

M. DE BALLORE'S CALCULATIONS ON EARTHQUAKE FREQUENCY.

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In the *Archives des Sciences Physiques et Naturelles*, Geneva (Tome XXII. 1889), is a short but comprehensive paper on earthquake frequency, by M. F. de Montessus de Ballore, Capitaine d'Artillerie. It appears to be the first of a promised series, in which their author proposes to discuss the cosmic and meteorological relations of earthquakes. As a first step to the study of this grand theme, he has compiled from all accessible sources a vast chronological catalogue, in which also the magnitudes of the earthquakes chronicled and the times of their occurrences are as fully as possible noted.

In the paper just published M. de Ballore has applied his very complete seismic statistics to two problems which have often been discussed by other seismologists. These are the questions as to the existence of a periodicity during (1) a solar day and (2) a lunar day: In other words, do earthquakes occur more frequently during the night than during the day or less frequently? And do they occur more frequently nearer the times of lunar culminations?

The idea that earthquakes happen often at night is one that is pretty general in earthquake countries. Year after year it has been customary to discuss the Japanese catalogues with

special reference to this question ; and the conclusion to which Professor Milne has come is that the apparent preponderance of night over day earthquakes is really a personal equation of the observers, who are better able to appreciate a moderate earthquake during the still night than during the noisy day. Instrumental records declare no night maximum.

M. de Ballore comes to the same conclusion. In five of the seven groups into which, for sound scientific reasons, he has divided the shaken regions, the numbers and curves alike show a night maximum and a day minimum. The grand mean for the first six groups, including 37,511 earthquakes, shows that the ratio of the day to the night earthquakes is as 8:10. By far the great majority of these earthquakes were not instrumentally recorded ; so that the problem is really as much one of human sensitiveness to seismic influence as one of earthquake frequency. M. de Ballore concludes in fact that this ratio of 8 to 10 represents the relative loss of day earthquakes caused by the physiological conditions of human activity.

In group VII., which was excluded in the above grand mean, a distinct preponderance of day earthquakes is shown. But group VII. consists of the Italian geodynamic stations, at which delicate self-recording seismographs are in use, working day and night. A large number of small tremors are registered, in which M. de Ballore thinks real seismic disturbances are mingled with motions due to human operations. Separating out the smallest disturbances, those namely of grade I. on the Rossi-Forel scale of intensities, we get a marked diminution in the apparent day preponderancy.

Then, again, an instructive corroboration of the conclusion given above is obtained by a discussion of the earthquakes in intensity groups. These are ten in number, according the Rossi-Forel conventional scale ; No I. being the small instrumental ones just mentioned, and No X. being disasters. The

ratios of the day and night earthquakes for the different intensities are as follows :—

INTENSITY.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Ratio of day to night.....	1·8...	·73...	·60...	·67...	·65...	·76...	·81...	·85...	1·27...	1·02

Thus we see at a glance that it is for intensities III., IV., and V., that the night maximum is specially obvious. Now these intensities are just the intensities that would be apt to be missed during the noisy day. The apparent day maximum for earthquakes of intensity I. has been already explained—these being all registered by delicate seismographs. In the higher intensities there is a tendency to equality—just as we should expect, since emphatic earthquakes will be as evident during the day as during the night.

So far, then, we have no evidence in support of the somewhat prevalent notion that earthquakes love the darkness rather than the light. Statistics, rationally interpreted, teach that the frequency of earthquakes is independent of the daily solar cycle.

Professor Perrey, of Dijon, was the first to discuss earthquake frequency from, so to speak, a lunar standpoint. From his discussion, he concluded that earthquakes were more frequent at new moon and full moon than at half moon; more frequent at new moon than at full; more frequent when the moon was in perigee than when in apogee; more frequent at times of meridian passage of the moon than at other times.

Such a conclusion fitted well in with the geological ideas prevalent at the time Perrey made his calculations. The hypothesis of a fairly solid but thin crust resting on a fluid centre within the earth was a very popular one. What more natural then than the tracing of subterranean disturbances to tidal actions of the sun and moon? Since Perrey's time, no systematic attack has been again made on the problem; yet there has been a strongly growing disposition to discredit the conclusions deduced by him. No discussion can be satis-

factory which is not based on a vast statistical catalogue. Perry's Catalogue is now forty-five years old; and in these forty-five years a much more thorough system of observation has been instituted. Indeed it is well within this interval that earthquake observatories have been established and organised. With so much more material to hand, a fresh investigation on Perrey's lines is well worth a venture.

M. de Ballore has, in the second part of his paper, given the results of his calculations into the relation (if any) between earthquake frequency and lunar culminations. His conclusion is wholly negative. Dividing the whole lunar day of 24h. 50m. into eight parts, of which the middle of the first corresponds to the time of the superior culmination, he finds the following grand total of earthquake distributions:—

Eighth.	No. of Earthquakes.
I.	5,579.
II.	5,558.
III.	5,611.
IV.	5,508.
V.	5,802.
VI.	5,564.
VII.	5,571.
VIII.	5,662.

To base any conclusion as to a periodicity in earthquake frequency on such numbers would be impossible; so that, so far as daily cycles of lunar change are concerned, Perrey's views get no support from M. de Ballore's statistics.

I may refer briefly to an argument bearing on this very point, which will be found in my paper on Earthquake Frequency.

Whatever may be the internal construction of the earth, we know it to be, as a whole, extremely rigid. G. H. Darwin's calculations have proved the non-existence of any appreciable tidal deformation of the earth under the influence of long period cycles of lunar and solar action. Such short period cycles as

are involved in the rotation of the earth cannot be expected to have the same importance under the dynamic circumstances of the problem. It would be a very surprising result indeed, if any appreciable increase in earthquake frequency should occur at the times of meridian passage of the sun or moon. Even if the moon had any such influence, the effect would certainly lag considerably behind the cause. The ordinary tidal wave passes the meridian in open sea about 2 hours after the moon; and any possible tidal disturbance in the earth would lag behind the moon to a much greater extent. Even if we established a half daily (lunar) periodicity in earthquake frequency, it would be impossible to refer it certainly to any definite position of the moon.

It is quite possible for earthquake frequency to be affected by various lunar changes. By this I do not mean that the action of the moon might be a direct cause of earthquakes. But it might be an accelerating factor in its influence on seismically sensitive regions. Its differential tidal stresses might, so to speak, shake a region, already under seismic strain, into seismic activity. But we should hardly credit short period cycles with such powers. In long period tidal actions, however, effects of the kind indicated may well show themselves. We shall therefore await with great interest M. de Ballore's further researches on earthquake frequency, and especially those in which the lunation and apsidal cycles are discussed.
