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Landslides and Sounds due to Earthquakes in relation to the Upper Atmosphere

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ABSTRACT. A survey is made of ' landslides ' and ' explosive sounds ' associated with violent tectonic earthquakes which occurred in India and neighbourhood during the past one and a quarter century, with special reference to the very large earthquake of 1950. Results of allied studies made elsewhere, are reviewed.

' Earthquake-sounds ' originate in the focal regions of the disturbances, travel in the rock with the speed of elastic waves and after refraction into the air, proceed at a very small angle with the vertical. However loud, such waves cannot return to the ground to be audible at any large distance from the place of emergence from the ground. Explosive sounds heard at large distances from the epicentres long after the earthquakes, are produced by landslides. They travel at small angles with the horizontal. After a detour of the upper atmosphere these sounds can return to the ground and, by successive recurvatures in the upper air and reflections on the ground, can be audible at different distant zones of audibility. The explosive sounds due to submarine earthquakes, like the ' Barisal guns ', appear to owe their origin to some volcanic phenomenon, either in association with the earthquakes or initiated by their effect elsewhere. Audibility of these sounds at large distances can then be explained by abnormal propagation through the upper atmosphere.

By an analysis of the observed elements of sounds and various characteristics of the earthquakes and by comparison with the results of explosion—natural and experimental—inferences are made regarding the time and place of occurrence and the number and dimensions of landslides relating to the sounds. Travel-times of abnormal sounds, due to earthquakes in India, are thus obtained and these afford a means of obtaining the temperature of the upper atmosphere, the form of trajectory and critical speed of sound. Preliminary examination shows that these results are approximately in agreement with those obtained from the ' explosion ' experiments made in India, during 1946-47.

The study emphasises the need for reorganising the existing system of voluntary observations of earthquakes.

1. Introduction

From a couple of days after occurrence of the earthquake of August 15, 1950, volumes of reports relating to various effects consequent upon the major upheaval began to appear in the press. These effects were of so much absorbing interest that minor phenomenon such as ' sound ' associated with the earthquake, almost escaped general attention.

The various characteristics associated with what were described in the press as ' mysterious ' sounds heard at sufficiently distant places from the epicentre after an appreciable time from the earthquake, appeared to be quite significant as indicating that the sounds, similar to those from explosions and produced by some major landslides somewhere near the epicentre, had travelled to the distant places after a detour of the stratosphere. Voluntary observers' reports on the effects of the earthquake, received a few days later from Lhasa ($\triangle$=538 km) and Tezpur ($\triangle$=426 km), also incorporated detailed particulars of the sounds heard at those places after the earthquake and appeared to confirm the original idea as to the mechanism of production and mode of travel of the sounds. It appeared to be of interest to collect more data for a closer investigation of the phenomenon.

2. Source of data

A circular letter was sent to a few selected places in Assam and Burma asking for information on ' abnormal sounds ' due to the earthquake in a specified form. Nineteen replies were received. These were supplemented by information from Poddar's[1] preliminary reports and replies to a special questionnaire relating to the effects of the earthquake, received from a large number of places in Burma, Assam, Bihar, Orissa, Uttar Pradesh, Madhya Pradesh and Lhasa in Tibet.

A summary of the particulars relating to abnormal sounds due to this and other Indian and Burmese earthquakes discussed in the following sections, has been given in Table 1. The distribution of the stations where abnormal sounds were heard after the earthquakes except the earthquake of 1881, in relation to their epicentres and probable places of origin of sounds, has been shown in Fig. 1. Directions from which sounds were observed to travel to the stations have also been plotted in the same figure. In respect of the earthquake of 1950, the positions of those stations in Assam and Burma where no sound was heard or for which no remark on sound is available, have also been given in the figure to enable one to judge whether or not the alternate zones of audibility and inaudibility of sounds exist.

3. Abnormal sounds in association with previous earthquakes

A reference to the publications on important earthquakes in India and Burma has revealed that similar abnormal sounds were also associated with the earthquakes of 1869[2], 1881[3], 1897[4] and 1912[5].

The question of the Kangra earthquake of 1905[6] presents some difficulty in coming to a straightforward decision on the subject. In this case the observers in a number of places in Central India and Rajputana described the sound as 'rumbling like a gun afar off' and in Uttar Pradesh 'like echoes as blasting', 'rattling as of cannon discharge' and 'strong blasting'. At a few places in Kashmir the particulars regarding these sounds are available. Landslips and rockslides from high precipices took place in a gigantic scale over the areas of the Kulu valley and north of the Kangra valley at the head of the Neogal gorge. Some of the slips were so terrific that they accounted for most of the deaths in the north Kulu valley, serious damage to property and even formation of big lakes such as the Larji and the Barwa lakes, over the area mainly enclosed by the isoseismal 9 in R.F. scale. Dust clouds due to landslides resembling volcanic phenomena, were observed extensively during the earthquake and for some months thereafter[6]. From these and the information given, though meagre, it appears possible that sounds observable at large distances were produced due to landslides but either for want of adequate information or appreciation of the significance of the phenomenon, further particulars were not recorded in the same way as Oldham did in the case of other ndian earthquakes.

Further search has revealed that similar abnormal sounds were also heard after the Buller (New Zealand) earthquake of 1929. Thompson[7,8] and later Hayes[9], have explained the phenomenon as due to travel of sound waves from the place of origin to the observing stations after a detour of the upper atmosphere. The two independent explanations of the same phenomenon, one relating to the Indian earthquakes and the other to the Buller earthquake, are. therefore, in agreement with each other, The author's conception of the origin of abnormal sounds is of course different from that of Thompson and Hayes.

4. Observation during the earthquake of 1950

Reports relating to explosive sounds are available from more than fifty stations in Assam and Burma. Reports on other types of sounds resembling those of 'passing train', 'aeroplane', 'rumbling' and 'booming' etc., preceding or accompanying the earthquake, number thirtyfour in Assam, one in Burma, ten in Bengal, six in Bihar, eighteen in Uttar Pradesh, and two each in Orissa and Madhya Pradesh.

The farthest place where sounds due to this earthquake were heard was Demagiri, at 757 km from the epicentre. Between 600 and 760 km, these were heard at six stations. It has also been reported that near about 2100 IST when remarkable 'seismic seiches' were observed, a sound resembling that of a 'motor' was heard at Tonda and that resembling 'the sound caused by the falling of a very heavy object in water' was heard at Unchgaon, both in Uttar Pradesh and about 1200 km away from the epicentre. The distance may appear to be too large for audibility of sound but it is not so when it is recalled that the sounds due to the historic Krakatoa explosions of 26-27 August 1883[10], were clearly audible as the discharge of a distant artillery even at Rodriguez at a distance of 4750 km away from Krakatoa. Too much importance, however, cannot be attached to the present observations.

5. Earthquake sounds

Kingdon-Ward's descriptions of sounds heard by him during one of the largest earthquakes of the world and published by him[11], will typically illustrate the nature of sounds due to large tectonic earthquakes, heard at or near the epicentral zones. These are variously described as 'deep rumbling', 'loud roars', 'terrible din', 'appalling noise', 'deafening and causing as great panic as the earthquake itself'. [4,6,7,11,12] They generally commence shortly before the earthquake, increase in loudness as the intensity of the shock and die down as the shaking of the ground subsides. Noises due to crashes of huge masonry structures within a few yards of observation are masked by earthquake sounds and even the terrific roars caused by gigantic rock avalanches pouring down through considerable heights and within a few hundred feet of the observer, may not be separable from the sounds due to the earthquake itself. The sound pervades over a large area, often enclosed by the isoseismal 5 in R.F. or Mercalli scale.[12,13] The intensity of sounds is generally maximum near the epicentre and gradually falls off towards the outer limit of the area of audibility.

Davison[13,14] has constructed the empirical scale of intensity of earthquake sounds and also studied their acoustic pattern on the basis of 'isacoustic lines' in relation to the isoseismal lines and the place of origin of earthquakes. In general, both the isacoustic and the isoseismal lines enclose the same epicentral region but do not always indicate precisely the same point as the source.

Sounds discussed above, originate in the focal region of earthquake shocks and travel through the rocks with the velocity of the elastic waves. The longitudinal waves, on striking the surface of the ground, are refracted into the air. The transverse waves cannot be so refracted. The frequency of vibrations of the ground waves is generally below the lower limit of human audibility. Of these, the frequencies of the longitudinal waves are higher than those of other waves. When the former reach the lower limit of audition (20 to 30 vibrations per second), they are audible as sounds after emergence from the ground into air. Earthquake sounds are often observed to emanate from the ground below and are not audible at large distances from the place of origin.

6. Abnormal sounds due to earthquakes

Sounds resembling those of explosions, which are audible at large distances from the epicentre, several minutes after the earthquakes, have been designated in this paper as abnormal sounds.

Thompson[7,8] and Hayes[9] appear to have held the view that the earthquake sound itself emanating from the ground above the seat of disturbance of the Buller earthquake, travelled through the upper atmosphere and returned to the earth to be audible as abnormal sound. This view is untenable on the following grounds. A prolonged earthquake sound of considerable duration near the epicentre should, on return to the ground from the upper atmosphere, be audible as such and not as discrete sounds of very short durations, exactly similar to the sounds from explosions. No conceivable conditions appear to exist in the atmosphere which can bring about this transformation of the earthquake sound during its passage through the atmosphere. Even if this were possible, the phenomenon of abnormal audibility should be general and not restricted to a few of the violent tectonic earthquakes only. Thirdly, after travelling with great velocity in the rocks and emergence into the air, the sound waves should proceed nearly vertically and at an angle not exceeding 13° with the vertical. No possible physical constitution of the atmosphere will permit the return of such waves to the ground. Whipple[7] expressed difficulty in understanding the phenomenon on the basis of return of the earthquake sound from the upper atmosphere to the ground.

The phenomenon can, however, be easily explained on the basis of sounds produced by landslides and rockfalls. These sound waves may be considered as somewhat analogous to the sound waves from explosions. The former are produced on the ground and can travel at suitably small angles with the horizontal to ascend to and descend from the upper atmosphere as the explosion waves do. The various characteristics resembling those of explosion waves, observed to be associated with abnormal sounds, will receive easy explanation on this hypothesis. Additional support is lent to this idea by the fact that abnormal sounds are observed only in the case of those tectonic earthquakes when landslides occur. The earthquake of 1950 will furnish an extreme example in that landslides due to this earthquake took place in an unprecedented scale and, as far as the author is aware, largest number of stations (above 50) distributed over a wide area, reported abnormal sounds after this earthquake.

Abnormal sounds are not observed when there are no notable rockfalls[15-20] but the converse may not always be true. For instance, though landslips occurred only on a small scale due to the earthquake of 1912,[5] mainly along and around the Kyaukkyan fault in the north Shan State where maximum intensity was exhibited, abnormal sounds were reported from three stations to the southwest of the epicentre approximately in the region of abnormal audibility. On the other hand, landslips occurred apparently on a larger scale during the Bihar-Nepal earthquake of 1934,[12] but no abnormal sound was reported. These slips took place in the Nepal-Himalayas and at two places about 5 and 9 miles to the northwest of Dhankuta, there were 30 and 13 deaths respectively due to the slips. Also, there were two areas of landslips near Taplejung. Detailed descriptions of the landslips due to these two earthquakes, however, are not available for a comparison of their relative magnitudes. Again, earth and land avalanches took place during the California earthquake of April 18, 1909,[21] chiefly along the sea cliffs on the coast (about 2000 feet high) and some inland, on the steep canyons (about 500 feet high) but no abnormal sound was reported.

During the Quetta earthquake[22] the mountain sides around Quetta, particularly the hills by the Brewery and along the whole length of the Chiltan range, were in many cases scarred by the falling of immense quantities of rock. No mention, however, has been made about any sound due to this earthquake. The earthquake occurred at about 3 A.M. and the area shaken was conspicuously small compared to the magnitude of the shock ($M=7\cdot5$). Consequently, complete observation on sound is not likely to be available. It has been reported that landslips were evidently numerous and widespread throughout Kutch during the earthquake of 1819,[15] when vast clouds of dust were seen to ascend from the summits of almost every hill. Only large masses of rock and soil got detached from the hills due to the earthquake and nothing more happened to them. In addition to the usual earthquake sounds being audible at Kutch and away from the epicentre at large distances, one or two observers reported the sound of a distant 'cannonade' shortly before and during the earthquake. It is clear from the topography of the epicentral region and the surrounding country that large scale rockfalls to produce abnormal sounds to be audible at large distances from the epicentre, was not possible. Due to the Baluchistan earthquake of 1909,[23] which was evidently not a large one, two small rockfalls took place near the Nari gorge tunnel. In addition to usual earthquake sounds, those resembling 'cracking sound' and 'sounds like guns' were heard but no abnormal sound was reported. During the Kashmir earthquake[24] which was also not a very major one, a large landslide occurred at Larri-dur about 7 miles south of Baramula, in addition to a few minor one elsewhere in the Kashmir valley. A sound similar to that due to 'a hundred guns going off at once' was heard during the earthquake by some observers. Sounds preceding the earthquake by a few seconds or during it and resembling 'distant thunder', 'discharge of artillery', and 'noise caused by blasting operations' but no abnormal sounds, were reported. It is to be noted that the earthquake occurred at 2-45 A.M. and the area shaken was not considerable. During the Pegu earthquake of 1930,[19] sounds resembling 'explosions' were heard by one or two observers at or about the epicentre. Fire also broke out during the earthquake. Some of these sounds resembling explosions etc. heard in addition to usual earthquake sounds, during and immediately after the earthquake, should be related to the falling of heavy objects near the place of observations.

During field survey in Assam after the earthquake of 1897, it was observed that slight shocks, felt or unfelt, were invariably accompanied by more or less distinct booming sounds and Latouche[4] stated that they closely resembled the 'Barisal guns' but were not so sharp and well defined. In his studies of British earthquakes, Davison[13,14] has classified the earthquake sounds heard, into different types. He has shown that the average percentage frequency of the type resembling explosions is 7 for strong, 8 for moderate and 26 for slight shocks. This sound is more frequent near the epicentre. Explosions relating to slight shocks may belong to the category of low and dull sounds resembling the Barisal guns referred to by Latouche. No particulars about landslides etc. relating to the strong and moderate shocks have been given by Davison. It is, therefore, not possible to see if there was any connection between these and at least some of the 'explosive' sounds relating to the strong British earthquakes. This is the picture that is available on sounds relating to Indian and British earthquakes.

It should be remembered that a number of factors govern the production, audibility and actual recording of sounds relating to landslides and these should be considered collectively in deciding whether or not abnormal sounds were produced due to landslides during an earthquake.

7. Time and place of origin of abnormal sounds

To compute the travel-times of abnormal sounds, the place of origin of the sound should be known accurately. As the sound is produced by rockfall, it is extremely difficult to know where and when the rockfall relating to a particular audible sound occurred. In general, it may be sufficient for this investigation, to consider the region of extreme violence of the shock, namely, the epicentral region as the place corresponding to the place of rockfall and consequently, the origin of the sound. In some cases the epicentre may not be known accurately (*e.g.*, in the case of the earthquakes of 1869 and 1897) and/or the rockfalls might have taken place over an extensive area which is asymmetrical with the epicentral region and for a long period of time (as in the case of the earthquake of August 1950). Such a case is indeed more complicated and the only solution is to locate the region of the most intensive rockfalls (if it can be so done) as the origin of the sound and find out by trial, if this or any other neighbouring spot would give a better fit for the times of travel of sounds observed at the different stations. Still more difficult is to get the time of origin of the sound, particularly when the duration of the shock has been considerable (*e.g.*, the earthquake of August 1950).

8. Earthquake of August 15, 1950

(*i*) *Landslides*

Results of detailed and systematic field survey of the areas in the Mishmi and Abor Hills round about the epicentre, which were subjected to maximum destruction and damage, are not yet available. In absence of these, it is difficult to arrive at any final conclusion as to the area where the deadliest rock-crashes might have taken place to produce the sounds for which the times of audibility are available. All that is known is from a brief press summary of the results of air reconnaissance of the area after the earthquake, a partial field survey of south and southeastern sectors of the area by the Geological Survey[1], Kingdon-Ward's note on the earthquake[11], cursory press reports and an early statement on the subject by the Assam Government. The information can be summarised as follows—

> Landslides occurred on a gigantic scale over the area between the Luhit valley and the Subansiri basin (mainly north of Lat. 28° N). The worst affected areas were the Dihang and the Dibang valleys where the landslips were strikingly more in contrast to the extent of small landslide in the hill ranges to the west of the Dihang river as also to the east

of Long. 96°E. In the latter place the slips though considerable, were smaller. Some places, such as the area to the northeast of the Tiding river, were severely affected. Over the area of landslips the hills several thousand feet high (even 13,000 to 14,000 ft) were badly sheared from top to bottom and in many cases the huge cliffs had crashed down. The fallen boulders showed that by far the most abundant rock is the granite.

(ii) Place and time of origin of sounds

A general analysis of the directions of sounds indicates two main regions, in the Dihang and the Dibang valleys as probable origins of sound. The first region, aligned north and south, is on the east of the epicentre. The other, farther west, is aligned northeast and southwest. A third smaller region, to the north of Lat. 28° N and Long. 96°E, is also indicated as a probable source. These regions are apparently separated by gaps and are shown by shading in Fig. 1.

The times of audibility of sound after the earthquake, have been reported from a number of stations from all directions of the epicentre except the inaccessible mountainous terrain to the north. Of these, the series relating to stations reporting more consistent and reliable observations agree in a general way with a small region on the northeast quadrant of the epicentre, as the source of sounds. This region has been doubly shaded.

Even at Rima about 100 km away from the epicentre, huge masses of granite rocks were torn off and hurled away from high precipices. The epicentre is known with sufficient precision[25] and extreme violence was exhibited at and near this position. It is, therefore, quite likely that a few major crashes of rocks relating to these sounds took place on the above area. Additional sounds due to landslides at other times and places must also have been heard, particularly at nearer stations. This is the general picture.

The observations were taken under varying circumstances and there are very few means of ascertaining the relative degrees of reliability of these observations. Nevertheless, a detailed analysis of the various elements, namely, the direction, number, time and period of audibility of sounds, appears to bring out a system in good agreement with the above inference relating to the place of occurrence of the rockfalls and sounds.

Out of twentysix stations reporting directions a group of eighteen indicates a small region round about the epicentre as the source. Of these, the directions from nine stations as they are, converge almost to the epicentre. Also the directions from the remaining nine, after adjustment by about ten degrees each, point to the small epicentral region. The fact that directions were reported generally in 45° of the compass, this small adjustment may not be unjustifiable. In the first group of nine stations five relate to single observations and four, to one selected out of two directions observed at each of them. Regarding the second group, seven relate to single directions and two refer to a direction selected out of two recorded at each of them. For Dilli Colliery, the mean of the two directions agrees with the epicentre. Single directions from four stations and one out of two directions from each of six stations, agree mainly with the central and southwest portion of the second source. These stations except two, are common to the first source of sounds. The rest of this region appears to be unimportant on the basis of this analysis.

Various stations reported that the shock became extremely violent from half a minute to one minute from the beginning. Presumably, in many cases, this was due to arrival of the group of transverse waves at the stations. As the whole area surrounding the epicentre was saturated by monsoon rainfall or waterlogged for over two months, it is possible that the major rock-crashes started shortly after the shock became extremely violent, say, about a minute from the beginning.

It is clear from Kingdon-Ward's observations that the 5 or 6 noises heard at Rima at the end of the earthquake, had originated somewhere to the northwest and came down from the sky at Rima after traversing the upper atmosphere. By the 'end of the earthquake' when the sound was heard, we may assume $6\frac{1}{2}$ to $7\frac{1}{2}$ minutes from the beginning. Assuming no inversion layer in the lower troposphere at the time and that reflection took place from the upper atmosphere (lower stratosphere ?) the travel-time of sound at Rima from $5\frac{1}{2}$ to $6\frac{1}{2}$ minutes will correspond to an approximate distance between 70 and 100 km to the northwest.

The sounds were heard at Rima 'in quick succession' and consequently it may be assumed that the rockfalls producing them must have taken place at short intervals of one another.

The observations at Dilli Colliery, Mogok, Shwegu and Rima may be considered as complete and appear to be more dependable than those at a large number of stations. The direction of sounds at these stations directly support a small region which is concordant with the source indicated by the observations at Rima alone. The times of audibility of sound at Tezpur and Lhasa also agree with this region but not the second region. The epicentre has, for all practical purposes, been adopted as the origin of sound and the △'s refer to this place.

(iii) Number of sounds in relation to their source

Of the stations supporting the first source, a group of six recorded all the four elements of sounds (direction, number, period and time of audibility) and four recorded three elements each. The corresponding numbers relating to the second source are three (including Monywa and Tezpur which are common to both the sources) and one respectively. The remaining stations recorded one or two elements only. The observations at stations reporting three or four elements have been taken to be more reliable than those relating to stations reporting one or two.

At each of the five more reliable stations out of six, and four others relating to the first source, an average number of 3 to 7 sounds at each station was audible. In general, five stations each reporting the average number of 5 to 8 sounds, are between 100 and 425 km, one at 663 km and six, reporting the average number 1 to 5, are between 450 and 730 km away from the epicentre. This will appear to be in agreement with the general expectation that the group of sounds heard at Rima was the loudest and travelled to other stations including the remotest one.

Observations of thirty sounds at Lhasa at 538 km away from the epicentre are apparently discordant with those from other distant places. A group of stations in the Brahmaputra valley at distances 197, 203, 222 and 241 km reported 30 to 40, 20, 6 to 7, 8 to 10 and 20 sounds respectively. Probably sounds produced at other sources and times but less loud, were heard at some of these places in addition to the important series discussed before. It may not be surprising if the configuration and alignment of the deep gorges where some of the sounds were produced, favoured the travel of sounds to some particular direction in preference to others and some such effect partly contributed to the anomaly.

(iv) Period of audibility of sounds in relation to their source

Dilli Colliery (△=303 km) and Myitkyina (△=367 km) reported 15 to 20 minutes as the period of audibility of sounds. From and beyond △ = 400 km, four observations relate to 3 to 6 seconds, two to 2 minutes each, one to 10 minutes and another to 30 minutes. From the nature of these reports and comparing them with instrumental records of waves from large scale experimental explosions,[26, 27] 3 to 6 seconds may be taken mainly as the duration of the rumbling of individual sounds. At Sinlum (△ = 490 km), 4 or 5 sounds were heard within about ten minutes and the longest interval between two consecutive sounds was two minutes. From this and a comparison with reports from a few stations at equal distances, near about five minutes in place of ten, will be more appropriate for the period of audibility at Sinlum. The last report relates to 2 or 3 sounds heard within 30 minutes and the maximum interval between consecutive sounds was 10 to 15 minutes. From the remaining seven stations distributed between distances 400 and 730 km an average of 4 to 5 minutes is obtained. Again, an average of about 5 sounds per station emerges from a group of seven stations within this limiting distance. These values agree with those from Tezpur ($\triangle = 426$ km) where about 6 sounds were heard within 5 minutes and the number and the absolute times of beginning and end of the sounds were carefully recorded. A common source of origin of these groups of sounds is thus indicated.

(v) Number and dimension of rockfalls producing the sound

Can a reasonable estimate be made of the number of rockfalls relating to the sounds which were audible at large distances from the epicentre? It is significant to notice that abnormal sounds due to earthquakes have been very often heard in groups of two or more exactly as the sounds due to the analogous phenomenon of the Barisal guns and explosions. Were there as many sounds at origin as those heard in the zones of abnormal audibility? There are no means of ascertaining the fact from the series of old observations. Careful scrutiny in a few cases of explosions shows that a single sound at the origin, for instance, that of the most violent Krakatoa explosion occurring on the forenoon of August 27, 1883,[10] was definitely heard as multiple ones at large distances away from the place of explosion. Results of recent experimental explosions confirm the phenomenon of multiplicity.[27,28]

During Indian experiments,[26,27] particularly during the summer trials discussed in the following paragraph, the wave from a single explosion was often recorded at many of the observing stations as two or three pulses, generally, at intervals of a few seconds to about a minute at nearer stations and approximately one and/or two minutes at the more distant ones from the centres of explosions. From this analogy and the fact that at Shwegu six sounds were heard at intervals of about one minute and the longest interval between two consecutive sounds was two minutes, we may take about one minute as the approximate average interval between consecutive sounds at the distant stations where five to six sounds during an average period of about five to six minutes were heard. This will indicate the occurrence of two or three major rock-crashes which produced the sounds.

With a view to study the abnormal propagation of sounds in India, large scale explosions were organised by the India Meteorological Department during the summer and the post-monsoon seasons in 1946 and winter of 1947. The explosions and recording of waves due to them, were made in the Central Provinces. The farthest recording station was set up at Kamareddi at a distance of 638 km to the south of one of the centres of explosions (Ponia). Sound ranging instruments employing hot-wire microphones were used to record the pressure pulses. The waves produced by detonating ten to fifteen tons of T.N.T. at a time were registered upto 638 km at Kamareddi but were not audible beyond about 100 km from the place of explosion.[27] In the Heligoland explosion of 18 April 1947, when 5000 tons of T.N.T. was exploded, the sound was heard southsoutheast of Heligoland, definitely at 252 km and possibly at 442 km and 509 km but not at 354 km, 630 km and 999 km.[29] The last was the farthest observing station. The microbarometric pulses were recorded at all these distances. It can, therefore, be inferred that the rockfalls due to the earthquake of 1950 producing the sounds which were clearly heard at the various distances upto 730 km away must have been of immensely gigantic proportions.

It is easy to visualise rockfalls of the requisite type through suitable heights due to an earthquake of this magnitude and energy, 3×10^{27} ergs,[25] when it is recalled that the Pamir earthquake of February 18, 1911, having an energy between $\cdot 8 \times 10^{21}$ ergs and $2 \cdot 4 \times 10^{21}$ ergs, was caused by the fall of a mass of rock having a volume of two to three cubic kilometres through a height of 300 to 600 metres,[30] and no reason is apparently traceable for this rockfall. The results of detailed field survey of the area at and about the epicentre of the present earthquake when available, will indeed throw light on the actual happening in that area.

9. Farthquake of June 12, 1897

Results of careful field survey for this earthquake[4] are known and it is comparatively easy to locate the regions of origin of sound. Landslips due to this earthquake also were produced on an enormous scale. These were especially abundant and conspicuous along the southern slopes of the Garo and Khasi Hills particularly in the neighbourhood of the Paniathit river and the hills to the west of it. Of the total number of persons killed during the earthquake, about 50 per cent was accounted for by landslips at and about Cherrapunjee where the deep valleys were scored by landslips to such a striking degree that, when looked at from a distance there appeared to be more landslips than untouched hillsides. Landslips were practically confined to the sides of the deeply cut valleys. Oldham has stated, " Nowhere that I know of are they so strikingly developed as in the small valley of the Mahadeo to the south of the Balpakram and Pundegru Hills ". It is at about Long. 91° E where the hills rise highest and most abruptly from the plains and being composed largely of nummulitic and supranummulitic rocks were more easily broken into landslips. The region of the valley of Mahadeo at about Lat. 25°·3 N and Long. 91°·0 E which is about 70 km west of Cherrapunjee, has, therefore, been adopted as the origin of sounds.

The shock at Shillong was of short duration and developed into destructive violence some 10 or 15 seconds after it was first felt. The violence of the shock may be imagined when it is stated that whole of the damage done (at Shillong) was completed in the first 10 to 15 seconds of the destructive shock. It has, therefore, been assumed that the main rock avalanches relating to the sounds under review, took place 20 to 30 seconds after the beginning of the shock in the valley of Mahadeo.

No point properly called the epicentre, has been located by Oldham in the vast area including the important places of Shillong, Cherrapunjee, Goalpara and Tura, where destruction to masonry structures due to the earthquake was universal. A point assumed by Oldham at Lat. 25° 45′ N and Long. 90° 15′ E as the seismic vertical, has been shown in Fig. 1.

10. Earthquake of January 10, 1869

Except passing reference here and there, no exhaustive discussion has been made of the landslides due to this earthquake.[2] This earthquake too was of great violence and even visible undulations of the surface of the ground due to the earthquake, were noticed at many places away from the epicentral region as during the earthquake of 1897. From available accounts it appears that the violence manifested on the surface and destruction at and about Silchar were exceptionally great. About this place, ' the landslides caused were numerous and extensive and many homesteads were carried down into the stream '. Considerable landslides were reported near the Jeerie river and important landslides also occurred at about Manipur, particularly in the border of Assam and Manipur. The hills to the northeast of Silchar appear to rise steeply from the plains and exhibit features which may render landslides easy. A point about Lat. 24°·8 N, Long. 93°·1 E within some 25 miles to the east of Silchar and agreeing with the observed times of audibility of sound, has been taken as the hypothetical origin of sounds. Even if the point is taken elsewhere in the northeast sector within some 25 miles of Silchar, the overall position will remain almost unchanged.

The mean duration of the shock from some 12 observations may be taken as 2 minutes. At Silchar and Imphal the duration reported was 1 and 1½ minutes. Again, according to reports from Silchar and a few other stations, the shock began with gentle undulations and after a few seconds, these rapidly grew into great violence. It has thus been assumed that the landslides producing the sound took place some 30 seconds after the beginning of the shock.

11. Buller earthquake of June 16, 1929

The earthquake[31] occurred in mid-winter and good rain had fallen over a long period

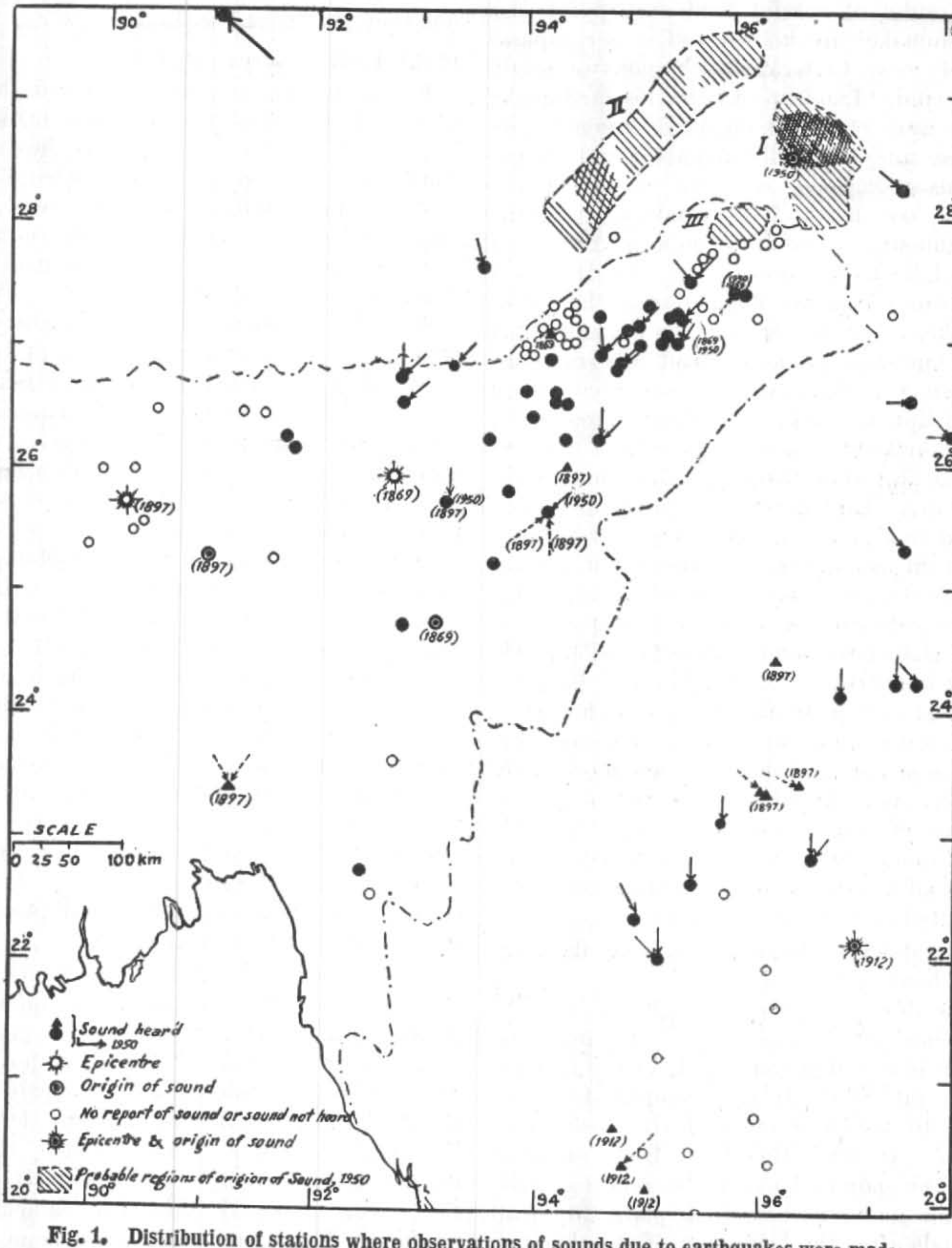

Fig. 1. Distribution of stations where observations of sounds due to earthquakes were made, with probable origins of sounds and epicentres

before occurrence of the earthquake. The soil and subsoil were quite saturated with water and over large areas which were subjected to severe shakings, multitudes of slips descended from the slopes of terraces, hills and mountains and these were responsible for most of the fatalities and greater part of the material damage. The large rockfalls noticed were from the cliffs a little inland from the mouth of the Little Wanganui. Slips in the upper basin of the Little Wanganui were exceptionally large and great massive blocks of granite had crashed down. The Karamea road was blocked for twenty miles by landslides and rockfalls. For five miles along the steep west face of the Mount Kilmernock, the rockfalls were many and large ; streams of debris flowed down the Six Mile Valley for a mile or more covering the firm land. The main high road through the Lyell gorge, and that between Seaddenville and Karamea could not be opened for wheeled traffic for many months. These were the more important landslides and rockfalls amongst others, in the large area of the Nelson district. It is, therefore, clear that the abnormal sounds due to this earthquake could also be associated with landslides and rockfalls. It has been reported that the sounds heard near the area of greatest destruction by most of the observers were 'tremendous subterranean explosions'. Very likely these were the sounds produced by rockfalls in the vicinity of the observers who heard the sounds directly from the source.

12. The submarine earthquake of December 31, 1881

The shock originated near Lat. 15° N and Long. 89° E in the Bay of Bengal and was felt over an area of 2,000,000 square miles. The 'tunamis' due to the earthquake[3] travelled upto the coasts of India, Ceylon, Burma, the Andaman and Nicobar Islands and Sumatra.

The origin and audibility of sound due to this earthquake appear to be similar to those associated with the Barisal guns. The phenomenon of the Barisal guns has been under observation and investigation for over three quarter of a century and only recently an explanation of the phenomenon has been offered.[32]

The acoustic seismic vibrations emanating from the rock at the bottom of the sea and propagating through the column of water into the atmosphere will, as explained before, emanate at a very small angle with the vertical and cannot return to the ground. Even if they could, it is difficult to know if sufficient energy will be left in the aerial vibrations to render them audible at large distances from the origin. Some kind of volcanic phenomenon should, therefore, be inferred as an alternative to explain the origin of sounds due to submarine earthquakes, the Barisal guns and allied phenomenon. Origin of sounds relating to the Barisal guns is under further investigation for discussion elsewhere.

A line of volcanic vents from Java and Sumatra, stretches through the islands in the east Bay of Bengal and terminates in Arakan. Some of the mud volcanoes in the Cheduba and Ramri groups of islands burst into eruption due to the severe earthquakes of 1833, 1839,[33] 1881[34] and 1897[4]. Loud reports accompanied the eruption at Kyaukpyu due to the earthquake of 1897 and after shocks in the night. The directions of abnormal sounds relating to this earthquake, except one at Kohima, however, do not point to Kyaukpyu as the source. No information of sound from the eruption due to the earthquake of 1881, has been recorded. The disastrous submarine earthquake of 1762 originating in the Bay of Bengal off the Arakan coast also initiated eruption of the volcanoes in the Seetakund Hills and loud explosive sounds were heard at Chittagong.[35] Submarine volcanic eruptions accompanied by issue of fire, noise and earth tremors, were also noticed off the Arakan coast in 1843 and 1845 and off Chandanagar near Madras coast, in 1757.[33] An eruption in the Indian Ocean near Lat. 6° S and Long. 89 ° E was also observed in 1883.[36]

The very large Andaman earthquake of June 1941, originated in the centre of the west coast of the South Andaman island. There were no 'tunamis' following the shock nor any information about sound is available. The disastrous Mekran coast earthquake of November 1945,[37] was responsible (according to press report) for throwing up, above water by 30 ft and 100 ft, two islets near each other and at about the position Lat. 25° 7′ N and Long. 64° 15′ E. They appeared to be of granite and were about 100 miles to the northeast of the seismological epicentre, in the sea. A loud rumbling noise was heard by the villagers (apparently on the Mekran coast) immediately after the earthquake and this was followed by a huge sheet of flame and columns of smoke from the sea. Disastrous 'tunamis' following the earthquake, travelled long distances along the Arabian Sea coast. No further particulars about sound are available.

The possibility of occurrence of submarine volcanic eruption in the Bay of Bengal, either in association with or as a result of seismic disturbances or without any known reason, visible or invisible, cannot, therefore, be precluded.

13. Particulars of earthquakes

A summary of the particulars relating to most of the important earthquakes discussed, has been given in Table 3. The values of magnitudes will give an idea about the relative intensities of the shocks.

14. Travel times of abnormal sounds

On the basis of hypothetical origins of sounds discussed in the preceding sections, the times of travel of sounds, due to the earthquakes of 1869, 1897 and 1950, from the source to the different observing stations, have been computed from the available data and given in Table 2. The resulting curves are shown in Fig. 2.

The difference between the times when the shocks were first felt and the sounds first heard are generally available. The absolute times of audibility of sounds in addition to the times of first feeling the shocks have also been reported by some observers. The differences between the two times at each station have been used. To these differences have been added the times of arrival of the seismic waves supposed to have been first felt at the different stations reduced by the period of assumed delay in production of the sound from the time of origin of the shock. It has been assumed that in all cases P was first felt up to $\triangle = 2° \cdot 6$, S from $\triangle = 2°.8$ to $3°.7$ and Sg at larger distances. The positions of epicentres of the shocks of 1869 and 1897 appear to be uncertain. Consequently, it was assumed that the seismic waves started from the positions of adopted origin of sound. This may possibly introduce some minor discrepancy in the travel-times but this is unavoidable.

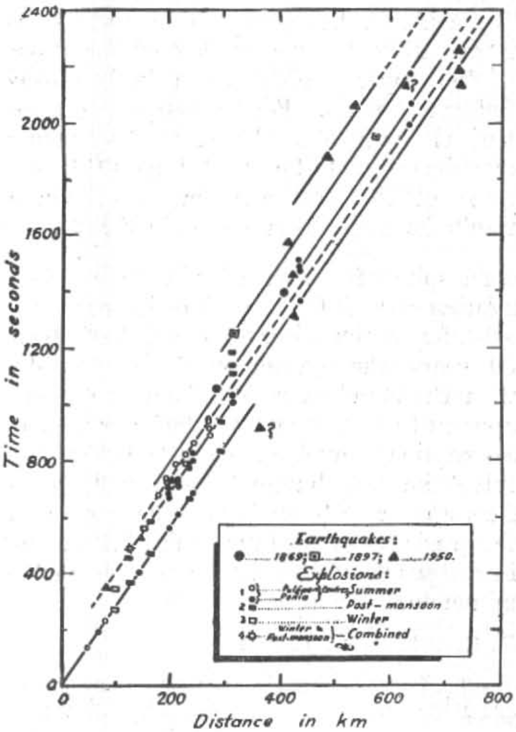

Fig. 2. Travel times of abnormal sounds due to earthquakes

At Monywa no earthquake shock
felt but sound heard at 1915
'the water in the river was fl
The latter was very li
seiches' and on
similar effects
turbances of w
observed at
Uttar Prades
being discusse
observation at
nearly to 2015 to
hand, nothing due

have been observed at this place at 1915 IST. If we, therefore, assume an error of an hour in the reported time we get 2015 IST agreeing with the expected time of arrival of the abnormal sound. Again, at Mogok no earthquake was felt but 2 or 3 sounds were heard between 1945 and 2015 IST. These observations are reconcilable with the expected results only if the beginning of sound is taken as 2015 IST and this has been done provisionally.

The results obtained from explosion experiments in India may be considered as representing the average thermal conditions of the upper atmosphere in India during different seasons. For the purpose of comparison the results relating to the summer experiments (30 May to 2 June 1946) and some of the post-monsoon and winter results have also been plotted in Fig. 2.

In spite of heterogeneity in observations relating to the different earthquakes occurring at different times during a period of about 80 years, the agreement of these results with the standard results from explosions, appears to be reasonably satisfactory. The assumptions involved in calculating the travel-times of abnormal sounds will, therefore, appear to be such as to have reduced the various uncertainties inherent in the investigations of this nature to a reasonable minimum.

15. Remarks about the results

The results deducible from the study are being discussed elsewhere. A preliminary examination shows that the thermal structure of the stratosphere over northeast India and Burma (latitudes 20° to 30° N), inferred from the abnormal propagation of sounds due to earthquakes, is nearly the same as that obtained from the results of planned experiments on explosions carried out in the central parts of India during 1946-47 which involved huge expenditure and colossal efforts of scores of persons over a long period. The India Meteorological Department has been collecting from 1908, information on the effects of earthquakes felt by voluntary observers. The observations are recorded in prescribed form which contains a column for 'sound' due to earthquakes. With a slight modification of the form and method of observation, it should be possible to collect, in course of time, useful materials for the study of seasonal variations of the upper air temperatures in India, without any extra efforts or cost. The accuracy of recorded time and vigilance on the part of the observers, are important and these should be stressed on them.

16. Acknowledgement

Much of the information relating to the earthquake of 1950 used in this paper was collected through the Director, Burma Meteorological Department and the District Officers of the various States in India. Dr. S. K. Pramanik and Dr. A. N. Tandon helped the author to collect the information and evinced interest in the work. The author has pleasure to acknowledge with thanks the help received from these authorities.

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TABLE 1

Particulars relating to abnormal sounds due to earthquakes

Station	(km)	Remarks about sound heard
August 15, 1950		
(1) *Rima*	106	'From high up in the sky to the northwest (as it seemed) came a quick succession of short, sharp explosion, five or six, clear and loud, each quite distinct like ack-ack shell bursting'
(2) *Mohanbari*	128	'Sounds of craker, just before and during shock', 'sound resembled very often whistle, sometimes firing of guns'
(3) *Dibrugarh*	132	'Rumbling sound', 'like firing of cannons just after the shock'; 'a flash of light seen in the northern direction, (Principal, Dibrugarh H. S. K. College),
(4) *Doom Dooma*	147	'Resembling long range cannon firing', 'breaking rock resembling gunfire'; 'after the earthquake'; '5 to 10 seconds after beginning' (presumably after conclusion of main shock and not after beginning, as stated); 'numerous'; 'from northwest to north-east'

TABLE 1 (*contd*)

Station	(km)	Remarks about sound heard
August 15, 1950—contd		
(5) *Bordubi road*	177	'Similar to cannon fire was heard in the air and similar to aircraft underground'
(6) *Jaipur*	180	'Several loud explosions like gunfire'; 'from northeast'
(7) *Langharjan*	185	'Resembling explosion of bombs'; 'just after shock'
(8) *Naharkatiya*	185	'Like gunfire'; 'after the shock'; 'heard by a few only'
(9) *Moderkhat*	189	'Like firing of cannons and also rumbling noise'
(10) *Borhat T. E. & Borhat*	197	'Like bombing after shock', 'similar to the sound of an anti-aircraft gun in action'; 'a number of sounds', 'approximately 30 to 40'
(11) *Dilli Colliery*	203	'Resembling anti-aircraft firing'; 'between northeast and southwest, and northnortheast and southsouthwest'; '20 distinct sounds, all of almost equal intensity'; 'for 20 minutes (according to another report, 15 minutes)'; 'heard 13 minutes after beginning of shock'; 'intervals between successive sounds,—30 seconds to 2 minutes'
(12) *Sapekhati*	209	'Unusual sounds during and after shock, also sound from underground'
(12A) *Kavi Marichatra*	209	'Like cannon fire'; '6 to 7 times'; 'from westsouthwest to northeast'
(13) *Khowang T. E.*	219	'Gunfire, after shock'
(14) *Dipling*	222	'Booming sound during shock and followed by sounds similar to cannon fire'; '8 to 10 in number'
(15) *Sissigaon*	229	'Booming sound during shocks'
(16) *Suprabum*	240	'Explosions due west at an estimated distance of 100 miles'
(17) *Charaideo*	241	'Loud booming'; 'nearly 20'; from northeast'
(18) *Sibsagar*	253	'Sounds like the cracking of bombs'; '6 to 8 in number'; 'from north and northeast'
(19) *Nazira*	255	'Booming sound from northeast'
(20) *Tangpre*	286	'Sounds of explosion'; '2 explosions due west and rest northwest'
(21) *Majuli*	289	'Rumbling noise', 'like firing of cannons'
(22) *Talap*	305	'Booming sound during and after shock'; 'from northnorthwest'
(23) *Jorhat*	306	'Like firing of cannons', 'booming like explosion of bombs'; 'just after the main shock'; 'many'
(24) *Mariani*	307	'Just like the bursting of some petrol tanks'
(25) *Titabar*	311	'Cannon fire reports'; 'immediately after the shock'; 'about 35'
(26) *Mock Chung*	315	'Rumbling noise like firing of cannons'; 'northnortheast'
(27) *Dergaon*	326	'Rumbling noise of cannon'
(28) *Tuensang*	332	'Like firing of cannons'
(29) *Borholla T. E.*	340	'Explosions like heavy artillery fire'; 'at intervals, throughout the night and part of following day'
(30) *Behali*	366	'Firing of cannon'; 'from northeast'; 'heard 7 times'
(31) *Myitkyina*	367	'Variously described as peculiar, mysterious loud explosions, like bombs exploding, booming of distant guns, cannon firing at a distance of 30 to 40 miles'; 'from northwest'; '12 to 16 sounds'; 'heard for a period of 15 to 20 minutes'; 'followed shock immediately', 'one minute after the shock', 'about 15 to 16 minutes after beginning of shock (as estimated from particulars sent by Dr. De Cruz to the author, in a private communication)'; 'heard by all at Myitkyina'; 'longest interval between two sounds,—3 minutes'
(32) *Kongon village*	380	'Unusual sounds resembling explosions'; 'after the shock'

TABLE 1 *(contd)*

Station	(km)	Remarks about sound heard
August 15, 1950—contd		
(33) *Kohima*	393	' Loud explosions', ' rumbling noise like firing of cannons' ; 'from northeast ' ; ' heard 4 minutes after beginning of the shock' (presumably after conclusion of the shock and not beginning, as reported) ; ' loud explosions heard for 20 minutes after the earthquake ', ' heard for a period of 5 minutes '
(34) *Dimapur*	402	' Like bursting of bombs ', ' rumbling noise like firing of cannons'; ' after and during shock '
(35) *Charduar*	414	' Booming sound resembling cannon fire ', ' like falling bombs somewhere during shock ' ; ' loud ' ; ' at a great distance ' ; ' just after ', ' after the great shock ' ; ' towards north', ' from northeast ' ; ' several ' (3 reports)
(36) *Tezpur*	426	' Like firing of cannon ' ; ' from northeast ' ; ' about 6 sounds heard at 2000 to 2005 IST '
(37) *Lumding*	448	' Buzzing sound before and during the shock and booming sound resembling the explosion of guns after the first shock', ' no sound in the beginning, rumbling sound from beneath ground when the shock was severest and during later part ' ; ' 4 or 5 sharp sounds, in quick succession, resembling distant gun firing' ; ' appeared to come from north ' ; ' there were clouds in the sky but no lightning and it could not be differentiated if the sounds were due to clouds or any other phenomenon ' ; ' heard 2 minutes 45 seconds after beginning of the shock '
(38) *Henima*	457	' Like firing of cannons '
(39) *Bhamo*	483	' Explosion of bombs and rumbling of thunder ', ' sounds of explosives or gunfires' ; ' heard in the direction of the village Naton, 52 miles north of Bhamo', ' from north ' ; ' heard for about 5 minutes ' ; ' heard 5 minutes after beginning of shock '
(40) *Sinlum*	490	'Firing of cannons' , ' gunfire was heard by every one during shock '; ' from northwest ' ; ' 3 to 4 sounds ' ; ' for a period of about 10 minutes ' ; ' heard 2 minutes after beginning of shock ' ; ' longest interval between two sounds,—approximately 2 minutes '
(41) *Shwegu*	490	' Very loud booming of distant cannon fire ' ; ' from north to south'; 'about six sounds, heard at an interval of about one minute' ; ' followed 30 minutes after beginning of shock ' ; ' maximum interval between two sounds, —2 minutes'
(42) *Gauhati*	531	' 4 cannon sounds during shock ', ' unusual sounds just like gunfire during and before ', ' one continuous rolling sound like booming of cannons simultaneously with shock '
(43) *Kamalpur*	533	' Booming sounds resembling those of dynamite explosions during shocks '
(44) *Lhasa*	538	' Like gunshots ' ; ' over 30 ' ; ' heard at about 2015 P.M. (cannot be explained by human action)' ; ' heard at a regular interval of approximately 1 to 2 seconds ' ; ' from a southeasterly direction '
(45) *Silchar*	556	' Unusual like shooting ', but according to Civil Surgeon, Cachar, 'sound resembling booming of guns, explosion of bombs etc., were not heard '
(46) *Kanbalu*	598	' Booming of distant gunfires or more appropriately, explosions of mortar bombs ' ; ' from north ' ; ' rumbling sounds of explosions heard for about five seconds ', ' about 2 minutes ' ; ' longest interval between sounds, —fraction of a second ' ; ' no earthquake shock felt '
(47) *Mogok*	630	' Booming of distant but distinct gunfire' , ' firing of cannons ' ; ' echo of vibrations heard from 1945 to 2015 IST ' ; ' from north to south ', ' origin about 20 miles to northeast '; '2 to 3 sounds ' ; ' heard within half an hour ', ' at intervals of 40 seconds each ' ; ' longest intervals between two sounds, —about 10 to 15 minutes ' ; ' no earthquake shock felt'

TABLE 1 *(contd)*

Station	(km)	Remarks about sound heard
August 15, 1950—contd		
(48) *Ye-U*	633	'Distant cannon fire'; 'from north'; '6 or 7 sounds'; 'within about 6 or 7 seconds'; 'maximum interval between individual sounds,—about 1 second'; 'no earthquake shock felt'
(49) *Kani*	704	'Booming of distant gunfires'; 'from northwest'; 'only one'; 'for about 3 to 4 seconds', '2 or 3 seconds'; 'after beginning of the shock'
(50) *Monywa*	730	'Firing of cannons heard by all'; 'booming of distant gunfires and explosions of bombs (heard at 1915 IST)', 'similar sounds heard throughout night till 5 A.M. next morning'; 'from north', 'northwest'; 'about 5 at intervals of 2 minutes', innumerable,' 'one for about 3 or 4 seconds'; 'no earthquake shock felt'
(51) *Demagiri*	757	'Like firing of cannons, but not so loud'
January 10, 1869		
(1) *Lakhimpur*	284	'Accompanied by low rumbling', 'followed by distinct reports like firing of distant cannons', 'shelling', 'explosive noises'; '15 minutes after', 'half an hour after'; 'several'; 'heard every day since 10th'
(2) *Jaipur*	358	'Followed by loud series of reports like artillery'; 'after about 5 minutes'; 'lasted about 5 minutes'
(3) *Dibrugarh*	412	'Sound of distant artillery'; 'repeated peals'; 'in the direction of Sibsagar'; '20 minutes after'
December 31, 1881		
Port Blair	536	'The sounds heard were mistaken for signals of distress and the station steamer at this place was sent for the supposed wreck'
June 12, 1897		
(1) *Comilla*	209	'Distant gunshots resembling Barisal guns'; 'two'; 'from north-east', 'from northwest'; 'before shock'
(2) *Lumding*	225	'Similar sounds as at Kohima'
(3) *Kohima*	313	'Several loud explosions like guns', three loud explosive sounds'; '4 or 5 minutes after', '15 minutes after'; from three-quarter of a mile northwest', 'from south or southwest'
(4) *Wokha*	342	'Similar sounds as at Kohima'
(5) *Mawlu (Katha Dist)*	533	'Booming sounds'; 'after'; 'four'
(6) *Tagaung*	555	'Booming sounds'; 'from northwest'
(7) *Pongong*	559	'Booming sounds'
(8) *Theingale*	575	'Twentyfive distinct booms like cannon shots, and some less distinct rattling later'; 'from northnorthwest'; 'about half an hour after water was found lapping up against bank of a river and trees were shaking'; 'interval between sounds,—3 or 4 seconds'; 'no earthquake shock felt'
(9) *Sigyaing (Katha Dist)*	—	'Four loud reports before shock'
(10) *North Bengal*	—	'Reports of distant artillery'
May 23, 1912		
(1) *Salin*	281	'Great noise like firing of cannons'; 'after'; 'three times from northeast at Sagu'
(2) *Sagu*	290	
(3) *Minbu*	297	

TABLE 2

Travel-time of abnormal sounds due to earthquakes

Year of earthquake	Station	Distance of reporting station from source of sounds (km)	Interval between time of first feeling the shock and hearing (*i*) first sound and (*ii*) last sound (sec)	Travel time of sounds (sec)
1950	Rima	106	—	360
1950	Doom Dooma	147	580	525
1950	Dilli Colliery	203	780	730
1869	Lakhimpur	284	1050	1064
1897	Kohima	313	1200	1260
1950	Myitkyina	367	900	920
1869	Dibrugarh	412	1325	1400
1950	Tezpur	426	(*i*) 1260 (*ii*) 1560	(*i*) 1306 (*ii*) 1606
1950	Shwegu	490	1800	1876
1950	Lhasa	538	1980	2059
1897	Theingale	575	1800	1952
1950	Mogok	630	—	2135
1950	Monywa	730	—	(*i*) 2130 (*ii*) 2250

TABLE 3

Particulars of some important earthquakes

Year	Date	Time of origin *h m s*	Epicentre	Magnitude
1819	June 16	18 45 00 to } LT 18 50 00	Cutch	$8\frac{1}{4}$ to $8\frac{1}{2}$(?)
1869	January 10	10 50 02 GMT	26 N 92·7 E(?)	—
1881	December 31	01 17 30 ,,	15 N 89 E	$8\frac{1}{4}$(?)
1897	June 12	11 4 45 to } ,, 11 5 30	27·7 N 90·2 E(?)	$8\frac{1}{2}$(?)
1905	April 4	00 50 00 ,,	33 N 76 E	8
1906	April 18	13 12 00 ,,	38 N 123 W	$8\frac{1}{4}$
1912	May 23	02 24 06 ,,	21 N 97 E	8·0
1918	July 8	10 22 07 ,,	$24\frac{1}{2}$ N 91 E	7·6
1929	June 16	22 47 32 ,,	$41\frac{3}{4}$ S $172\frac{1}{4}$ E	7·6
1930	May 5	13 45 57 ,,	17 N $97\frac{1}{2}$ E	7·3
1930	July 2	21 03 42 ,,	$25\frac{1}{2}$ N 90·0 E	7·1
1930	December 3	18 51 44 ,,	18 N $96\frac{1}{2}$ E	7·3
1931	August 24	21 35 22 ,,	$30\frac{1}{4}$ N $67\frac{3}{4}$ E	7·0
1931	August 27	15 27 17 ,,	$29\frac{3}{4}$ N $67\frac{1}{4}$ E	7·4
1934	January 13	08 43 18 ,,	$26\frac{1}{2}$ N $86\frac{1}{2}$ E	8·3
1935	May 30	21 32 46 ,,	$29\frac{1}{2}$ N $66\frac{3}{4}$ E	7·5
1941	June 26	11 52 03 ,,	$12\frac{1}{2}$ N $92\frac{1}{2}$ E	8·1
1945	November 27	21 56 50 ,,	$24\frac{1}{2}$ N 63 E	$8\frac{1}{4}$
1950	August 15	14 09 30 ,,	28·6 N 96·5 E	8·6