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Generation of Microseismic Storms in the Coral Sea

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The Generation of Microseismic Storms in the Coral Sea

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The study of microseismic storms recorded in Queensland has been continued in more detail since the results of the initial work in this field were published in 1956. These investigations have been made with the co-operation of the Commonwealth Bureau of Meteorology, in order to gain further information for the study of the generation and propagation of these storms* and also to determine their use to forecasters as an early warning of cyclone development and possible tracking aid.

A Sprengnether seismometer with the same characteristics as the Brisbane instrument was set up at the Meteorological Office in Townsville in February 1956. Both the Townsville and Brisbane recorders are fitted with a special switching device (Upton, 1956a, p. 11) which while allowing almost continuous recording of the very large microseisms generated during these storms, gives a wholly readable record. Simultaneous records are obtained for both stations.

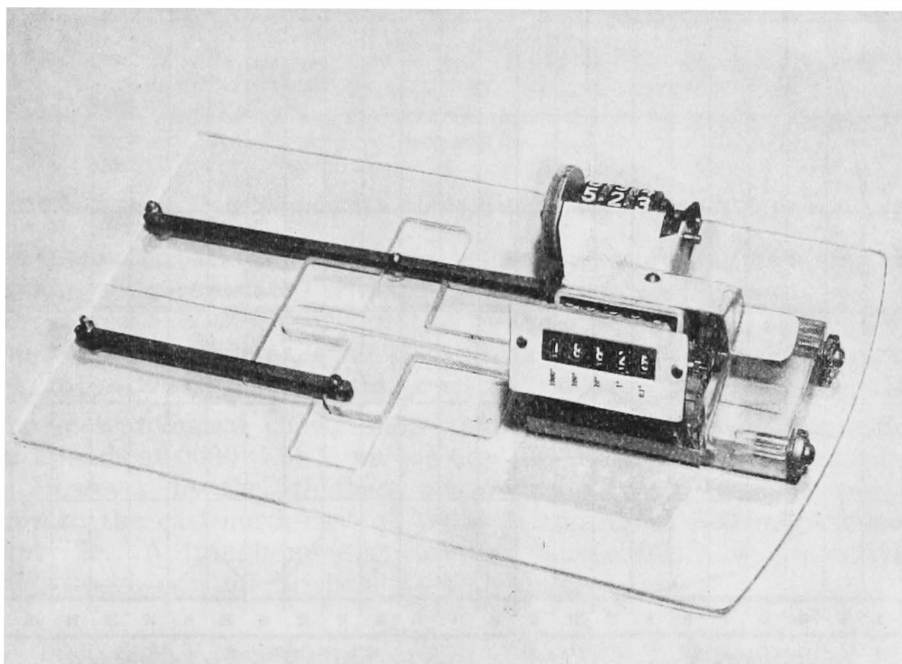

Fig. 1—Microseism Scaler. Instrument used to determine microseism amplitude.

An improved version (Fig. 1) of the measuring device described earlier (Upton, 1956a, p. 11) has been built and this has enabled more detailed analyses of the records to be made. Daily microseism readings were made for both Townsville

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*The term "storm" is used only with reference to microseism storms in this paper.

and Brisbane from April 1956. In general the readings for both stations show a good correlation (Fig. 2). The readings for Brisbane are given for March and April together with the times of all tropical depressions (as listed by Newman, Martin and Wilkie, 1956). The readings for Townsville for April are also given. It will be seen that each microseismic storm can be correlated with either a cyclonic disturbance or a cold front.

The frequency spectra of the microseisms associated with the cold fronts are much shorter and their appearance more irregular than those associated with the cyclonic disturbances (Upton, 1956b, p. 1). These short period microseismic storms were rarely recorded at Townsville—only on occasions when the frontal activity extended well up into Queensland.

The investigations have been concentrated on the regular group microseisms (5″ to 6″ period) generally associated with the tropical cyclones. Owing to the comparatively infrequent occurrence of the major cyclones, progress has been rather slow. The microseism records at Brisbane and Townsville for the major storms were examined and readings made every six hours except when it was necessary to check on any sudden change of amplitude at either station. In particular the amplitude ratios have been studied to determine their use for tracking the cyclones.

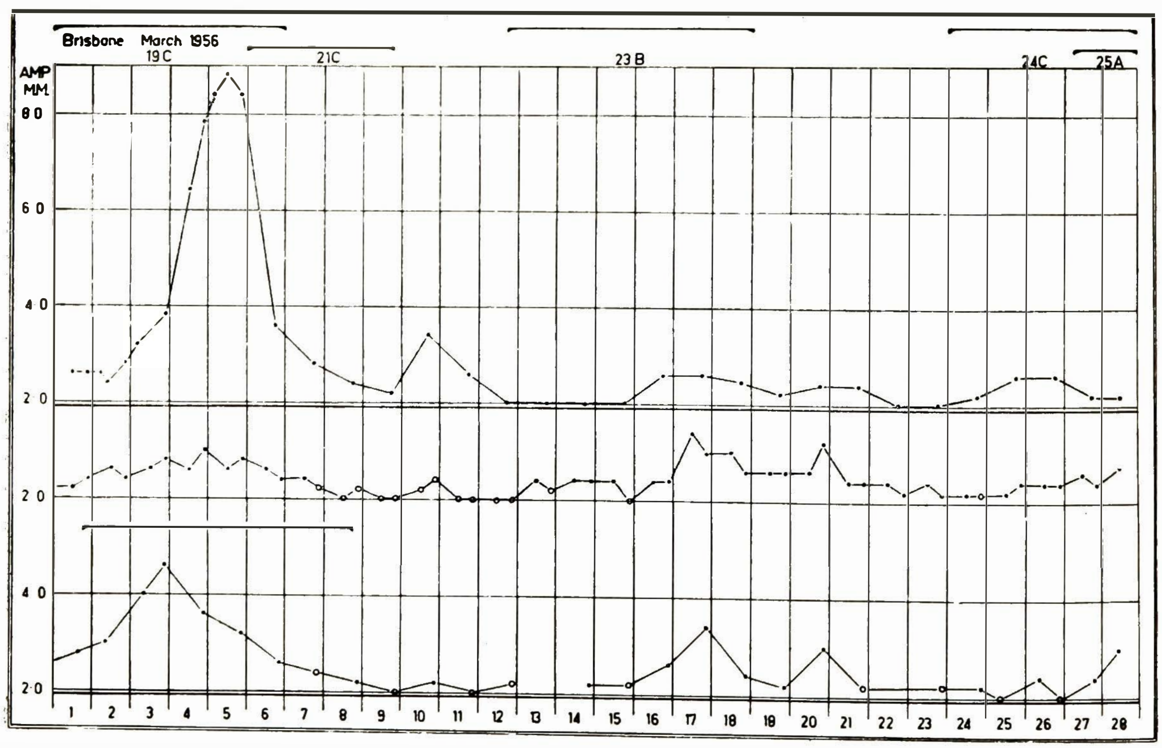

Fig. 2—Microseism amplitudes at Brisbane for March and April 1956, and at Townsville for April 1956.

As a preliminary investigation, four pairs of situations were selected for study, to attempt to determine the meteorological conditions required for the generation of the group microseisms and to find whether there was any correlation between either the group microseisms or the ragged short period microseisms (less than 3 seconds) recorded by the Benioff instruments, and the sea conditions along the coast near the station. The situations selected were not unique occurrences but representative of the different types of storms.

TABLE I

			Seismological Data					Meteorological Data		
	Date	Time G.M.T.	Station	Micro-Amp. mm.	Type	Period sec.	S.Period Micro-Amp	Sea	Wind	De-pression
1	6 June 1958	0000	B	3.0	r	—	M	M	C	No
			T	3.0	r	—			l/S.E.	
	7 June 1958	1800	B	3.6	G	5	L	M	M/S.E.	Yes
			T	3.8	G	5		M	l/S.E.	
2	4 Sept. 1958	0000	B	2.5	r	—	S	S	l/S.E.	No
	4 Sept. 1958	0900	B	6.0	G	4½	S	Sl	l/W.-S.W.	Yes
3	17 Feb. 1959	0600	B	3.0	r	4—5	L	M—R	l/S.-S.E.	Yes
			T	2.5	r	4—5			l/W	
	17 Feb. 1959	1800	B	9.0	G	5	L	R	M/N.-N.E.	Yes
			T	2.2	r	—				
4	2 Feb. 1959	0000	B	m	r	—	L	R	20/S.E.	No
			T	m	r	—	—	R	20/S.E.	
	4 July 1958	0000	B	4.4	G	7	S	Sl	C	Yes
			T	4.2	G	7	—	—	C	

Table I—Summary of the microseism amplitudes and periods for Brisbane and Townsville together with the state of the sea and the wind direction.

B=Brisbane; T=Townsville; r=ragged, irregular; G=groups; m=below 2 mm.; M=moderate; L=large; S=smooth or small; l=light; R=rough.

Micro-Amp. is defined as average amplitude of all waves greater than 2 mm. double amplitude occurring in a twenty minute interval.

CASE 1. 0000 G.M.T. 6 June 1958. 0000 G.M.T. 7 June 1958.

These two situations were taken before and after the beginning of a storm of the type usually associated with tropical cyclones in the Coral Sea. Although the actual increase in amplitude of the microseisms at both stations was small, their form was more regular on the 7th and the dominant period the same for both stations. The Brisbane short period microseisms were large in both cases.

The meteorological charts show that there was a weak depression in the Louisiade Islands at 0000 G.M.T. on the 6th June with no strong pressure gradients present. However, by the 7th there was a strong cyclone moving south over the deep water to the east-north-east of Willis Island about 800 miles from Brisbane and Townsville. A trough moving eastward across the New South Wales coast was causing rough seas off Brisbane at both times.

CASE 2. 0000 G.M.T. 4 September 1958. 0900 G.M.T. 4 September 1958.

The normal microseism storms begin slowly with the increase in amplitude continuing for a day or more. Occasional storms begin very suddenly, with the increase to maximum taking only a few hours. A storm of this latter type occurred on the 4th September, with a very sudden build-up of regular 4 second microseisms at 0200 G.M.T. The short period microseisms were small at both times but showed an increase about 1800 G.M.T.

A strong high pressure system was situated over the New Zealand area at 0000 G.M.T. and a strong high was advancing from the west with an active front just westward of the New South Wales coast. By 0900 the front had crossed the coast and a strong compact cyclone had developed; this moved out to sea to the south-east. The sea off Brisbane was smooth at 0000 with a very slight increase by 0900. This increase continued, resulting in rough seas along the coast the next day.

The beginning of this storm was not recorded at Townsville, but a definite build-up started on the 5th, with microseism period around 6 seconds. The period at Brisbane increased from four seconds to six seconds as the cyclone moved out to sea.

CASE 3. 0600 G.M.T. 17 February 1959. 1800 G.M.T. 17 February 1959.

This storm, starting at 0600, was similar to the last one in that it began very abruptly, but the period and grouping of the microseisms were very much more regular. The short period microseisms were very large throughout the 17th. The storm was not recorded at Townsville.

In this case, however, there is no clear indication of any difference in the meteorological situation for the two times. A strong cyclone was situated over eastern Queensland and gradually losing intensity as it moved south at about 20 knots. It was situated to the east of Bundaberg at 0600 and the winds in Brisbane were light south-easterlies. By 1800 the cyclone had moved to a position about 100 miles west of Brisbane, which was then inside the area of strong winds. The seas along the Queensland coast were rough during the 16th, 17th and 18th.

As the cyclone moved south there was an area with a sharp change in the direction of the wind on the coast, and this moved south with the cyclone. The maximum microseisms occurred when this wind reversal area was closest to Brisbane. If this area was the generating area, there arise several problems concerning propagation and attenuation which will be dealt with in a later section.

CASE 4. 0000 G.M.T. 2 February 1959. 0000 G.M.T. 4 July 1959.

These two do not constitute a pair in the same manner as the previous cases in that they represent two unrelated, but frequent, events. During the winter months microseism storms with a period of around 7 seconds are often recorded simultaneously at Brisbane and Townsville. The short period microseisms are usually small at these times. The July situation is a typical one. The February reading was included as a contrast, as the short period microseisms were large and the longer period ones very small and the meteorological situation was normal for the summer.

In July there was an intense extra tropical cyclone situated to the south of Tasmania. Observations have shown that the peaks of these microseism storms usually coincide with the closest approach of these cyclones to Tasmania. The seas along the Queensland coast were slight. In February, however, a strong high pressure system was centred over the Tasman Sea and strong south-easterlies had been blowing for several days with resulting rough seas along the east coast.

TABLE II

		Microseisms			
		Short Period		Group	
		Large	Small	Present	Absent
Sea	Rough	5		2	3
	Smooth		3	2	1
Depression	Present	3	2	4	1
	Absent	2	1		3

Table II—Correlation of the types of microseisms with the meteorological conditions. The numbers show the frequency of occurrence of the various combinations of microseisms and meteorological phenomena.

It can be seen from Table II that there is no correlation between the group microseisms and the state of the sea along the coast adjacent to the station. However, it appears that the development of an active depression, normally over the sea, is required for the generation of the group microseisms. This does not explain the microseisms associated with the passage of a cyclone to the west of Brisbane.

One other point of note is the absence of microseisms at Townsville during the two cases, Nos. 2 and 3, when cyclones were inland or just off the coast and well south of Townsville, the microseism period being less than 5 seconds. In Case 2 the period lengthened as the cyclone moved out to sea and there was a build-up of the microseisms at Townsville with a period of around 6 seconds, as

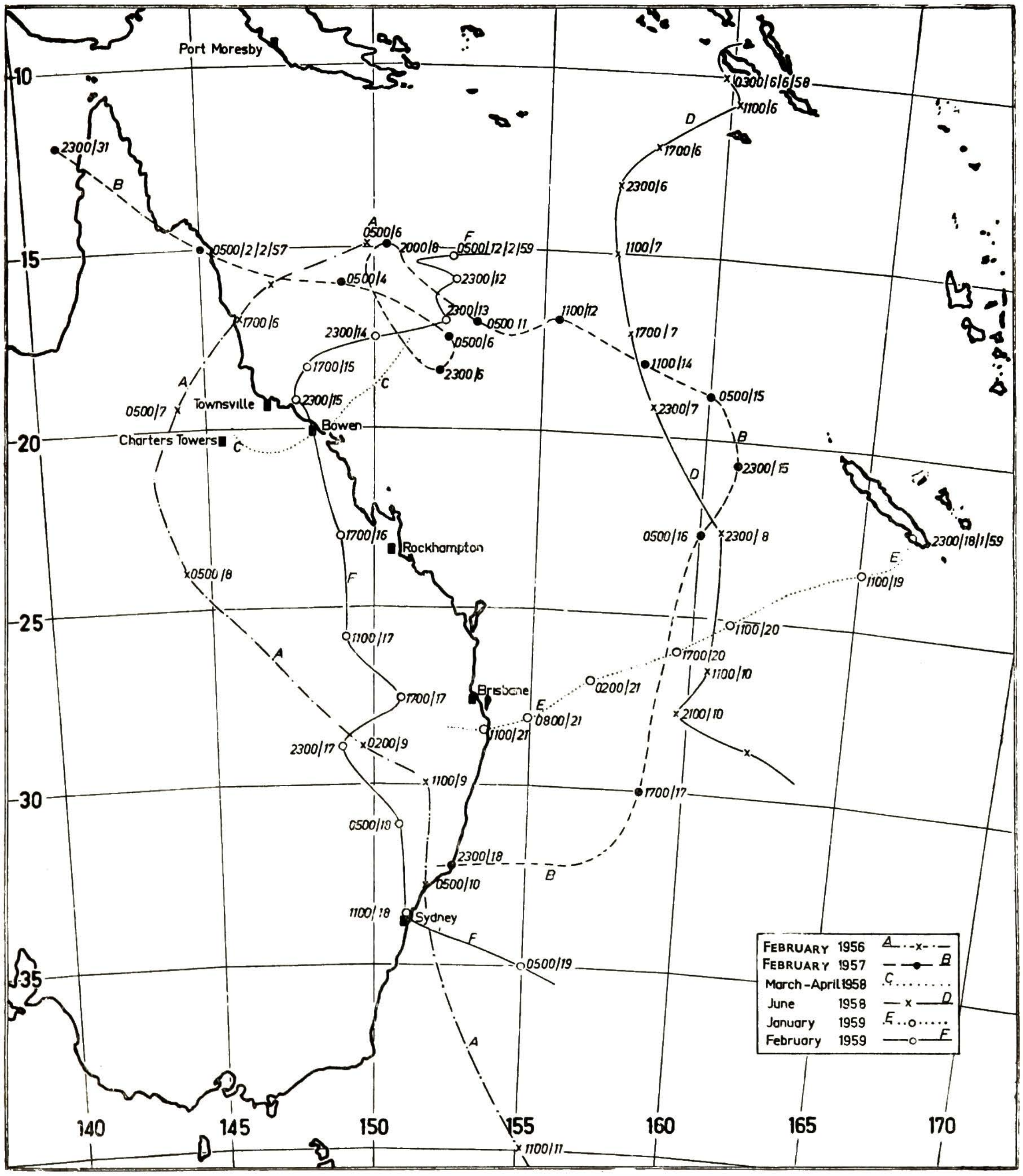

Fig. 3 Map of the South-West Pacific showing the tracks followed by the cyclones referred to in this paper.

it was also in Brisbane at that time. Similarly, it should also be noted that active depressions in the Gulf of Carpentaria and just off the east coast of Cape York Peninsula cause microseism storms at Townsville and Charters Towers but not at Brisbane. This effect would seem to suggest a barrier of some type between Brisbane and the northern stations. A difference which has been commonly observed in the short period modes of surface waves of Banda Sea earthquakes as recorded at Brisbane and Charters Towers would tend to confirm the existence of such a barrier.

Two types of cyclones occur in the Coral Sea region, firstly those which form somewhere in the island arc to the east of the Coral Sea and develop into major cyclones as they move across the Coral Sea. With these the chief difficulty is in tracking them once shipping has moved out of the area. Secondly those cyclones—often out of the main cyclone season—which develop suddenly in the centre of the western Coral Sea and move rapidly towards the coast. An early warning of the development of the latter is required. These aspects will be dealt with in this paper.

THE EFFECT OF DISTANCE AND STRUCTURE ON MICROSEISM AMPLITUDE.

Cyclones of February 1957 and June 1958. (Fig. 3, tracks B and D).

A relation between microseism amplitude and cyclone distance of the form $A = K\ D^{-\frac{1}{2}}$ was found for the March 1955 cyclone (Upton, 1956a, p. 9)

where A = microseism amplitude

D = distance of the cyclone from the recording station

K = station constant.

As this particular aspect of microseism generation has been the centre of controversy concerning these microseism storms, the records of the February 1957 and June 1958 cyclones were used to check the earlier results.

If we assume that the area of generation of the microseisms is close to the centre of the cyclone and develop theoretically an equation linking the microseism amplitude with distance, we should be able to determine from the correlation of the amplitude with distance whether this relation holds.

The February 1957 cyclone was chosen as its path covered a large area of the Coral Sea thus involving a large variation of distance from Townsville and from Brisbane, as well as variations of water depth at its centre. The second cyclone was chosen because part of its path duplicated part of that of the 1957 cyclone.

The February 1957 cyclone developed over the weather station at Willis Island on the 5th from a rain depression which had moved eastwards from the Gulf of Carpentaria. After completing a loop to the south, the cyclone passed over Willis Island again on the 7th accompanied by 100 knot winds and moved slowly northwards into deep water on the 8th. At this time there was a marked increase in the amplitudes at Brisbane and Townsville (Fig. 4). This increase could be explained, in part, by the continued increase in the intensity and area of the cyclone, but a marked change in ratio of the Townsville and Brisbane microseism amplitudes also occurred at this time, suggesting that an additional factor is involved.

During the 8th to 10th the cyclone moved very slowly south-east and the microseisms at both stations showed evidence of a diurnal variation, a variation confirmed by a more detailed analysis—two hourly readings throughout the period. On the 12th a very noticeable decrease in the microseism amplitude occurred at Townsville, during which time it is possible that the cyclone was over the shallow

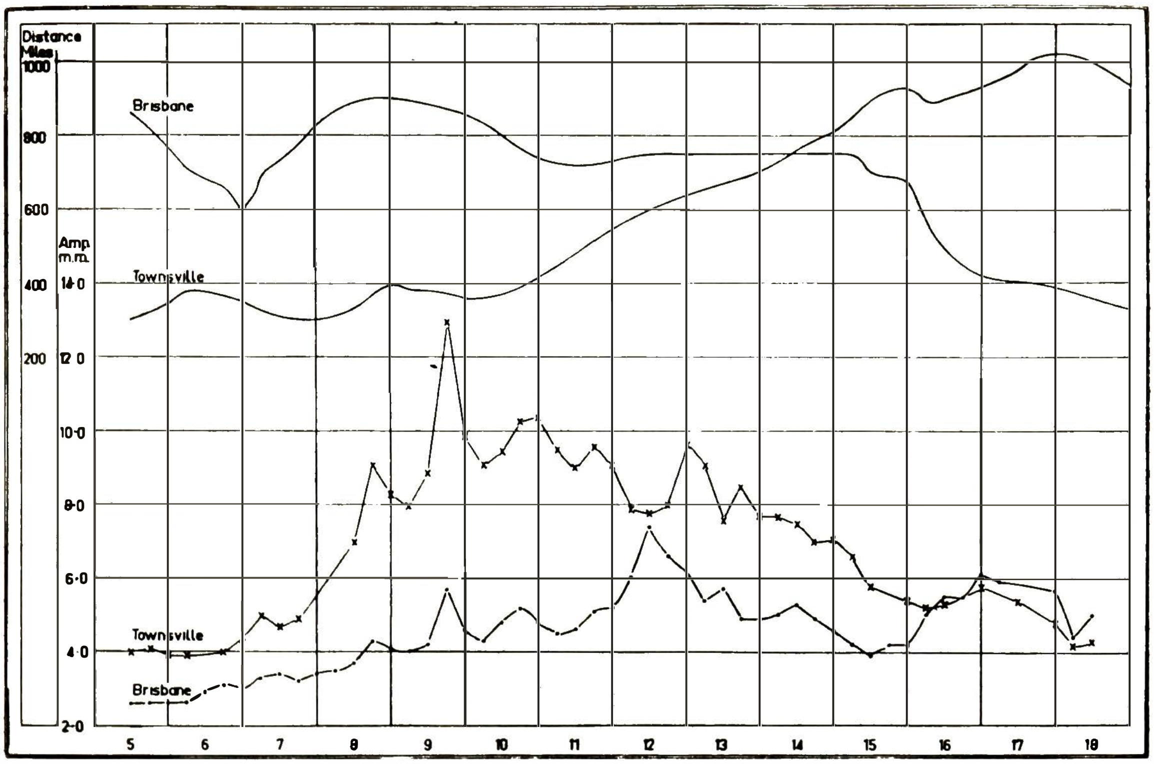

Fig. 4—Townsville and Brisbane microseism amplitudes compared with distances to the centre for the cyclone of February 1957.

water to the east of Willis Island. The cyclone then moved slowly around the Coral Sea until it passed inland about 350 miles south of Brisbane on the 19th and filled in.

The 1958 cyclone developed over the Solomon Islands on the 4th June and moved out to sea on the 6th. The microseisms began to build up on the 7th (Fig. 5) when the cyclone was still 1,000 miles from Brisbane. The Townsville readings were incomplete owing to instrument disturbances. The cyclone moved in a southerly direction and from the 9th to the 11th followed (approximately) the path of the 1957 cyclone.

If we assume that the microseism amplitude 'A' is a function of the intensity of the cyclone 'I', its position 'P' and its distance from the seismograph station 'D' we can write

$$A_1 = k_1 f(I,P,D_1)$$

For a second station, the factors 'I' and 'P' will be the same at a given time,

$$\therefore A_2 = k_2 f(I,P,D_2)$$

The ratio of the amplitudes is some function of D_1 and D_2 and, as a first approximation, we write,

$$\frac{A_1}{A_2} = KF\left(\frac{D_1}{D_2}\right)$$

and further, assuming a simple power relation with distance, as is to be expected from theory if the microseisms are surface waves generated near the cyclone centre, we can write

$$\frac{A_1}{A_2} = K\left(\frac{D_1}{D_2}\right)^n$$

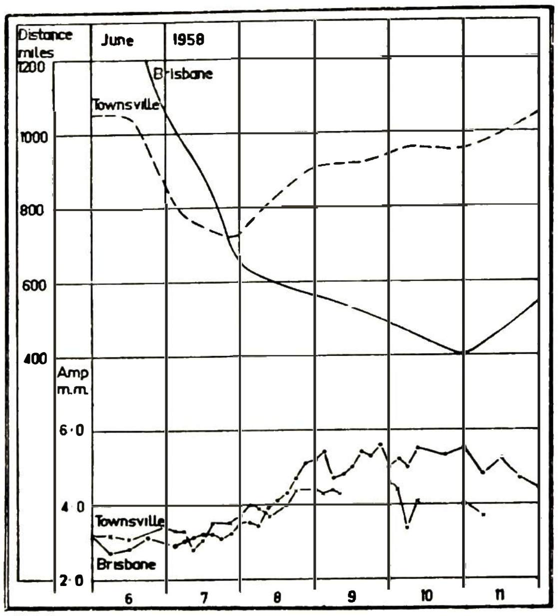

Fig. 5—Townsville and Brisbane microseism amplitudes compared with distances to the centre for the cyclone of June 1958.

If we plot A_1/A_2 against D_2/D_1 we can find,

(*a*) from the correlation between the distance and amplitude whether this relationship is true and therefore whether the origin of the microseisms is near the cyclone centre or not.

(*b*) the values of K and n. As both stations are equipped with Sprengnether seismographs with the same period and magnification, the factor K will be chiefly governed by the structural differences in the sites. The Townsville instrument is situated on reclaimed land, with the water table in the wet season (January-March) sometimes above ground level and the Brisbane instrument is on welded tuff; thus there are likely to be considerable differences in the response of the two instruments (Gutenberg, 1957).

The ratios of the microseism amplitudes and distances for the February 1957 cyclone are shown in Figure 6. The points fall into two groups, one group for times when the cyclone was over the shallow water extending out from the coast. The second group covers the rest of the Coral Sea including the shallow water around the Chesterfield Reef. The line of regression for each group of points was determined to find the best straight line for each group. (Fig. 6).

The deep water group gives a value of $n = 0.47$ and $K = 1.5$; the correlation coefficient is 0.96 with 33 observations. The shallow water group gives a value of $n = 0.42$ and $K = 1$; the correlation coefficient is 0.86 for the 14 observations obtained at this time. A similar graph for the June 1958 cyclone (Fig. 7) shows all the points falling into one group with $n = 0.49$ and $K = 1.2$, the correlation coefficient for the 13 observations being 0.91.

These results give a relation between the microseism amplitude and the distance of the form:—

$$\frac{A_1}{A_2} = K\left(\frac{D_1}{D_2}\right)^{-\frac{1}{2}}$$

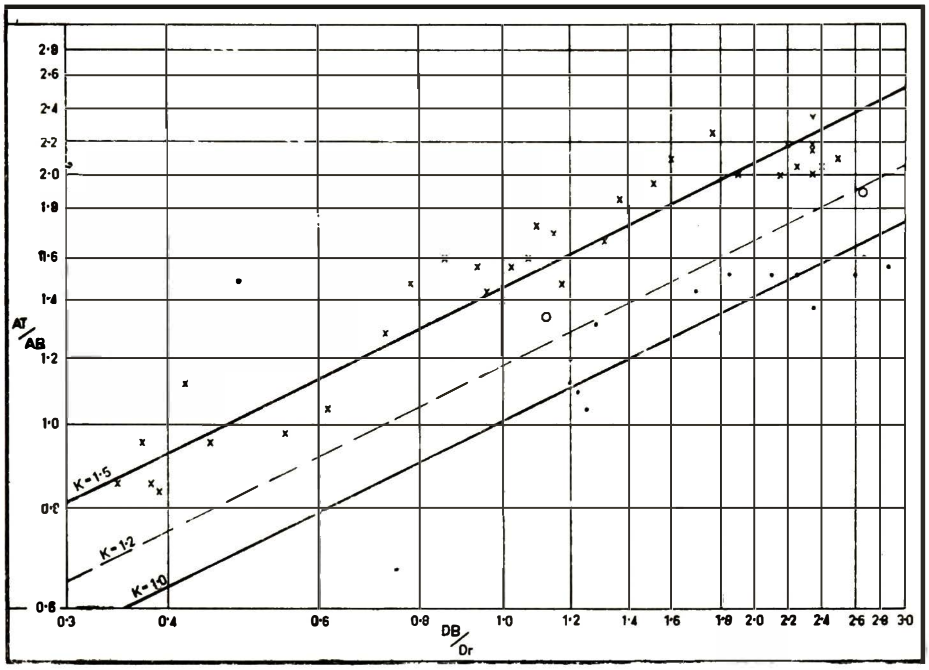

Fig. 6—Relation between distance and amplitude ratios for the cyclone of February 1957, showing the curves

$$\frac{A_T}{A_B} = 1.5 \left(\frac{D_B}{D_T}\right)^{0.47} \text{ and } \frac{A_T}{A_B} = 1.0 \left(\frac{D_T}{D_B}\right)^{0.42}.$$

Two main factors arising from these curves are the variations of 'K' and the values of 'n'. In the theoretical discussion it was stated that 'K' should depend on differences in structure at each station, in which case it should be a constant for a given pair of stations. It is seen, however, that this is not the case. However, there are possible explanations for both the variations in 'K' during the February cyclone and for the difference between the two cyclones. The changes in 'K' during the February cyclone coincide, as closely as can be determined from the meteorological information available, with changes in position of the cyclone relative

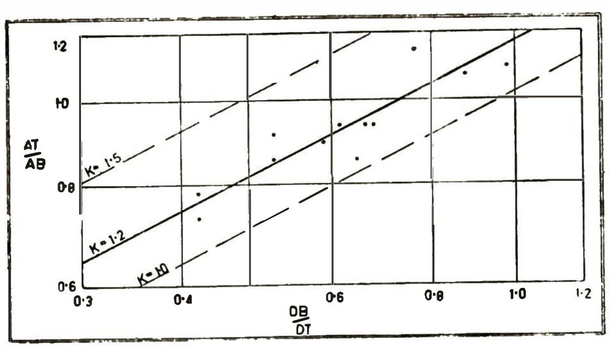

Fig. 7—Relation between distance and amplitude ratios for the cyclone of June 1958, showing the curve

$$\frac{A_T}{A_B} = 1.2 \left(\frac{D_B}{D_T}\right)^{0.49}$$

to the "shelf".* It appears that another factor should have been included in the original theory, namely, the path of the waves to the station. A change in the crustal structure will affect the attenuation of the waves and therefore the ratio of the recorded amplitudes, if such change in structure affects one path only.

The differences in 'K' for the two cyclones when they were in the same area can only be explained in terms of differences in reception of the two cyclones at either one or other of the stations. As a result of work done in California (Gutenberg, 1957) it was found that not only was the response of a seismometer affected by the nature of the material on which the pier is built, but also in the state of that material, *i.e.* whether it is wet or dry. The amplitudes recorded on wet alluvium will be larger than those recorded under dry conditions and alluvium, whether wet or dry will give larger amplitudes than those recorded on a more solid base.

The decrease in the value of 'K' for the June cyclone means that the Townsville amplitudes were smaller than expected in comparison with the February figures, if the Brisbane readings remained unaffected by any difference in conditions. A check of the relevant meteorological information shows that in February the ground at Townsville was saturated after very heavy rain, while in June the ground was dry. These conditions could account for the lower values of 'K' during the June cyclone.

The values of 'n' in these three cases are well within the expected range of values, but it will be noticed that they all lie below $\frac{1}{2}$, whereas, with an average distribution, we would expect some to be greater than $\frac{1}{2}$. A slight error in the positioning of the cyclone at any time will, in nearly all cases, affect the two distances involved in the same way and by nearly the same amount. Examination of the curves show that the slope will be increased if all distances are increased by a fixed amount. In fact, an increase of ten miles on all the distances will give a slope of just over $\frac{1}{2}$. As the position of the cyclone is rarely known within twenty miles and the scale and projection of the map used for plotting restricts the distance measurements to this order of accuracy, the slight change required to correct the slope is less than the accuracy to which the distance measurements can be made.

The results using amplitude ratios confirm those obtained in 1955 using data from one station and firmly establish the relationship between the microseism amplitude and the distance of the cyclone from the recording station. This, therefore, confirms the earlier indications that, in the Coral Sea region, these microseisms are generated close to the centre of the cyclone and are propagated through the earth's crust.

One controversial point in this connection has been the propagation and attenuation of surface waves of these periods (4 seconds-10 seconds) across deep water and continental margins. There is evidence from North American sources that waves of these periods are not recorded from hurricanes in the Atlantic while the storm is over deep water, nor are surface waves of these periods recorded from earthquakes whose paths traverse ocean areas. However, the situation in the Coral Sea and the northern Tasman Sea appears to be different. Crustal structure studies carried on here confirm the findings of Officer (1955) that the crustal thickness in the region to the east of Australia is around 15 km. Although there is deep water to the east of Brisbane, it overlies a comparatively thick crust as compared with the western Atlantic, where there is a 3 km. ocean over a 5 km. crust. The surface waves of earthquakes occurring to the east of Australia, as far south as the North

*The term "shelf" is used to denote the area inside the 1,000 fathom line and not the edge of the continental structure as indicated by the thickness of the crust.

Island of New Zealand, show signs of short period surface waves, either in the usual, higher mode, or in some other low velocity mode. As waves with periods of around 5 seconds are recorded from these earthquakes, there appears to be no obstacle to waves of these periods being recorded from cyclones in the same areas.

THE EFFECT OF APPROACH TO THE COAST ON THE MICROSEISM AMPLITUDES.

Cyclones of January and February 1959. (Fig. 3, tracks E and F).

The relation between the microseism amplitude and the distance, obtained in the previous section, appears to hold only when the cyclone is out to sea. The amplitude-distance graph of the cyclone of March 23, 1955 showed a decrease in amplitude with decreasing distance when the cyclone was within 200 miles of the station. At that time it was not known whether this effect was due to the distance from the coast or the distance from the station.

Unfortunately, after March 1955 no cyclones approached within 200 miles of a station until January 1959. This cyclone came across from New Caledonia towards Brisbane, causing the largest microseisms that have been recorded in Brisbane. The Townsville records, unfortunately, are unreadable at this time owing to the failure of the selector switch. The long-period Benioff records from the Charters Towers station (65 miles west of Townsville) have been read to give an indication of the variations in microseism amplitude in the north. The peak showing on the curves at 0600/20 (Fig. 8a) was due to a small depression moving out to sea near Cairns. The microseism period at this time was shorter than for the storm which followed. The main peak at 0000/21 occurred eleven hours before the cyclone crossed the coast, while it was still about 250 miles off the coast near Brisbane and over deep water.

The February 1959 cyclone (Fig. 8b) developed in the Coral Sea to the east of Willis Island and intensified as it moved westwards. The Townsville records were disturbed by the strong winds as the cyclone approached the coast and the Charters Towers records were again used. The maximum amplitudes at Brisbane and Charters Towers occurred as the cyclone came closest to Townsville. After this the cyclone moved south along the coast and finally moved inland near Bowen about six hours later.

This cyclone was the most intense recorded along the Queensland coast. The lowest pressure at Bowen was 956 mb. and winds of over 116 m.p.h. (upper limit of anemometer) were recorded there for two and a half hours. The microseisms at Brisbane and Charters Towers, however, were much larger during the January cyclone than during this one.

The effect of the microseisms as the cyclone approaches the coast appears to be different for each of the cyclones examined, although a closer study of the cyclones shows that the speed and direction of approach to the coast were different in each case. The two 1955 cyclones approached the coast rapidly and as at that time records were taken at only six-hourly or even longer intervals, it is not possible to obtain exact information on the microseism variations. The 1956 cyclone (Upton, 1956b) gave the peak microseisms as the cyclone came to the Barrier Reef. The amplitude was maintained as the cyclone moved slowly northwards parallel to the coast and inside the Reef. The peak of the microseisms for the February 1959 cyclone occurred when the cyclone was 50 miles off the coast, within the Reef, and as it started to move along the coast. In these last two cyclones the approach to

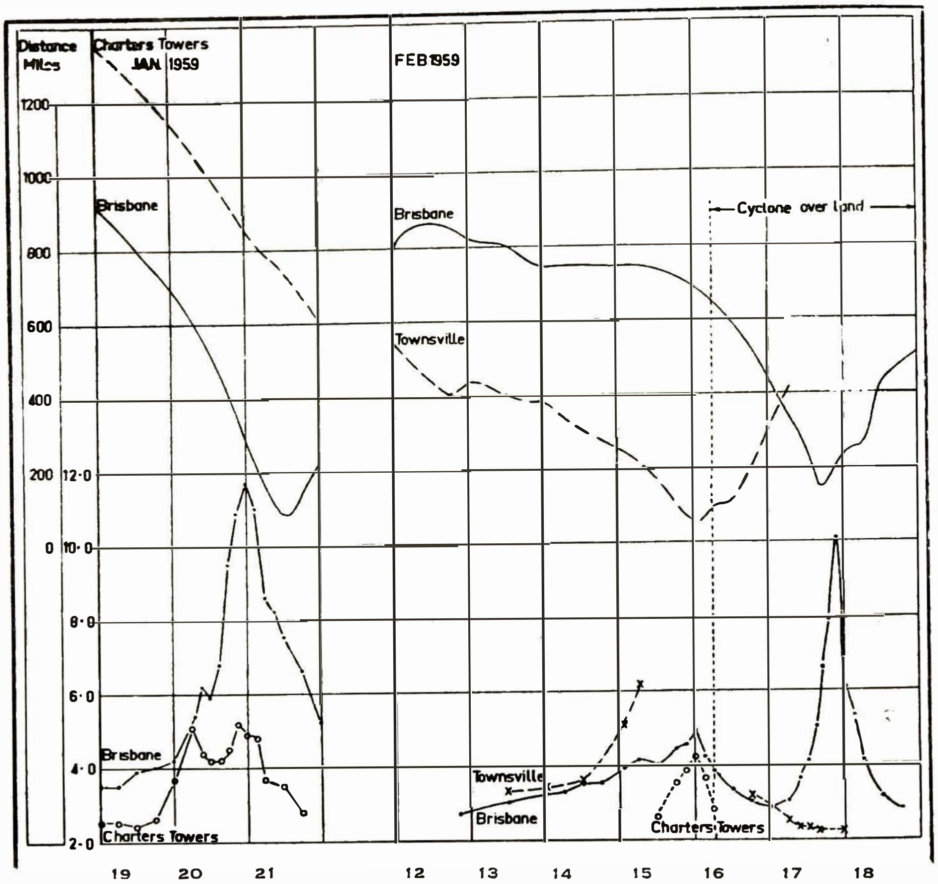

Fig 8a (left)—Charters Towers and Brisbane microseism amplitudes compared with the distance of the centre from Brisbane for the cyclone of January 1959.

Fig 8b. (right)—Townsville, Charters Towers and Brisbane amplitudes compared with the distances to the centre for the cyclone of February 1959.

the coast was much slower than that of the 1955 ones and it has been possible to examine the microseism variations in more detail. Apart from the January 1959 cyclone, the results show that as a cyclone moves near the coast and the effective area over the sea becomes less, then the microseism amplitude begins to decrease.

MICROSEISM STORMS ASSOCIATED WITH INLAND CYCLONES.

Cyclones of February 1956 and February 1959. (Fig. 3, tracks A and F).

Microseism storms with very regular groups have been associated with the passage of a cyclone passing to the west or south-west of Brisbane. In February 1956 a weak cyclone moved inland near Cairns and maintained intensity as it moved down through Queensland. A marked microseism storm occurred on the 9th as the cyclone approached the coast to the south of Brisbane, but while it was still inland. The build-up began when the cyclone was 150 miles from Brisbane and about 100 miles from the coast.

The February 1959 cyclone was also accompanied by a very intense microseism storm (Fig. 8b) as it passed to the west of Brisbane. The microseism amplitudes at Charters Towers, Townsville and Riverview (Sydney) showed no increase.

The appearance of the microseism amplitude curves for all the stations would suggest that two different sources of generation were present. While the cyclone was out at sea all three stations showed similar variations, with the peak as the cyclone approached the coast, suggesting that the propagation for this mode of generation was uniform in all directions. This area of generation decreased as the cyclone neared the coast.

The microseisms associated with the inland portion of the cyclone track were recorded only at Brisbane. It was suggested in an earlier section that the area of wind change off the coast might be the generating area and the regular rise and fall of the microseism amplitudes would support a generating area of this sort moving steadily down the coast. This area would be one with very 'broken' seas, rather than merely rough seas. It has been suggested by Donn (1957) that the action of waves breaking at sea may be the origin of these microseisms. The regular microseisms that occur at times when a very strong front moves across the coast to the south of Brisbane and develops a closed low pressure area, would also support this method of generation.

The marked difference in the amplitudes recorded at Brisbane and Townsville is difficult to explain in view of the results of all the other microseism storms. The only suggestion that can be offered at this stage to explain the anomalous propagation is the possibility of some channelling effect being present, similar to that suggested by Oliver and Ewing (1958) to explain the low velocity short period surface waves recorded in parts of North America. There is some evidence that similar waves are recorded at Brisbane from some earthquakes in the New Hebrides region.

GENERAL

The microseism studies during the past few years have shown the value of microseism records to give an early warning of the development of cyclones and changes in intensity of known cyclones. In March 1958 a small depression off the coast near Bowen (Fig. 3 track C) suddenly developed into a small but very intense cyclone. Upper air information, obtained at 0200 on the 31st, showed that cyclogenesis was possible, but the surface charts did not show any significant development until the following day. The microseism records confirm the earlier suspicions by the appearance of regular groups on the records from 1200 on the 31st. The period of these groups (4 seconds) was the same as that associated with the 1957 cyclone when it was over the shallow water to the north-east of Bowen.

The Commonwealth Bureau of Meteorology is installing Sprengnether seismometers with pen recorders at a number of points along the Queensland coast and on Willis Island. Their primary purpose will be to form an early warning system for the development of cyclones.

The results obtained for the amplitude ratio method of tracking cyclones do not appear to be useable at this stage. Although consistent results have been obtained for any one cyclone, there is some as yet unknown variable which prevents the information obtained from one cyclone being used to track another one. This, however, may be due mainly to the poor instrument site at Townsville.

The results obtained from the cyclones occurring out at sea show that the area of generation is close to the centre of the cyclone. With the establishment of extra stations it will be possible to check the nature of the "constants" obtained from the work to date, particularly the effect of the "shelf" on microseism propagation and the attenuation of surface waves from all sources.

The variation of period with position was mentioned briefly in an earlier paper (Upton, 1956b). No further work has been done on this aspect of the microseism storms. A more detailed and accurate method of analysis is required to obtain consistent results and the time required to do this manually would seriously limit the number of observations which could be made.

In order to carry out detailed work for the increased number of stations it will be necessary to develop automatic equipment for the determination of the microseism amplitude and period. Preliminary designs have been made for a low frequency analyser and for equipment to determine the microseism amplitude automatically.

Although this work has revealed some of the factors causing changes in microseism amplitude, the parameters controlling the actual generation and governing the amplitude from cyclone to cyclone have not been discovered. More detailed examination of various meteorological data such as pressure gradients, speed of movement and area of strong winds, together with study of microseism records from the Willis Island station, may help to solve this problem.

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