550.342 : 551.515(26 : 54)

Microseisms from storms in the Indian Seas

A. N. TANDON

Central Seismological Observatory, Shillong

(*Received 27 September 1955*)

ABSTRACT. The present state of our knowledge of microseisms is summarised. A study of the microseisms recorded by the Seismological Observatories at Calcutta, Hyderabad, Kodaikanal, New Delhi and Poona, during the passage of the Bombay cyclone of November 1948, Andhra cyclone of October 1949 and the Bay cyclone of December 1951, is presented. The results show that microseisms of significant amplitudes are recorded at all the stations only when the region of low pressure at sea reaches the stage of a cyclonic storm. The amplitudes then rise and fall simultaneously at all the Indian stations, reaching the maximum value at the same time. Microseisms are not recorded for all positions of the storms. The periods of microseisms generally show a rise with increasing amplitudes and seem to have no dependence on the distance.

1. Our present knowledge on the subject

Microseisms having a range of periods between 2 and 10 seconds have long been known to be associated with large sea waves caused by cyclonic storms and high winds over the sea. In India, Banerji (1930) had shown that microseisms were recorded on all seismographs whenever a cyclonic storm was formed in the Bay of Bengal. Later work by Pramanik, Sen Gupta and Chakravortty (1948) corroborated the same view. They, however, noticed that the microseisms from storms in the Bay of Bengal were not recorded at Calcutta when the storm was positioned in certain regions. Two theories had been proposed to account for the generation of microseisms. One presumed that microseisms were generated in the area of the cyclonic storm or high waves and the changes of pressure on the sea surface were communicated to the sea bottom and generated waves of the Raleigh type (Banerji 1930), while the other attributed the generation of microseisms to the beating of surf against a rocky coast (Gutenberg 1936, 1947). Although the latter could account for the energy of the microseisms, it failed to explain the recording of microseisms at places where there was neither a steep coast nor any noticeable surf. Even a few years ago it was accepted by most workers that microseisms were generated in the region of cyclonic storms, and this eventually led the American Navy to develop the tripartite method of tracking hurricanes in the sea (Ramirez 1940, Gilmore 1946, 1948). Several years' experience in tracking hurricanes by the tripartite method, however, showed that the bearings of the storms could be calculated fairly accurately only when the storm was centred in specific areas. In some positions the bearings calculated by tripartite method were grossly discrepant with actual observations of storm centres. The failure of the tripartite method to give correct bearings of storms in all positions has in recent years led to a controversy in the United States of America regarding the mechanism behind generation of microseisms, as a result of which the current views on microseisms have become rather confused. Workers of the Lamont Geological Laboratory, Palisades, still believe that microseisms are generated in the region of the hurricanes. According to Donn and Blaik (1952) the failure of the tripartite method is due to the inherent large standard errors in the method itself. Refraction of waves at the continental shelf or at other geological discontinuities causes further complications. According to him bearings of the storms could be determined approximately only when either the storm is on the same geological unit as the recording station or on an azimuth fairly normal to the coast. Donn (1951) has also observed that the recorded amplitudes of microseisms are appreciably higher when the storm is on the continental shelf in comparison to its being on deep sea; the microseismic energy being dissipated at the edge of the continental shelf. He believes that the absence of a granitic layer in the Atlantic is responsible for this.

Contrary to the view of Donn and others, Kammer and Dinger (1951), and Dinger and Fisher (1955) of the Naval Research Laboratory, Washington have concluded from their observations that microseisms are not generated under hurricanes which are over remote deep water. According to them water waves over relatively shallow water are responsible for the generation of microseisms. Following the theory of Longuet-Higgins and Ursell (1948) they attribute the generation of microseisms to the interference of sea swell of the same period travelling in opposite directions. For those cases, in which the presence of hurricanes in the sea has failed to record microseisms, the above conditions are not fulfilled. Interference of swell could take place near the shore by reflection of the swell from the shore, or due to simultaneous presence of two hurricanes, or due to a hurricane and another frontal system. According to these ideas, therefore, microseisms can be generated at different positions with respect to the hurricane centre, and hence the failure of the tripartite method to locate the correct bearings of storm centre.

Dinger and Kammer's ideas about the area of generation of microseisms do not agree with those of Gilmore (1951) who has studied microseisms from hundreds of tropical storms. As has already been mentioned, the tripartite station method used by him earlier for tracking storms had only a limited success. He has however, been able to use the data collected by him in developing an empirical method of tracking storms and predicting their day-to-day variations in intensity. He has pointed out categorically that studies of swell data from Guam show absolutely no correlation to the rise and fall of microseismic amplitudes. According to Gilmore microseismic data collected from standardised instruments can be used for (1) early storm detection, (2) for tracking tropical storms and (3) for finding the intensity of a tropical storm. The accuracy of storm detection and tracking is dependent mainly on three factors, namely (1) number and location of microseismic stations within the range of the storm being tracked, (2) the amount of past microseismic data available for each station and for each pair of stations and (3) the accuracy of the storm and microseismic data used in the making of micro ratio and amplitude charts.

In addition to hurricanes, extra-tropical storms and cold fronts during their passage over the sea have also been found to generate microseisms. Donn (1951) has shown that they appear soon after a cold front passses seaward from land and when the front is on relatively shallow water. He also concluded from his observations on frontal microseisms that surface wind waves and swell is of little consequence in the production of frontal microseisms. Gilmore (1951) has also observed that large microseismic storms are generated continuously along the entire length of cold front when the cold front is over water. He associates frontal microseisms with the passage of cold front only. While large microseismic storms are generated by cold fronts over water with a wind velocity of only 30 knots behind the front, warm fronts with winds up to 50 knots in advance seldom cause microseisms. This shows that the density of the air mass also plays an important role in the generation of cold front microseisms.

Gutenberg (1953) has studied microseisms recorded in Southern California due to extra-tropical disturbances between the period 29 November 1951 to 4 January 1952. He finds that the maximum amplitudes of microseisms lagged behind the centres of these extra-tropical storms by about 2 days. In all microseismic storms he observed that the increase or decrease of amplitudes was delayed with increasing distance from the storm centre. The maximum amplitude usually coincided with the highest breakers and waves on the Southern California coast. Miscroseisms generated by extra-tropical lows are apparently of frontal origin and the lag between the storm centres and maximum microseismic activity recorded at the Southern California stations is due to the fact that the cold front associated with such storms arrive in Southern Californian water a day or two after the storm has entered inland. As observed by Donn, relatively larger amplitudes will be recorded when the front is on the continental shelf, which may account for the microseismic maxima coinciding with the highest wave activity on the coast.

Studies of microseisms in the U.S.A. are largely handicapped due to large expanse of water surrounding the continent. The presence of more than one source of microseisms on the sea is not very unusual. The normal amplitude of microseisms as recorded on routine seismograms used for this purpose is considerable. In these respects the storms occurring in the Indian seas give better material for study. These storms occur mostly in the pre-monsoon and post monsoon periods when the sea is not rough and consequently the amplitudes of microseisms on routine seismograms is very small. Presence of two storms at the same time is a very rare occurrence and the microseismic picture is not further confused by other meteorological phenomenon such as passage of cold fronts over the sea. The presence of storm type microseisms on seismograms has always been a sure indication of the presence of a storm in the sea and this fact has often provided the routine forecaster with additional evidence whenever he has been in doubt.

2. Scope of the present study

In view of the conflicting theories on the origin of microseisms a study of three storms in the Indian Seas has been made in the present paper using the available data from Indian seismological stations. The three storms selected for the study represent the usual types that occur in the Bay of Bengal and the Arabian Sea. In this connection it may be mentioned that the cyclonic storms which usually occur in the Bay of Bengal and the Arabian Sea are much weaker than the hurricanes of the Atlantic Ocean studied in the U.S.A. The winds associated with hurricanes are often 2 to 3 times stronger than those encountered in the cyclonic storms of the Bay of Bengal. The amplitude of the associated microseisms from the storms as recorded on microseismographs is much smaller than those recorded for hurricanes in the U.S.A. The data used in the present investigation have been obtained mostly from records of Milne-Shaw seismographs, except in the case of Poona for which records of a Wood-Anderson seismograph (period 2 sec) have been used in the study of Bombay cyclone of November 1948, and records of Sprengnether microseismographs ($To = Tg = 7$ sec) have been used for the Andhra cyclone of October 1949, and the Bay cyclone of December 1951. In order that the data from different types of instruments may be compared, the ratio of the observed microseismic amplitude to the normal microseismic amplitude has been used instead of amplitudes in millimetres as recorded. The normal amplitude has been taken as the average microseismic amplitude on records prevailing soon before the occurrence of the storm. The amplitudes measured are the average amplitudes of about 5 good build-ups at the time of measurement. The periods represent the average period of the same groups used for amplitude measurements.

Weather data for the Bombay cyclone of November 1948 and for the Andhra cyclone of October 1949 were obtained from the published accounts given in *India Weather Review, Annual Summaries*, Part C for 1948 and 1949. Weather data for the Bay cyclone of December 1951 was kindly supplied by the Meteorologist-in-charge, Weather Central, Poona. The tracks of the three storms with their centres at times of observations are shown in Fig. 1. The Bay cyclone of December 1951 is remarkable for the fact that it practically traversed the whole length of the Bay of Bengal. Ratio of the observed microseismic amplitudes to the normal amplitudes and the average periods for Calcutta, Hyderabad, Kodaikanal, New Delhi and Poona have been plotted against time. These are shown in Figs. 2, 3 and 4 for the storms of November 1948, October 1949 and December 1951. The interpretation of the plotted data will now be discussed for each storm.

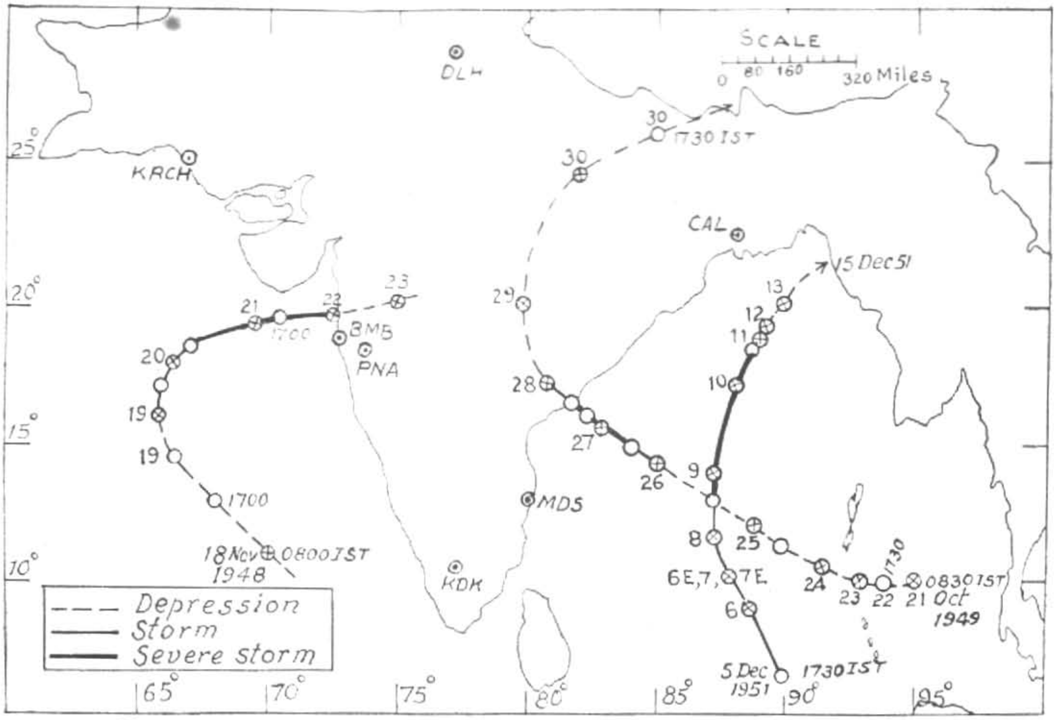

Fig. 1. Tracks of Bombay cyclone of November 1948, Andhra cyclone of October 1949 and Bay cyclone of December 1951

Crossed circles indicate the positions at 0800 or 0830 IST and open circles at other hours, 0130, 0200,1700, 1730 IST

3. Bombay cyclone of November 1948

According to the weather maps a low pressure area from the east passed out into the southeast Arabian Sea on the afternoon of 16 November 1948. This low pressure area concentrated into a depression by the morning of 18 November with its central region near Lat. 11°N, Long. 70°E. Ships' observations received by the Weather Central at Poona indicated that by 1700 IST of the 19th, the deep depression had probably become a cyclonic storm with its centre near Lat. 17°N, Long. 66°E. At this stage the storm began to recurve changing its movement from a northerly to northeasterly direction. It further intensified and by 1400 IST on the 20th it was a severe cyclonic storm centred near $18\frac{1}{2}$°N, $66\frac{1}{2}$°E. A glance at Fig. 2 will show that throughout the period, 16 to 20 November, the amplitudes of microseisms at any of the Indian observatories had shown no increase at all. It is only after midnight of 20 November that the amplitudes started rising abruptly. The observations thus clearly show that within the period 1700 IST of 19 November to midnight of the 20th no microseisms were recorded although a cyclonic storm existed in the sea off the Bombay coast. No noticeable increase in microseismic amplitude was observed even in the seismograms at Poona which was not very far from the storm. Soon after midnight of 20 November when the storm centre was near Lat. 19°N, Long. $68\frac{1}{2}$°E, microseismic amplitudes at all Indian stations began rising rather abruptly. This would indicate that before this time microseisms were either not generated at all or the propagation of microseismic waves from the storm region was stopped by the intervention of some sort of a barrier.

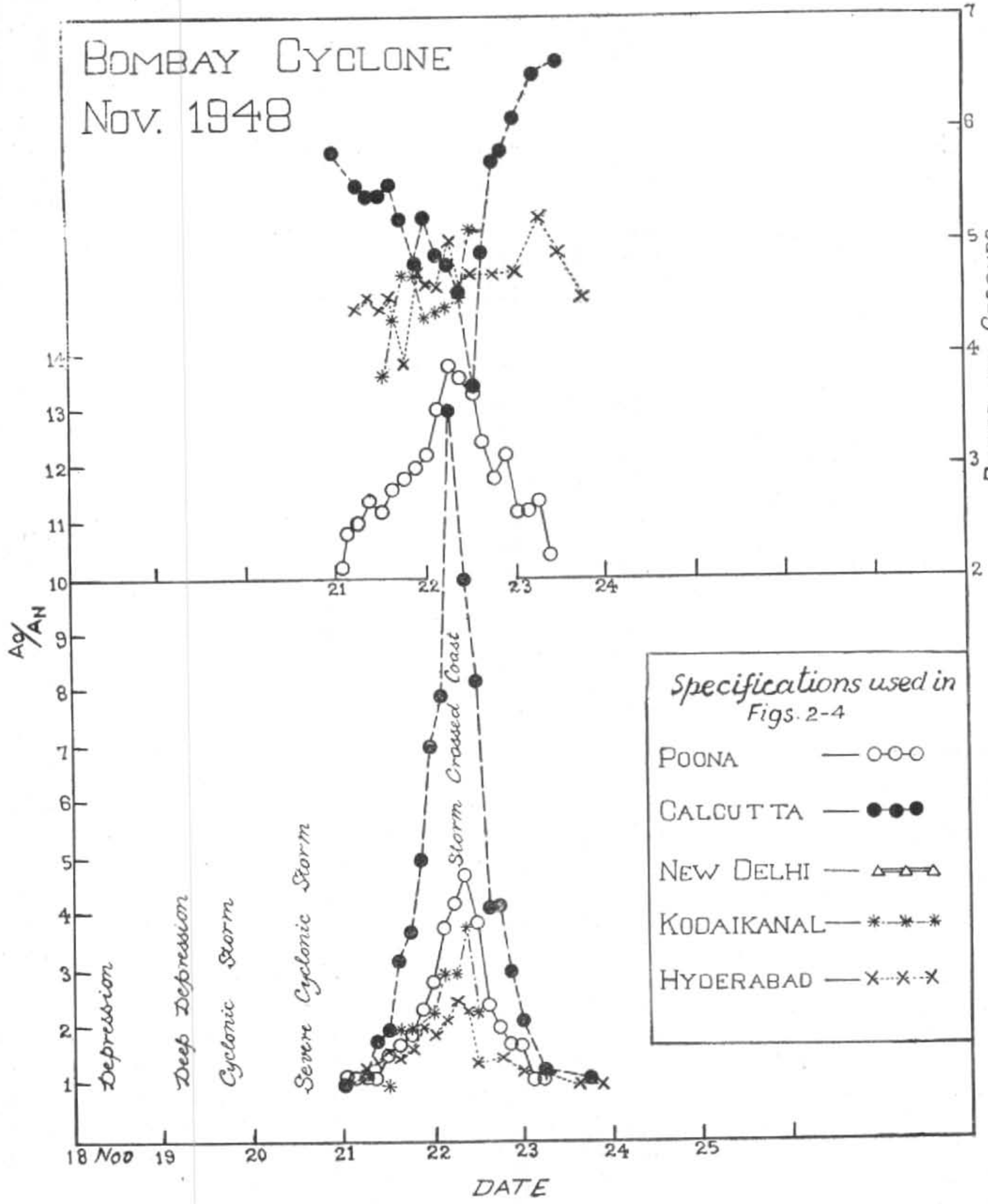
BOMBAY CYCLONE
NOV. 1948
PERIOD IN SECONDS
2
3
4
5
6
7
Ao/AN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
21
22
23
24
Depression
Deep Depression
Cyclonic Storm
Severe Cyclonic Storm
Storm Crossed Coast
Specifications used in Figs. 2-4
POONA
CALCUTTA
NEW DELHI
KODAIKANAL
HYDERABAD
18 Nov
19
20
21
22
23
24
25
DATE

Fig. 2

The storm crossed the coast at 0930 IST of 22 November and we find from Fig. 2 that the microseismic peak also was reached at about the same time at all Indian stations. After this time the amplitude decreased sharply and became normal at about midnight of the 22nd. The period of microseisms recorded at different stations are also shown in Fig. 2. At Poona the records of a Wood-Anderson seismograph having a period of 2 sec were used. The predominant period recorded, rose during the storm from 2 to 4 sec. At each stage the periods show a conspicuous rise with amplitudes. For the rest of the stations records of Milne-Shaw seismograph having a period of 12 sec were used. The average periods for Hyderabad and Kodaikanal is between 4 and 5 seconds. The average periods measured from Calcutta records are rather anomalous, and decrease with the amplitudes of microseisms. This is difficult to explain in view of the other observations, and can only be attributed to local and instrumental peculiarities.

4. Andhra Cyclone of October 1949

Amplitudes and periods recorded for the Andhra Cyclone of October 1949 are plotted in Fig. 3 for Calcutta, Hyderabad, New Delhi and Poona. Except for Poona, where records of Sprengnether microseismograph were available the rest of the measurements have been made from Milne-Shaw seismograms.

Weather became unsettled in the Andaman Sea on the morning of 20 October 1949 and by the morning of the 21st a shallow depression was formed with its centre near Lat. 10°N, Long. 95°E. The depression intensified and by 1730 IST of 22nd it became deep and was centred near Lat. 10°N Long. 94° E. At 0830 IST of the 25th it lay as a cyclonic storm with its centre at Lat. 12°N, Long. 89°E. The storm further intensified and became severe and was centred at 1730 IST of 26th with its centre at Lat. 15°N, Long. $84\frac{1}{2}$°E. The cyclone continued to move northwest and finally crossed coast at about 0200 IST of 28 October.

Referring to Fig. 3, we find that the amplitudes of microseisms did not show any appreciable rise until the 25th morning when the depression had already become a cyclonic storm. Even at this point the rise in amplitudes is slow. The amplitudes started increasing rapidly from the midnight of the 25th when the cyclonic storm was further intensifying. The amplitudes at all the Indian stations reached their maximum value just after midnight of the 28th while the storm was crossing coast and then began to register a decrease. They returned to their normal value by the midnight of 29 October.

Average periods recorded during the storm at the Indian stations ranged from 4 to 6·5 seconds. The periods show a general tendency to rise with amplitudes, and show no relation to the distance of the storm from the recording station.

5. Bay Cyclone of December 1951

The microseismic data associated with this cyclone from 4 December to midday of 15 December are plotted in Fig. 4. The weather map on 4 December 1951 showed markedly unsettled conditions south of the Andaman Sea due to the presence of a trough of low pressure. By the 5th evening a depression with its centre at Lat. $7\frac{1}{2}$°N, Long. 90°E had formed. The microseismic amplitudes at all the Indian stations showed no increase at all. As a matter of fact the amplitudes decreased somewhat upto the midnight of 5 December. The depression deepened by the 6th morning and by the afternoon had become a cyclonic storm centred at 1730 IST near Lat. 10°N, Long. 88°E. From about this time the microseismic amplitudes at all Indian stations began rising steeply except those at Hyderabad and New Delhi which began rising a little after midnight. The rise in the amplitudes at New Delhi became very steep from midday of 8 December when the storm was further intensifying. At 1730 IST on the 8th the storm was declared as a severe cyclonic storm centred near Lat. 13°N and Long. $87\frac{1}{2}$°E. At this time the storm also started changing its track from a westnorthwest direction to a northeasterly direction, and by the morning of 10 December was centred

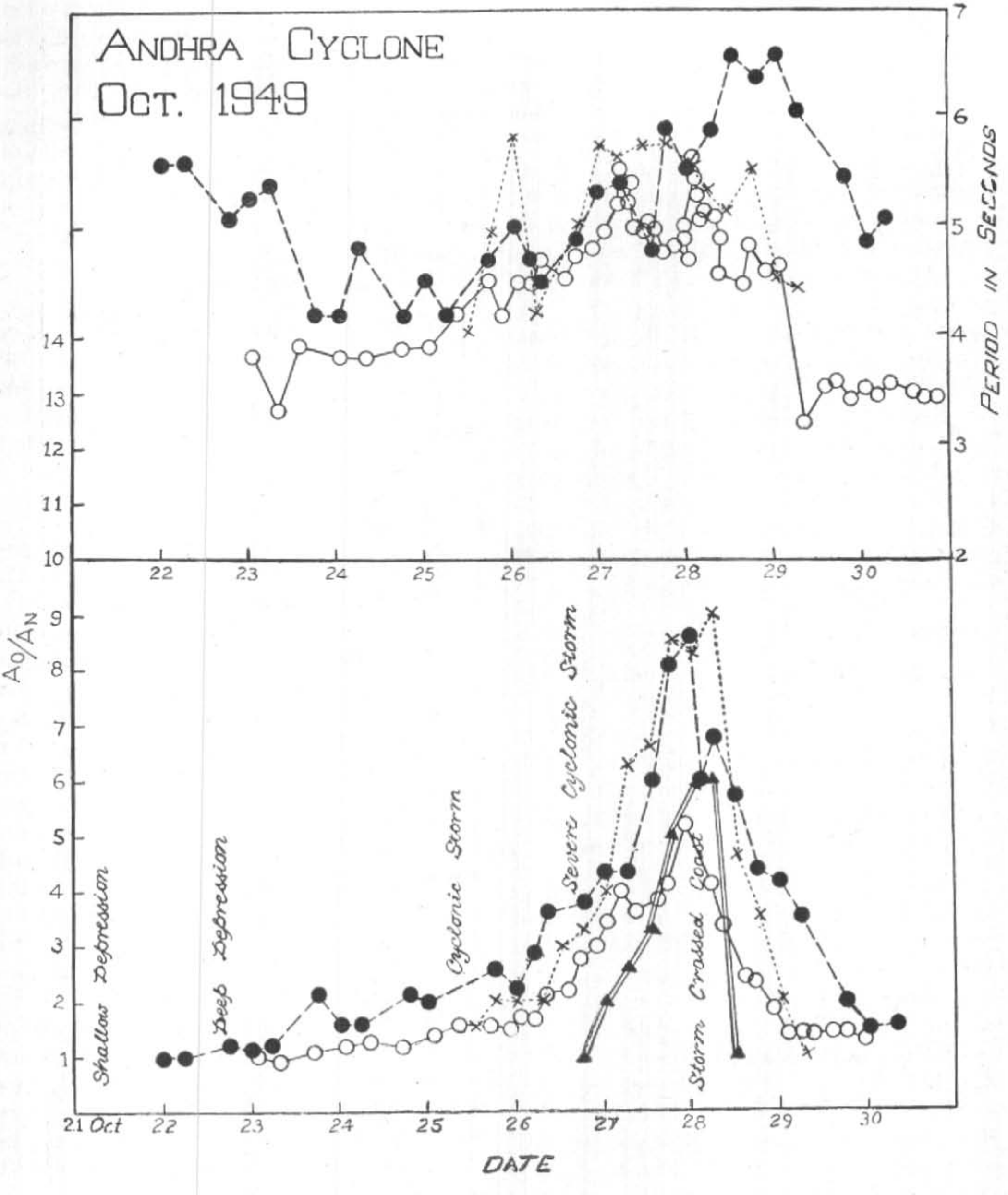
ANDHRA CYCLONE
OCT. 1949
PERIOD IN SECONDS
7
6
5
4
3
2
14
13
12
11
10
22
23
24
25
26
27
28
29
30
Ao/An
9
8
7
6
5
4
3
2
1
Shallow Depression
Deep Depression
Cyclonic Storm
Severe Cyclonic Storm
Storm Crossed Coast
21 Oct
22
23
24
25
26
27
28
29
30
DATE

Fig. 3

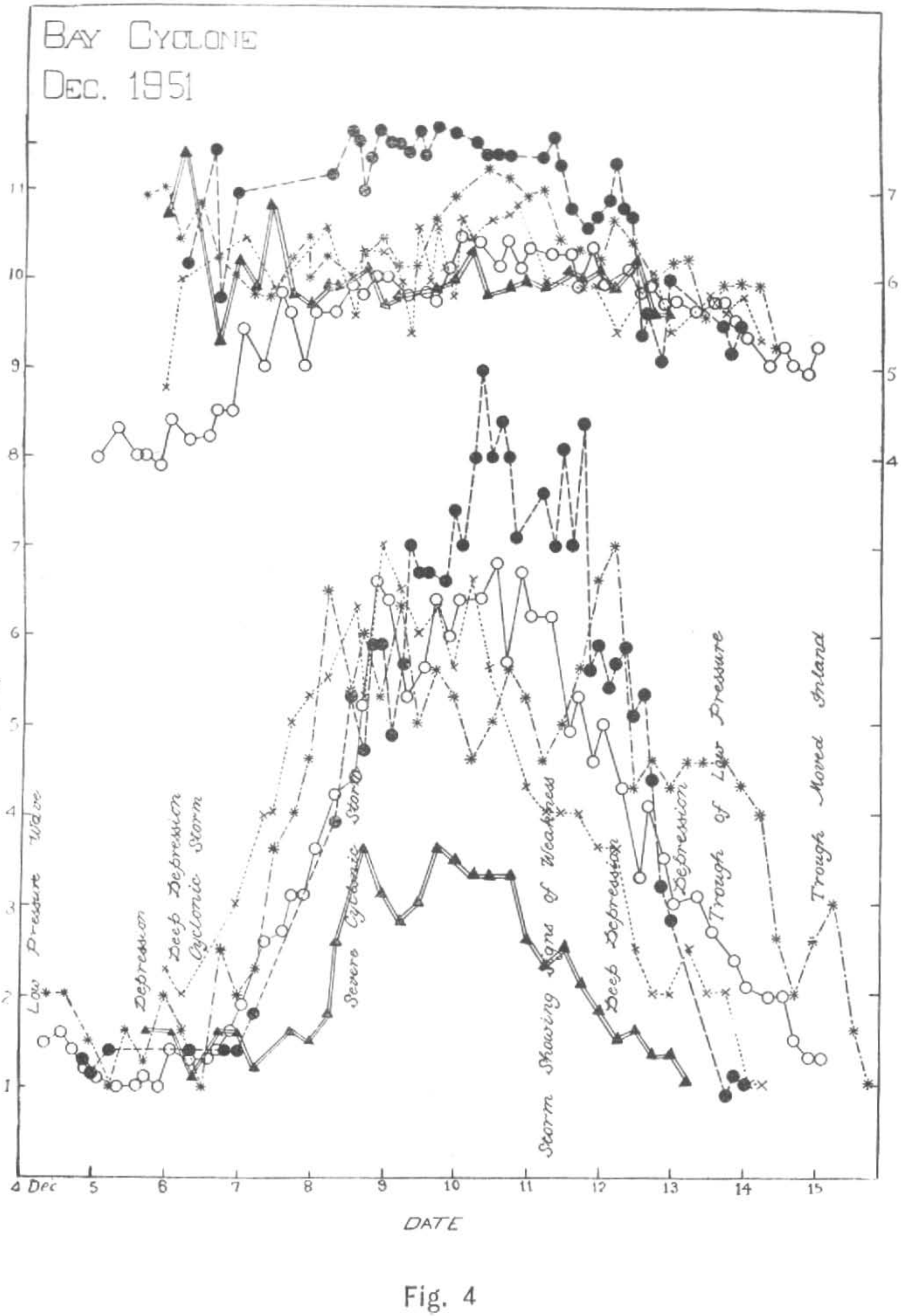
BAY CYCLONE
DEC. 1951
A_9/A_1
1
2
3
4
5
6
7
8
9
10
11
4
5
6
7
PERIOD IN SECONDS
4 Dec
5
6
7
8
9
10
11
12
13
14
15
DATE
Low Pressure Wave
Depression
Deep Depression
Cyclonic Storm
Severe Cyclonic Storm
Storm Showing Signs of Weakness
Deep Depression
Depression
Trough of Low Pressure
Trough Moved Inland

Fig. 4

near Lat. 17°N, Long. 88½°E. Ships' observations at this stage still indicated that the storm was severe and had a core of violent winds. The amplitudes of microseisms at nearly all the Indian stations reached maxima between the 8th morning and midnight, and thereafter became somewhat steady or declined a little until midday of the 9th when they started rising again. It is significant to note here that the storm during this time was recurving and was most probably weakening in this process which may account for the diminution in microseismic amplitudes. The microseismic amplitudes reached a second maximum between 9th evening and 10th evening and then began decreasing steadily at all the stations. According to the weather report for 11th morning, the storm was centred near Lat. 18½°N, Long. 89°E and was showing signs of weakening. The microseismic amplitudes reached another maximum at Calcutta on the 11th night, which could be attributed either to a temporary increase in the intensity of the storm or due to geological factors governing the transmission of microseismic waves between the storm centre and Calcutta. Kodaikanal also showed a rise in microseismic amplitudes from 11th midnight to 12th midnight which seems to be rather anomalous and difficult to account for. By the morning of 13 December, the storm had weakened into a depression centred near Lat. 20°N, Long. 90°E and the microseismic amplitudes at all the stations had decreased considerably, and returned to their normal value by the 14th morning.

The average periods of microseisms recorded during the storm are also plotted in Fig. 4. It is difficult to infer much from the curves drawn due to large uncertainties in the measurements, and their irregular nature. The curves, however, show in general that the periods rise along with the amplitudes, or with the intensity of the storm. The readings for Poona were taken from records of Sprengnether microseismograph with a large magnification and they clearly show this tendency. The average period for the peak of the storm for all the Indian stations would come out to be about 6½ sec. The average periods seem to have no correlation with the distance of the station from the storm. New Delhi which was the farthest from the storm during the peak of the storm has recorded the lowest periods while Calcutta which was the nearest has recorded the highest periods.

6 Conclusions

From curves shown in Figs. 2, 3 and 4 the following general results can be inferred—

(1) Shallow or even deep depressions when situated in water remote from the shore may not be able to generate microseisms of sufficient intensity which can be recorded at distant seismographs.

(2) When depressions intensify and reach the stage of cyclonic storms, they usually generate microseisms, which are recorded at all coastal and inland stations. This, however, is not true for all positions of the storm. While microseisms from storms situated anywhere in the west Bay of Bengal are generally recorded at the Indian stations, this does not seem to be the case with the Arabian Sea. This is clearly suggested by the failure of microseisms generated by the Bombay cyclone of November 1948 to be recorded between 1700 IST of 20 November and the morning of 21 November.

(3) The microseismic maxima for those storms which form at sea and eventually enter land seem to occur at the time when the storm is crossing the coast into land. The amplitudes then slowly return to normal. The time lag between the maxima and return to normalcy seems to depend upon the extent of the storm. For those storms which do not enter land as storms, the microseimic amplitudes seem to depend upon the intensity of the storm.

(4) The amplitudes of microseisms when recorded show a simultaneous rise at all coastal and inland stations the maximum amplitude being recorded at all the stations at nearly the same time.

(5) The ratio of observed to normal amplitude of microseisms for any storm seems to be much larger for stations where the seismographs are installed on an alluvium foundation. Thus Calcutta records considerable larger amplitude ratios than the other stations. Even for the Bombay cyclone of November 1948 the amplitude ratio at Calcutta was nearly 3 times that at Poona where the seismograph pillars have a foundation on solid rock.

(6) Predominant microseismic periods recorded for any storm seem to be dependent on the type of instrument used for recording besides other factors.

(7) The periods do not appear to show any relationship with the distance of the storm centre from the recording station.

(8) There seems to be a general tendency for the periods to rise and fall with amplitudes. In the case of the Bombay cyclone of November 1948, however, the periods recorded at Calcutta actually show a decrease with rising amplitude.

REFERENCES

Banerji, S. K.	1930	*Phil. Trans.*, A., **229**, p. 287.
Dinger, J.E. and Fisher, G. H.	1955	*Trans. Amer. geophys. Un.*, **36**, p. 262.
Donn, William L.	1951	*J. Met.*, **9**, p. 61.
Donn, Willian L. and Blaik, Maurice	1952	*Tech. Rep. Seism.*, 19, Lamont Geological Laboratory, Palisades N. Y.
Gilmore, M. H.	1946	*Bull. seismol. Soc. Amer.*, **36**, p. 89.
	1948	*Ibid.* **38**, p. 195.
	1951	*Bull. Amer. Met. Soc.*, **32**, p. 346.
Gutenberg, B.	1936	*Bull. seismol. Soc. Amer.*, **26**, p. 111.
	1947	*J. Met.*, **4**, 1, p. 21.
	1953	*Trans. Amer. geophys. Un.*, **34**, p. 161.
Kammer, E. W. and Dinger, J. E.	1951	*J. met.*, **8**, p. 347.
Longuet-Higgins, M. S. and Ursell, F.	1948	*Nature*, **162**, p. 700.
Pramanik, S. K., Sen Gupta, P. K. and Chakravortty, K. C.	1948	*India met. Dep. Sci. Notes*, **10**, 120.
Ramirez, J. E.	1940	*Bull. seismol. Soc. Amer.*, **30**, p. 139.