NOTE ON THE SOUND PHENOMENA OF EARTHQUAKES.

BY JOHN MILNE.

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1.—GENERAL CHARACTER OF THE SOUNDS.

Many observers who have experienced heavy earthquakes have given an account of the sounds which have preceded, accompanied, or occurred subsequent to the disturbance. Some compare these sounds to subterranean thunder, others to the rattling of chains, others to the escape of steam. Some compare what they heard to an explosion, to the rumbling of a heavy waggon or to the rattle of musketry.

In short the sound phenomena of earthquakes appear to be as variable in their character as the earthquakes themselves.

Old writers called these disturbances in the air, airquakes. The following are a few examples of such disturbances.

A correspondent of the *Gentleman's Magazine* of 1750 describing an earthquake felt in Lincolnshire on August 23rd of that year, says: "suddenly there came a sound from the earth as of a rushing mighty wind and it shook all the house with everything that was therein."—[*Gent. Mag.*, XX. p. 456]. A writer on the earthquake of New England in 1727 says that the accompanying sound as described by many, was like that produced by carts and coaches rolling over pavements, or shooting out loads of stones. He himself thinks that it was a "*sonus sui generis*," and there is no describing it.—[*Phil. Trans.* XXXIX.] The sounds which accompanied the Owen's Valley Earthquake of 1872, are said to have been more like the crackling and grinding of rocks under tension than to explosions of detonating gases.—[*Am. Jour. Sci.* IV. 1872.] In a description of the Jamaica Earthquake of 1692 the sound which foreran or immediately accompanied the shocks is said to have been like that produced by putting the tongue to the top of the mouth and pronouncing *hur-r-r-r-r*.

The New England Earthquake of November 18th, 1755, was preceded for about one minute by a roaring sound.—[*Phil. Trans.* L.]

A sharp earthquake felt on January 30th, 1739, at Halifax in Yorkshire is described as ending with a "hizzing, hollow report, and quivering of all things on the surface."—[*Gent. Mag.*, 1739.] The sounds which accompanied the London Earthquake of February 8th, 1749, are described by various observers as being like thunder,—like the falling of heavy bodies,—as an explosion produced by the blowing up of a mine—as a rushing noise—like 10,000 cannon—a dull sound —the rumbling of a cart.—[*Gent. Mag.*, XXIII. 1753.]

It is probable that the nature of the sounds which are heard depend in a large measure on the position of the observer relatively to the origin, to the intensity of the disturbance, and the nature of the rocks through which the disturbance is propagated.

In a description of the earthquakes which shook Maestricht in 1751, we read that when the shocks were slight the preceding noise was like that of a cart deeply loaded, but when they were strong they resembled the sound of a coach rolling swiftly. —[*Gent. Mag.*, XXVII. p. 508.]

From the account of an earthquake which on October 23rd, 1858, shook New York, we see that observers differently situated described the sound phenomena which they heard differently. At Buffalo the sound is said to have been like that produced by a multitude of carriages rapidly drawn underground or the dull sonnd produced by dumping material. At Toronto and Lockport the sound also was rumbling.

At Fredonia the noise was sharp as if produced by the falling together of pieces of furniture. At Erie the sound is described as having been like that of heavy waggons passing over frozen ground, &c.—[*Am. Jour. Sci.* XXVI. 1858.] No sound was heard to accompany the Neapolitan Earthquake of 1857 excepting in a limited area near its centre.

That the area over which sound is heard is chiefly confined to the neighbourhood of the origin is common to many earthquakes. Humbolt tells us that the great shock of the earthquake of Riobamba (4th February, 1797), which is probably the most terrible phenomena of its kind of which we have records, was not accompanied by any sound whatever.

The tremendous noise (el gran ruido) heard beneath Quito and Ibarra occurred twenty minutes after the destruction at Riobamba.—[*Humb. Cosmos.* I., p. 203.]

In a like manner fifteen minutes after the earthquake of Lima and Callao (October 28th, 1746) a subterranean noise like a thunder-clap was heard at Truxillo.—[*Humb. Cosmos.* I., p. 203.] The occurrence of sounds *after* a shaking has been felt, are exceptional, and it is not unlikely that they are independent phenomena.

Of subterranean sounds like those which accompany or precede earthquakes, occurring in earthquake regions, we have numerous examples.

On April 30th, 1812, a noise resembling that of thunder was heard, unaccompanied by an earthquake, in the valley of the Orinoco. It extended over an area of 9,200 square miles. At the same time the volcano of S. Vincent in the Antilles commenced to erupt.—[*Humb. Cosmos.* I. p. 204.]

In the valley of Visp in 1855 and 1856, and even up to 1861, sounds unaccompanied by earthquakes were heard.—[*Am. Jour. Sci.* XXXVII. p. 1.]

A remarkable instance of uninterrupted subterranean noise unaccompanied by earthquakes is one which continued for about a month in Guanaxuato, commencing about midnight on January 9th, 1784. The district over which it was heard was only a few miles in area and it died out gradually as it had begun. The sounds were like slow rolling thunder, interrupted with quick claps.

Almost all the inhabitants were seized with a terror which caused them to leave the city. Humbolt tells us that when the terror was at its height the magistrates issued stringent measures punishing the flight of a wealthy family by a fine of 1,000 piastres and that of a poor family with two months' imprisonment, all fugitives being brought back by the militia.—[*Humb. Cosmos.* Vol. I., p. 205.] These underground noises or *bramidos*, Fuchs says, are common in Nicaragua and Guatemala, where heavy thunderings will sometimes continue for weeks.

The noises which are attendent on earthquakes seem in the majority of cases to have *preceded* the shaking of the ground as was the case for instance in the Lisbon Earthquake of 1755.

In the Tokio seismic area, sounds accompanying earthquakes are rare. Although the author has observed many earthquakes when sounds are said to have been heard, it has only been once during a period of several years that he can say that he distinctly heard a sound. This was on March 11th, 1881, when a sound between a hissing and rumbling, was heard. Other instances have come before the author's notice where residents in Tokio have heard a rushing noise before an earthquake, but not a single instance where it has been observed after the disturbance.

One simple explanation of this phenomena, for a large city like Tokio, situated on alluvium through which we know that a shock may sometimes travel slowly, is that a disturbance reaching one side of the city, by shaking shutters and other loose objects may create a rattling or roaring sound which will cross to the opposite side of the city at a quicker rate than the motion is propagated through the soil. From my own experience, however, the character of the noise is hardly that which would be expected to originate from a cause like the one just suggested.

Noises which will not admit of an explanation like the above inasmuch as they occur in country districts are common in certain portions of Japan, as for instance at Kamaishi 120 miles N.N.E. from Tokio.

This place is situated on the sea coast at the mouth of a narrow valley bounded by steep hills running back inland. Almost all the shocks at this place are heralded by a rumbling roar which it is said have sometimes lasted two minutes before the shaking commences. A noticeable point which has been remarked upon is that the greater the noise the less has been the shock, a fact which we may remark is paralleled by explosions in mines. Sometimes there are rumblings without any shocks.

In Yamaguchi Ken in the South of Japan some years ago during a period of unusual seismic activity, phenomena similar to those at Kamaishi were observed. And to this might be added the phenomena which occurred so recently in connection with the destructive shocks at Agram.

The nearest parallel to these explosive noises appears to be the throbbing and mutterings of a geyser like those which may so often he heard at the well known geyser in Iceland, where probably owing to the sudden evolution and condensation of steam, sounds and shakings are produced, often preceding the final pulse which causes the eruption. In a few instances the sound which accompanies an earthquake appears to have been transmitted to great distances. Some writers affirm that the rumblings which have been heard in mines have been more intense than those which were heard upon the surface. The earthquake of March 15th, 1835, which took place at St. Martha, in Columbia, was accompanied by detonations which were heard over an area of 350 miles.

A curious fact mentioned by Fuchs in connection with these sounds is that during the earthquakes at Brussa the vertical shocks were not accompanied by sounds whilst the horizonal shocks were accompanied with noises. This observation it must be observed is contradictory to many other observations, as for instance those of Signor Abella of Manila, who in 1881 when seeking for the origin of the disturbances which had so severely shaken the province of Neuva Viscaya, arrived at the conclusion that where vertical motion had occurred which was above the origin, it had been simultaneously accompanied with sounds. The farther he receded from this origin, however, the greater became the interval between the motion and the sound.

Cause of Sounds.

On account of the want of accuracy and detail in the various observations which have been made with respect to the phenomena which have been described, it appears as yet impossible to assign for them an originating cause which shall be free from criticism. It has been suggested that certain of the sounds are the result of disturbance on the surface by the shaking of buildings and other objects—noises like detonation and thunder may possibly be due to explosions of steam—noises with a metallic ring, a grinding, whistling, or rattling, Fuchs suggests may be due to the friction between dislocated portions of the earth crust.

Mallet attributes the origin of the Neapolitan Earthquake in 1857 to the inrushing of steam into a fissure which in consequence was rent open to the right and left to form a cavity. During the rending, rushing rolling sounds were produced which, however, varied as might be expected with the positions of the various observers.

To these explanations another might be added founded on some of the recent observations of earthquakes, which show that the stronger shocks are preceded by a series of rapidly recurring tremors. These tremors as recorded by a seismograph commence with a frequency of about 6 per second but become slower before the shock takes place. They extend over an interval of time closely corresponding with the interval of time by which sounds usually precede earthquakes. From General Abbot's experiments it would seem that still smaller tremors precede those which are recorded by seismographs. These small motions, although in every probability felt by some of the lower animals like pheasants, which may be often heard to scream before a shock, are usually unnoticed.

If we admit that motions of this description have a period of over 16 per second we see the possibility of rocks emitting a musical note.

A remark of Dolemieu when describing the Calabrian Earthquake of 1783 bears upon this point. He says that in the granite regions the sound was heard before the shock was felt, but in the alluvial plains the reverse was the case.

The explanation of this may be that the sound was only produced on the granite district, and that this after it reached the boundaries of the alluvium being so longer produced, it travelled through the air at a rate less than the motion through the soil.

In Japan also it may be remarked that the regions where sound accompanies earthquakes consist of hard plutonic and metamorphic rocks, whereas areas like the Tokio plain where sounds are but seldom heard, consist of alluvium.

The sounds emitted by the vibrations of glass rods, and the banks of musical sand in the Sinai Peninsula have a relation to this question.

One of these banks, described by Col. H. S. Palmer, R.E., is about 200 feet high and 80 yards wide. It is situated about 5 miles north of Tor. By wind, heat, passing travellers, and other causes, the sand gradually rolls down the surface of the bank in thin waves producing a deep swelling vibratory moan gradually rising to a dull roar. It may sometimes be likened to the noise produced by the rushing of air into the mouth of an empty metal flask. The sand which is quartzoze, gives out the greatest sound when heated. Similar phenomena have been observed near Cabul and on the plains of Arequipa. [Report of British Association 1871, p. 188.]

The fact that miners underground have heard these sounds as if they were above their heads, whilst those on the surface thought the sounds came from the earth, is a fact tending to support the suggestion here advanced.—[*Phil. Trans.* XLIX., p. 546.] Viz., that the majority of earthquake sounds are produced by short period surface vibrations of the earth and these vibrations are portions of and continuous with the earthquake that accompanies the sound.

Use of Sound Observation.

When underground noises precede earthquakes, as they usually do, these phenomena at once become timely warnings of approaching danger. Instances of this will be quoted further on.

Professor J. Henry, in a note upon the seismic disturbances in North Carolina, remarks that if an area is being depressed the tension of the rocks would cause deep-seated cracks with attendent noises, whereas where the land is rising these would be near the surface. [*Ann. Rep. Smithsonian Inst.* 1874, p. 254.]

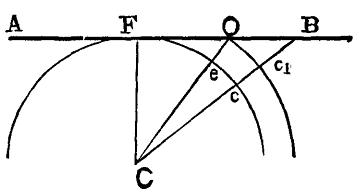
Subterranean noises might therefore possibly indicate depression, whilst noises near the surface would indicate elevation. From the duration of a sound and from its character as observed at different stations, important deductions may be made with regard to the area from which an earthquake originates.

The principles which guide us in such investigations are as follows:—

First, let us assume that *the sounds originated at the origin of the earthquake and were transmitted to the surrounding districts through the air.* And secondly, that the time at which the sound was heard at a number of stations round the origin was also known. If we also know the difference in time between the sound and shock at the different stations we have the means of increasing the methods of calculation. With these we are in the same position to determine the origin of a shock, assuming it to originate from a point, as we are when we have time observations at several stations upon disturbances on the land or in the ocean. (See Earthquakes, by J. Milne, p. 200-208. International Scientific Series.)

One great assistance is knowing the velocity with which sound is transmitted through the air. If, however, from the form of our isoseismals or curves of equal effect, or from other reasons we are led to the supposition that the disturbance originated from a fissure certain modifications must be introduced in the calculations.

For instance let us take the case of a fissure which by an explosive effort is rent open simultaneously along its length. In such a case observers situated on a line bisecting such a fissure at right angles would have a single sound, the duration of which would be shorter the further the observer was removed from the origin. Observers situated to the right or left of this bisecting line would hear a sound lasting over an interval taken for sound to travel the difference of distance between the nearest point and the farthest point on the fissure from the observers' station.



Thus, if *A B* represents a fissure which is rent open simultaneously along its length, the duration of the sound produced by the rending as heard at *C* would be equal to the time taken by sound to travel the distance *C B*—*C F* or *B c*. Another supposition which may be made is that the fissure is rent open to the right and left from a central point *O*. To take a general case, let the observer be situated at some eccentric point *C*. From centre *C* describe two arcs one passing through *O* and the other through *F*, the nearest point on the fissure to the observer at *C*. If the interval taken to rend the fissure from *O* to *F* is greater than the time taken for sound to travel the distance *Oe*, then the duration of the sound will equal the time taken for sound to travel from *B* to c_1. If this interval is smaller than the time taken to travel through the distance *Oe*, then the duration of the sound is equal to the time taken to travel the distance *B c* plus the time taken to rend the fissure between the points *F* and *B*.

When we have a large number of observations on the duration and nature of sounds which are heard at the time of an earthquake the value of these observations must be very great. If the tremors which so often precede a large shock are produced by a rending action during the formation of a fissure, observations on their duration as experienced at different stations might be employed in a manner similar to the sound phenomena.

If it should be definitely shown that in a given case the sound phenomena were produced by the *transit* of the disturbance, these latter remarks will be inapplicable.

The sound phenomena of earthquakes form a branch of seismology which has hitherto been greatly overlooked, the investigation of which will undoubtedly yet be made to yield facts of great importance.