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A preliminary note on Short Period Microseisms recorded by Benioff Seismograph at Shillong

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ABSTRACT. It is observed that short period group microseisms of period very close to one second occur in the records of the short period vertical component Benioff Seismograph at Shillong on some occasions. It was observed by Walsh (1956) that great majority of the short period microseisms of period very near to 0·3 second are associated either with the approach or passage at the station of cold frontal type discontinuity or both or with local non-frontal convective activity. The occurrence of microseism-storms under study indicates that these are not associated with each and every convective activity at the station. It is, however, believed that they are associated with the passage of cold fronts in association with the secondaries of the western disturbances which move from west to east during the premonsoon months. The probable mechanism of generation of these microseisms is discussed.

1. Introduction

With the discovery of fairly sensitive seismographs, seismologists could know about the existence of small ground vibrations called microseisms. These are continuous but minute vibrations of the ground. Considerable studies have been made for microseisms whose periods are from about 3 to 10 seconds and the sources of the microseisms are associated with ocean and other large bodies of water. Banerji (1930), Gutenberg (1936, 1947, 1953) and Longuet Higgins (1950) have proposed different theories to explain the generation of microseisms from considerations of wave and surf interaction to the bottom of the sea. It is believed by the workers in the field of study of this type of microseisms, that they are generated when a cold front or cyclonic storm is over the sea surface. The type of short period microseisms under the present study was not reported and investigated in great detail. It was Walsh (1956)who first pointed out the existence of this type of microseisms of period 0·3 to 0·4 second. The present writer observed similar microseisms with slightly different period characteristics, *viz.*, the predominant period of one second, recorded by short period Benioff Seismograph. It is, however, remarkable that meteorological disturbances over the land surface also could generate microseisms having periods shorter than those observed during the passage of cold fronts and cyclones over the nearby ocean or large bodies of water. It is, however, seen that these short period microseisms are recorded when the local weather condition is appreciably disturbed.

The short period Benioff Vertical Seismograph ($T_o = 1^s \cdot 0$, $T_g = 0^s \cdot 18$) was installed at the close of the year 1953. It was noticed since its installation that short period microseisms are recorded on some occasions. With a view to examine its correlation with the local weather conditions,a meteorological observatory was set up in the compound of the observatory and the same is operating since 1957. It has, however, not been possible to install a short period micro-barograph to record short period atmospheric oscillations as observed by Walsh. The construction of the barograph is being taken up and a detailed report will be published when sufficient comparative observations become available. It is, however, intended that a preliminary report incorporating local weather conditions along with their associated synoptic situation may not be out of place. Although seismographic records are available from November 1953 but detailed local weather observations are available only from January 1957. Accordingly it is possible to make a comparative study for the period from January 1957 to July 1960 only. As regards the observations of short period microseisms it has already been pointed out by Walsh that similar microseisms are recorded rather regularly at many stations particularly those employing short period Benioff Seismometers and it has also been mentioned in the Progress Report, Seismological Laboratory, California Institute of Technology, 1954 that a recorder for magnetic field fluctuations was designed with a view to investigate possible relations between the magnetic field variation, and the occurrence of short period microseisms, in the range 0·5 to 2·0 second periods which are frequently associated with rain.

The present study of the microseisms in the period near about one second was taken up with a view to examine whether the weather correlations found by Walsh hold good in this type of microseisms also. It is, however, observed that the frequency of occurrence of convective activity over the station is very high as compared with the frequency of occurrence of short period microseisms. The usual types of microseismic storms of the period range 3 to 8 seconds are always associated with the passage of cold fronts or cyclonic storms over ocean, and other large bodies of water. These short period microseisms are not in any way related to the local wind effects on the neighbouring hills or with the passage of meteorological disturbance over ocean area or any vast mass of water. The gusty wind in Shillong had no effect on the Benioff Seismometer. Accordingly the atmospheric pressure oscillations observed by Walsh in association with the occurrence of short period microseisms are transmitted to the ground by some coupling mechanism and result in this type of microseism-storm.

2. Scope of the study

These short period microseisms are recorded mostly during the premonsoon months (March-May) and monsoon months (June-September) and they are practically absent during the period from October to February. For the study of this type of micro-oscillation, the undisturbed background of the short period Benioff records at Shillong proves to be very satisfactory and useful. The background is disturbed only for a few hours in the day on account of local traffic disturbances. These disturbances could, however, be clearly distinguished from the typical micro-oscillations under study.

It is generally observed that the occurrence of short period microseismic storm is associated with local rain and thunderstorms but it is also observed that these are conspicuously absent during some occasion when the station experiences apparently similar local weather conditions. Accordingly it is necessary to examine critically the synoptic situations to correlate their occurrence. The author is not, however, very hopeful how far this will be possible from available main synoptic charts at 0300 and 1200 GMT. The phenomena probably depend either on the micro-meteorological conditions which is very difficult to estimate from the all India synoptic charts available for study or depend on the passage of diffuse cold fronts in association with the secondary western disturbances to be discussed later.

3. Description of the recorded microseisms

During the premonsoon months the recorded microseisms appear as a fine pattern of regular waves displaying a pronounced group or beat effect with characteristic period close to one second and with usually small amplitudes which at times rise to two millimetres. In most occasions the amplitude gradually increases and reaches a maximum value at the middle of the train and then decreases gradually. The duration of these microseisms varies from one hour to several hours, on some occasions they appear in two or three spells separated by intervals of one to several hours.

During the monsoon season on many occasions there is a continuous background of microseisms of smaller amplitude and at times these are intensified. It will, however, be noticed that the short period oscillations shorter than the waves of one second period are superimposed on the group microseism of one second period. On other occasions, microseisms of one second period commence,

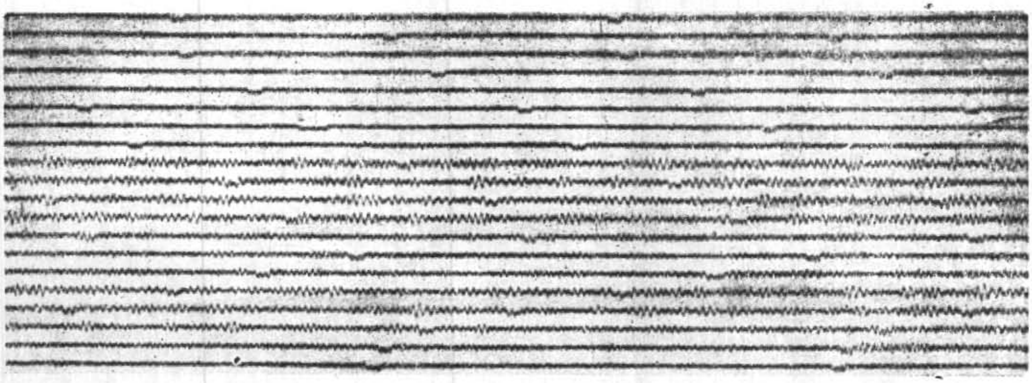

Fig. 1. Section of Shillong Vertical short period record, 11-12 April 1959

(Time scale 60 mm per min. The time interval between corresponding points on consecutive line is 15 min.)

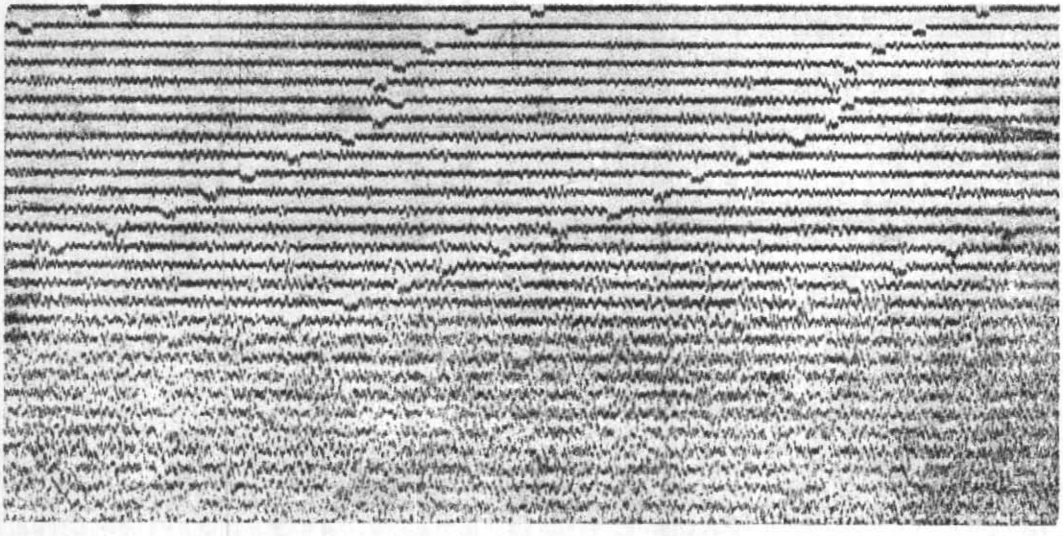

Fig. 2. Section of Shillong Vertical short period record, 17-18 July 1960

on a quiet background and during the maximum phase of the microseism-storm there is a superimposition of smaller period oscillations. In these type, the maximum amplitude and the duration of the microseism storm is much greater than those recorded during the premonsoon months, the maximum amplitude reaches about 3 to 4 millimetres. The trace amplitude has been expressed in millimetre as no calibration curve is available for the Benioff Seismograph at Shillong. Typical examples of these two types are reproduced in Figs. 1 and 2. In this paper the study will be confined to the most regular group microseisms and the continuous background microseism will not be taken into consideration.

It may be mentioned here that one horizontal component (E-W) Sprengnether microseismograph ($T_o = 6^s \cdot 8$, $T_g = 6^s \cdot 8$, both seismometer and galvanometer critically damped) was in operation at the station during the period. Four to eight second period microseisms are recorded by the instrument when there is a cyclonic storm in the Bay of Bengal. But it is most significant to observe that the background of the microseismogram is almost quiet when the short period microseisms are recorded both during the monsoon and premonsoon months. The four to eight second period microseisms are most active during the post monsoon season when the cyclonic storms are formed in the Bay of Bengal. When these microseisms are recorded well in Sprengnether microseismograph, these are also recorded with diminished amplitude in the short period Benioff instrument but no short period microseisms are recorded at that time.

The short period (period close to 0·3 seconds) microseisms reported by Walsh were recorded by the Wood-Anderson (short period) seismographs at Florissant and St. Louis. Although one double horizontal component Wood-Anderson seismograph ($T_o = 0^s \cdot 8$ peak magnification 1000) was in operation during the period but the short period microseisms were not, however, recorded by the instrument probably because the dynamic magnification for the waves of one second period is only about 500 which is probably too low for this type of micro-oscillations to be recorded. Walsh did not however, mention the magnification of the Wood-Anderson Seismographs in use there.

4. Meteorological study

The examination of synoptic maps on occasions of microseismic disturbances atonce reveals that the short period microseisms appear more or less unrelated to broad synoptic situations. But one thing is very clear that they are associated with some thunderstorm or rain-storm over the station near about the time of occurrence of microseismic storms. Walsh has pointed out that the synoptic situation which is best related to microseismic storms is that of the approach or passage of a surface cold front or both, a cold front aloft, a squall line, or a trough. This association is in good agreement with the findings of Roschke (1952) for short period micro-oscillations, with which these microseism, are correlated in that a cold frontal passage........ 'is characterised by a significantly large percentage of the (atmospheric) micro-oscillations of maximum amplitude and a rather small percentage of the total quietude'. It will be seen from Table 1 that the number of convective activity, *viz.*, development of cumulonimbus clouds and thunderstorms during the monsoon and premonsoon months far exceeds the number of occasions, when microseismic storms were recorded. Of course, during the premonsoon season the convective activities could be easily singled out whereas in the monsoon it is extremely difficult to single them out.

TABLE 1

Month (1)	Total No. of cases of development of *Cb* cloud lightning (2)	Total No. of occasions of spells of thunderstorm (3)	Total of (2) and (3) (4)	No. of occasions of microseismic storm (5)
Jan	2	2	4	Nil
Feb	8	7	15	Nil
Mar	19	19	38	1
Apr	38	30	68	6
May	38	49	87	30
Jun	19	42	61	20
Jul	22	31	53	10
Aug	28	18	46	6
Sep	36	26	62	6
Oct	25	15	40	2
Nov	9	0	9	0
Dec	0	0	0	0

As regards Table 1, it may be mentioned that the cloud observations are available only during the two main synoptic hours, *viz.*, 0300 and 1200 GMT whereas the significant weather like thunderstorm, lightning, rain etc are recorded throughout 24 hours. In calculating the number of occasions of convective activity, one spell of activity lasting for a considerable period has been taken as one occasion. For instance, if there was development of cumulonimbus cloud in the afternoon which gave rise to lightning before midnight and subsequently resulted in thunderstorm over the station which lasted till the forenoon of the following day, the

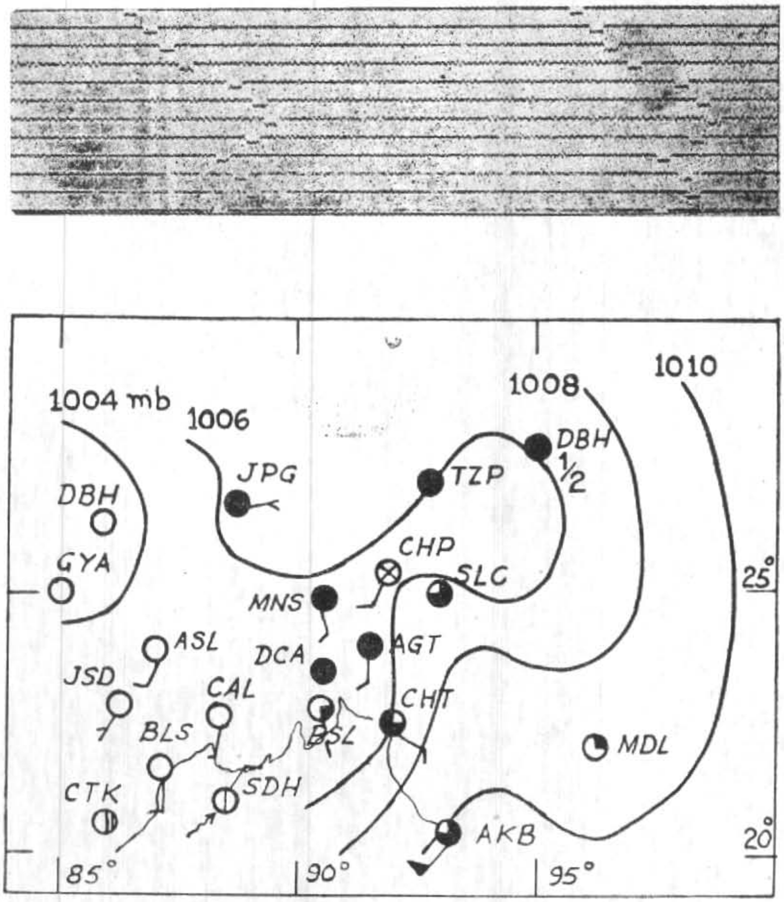

Fig. 3. Section of Shillong Vertical short period record, 5 May 1957 (morning) and synoptic situation on 5 May 1957

whole sequence of convective activity has been taken as one occasion of thunderstorm. Similarly the microseismic storms recorded in spell, separated by a few hours have been considered as one occasion.

Case histories

During the month of May 1957 it was observed that microseismic storms were recorded consecutively on 4th, 5th and 6th at different hours of the day. Accordingly the records of microseisms and the synoptic surface charts (from the Indian Daily Weather Report) at 0300 GMT of 5th and 6th are reproduced in Figs. 3 and 4. The following extracts from the above report are given below as these appear quite interesting from the standpoint of the present study.

5 May 1957—"The trough over Chotanagpur and Gangetic West Bengal has apparently become less marked after sending out *wave which is moving across Assam*".

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The day temperatures were appreciably to markedly below normal in Assam.

6 May 1957—"In association with a well marked trough over the region extending from east Uttar Pradesh to Gangetic West

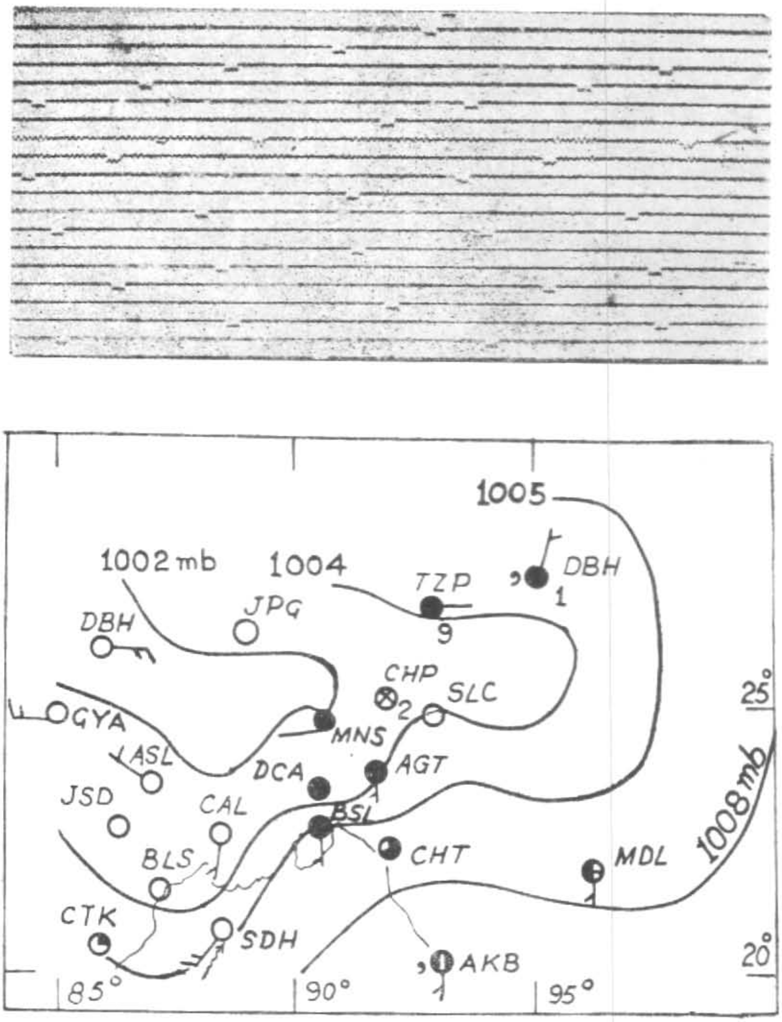

Fig. 4. Section of Shillong Vertical short period record, 6 May 1957 (morning) and synoptic situation on 6 May 1957

Bengal and yesterday's low pressure wave which is moving across east Assam, a pronounced incursion of moisture is taking place into Assam across East Pakistan.

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Day temperatures are below normal in Upper Assam".

From the above it is clear that the days of microseismic storms are characterised by the passage of low pressure waves which move from west to east during the premonsoon months. The diffuse cold front in association with the low pressure waves is believed by the author to be the generating cause of the microseisms. Of course on many occasions, the passage of the low pressure waves is likely to go undetected in the routine weather analysis but they are sure to leave an impression on the seismograph being recorded as microseisms. The peculiar loop pattern in the isobaric chart over Assam and neighbourhood is the most common feature of the synoptic situation when short period microseisms are recorded by the Benioff Seismograph at Shillong.

5. Diurnal and seasonal variation

It has already been mentioned that these microseisms occur only during the premonsoon and monsoon months and they are mostly absent during the period from October to February. It was observed by Walsh that the microseisms reported by him have peak frequency near about mid-day when the local solar heating was maximum. The microseisms under study do not, however, indicate any such peak frequency at any specified time of the day. This probably goes to suggest that the local convection due to solar heating does not probably play any important role in the generation of this type of microseisms. They may have something to do with the passage of cold fronts during the premonsoon months or with the upper air discontinuities during the monsoon season.

From the above observations it is clear that microseismic storms are not generated during each and every convective phenomena and there must be some difference between the convective phenomena associated with the microseismic storms and those without any appreciable effect on the seismographs. The matter will be further discussed later in the light of the earlier conclusions of the author (1960) in his study on the microseisms generated during the passage of Nor'westers over the head Bay of Bengal.

The limitations of the meteorological information must be considered. It is known that the frontal characteristics are not properly magnifested in the tropics, or in other words the front is rather diffuse or uncertain in the average picture of the wind and pressure distribution during the passage of secondary low pressure waves. Accordingly the fronts could not be located in the synoptic charts under these limitations, and it does not seem entirely unreasonable to assume that the passages of cold fronts may go undetected by analysis of weather data and yet show its effects on the seismograph or short period microbarograph.

6. Discussion and Conclusion

It has already been pointed out by Walsh that since these short period microseisms are apparently recorded by instruments of such divergent construction and instrumental constants as short period Benioffs, Wood-Andersons, Sprengnethers, and instruments of individual design at many widely scattered stations, it appears that the recorded oscillations are not due to mere instrumental difficulties. Moreover, the dissimilarities in period, wave form and group form between the ordinarily recorded microseisms and atmospheric micro-oscillation indicate that these disturbances correlated in time are not atmospheric micro-oscillations recorded on seismographs or microseism on micro-barographs. The fact that these are recorded by horizontal component Wood-Anderson seismographs goes to show that the micro-variations of the earths' magnetic field or the micro-variations of the density of the atmospheric air caused by the micro-oscillation of the atmospheric pressure has no bearing on the generation of these microseisms. Of course there is a time correlation between the true ground oscillations and true atmospheric oscillations recorded at the same place. Haskell (1951) has, however, observed that there can be little doubt that the ultimate source of most microseisms is in pressure fluctuations in the atmosphere and all theories on the origin of microseisms may be considered as attempts to explain how in view of great contrast in acoustic impedance, a significant transfer of energy can take place from air to solid rock. In the case of microseism with periods in the range 4 to 8 seconds, the most important impedance matching elements appears to be ocean. Now the observation indicates that the ordinary microseisms in the period range 3 to 10 seconds are associated with weather phenomena over the sea surface while the shorter period microseism with period one second or less are always observed in association with weather over the land area. The above idea of Haskell may also explain the generation of short period microseisms of land origin if we assume that the most important impedance matching elements appear to be the surficial layer through which the atmospheric forces are transmitted to the crystalline basement. If it is further assumed that the surficial layer consists of material having. Density $p = 2 \cdot 50 \times 10^3$ kg/m^3, Velocity of longitudinal waves near the surface $V_e = 2 \cdot 0 \times 10^3$ m/sec, and Velocity of torsional waves $V_s = 1 \cdot 2 \times 10^3$ m/sec, Characteristic impedance $Z_l = 5 \cdot 0 \times 10^6$ kg/sec-metre^2, $Z_s = 3 \cdot 0 \times 10^6$ kg/sec-metre^2.

The values are of the same order as those for liquids such as water which has the characteristic impedance

$$Z_o = 10^3 \times 1 \cdot 5 \times 10^3 = 1 \cdot 5 \times 10^6 \text{ kg/sec-metre}^2.$$

It is quite probable from the above consideration that the surficial layer plays the role of ocean in the generation of microseisms. In this case the ground layer is equivalent to some kind of filter which allows only certain discrete frequencies to be transmitted to crystalline basement. If we assume the so called quarter wavelength law asserted by Tazime (1957) to hold good in the case of atmosphere—surficial layer coupling. The peak periods T for waves transmitted to crystalline basement are given by $T = 4H/V_P$, where H=Thickness of the low velocity surface layer and V_P =Velocity of seismic P waves.

The above relation also suggests that the observed period of 0·3 sec by Walsh and 0·4 second by Chakrabarty and Sarkar (1958) may be due to low value of the thickness of surficial layer at the place of observation assuming that the seismic wave velocities are same in the low velocity surface layers. The above relation appears to be too simple to explain all observations. It is quite likely that it may be possible to determine the value of the thickness of the layer from the surface wave dispersion curve in the short period range for an appropriate crustal structure. The period of the microseisms may correspond to a minimum of the group velocity of the dispersion curve.

The preponderance of shorter period oscillations (Fig. 2) much shorter than period of 1 sec could be explained in two different ways. One explanation will be from the consideration of M2 mode dispersion curve appropriate to the crustal structure. Alternatively it might also be possible that short period microseisms of 1 sec period recorded at Shillong might be due to disturbance at a distance where there is thicker section of the sedimentary crust and the shorter period microseisms of period much shorter than period of 1 sec would correspond to the structure proper for Shillong plateau.

The observations indicate that the short period microseisms under consideration are associated with some convective activity in or near the station but it is noteworthy that all convective activities near about the station does not give rise to the appearance of the short period microseismic storm. In a previous study on the microseisms of sea origin during the passage of Nor'westers over the head Bay of Bengal, the author (1960) has concluded that the ordinary heat or single air mass thunderstorm passing over the head Bay of Bengal could not generate microseisms while the thunderstorms associated with the cold fronts of the secondary low pressure waves whenever they happen to pass over the vast water mass can give rise to frontal microseisms of the sea origin. It may be in the case of short period microseism of land origin also that only those convective phenomena developed in association with the cold front or with the upper air discontinuity could give rise to microseisms under study. On account of the limitations already pointed out, no definite conclusions could be drawn as the frontal characteristics are not properly manifested in the tropics. But it certainly goes to suggest that there is a good correspondence between the synoptic situation and the occurrence of short period microseism under study. The observations also indicate that the short period microseisms are more frequent during the premonsoon and monsoon months and they are practically absent during the period from October to

February. This is in perfect accord with the meteorological observations that the secondary low pressure waves induced by the extra-tropical depressions of the middle latitudes known as Western disturbances 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 comparatively high latitudes and accordingly thunder rain is more in the northern part during the winter months. Only during the premonsoon months, these secondary low pressure waves move along lower latitudes causing appreciable thundershowers in this part of northeast India. The diffuse cold front present in the low pressure waves is accentuated by the incursion of moisture at lower levels from the Bay of Bengal across East Pakistan. It has further been pointed out by Walsh that the occurrence of shorter period microseism observed by him is always associated with observation of micro-barographic oscillations of the atmosphere during the advection of the convective phenomena either due to cold frontal activity or solar heating. Roschke's study on the relation between air pressure micro-oscillations and concurrent synoptic pattern is in agreement with the above finding. But it could be shown following Haskell (1953) that the mechanism is of questionable quantitative significance. In the illustrations Roschke (1952) gives of typical high barometric activity immediately following the passage of a cold front, the double amplitude appear to run around 6 dynes/cm^2 having periods in the neighbourhood of 5 secs. The displacement amplitude at the bottom for an oscillation of period T will be of the order of $TP_o / 2 P_s C_s$ where P_o = pressure amplitude at the surface and P_s=density of the surficial sedimentary layer and $C_s = V_e =$ Velocity of compression waves. The displacement amplitude comes out to be $0 \cdot 01$ micron for T=1 sec. Assuming that the Benioff Seismometer has a peak magnification of 10,000 for waves of 1 sec period. For the recorded amplitude of the order of a millimetre, the ground motion comes out to be $0 \cdot 1 \mu$. There seems to be discrepancy by a factor of 10 or more.

In conclusion, the author is of opinion that the role of colder air mass present either in the cold front or in the cyclonic storm with cold sector is of paramount importance in the production of atmospheric turbulence which by some coupling mechanism through extended water mass or through the surficial layer is transmitted to the ground to cause micro-oscillations of the ground to be recorded as microseisms by seismographs. The hypothesis suggested by Haskell (1951) appears to be more general in explaining both types of microseisms of land and sea origin. These short period microseisms like the longer period microseisms of 3 to 8 seconds periods are nothing but surface waves on the upper surface of the crust and it may be that the peak periods observed in microseisms depend on the thickness of the upper surficial layer or the thickness of the water unconsolidated sediment through which the atmospheric disturbances are transmitted to the crystalline basement. From the study of the peak periods observed in microseisms in different parts of the world it may be possible to ascertain the thickness of the surficial layer or the thickness of the water-unconsolidated sediment in any part of the world if it is possible to determine the velocity of the seismic waves in those places. Chakrabarty and Sarkar (1958) have also come almost to the similar conclusions in connection with their study on microseisms associated with Nor'westers. They have observed similar microseisms with period of $0 \cdot 4$ sec in the records of the Benioff seismograph at Howrah when the Nor'wester disturbance was near the station just before its passage into the Bay of Bengal. Soon after the passage of the disturbance into Bay of Bengal, they however, observed microseisms in the period range of 2 to 3 secs. The above observations support splendidly the idea of the author that meteorological disturbance, *viz.*, cold front associated with Nor'westers could give rise to microseisms of different periods when the disturbance is over the land or ocean.

On account of higher attenuation for shorter period waves it is quite probable that these short period microseisms of very low amplitude are recorded by seismographs of very high magnification operating near the source while the longer period large amplitude microseisms are, however, recorded on a wider scale by seismographs of divergent construction all over the country.

7. Acknowledgement

The author wishes to express his sincere thanks to Dr. R.C. Banerji for his kind encouragement during the progress of the work. His thanks are also due to Prof. S.K. Chakrabarty for pointing out to the author about the appearance of similar short period microseism in his three component Benioff records at Howrah just before the passage of Nor'wester disturbances into the head Bay of Bengal. On account of smaller time scale and different instrumental constants, these microseisms are not as prominent as they are in Shillong records.

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