.

18 *to* 22 *October* 1945

In this example, there is a deep depression approximately 300 miles south of Greenland. The meteorological chart for 06.00 hr. 19 October is reproduced in figure 1, and frequency analyses of approximately 20 min. records of waves and microseisms

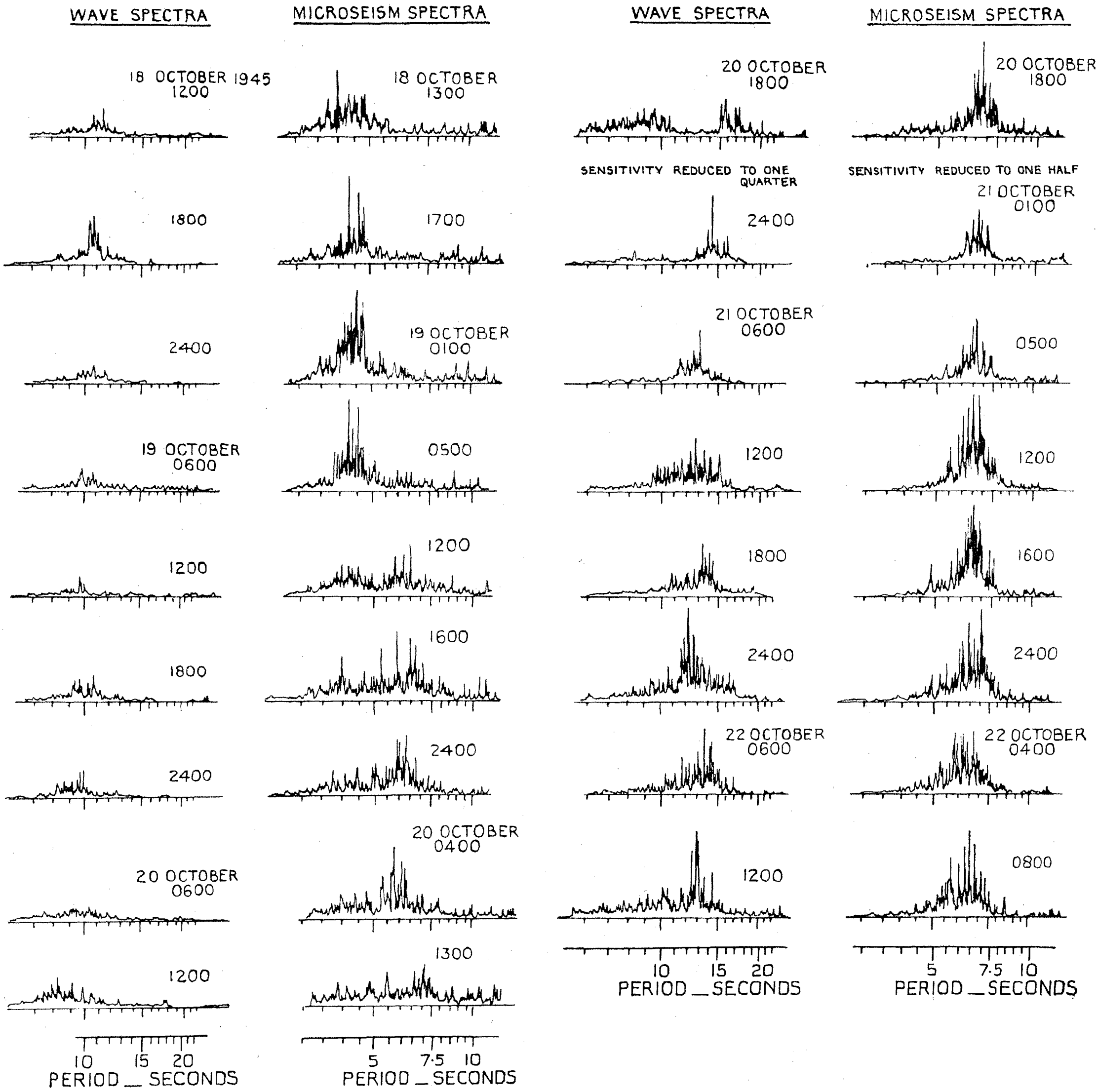

FIGURE 2. Simultaneous wave and microseism spectra, 18 to 22 October 1945.

are shown in figure 2. The first four pairs of analyses show the presence of one band of wave periods and one band of microseism periods with mean periods of 10 to 11 and 4 to 5 sec. respectively. A second band of microseism activity with a mean period of 6 to 6·5 sec. began to appear at 12.00 hr. 19 October, and the absence of a corresponding band in the wave analyses suggests that the new microseism activity had its origin outside the coastal region west of the British Isles. The storm south of Greenland was the only prominent wave-generating area, and the 12 to 13 sec. waves required by the new theory could only be generated there. The wave interference required by the theory was probably occurring where the waves generated in the northern sector of the storm were reflected from the east coast of Greenland. Swell from the southern sector of the storm began to arrive at Perranporth between 12.00 and 18.00 hr. 20 October, after an interval which is approximately the time required for the travel of the first waves generated in the storm, and as soon as it reached the coastal region, a third band of microseismic activity developed with a mean period of 6 to 8 sec. This could be attributed to interference in the coastal region between incoming and reflected waves. The mean period of the swell when it first arrived was 15 to 18 sec., but it soon decreased to between 12 and 16 sec. in good agreement with the two to one ratio.

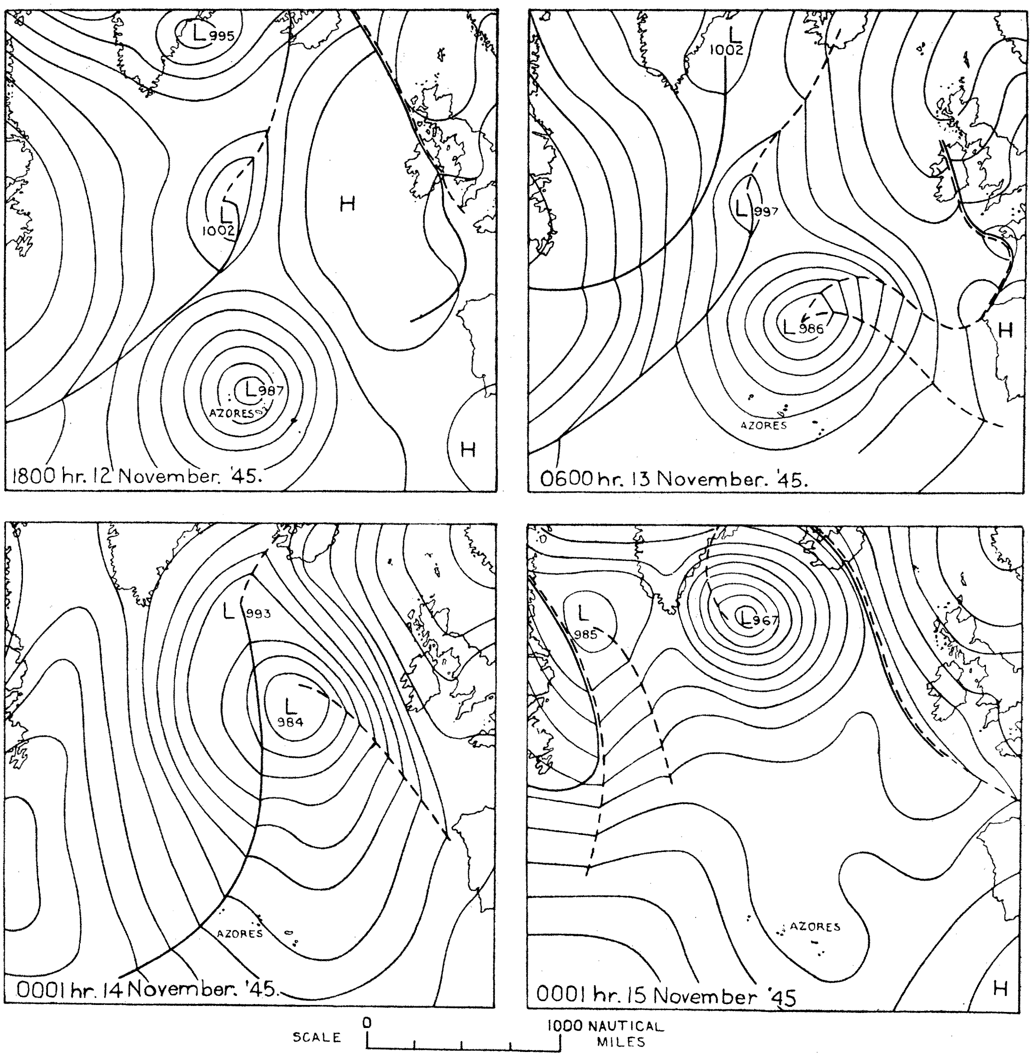

FIGURE 3. Meteorological charts of the North Atlantic Ocean, 12 to 15 November 1945.

12 to 16 *November* 1945

This example was chosen to study the effect of a fast-moving depression over deep water. The depression developed west of the Azores on 12 November and moved along a curved path north-east, north and north-west as indicated by the four charts

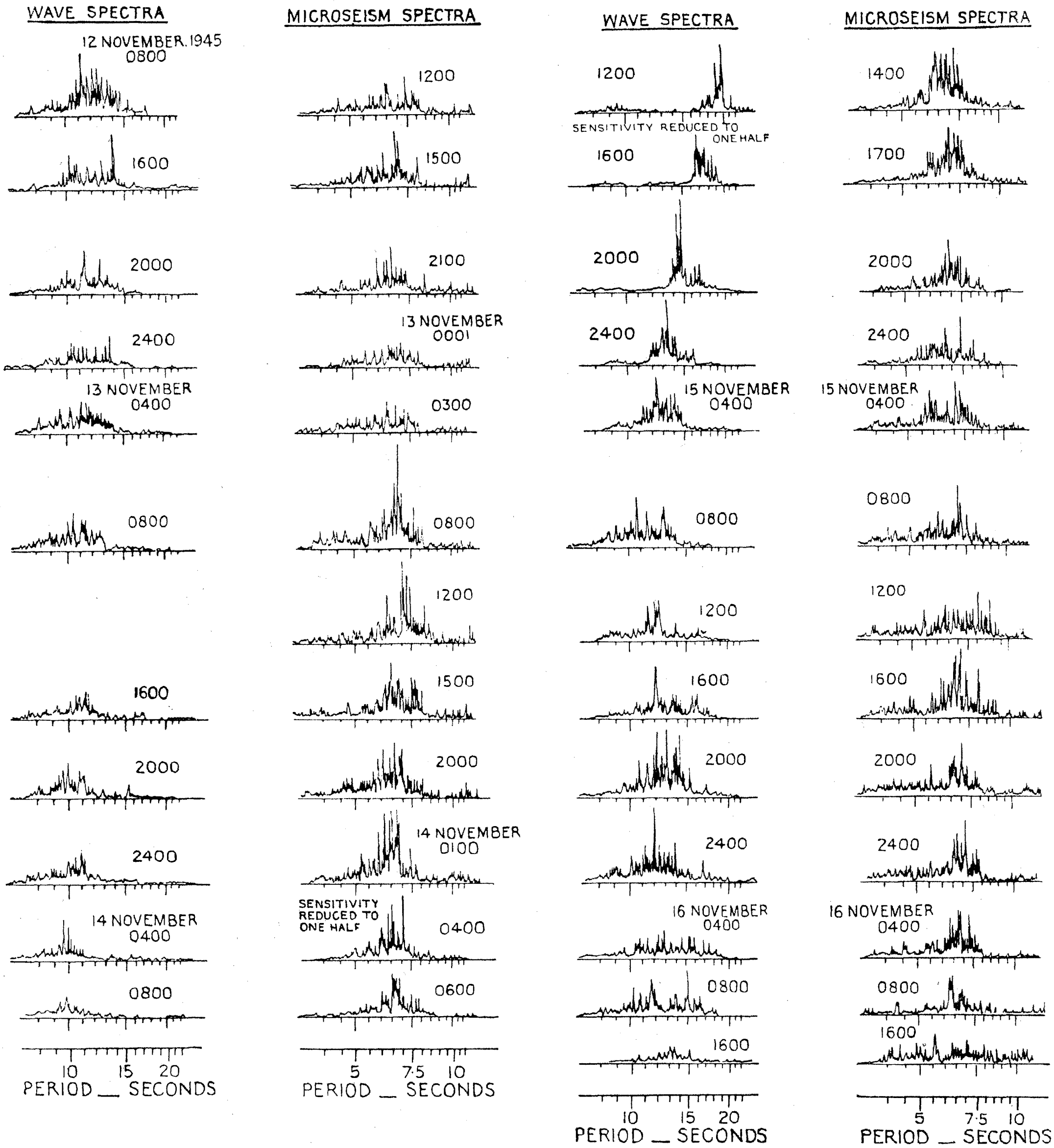

FIGURE 4. Simultaneous wave and microseism spectra, 12 to 16 November 1945.

in figure 3. Corresponding analyses of 20 min. wave and microseism records are shown in figure 4. The first five analyses show one wave band of period 10 to 14 sec., and one microseism band of period 6 to 8 sec. Between 03.00 and 08.00 hr. 13 November, there was a marked increase in the microseisms without any corresponding increase in the wave activity in the coastal region. Except for a moderate sea in the Davis Strait, the storm near the Azores was the only active wave-generating area, and conditions likely to produce interference between two trains of waves of 12 to 16 sec. period travelling in opposite directions were associated with it. Examination of the charts in figure 3 shows that there was a large sea area north of the Azores in which the wind backed from east to west between 18.00 and 06.00 hr. 12 to 13 November, and it appears probable that interference between similar wave trains generated in the outer parts of the area would take place at about the same time as the increase in microseismic activity shown in figure 4. Similar wave interference could be expected along the subsequent path of the depression, and the further increase in microseismic activity after 01.00 hr. 14 November could be attributed to the widening of the region of wave interference and its closer approach to the British Isles. The swell from the storm began to arrive between 08.00 and 12.00 hr. 14 November, and there was an increase in microseismic activity during this period. The mean period of the microseisms after the increase at 08.00 hr. 13 November, 6 to 7·5 sec., was very nearly half that of the waves of 11 to 14 sec. period which arrived at Perranporth 1 day later, the approximate travel time from the probable region of wave interference north of the Azores. The first swell to arrive had a mean period of 18 to 20 sec., but there were no microseismic waves of 9 to 10 sec. period to correspond with it. A possible explanation is that the effect of such long low swell would be small compared with that of the heavier swell of shorter period. Except for this onset of the swell, the wave and microseism periods are in the ratio of two to one. The example shows that the analyses allow an individual band of microseismic waves, or a change of activity, to be identified with the wave activity in the coastal regions and the Atlantic Ocean.

12 *to* 16 *March* 1945

This example is concerned with a deep depression which developed in approximately 42° N, 45° W in the early morning of 12 March and reached a position 55° N, 40° W 2 days later. Meteorological charts for these two times are shown in figure 5, and the wave and microseism spectra for 12 to 16 March in figure 6. Because of the great magnification required in this case to bring the seismological records into an analyzable form, the background on the analyses is greater than usual, but there is no doubt about the presence during the first 2 days of a band of microseisms of mean period 5 to 7 sec., which is half the period of the swell reaching Pendeen. A second band of microseisms with a mean period of approximately 9 sec. began to arrive at 23.00 hr. 13 March, and this fresh activity can only be due to the storm shown in figure 5. There is, however, some uncertainty about the precise area in which the microseisms are generated.

Low swell with a period as much as 23 sec. began to arrive at Pendeen at 13.00 hr. 14 March, and much higher swell of approximately twice the period of the new microseisms followed at about 23.00 hr. If the microseismic waves which appeared 24 hr. earlier had been caused by this swell being involved in wave interference on its way to Pendeen, the region of interference could not be more than 720 miles from Pendeen. The meteorological conditions give no reason to suppose that two trains of waves of such long period could have been travelling in opposite directions so near

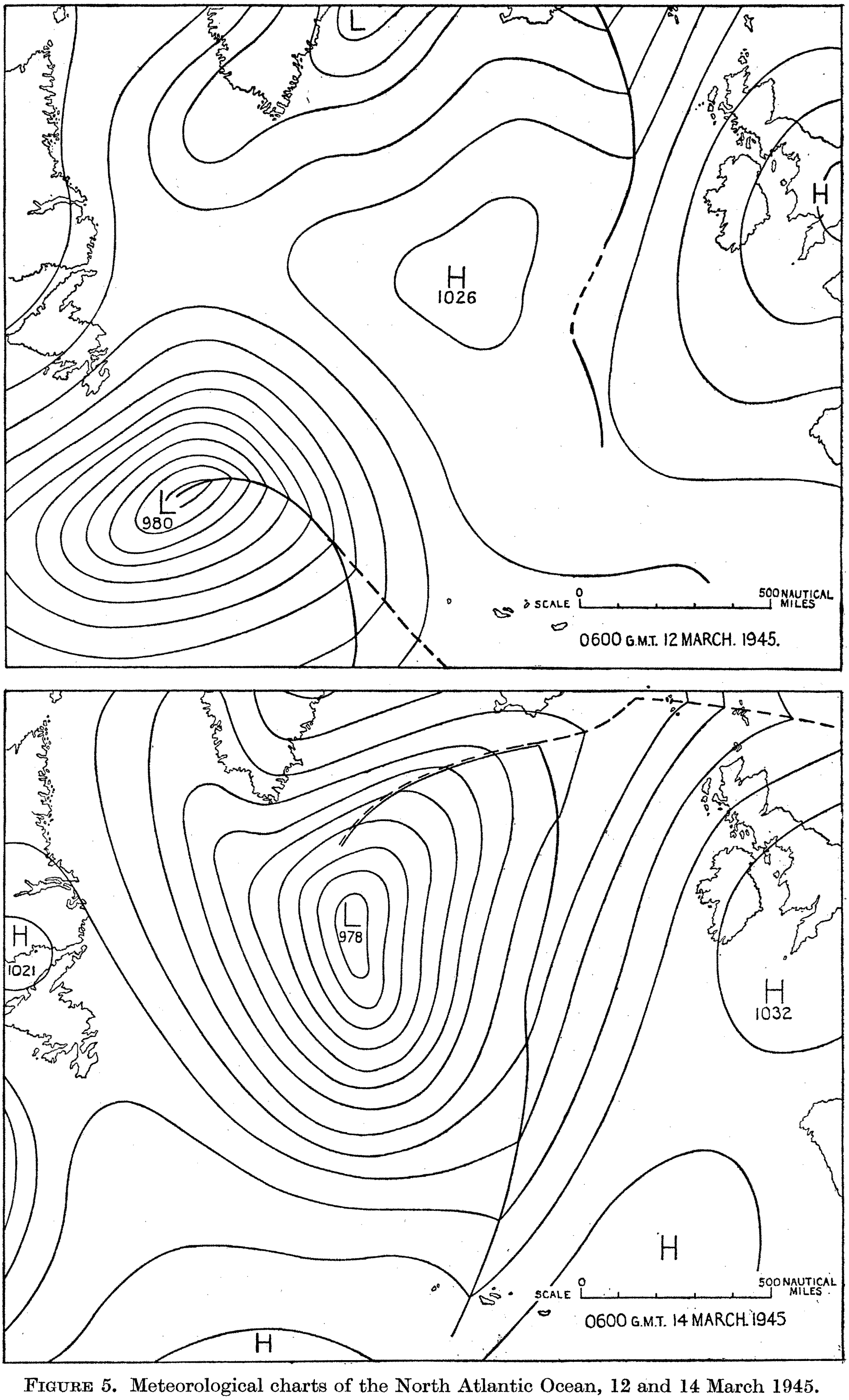

FIGURE 5. Meteorological charts of the North Atlantic Ocean, 12 and 14 March 1945.

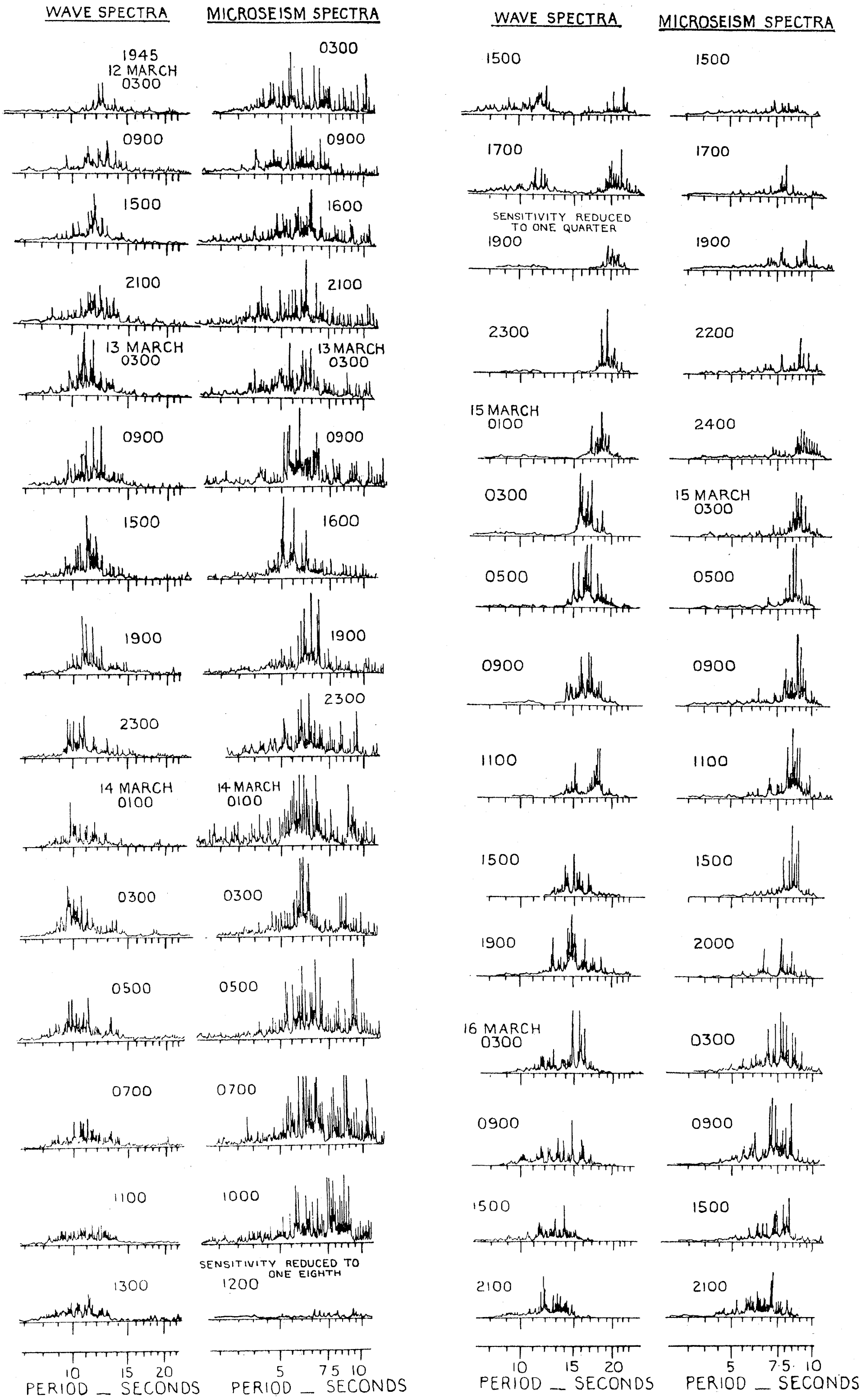

FIGURE 6. Simultaneous wave and microseism spectra, 12 to 16 March 1945.

the British Isles, and it is more reasonable to conclude that the microseisms were generated when the swell from the northern sector of the storm, as shown in figure 5, was being reflected from the east coast of Greenland. A wave prediction based on this and the preceding charts indicated that waves of 18 to 20 sec. period would reach the coast of Greenland at approximately 18.00 hr. 13 March, and their height would be about 15 ft.

There was a further increase in microseism activity when the swell from the storm reached the coast of Cornwall. The longest microseisms had a mean period of 9 to 10 sec., and there is no clear indication that the first low swell of more than 20 sec. period produced longer oscillations. The narrowness of the wave and microseism bands on 15 March affords a remarkable opportunity of checking the two to one ratio between the dominant periods, and, within the limits of accuracy set by the measurements and the tidal streams, the theoretical ratio is well upheld. The microseism band broadens towards shorter periods like the waves, and the mean periods show the same trend.

Conclusion

The three series of simultaneous wave and microseism records which have been presented give a clear indication that bands of microseismic waves from different sources can be distinguished by submitting seismograph records to frequency analysis. The agreement between the results of analysis and the theoretical expectation from the prevailing meteorological conditions appears to justify the assumption that microseismic waves of different periods travel independently. Under simple meteorological conditions each band of microseismic activity can be identified with a band of sea waves of twice its period. The existence of this two to one ratio between the period of waves and microseisms affords some confirmation of the theory that microseisms are produced in a region of interference between similar sea wave trains travelling in opposite directions either near the coast or in deep water.

The author expresses his gratitude to the Superintendent of Kew Observatory for the loan of the seismograph records on which the investigation is based; to Dr Beer, formerly of the staff of Kew Observatory; to Dr G. E. R. Deacon and other members of the Oceanographical Group in the Royal Naval Scientific Service for advice and assistance in preparing the paper; and to the Admiralty for permission to publish the work.

References

Barber, N. F. 1949 *Proc. Roy. Soc.* A, **198**, 81.
Barber, N. F. & Ursell, F. 1948 *Phil. Trans.* A, **240**, 527.
Barber, N. F., Ursell, F., Darbyshire, J. & Tucker, M. J. 1946 *Nature*, **158**, 329.
Bernard, P. 1941 *Bull. Inst. océanogr. Monaco*, **38**, 800.
Deacon, G. E. R. 1947 *Nature*, **160**, 419.
Gilmore, M. H. 1946 *Bull. Seism. Soc. Amer.* **36**, 89.
Longuet-Higgins, M. S. 1950 *Phil. Trans.* (in the Press).
Longuet-Higgins, M. S. & Ursell, F. 1948 *Nature*, **162**, 700.
Miche, M. 1944 *Ann. Ponts Chauss.* **2**, 42.
Ramirez, J. E. 1940 *Bull. Seism. Soc. Amer.* **30**, 35, 137.
Seiwell, H. R. 1949 *Proc. Nat. Acad. Sci., Wash.*, **35**, 518.
Seiwell, H. R. & Wadsworth, G. P. 1949 *Science*, **109**, 271.
Tucker, M. J. & Collins, G. 1947 *Electronic Engng*, **19**, 398.
Tucker, M. J. & Collins, G. 1949 *Ass. Séis. Météorol. Océanog. Phys., Séance Commune*, p. 16.