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Microseismic evidence for the existence of cold fronts in association with the Nor'westers

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ABSTRACT. Group or storm type microseisms were recorded during the passage of Nor'westers over the head Bay of Bengal. These microseisms are of frontal type and in the present paper they have been ascribed to cold fronts associated with the Nor'westers. No direct methods based on meteorological observations could be successfully used to prove the existence of the cold fronts associated with Nor'westers during pre-monsoon season. It is considered that records of microseisms furnish indirect evidence about the existence of the cold fronts in Nor'westers.

1. Introduction

The thundersqualls which occur in north-east India and Pakistan during the premonsoon months are commonly known as *Kalbaisakhi* because of their violence and the destruction they cause. This phenomenon has been the subject of study of the meteorological workers in India from very early times—Sen 1931, Das 1949, Roy 1949, Malurkar 1949 and others—who have dealt with the various aspects of the phenomenon. There is some difference of opinion amongst them in one respect, *viz.*, about the existence of cold fronts in nor'westers. According to some authors, nor'westers are single air mass thunderstorms while according to others nor'wester thunderstorms are associated with cold fronts moving with the passage of extra-tropical disturbances. It is well known that the frontal characteristics are not often properly manifested in the tropics, the front being rather diffuse or uncertain in the average picture of the wind and pressure distribution during the passage of secondary low pressure waves. It is not always possible to locate fronts on synoptic charts, and it becomes difficult to draw definite conclusions about the existence of fronts from a study of synoptic situations alone. The intention of the present author is to prove the existence of cold fronts in nor'wester thunderstorms from the evidence of the existence of the group or stormtype microseisms recorded by the Milne-Shaw Seismographs in operation at Alipore, Calcutta with the passage of nor'westers over the head Bay of Bengal.

2. Microseisms and weather

With the discovery of sensitive seismographs, seismologists have been able to know about the existence of small ground movements called microseisms. It was noticed by many workers beginning with Bertelli that there exists some connection between microseisms and general meteorological conditions. The exact mechanism of generation of microseisms and meteorological conditions is not yet known. Many theories have been advanced by workers all over the world (Banerji 1930, Gutenberg 1936, Longuett-Higgins 1950). Two types of microseisms are usually observed in association with the disturbed seas. Widespread monsoon winds produce irregular type microseisms, whereas those generated by restricted cyclones show a group pattern. According to Banerji (1950) the group microseisms are produced in some manner near the storm centres at sea and are propagated through the earth's crust to the continents. The storm or group type microseisms have periods ordinarily ranging from 3 to 6 seconds but their amplitudes show very characteristic irregular vibrations with periodic waxing and waning, suggesting superimposition of waves of different periods. These microseisms are generally recorded when there is a well-marked depression or cyclonic storm in the neighbouring sea. Pramanik *et al.* (1948) found that microseisms give reliable information about disturbed weather at sea and that some times they appeared much before the swell or strong wind reached the coast. Recently, Tandon (1957) has summarised the present state of our knowledge of microseisms in his paper on 'Microseisms from storms in the Indian seas'. The fact that group or storm microseisms are generally recorded when a cyclonic storm or cold front is out in the sea led Gilmore (1946) and others to develop methods for location of storm centres with the help of microseismic data. The purpose in these methods led to the tripartite method of locating storm centres, and to the micro-ratio technique of tracking storms. The latter is more reliable as the bearings of storm centres obtained from tripartite method are liable to be affected due to refraction and reflection at local geological discontinuities.

The author (Saha 1951) pointed out the existence of group pattern microseisms recorded during the passage of low pressure waves over the head Bay of Bengal. Because of the diffuse nature of fronts in the tropics as already stated, it was not possible for the present writer to attribute them to the cold fronts associated with the low pressure waves mentioned in the above communication. Gilmore (1948) and Donn (1950, 1952) independently observed group microseisms and attributed them to the passage of cold fronts over waters. According to these authors frontal microseisms are generated whenever any cold front passes seaward from land and while the front is over relatively soal and restricted waters. Donn concluded from his observations on frontal microseisms that surface wind or swell are of little importance in the production of frontal microseisms. Gilmore observed that large microseism storms are recorded whenever a cold front is over water with a wind velocity of 30 knots behind the front, while warm front with wind velocity as high as 50 knots seldom cause microseisms. The above observations on frontal microseisms made by Donn and Gilmore led the present writer to correlate the reported microseisms with the cold front associated with nor'westers of Bengal. Recently Chakrabarty and Sarkar (1958) also have pointed out that prominent microseisms appear for a few hours associated with the passage of nor'westers from land into the sea.

3. Synoptic situations favourable for the occurrence of nor'westers

It may not be out of place here to describe the general synoptic situation which prevails during the nor'wester season. During these months moist air from the Bay of Bengal, having a high degree of latent instability is generally present at lower levels (5000 ft) of the atmosphere. According to Malurkar (1949) the nor'wester days have to be explained on the basis of the movement of secondary low pressure areas induced by the extratropical depressions of middle latitudes known in the Indian meteorological literature as 'Western Disturbances'. These secondary low pressure areas move from west to east and there is a sort of regeneration or intensification of these lows by the injection of moist air at lower levels from the Bay of Bengal when they cross longitude 85°E. Some workers believe that these secondary low pressure waves are associated with diffuse cold fronts and the thunderstorms or thundersqualls in nor'westers are of frontal type while others believe that these are purely heat thunderstorms of single air mass type. Malurkar has tried to show from meteorological considerations that the nor'wester squalls are of the frontal type. These secondary low pressure waves which happen to pass out into the Bay of Bengal are according to the present writer responsible for the generation of frontal type of microseism (Saha 1951).

4. General description, characteristics and nature of the microseismic records

The microseisms reported here have the same group pattern as observed in those associated with cold fronts and cyclonic storms out into the sea. But on account of restricted water surface, there are some differences in characteristics so far as their development and duration on life are concerned. The maximum phase of the microseismic storm recorded in association with the cyclonic storms is recorded after several days while in this case the maximum phase is recorded in course of several hours. In the case of cyclonic storms the life or duration of the associated microseismic storms is several days while the life or duration of the microseismic storms associated with nor'westers is only several hours. The short life or duration is partly due to the rapid movement of the secondary lows and partly due to the limited available water surface at the head of the Bay of Bengal. The life of the cold fronts over water surface in the case of nor'westers becomes very much less as they again enter land surface immediately after crossing the head Bay of Bengal. These types of microseismic storms are recorded during the pre-monsoon months when according to meteorological studies, the secondary low pressure waves move from west to east at fairly low latitudes. During winter months, the secondary low pressure waves move along the foot hills of the Himalayas at fairly high latitudes and consequently the path is entirely of land origin. Only during the pre-monsoon months these secondary low pressure waves move along the low latitudes so that their paths are partly oceanic and can cause group microseisms of the type under study.

5. Scope and purpose of the present study

The intention of the present study is not to give an idea about the physical mechanism of generation of microseisms observed in association with the cyclonic storms or cold fronts. It has already been stated before that cold fronts passing from land to sea can cause frontal microseismic storms. This phenomenon is also in accordance with the observations of Bath (1949, 1950) that the passage of a cold front over Upsala Observatory does not produce any microseism although its passage over the Norwegian coast is accompanied by sharp increase of microseismic amplitudes. Chakrabarty and Sarkar (1958) have also pointed that microseisms do not appear in the records until the centre of generation is over water. The presence of such group microseisms on records could, therefore, be used to infer about the passage of cold fronts over water surface particularly when there is no cyclonic storm in the neighbouring waters. The group microseisms reported here were recorded when there was no cyclonic storm in the neighbouring sea. But in all the cases nor'westers or thundersqualls had preceded the appearance of the microseismic storms.

The microseismic record reproduced in this paper are from the Milne-Shaw seismograph in operation at the Alipore Observatory. The constants of the instrument are given below—

To=Free period of the pendulum=12 s

Vs = Magnification = 250 component E–W

Damping ratio 20 : 1

The weather chart and the extracts taken from weather reports are from the *Indian Daily Weather Reports* as published by the India Meteorological Department. The purpose of the present study is to show the existence of cold fronts from the evidence of group microseism recorded during the passage of secondary low pressure waves across the head Bay of Bengal. It could not however be concluded from the above study that (*i*) each and every nor'wester is associated with a cold front, and (*ii*) that cold fronts associated with nor'westers do not, in all cases, pass out into the sea and can cause frontal microseisms, but it could be definitely said that some of the secondary low pressure waves which cause nor'westers inland and later pass out into the sea, are associated

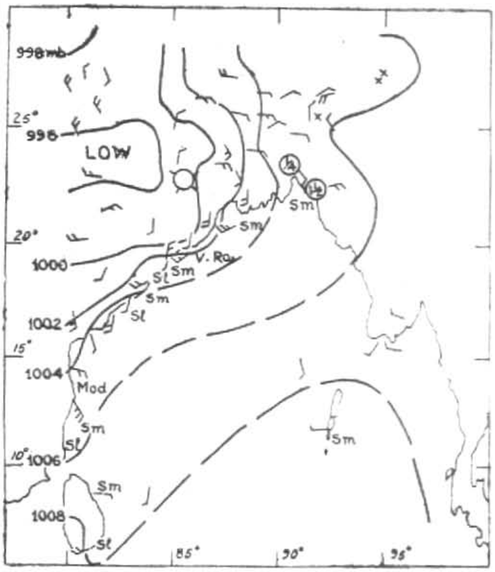

Fig. 1(a). Weather map of 25 April 1948 at 1130 GMT

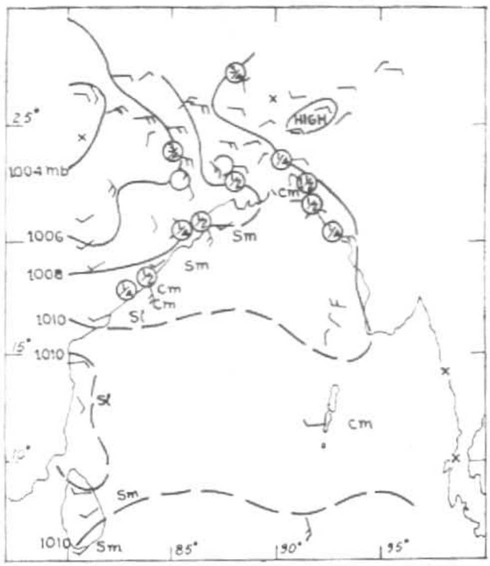

Fig. 1(b). Weather map of 26 April 1948 at 0230 GMT

with cold fronts or in other words some nor'wester thunderstorms or thundersqualls are of frontal origin, although the associated front is not manifested properly to be identified from meteorological considerations. It is possible that we may have nor'westers without any associated cold front. This is also in accordance with the findings of Chakrabarty and Sarkar (1958) who observed that at times Saugor and one or two coastal observatories have recorded nor'westers of intensity similar to those analysed by them but with no recording of microseisms. The absence of group microseisms in the cases cited by them is not due to the assumption by the authors that the core of maximum turbulence did not travel far enough from the coast and thus did not produce microseisms. It does not appear probable that these disturbances die out before reaching the optimum depth mentioned by the authors. The growth or decay of a meteorological phenomenon depends entirely on its environmental conditions. The present writer thinks that the type of nor'westers which could not produce microseisms were of the so-called single air mass type without any cold front associated with them. The fact that heat or single air mass thunderstorms cannot generate microseismic storms suggests that the unstable conditions and turbulence in the cold air mass at the front have something to do with the mechanism of generation of microseisms.

6. Discussion

The present writer while working at the Alipore Observatory had many occasions to witness the appearance of frontal microseisms on Milne-Shaw records. No useful purpose will be served by exhibiting all such observations. A few typical cases along with the synoptic situations are given below.

CASE 1: 25-26 April 1948—It will be seen from the weather maps in Figs. 1 (a) and 1 (b) that there was no cyclonic storm or deep depression in the Bay of Bengal. The weather was perfectly seasonal over the sea area.

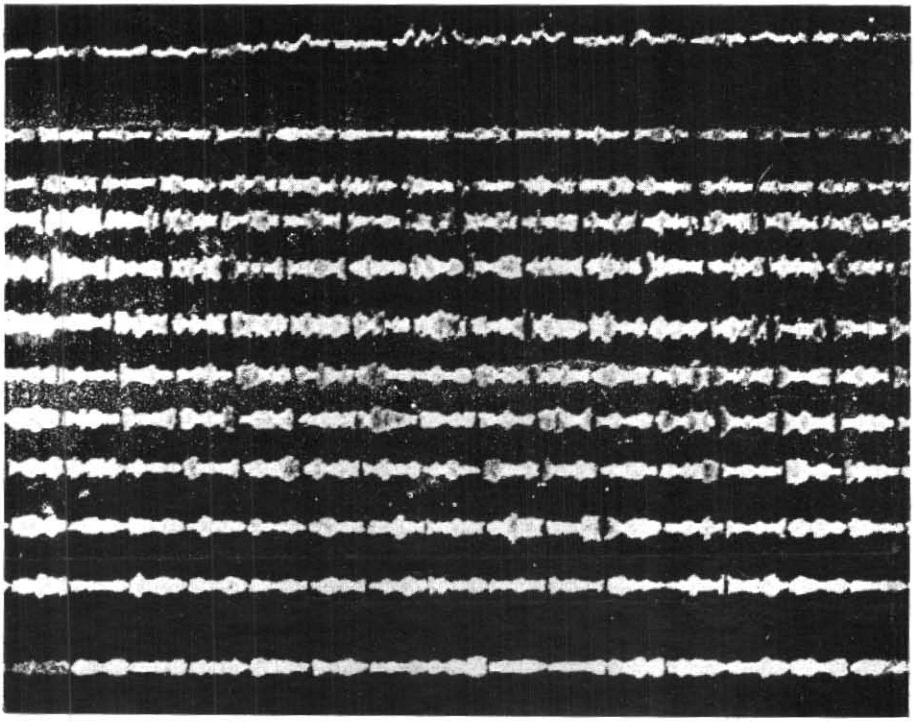

Fig. 2. Microseismic record of 25-26 April 1948

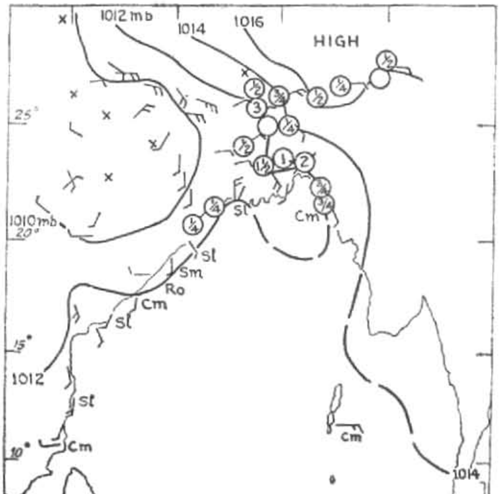

Fig. 3. Weather map of 31 March 1946 at 0230 GMT

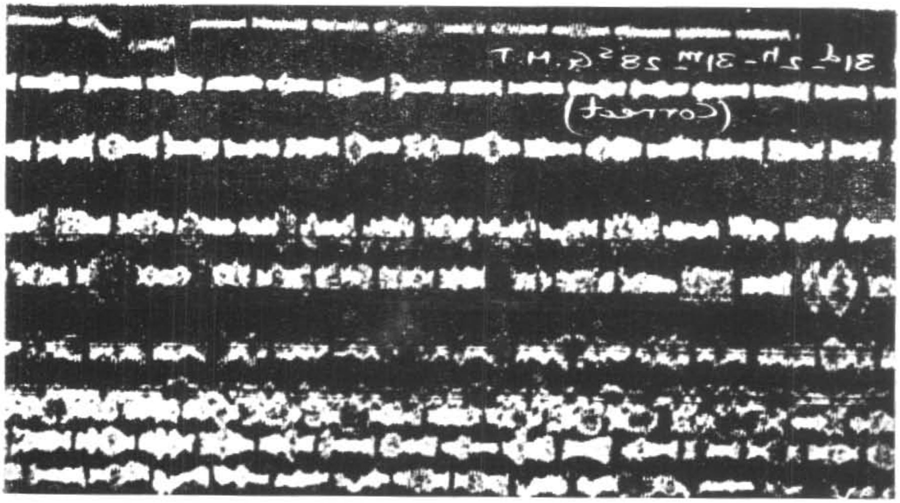

Fig. 4. Microseismic record of 31 March—1 April 1946

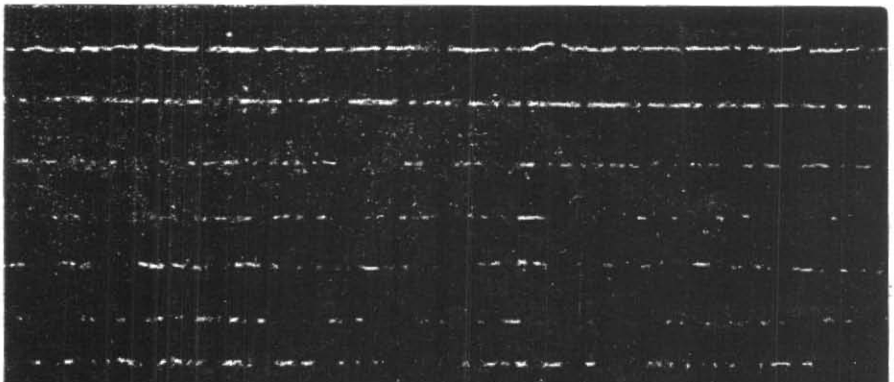

Fig. 5. Microseismic record of 6 January 1945

The summary of observations recorded at 0230 GMT of 26 April 1948 is given below. "The thunderstorms have been widespread in Orissa, local in Eastern Pakistan and Chota Nagpur".

These thunderstorms and thundersqualls occurred in the afternoon/evening of 25 April 1948.

The group or storm microseism commenced appearing at about 1500 GMT on 25 April 1948 and continued till 0200 GMT of the following day reaching maximum near midnight (1900 GMT) and indicating that the cold front associated with the secondary low pressure waves was over the sea surface during the above period. The diffuse cold front associated with the secondary low pressure waves was responsible for widespread and local thunderstorms mentioned above while it was over the land area. With the progress of time the disturbance moved out into the sea and caused the microseismic storm shown in Fig. 2. It is not possible to attribute these microseisms to some distant cyclonic storms as it is seen that there was no cyclonic storm or deep depression over the Bay of Bengal.

CASE 2: 31 March–1 April 1946—From the weather map of 31 March 1946, it will be seen that there was no cyclonic storm or deep depression in the Bay of Bengal. The weather was perfectly seasonal over the sea area.

The summary of observations recorded at 0230 GMT of 31 March 1946 is quoted below.

"The thunder rain has been widespread in Assam, Bengal and Orissa".

In this case the microseisms commenced appearing at 0200 GMT on 31 March 1946 and reached maximum at 0700 GMT becoming normal by 1800 GMT. On most of the occasions the nor'wester thundersqualls or thunderstorms occurred in the afternoon/evening on land and hence the passage of the front over the sea surface was between 1200 GMT and 0230 GMT synoptic observations. No synoptic observations are normally available during the period the front was over the sea surface. In this particular occasion the front was over the sea at a time when synoptic observations were available. Although the observations are very scanty at the head of the Bay of Bengal, some peculiarity is noticeable from the loop pattern in the isobar indicated in the above weather map (Fig.3). Had there been a good network of observations over the head Bay of Bengal it might have been possible to locate the diffuse cold front giving rise to the frontal microseism recorded in Fig. 4.

The author likes to conclude his discussion by giving another example of frontal microseism. Normally the microseisms recorded after the passage of the nor'westers have a very short life for reasons already pointed out. On one occasion however, the microseism continued for several days. This was during a winter month just before the so-called nor'wester season. During winter months, the secondary western disturbances move at higher latitudes and accordingly they have little chance to come over the sea surface. On one occasion, however, during January 1945 a secondary western disturbance moving at low latitudes slipped into the Bay of Bengal off the Circars coast and gave rise to a depression which according to Indian meteorological literature means well developed low pressure area. The microseismic storm recorded in association with it is reproduced in Fig. 5. It has been observed by Tandon (1957) that shallow or even deep depressions could not generate microseisms of sufficient intensity to be recorded at distant seismographs. The present author has also observed that the frequent depressions formed at the head Bay of Bengal during the southwest monsoon season fail to generate microseisms which would be recorded by the Milne-Shaw seismographs at Alipore. The cause why the depression under reference could give rise to microseisms is probably the existence of a cold front associated with the secondary western disturbance. The absence of microseisms in association with the depressions during southwest monsoon months probably indicates the absence of cold fronts in monsoon depressions.

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REFERENCES

Banerji, S. K.	1930	*Phil. Trans. roy. Soc. London*, A, **229**, p. 287.
Bath, M.	1949	*Meddelande meteor. Inst. vid. Kungl. Univ. Uppsala*, 14, pp. 168.
	1950	*Ark. Geofys.*, **1**, 267-68, 359-393.
Chakrabarty, S. K. and Sarkar, D.	1958	*Bull. seism. Soc. Amer.*, **48**, p. 181.
Das, A. K.	1949	*Beitr. Geophys.*, **39**, p. 144.
Donn, W. L.	1952	*J. Met.*, **9**, p. 61.
	1950	*Ibid.*, **8**, 6.
Gilmore, M. H.	1946	*Bull. seism. Soc. Amer.*, **36**, p. 89.
	1948	*Ibid.*, **38**, p. 195.
Gutenberg, B.	1936	*Ibid.*, **26**, p. 111.
	1947	*J. Met.*, **4**, p. 21.
	1953	*Trans. Amer. geophys. Un.*, **34**, p. 161.
Longuett-Higgins, M. S.	1950	*Phil. Trans. roy. Soc., London*, A, **257**, p. 1.
Malurkar, S. L.	1949	*Proc. nat. Inst. Sci. India*, **15**, p. 161.
Pramanik, S. K., Sen Gupta, P. K. and Chakravortty, K. C.	1948	*India met. Dep. Sci. Notes*, **10**, 120.
Roy, A. K.	1949	*Proc. nat. Inst. Sci. India*, **15**, pp. 289-300.
Saha, B. P.	1951	*Indian J. Met. Geophys.*, **2**, p. 78.
Sen, S. N.	1931	*Nature*, pp. 128-129.
Tandon, A. N.	1957	*Indian J. Met. Geophys.*, **8**, p. 33