THE GREAT EARTHQUAKE OF LISBON.

By E. J. Pereira.

[Read October 3rd, 1887.]

On the 1st November, 1755, at about 9.40 a.m., the town of Lisbon was almost entirely destroyed by one of the most appalling and calamitous earthquakes that ever occurred in Europe. This earthquake was followed by several other violent shocks, which caused a tremendous loss of life, calculated to have been between fifty and sixty thousand persons. The most extraordinary peculiarity connected with this event was that the weather, during ten days preceding the earthquake and the week following it, was remarkably clear and mild. It was also unusually dry for the time of the year.

Many accounts have been published of this memorable catastrophe, the effects of which were felt even as far as Germany and Ireland; but most of these accounts are filled with incidents of individual sufferings and hardships experienced during the catastrophe, rather than with any particulars of the phenomena observed during that extraordinary visitation.

There exists, however, a very rare pamphlet published in Lisbon in 1756 by a printer called Manoel Soares, and entitled: "A new and faithful account of the earthquake experienced in Lisbon and over Portugal on the 1st of November, 1755, with a few curious remarks and explanations of its causes," reproduced in the *Comercio de Portugal*, (October 31st, November 6th, 7th and 11th, 1886.) The author of this very interesting pamphlet gives a full description of all the circumstances preceding and following the earthquake, and informs us that, after the second shock a strong gale of wind

sprang up from the north-east, and a tidal wave swept along the coast. He also mentions that when the earthquake occurred, the weather was calm, the sky clear, the thermometer stood at 14 degrees (Reaumur) above freezing point, and the barometer marked 27 inches and 7 lines.

After giving his own theory on the causes of this extraordinary phenomenon, which he attributes to currents of air produced by subterranean explosions of condensed gas, the author proceeds to inform his readers of some remarkable observations made by him on that occasion, which I cannot better expound than by giving an abstract from the original narrative :—

The first shock, although preceded by a dreadful rumbling noise, was so slight that it scarcely frightened anybody, although it lasted over one minute. However, after an interval of from 30 to 40 seconds, the next shock came so violently, that houses began to crumble. The day turned dark owing to the thickness of the dust, and the tremors continued for a little over two minutes. After a lapse of less than a minute, the earthquake recommenced with great force. The houses, which had resisted the previous shocks fell with a terrible noise, the sun became dark, and the oscillating soil seemed to threaten utter destruction. The groans of the dying, the cries of thousands imploring divine mercy, the incessant shocks, and the darkness, all helped to increase the horror, fear, and tribulation. At last, after two or three minutes of the greatest suffering, the bustle subsided. The height of misery, however, had not yet been attained. Scarcely, says the author, had we begun to breathe more quietly, when a fresh shock came to foretell further disasters. A strong north-easterly gale sprang up ; and the sea rose suddenly and afterwards retired with equal haste. It carried away all it met, and then threw back all it had carried. The infuriated waves invaded the streets, squares, and gardens. Many of the people who sought refuge on the banks of the river were swept away by the sea without there being any one able to assist in saving

them. Those who jumped into the boats foundered with them; and the river Tagus, with its ebb and flow, was soon converted into a confused forest of entangled masts, and a horrible cemetery of floating corpses!

"Nothing can describe the deplorable condition in which the city of Lisbon was left. The town was first destroyed by the earthquake, then razed by fire, and pillaged by robbers. On the sites of wealthy palaces and mansions nothing remained but gloomy ruins and mounds of stones and rubbish.

"The first ten or twelve days after this terrible event, the tides had no regular course. Sometimes they were late, and at other times slow. There were at times seven and eight hours of high water, and then three or four hours of low water. During all this period the earth shook with more or less violence. On the 8th day at 5.30 a.m., the earth shook with fearful impetus, but the shock lasted very little time; the 15th day at 5 a.m. there was a severe shock; the 16th day at 3.30 p.m., the explosion was terrific. During the night of the 17th and 18th day a fearful underground noise was heard towards the north, followed by an earthquake; and on 8th December, between 11 and midday, all the people fled precipitately from their houses.

"On the 31st October the tide was two hours later than usual, and nearly two hours on 10th December. A pilot, having observed that the delay of the tide on 31st October was followed by such a tremendous earthquake, and noticing that the same thing occurred on the 10th December, went about the populous quarters of Lisbon, warning everybody not to remain under a roof that night, lest there might be an earthquake. This prediction turned out true; for on the 11th, at 4 a.m., the earth shook twice with great violence. A dreadful rumbling noise preceded these two explosions; but the duration of both shocks was not more than a minute and half. On the 21st of the same month, at 9 a.m., the earth trembled twice. The first shock, although severe, was followed by a

still more fearful explosion; and, although these movements lasted only one minute, they caused a good deal of destruction.

"As the earthquake of the 1st of November proceeded from south-west to north-east the sea followed the same direction; and this was the salvation of all the lower part of Lisbon; because, the waves breaking against the entrance of the river, they there lost their greatest force.

"Several ship captains, who were out at sea on the 1st of November, reported that at thirty, forty, and sixty leagues out, they had suddenly felt their ships jerk so violently that it seemed as if all the parts that composed them were going to pieces; and that they saw the guns jump on their carriages. The cause of this can be explained in the following way. The bottom of the sea is a continuation of the land; if this land is agitated it communicates its movement to the sea that covers it. The ships partake of this movement, because, floating in a fluid they balance a column of water equal to their mass; and the water moving with an irregular motion, the ship which forms part of the same fluid, follows the irregularity of the movements that agitate it.

"The disastrous effects of the earthquake of the 1st November were felt all over the kingdom of Portugal, but more especially in the province of Algrave, where the towns of Faro, Lagos, and Silves were completely destroyed, and Tavira, Albufeira, and Castro-Marim in greater part ruined.

"It is said that a portion of Lisbon Rock gave way, as also portions of the coast at Cascaes and Peniche.

"It has been remarked," continues the author, "that places near the sea-side have suffered more by these earthquakes than those inland. This observation has often and repeatedly been made; and it appears to me that the cause is this. Perhaps the quantity of inflammable matter deposited in the bowels of the earth is so disposed, that the mere contact of water can inflame it. When the sea rises higher, either during

high tides, or when the wind pushes it further, it may get introduced into various subterranean canals; and the water may thus penetrate where it never can without some such cause. I am persuaded that, in the same way as the movements of the moon have influence on the tides, so they may produce an equal influence on earthquakes and volcanoes; I have observed that the most violent explosions are always felt at syzygies and quadratures of the moon.

"I am also persuaded that the heat of the sun contributes towards the earthquakes that we are feeling daily. We find that the heat of the sun helps to inflame the materials which chemists mix in order to imitate the causes of volcanoes. What confirms me more than ever in this opinion are the repeated observations I have made that when a cloudy and rainy day is followed by a burning sun, there always occurs a violent explosion.

"I am convinced that the cause of so great a destruction of buildings on the 1st of November, was due to the strange character of the shock, which was at times vertical, and at times horizontal. In fact the movements were so contrary and opposed to each other that the strongest and thickest walls got separated, and crumbled. But although the shock at the time of the earthquake was dreadful, still I am sure it would have done less damage if the houses were built with more security. Unfortunately most of our houses have the following defects:—

"1.—The blocks of the angles or corners of the house are not in union with the walls, because they have not sufficient width or thickness.

"2.—On an equal level the stones have not an uniform height.

"3.—As the stones forming the lintel of the window, have not more width than the lintel, nor the thickness of the frame, they do not fit the wall, except by an angle which is in most cases roundish.

"4.—The walls are built with various sized stones, and the hollows are filled up with a bad mixture of clay, sand, and water.

"5.—The clay is allowed to cool, long before it is used, and it therefore gets dried and calcinated.

"6.—Very often the mortar is prepared, not with sand, but with the earth obtained from the foundations.

"7.—The sand used by our bricklayers is invariably sea-sand.

"8.—The clay obtained from the oven is prepared with salt water, by which process the saline particles mixing with the clay and sand prevent the walls from getting united and firm.

"In conclusion, the wood frame of the roof being always built without beams, the rafters lean against the wall itself; so that the weight of the roof and ceiling has the effect of a wedge which pushes the walls outwardly. At the commencement of an earthquake the walls get detached from the rafters, and the roof sinks; then the walls returning to their natural position meet the roof and, with the following oscillation, lose their equilibrium, and fall.

"It was noticed that large buildings suffered more than small ones, during the earthquake. For a reason easily understood this must always be the case. In the horizontal movement of the quake, all houses describe an arc, which is wider in proportion to the height of the house and its greater distance from the centre. This can be explained in the following way. Similar arcs are related to similar circles as circles are to their diameters.

"Diameters have between them the same proportion of rays. Therefore similar arcs have similar rays. The height of a house is the ray of a circle described by that house in its oscillation; consequently, the larger the arc the greater the ray, and the worse the damage. Moreover, similar velocities are like equal times; and the spaces being the arcs described by the roofs of the houses, the velocity is therefore greater on the

roof of houses; and it decreases towards its foundations. It is also greater in a high house than in a low one. Ruin is, for that reason, more imminent with large buildings.

"Another remarkable fact observed during the earthquake was that in the same street some houses were not in the least damaged, whereas others were completely destroyed.

"The only way in which this can be explained is by supposing that the underground vaults are raised with more violence in some places than in others, and that the direction of the effort depends on the horizontal or inclined position of the vault; so that it is from its extent, thickness, the nature of its formation, and the way in which the buildings are lined, that we are to account for their being in some places safe and in others completely ruined.

"In our history there are three remarkable periods relating to earthquakes. The first is the earthquake which occurred in Portugal in the year 1309; the second, the shocks and oscillations which did so much damage to Lisbon in 1531; and the third the disastrous earthquake of which we had such a sad experience in 1755. These three periods give me the idea of a hypothesis, which may appear very extravagant to many people, but which may not be without foundation. I am persuaded that between the years 1977 and 1985 there will be a great earthquake in Portugal.

"It has been observed that at Lima, a city in Peru, there is a formidable earthquake every sixty years. Why should not the same fact be applied to Portugal, in the history of which we find three seismic periods, with equal intervals of two hundred and twenty-two years.

"The following (says our author) are the most remarkable earthquakes that have occurred in Portugal, and more especially in its capital, the city of Lisbon: 22nd February, 1309, a terrible shock at daylight; 9th December, 1321, three very severe earthquakes; 24th August, 1356, the earth shook for 15 minutes and many houses were destroyed in Lisbon.

"7th February, 1531. Fearful shocks, causing many victims in Lisbon, and forcing people to live in the open air, for fear of being buried under the ruined houses. On the 26th of the same month there was a terrible shock in Lisbon, which was felt within a circle of seventy leagues. In the city about fifteen hundred houses were destroyed, killing scores of people. Churches were ruined, and ships sunk in the river. The shocks lasted several days; causing the Royal family and a large portion of the inhabitants to retire to the country in the neighbourhood.

"On the 28th January, 1551, an earthquake destroyed two hundred houses in Lisbon, killing over two thousand persons.

On the 7th June, 1575, at about noon, the land about Lisbon began to shake so severely that the inhabitants cleared out of their houses.

"In 1597, on 21st July, during an earthquake, the hill in Lisbon, known as St. Catherine's, sank and disappeared quite suddenly in the river.

"On the 28th July of the following year (1598) at 5.30 p.m., the people in Lisbon were startled by a smart shock, followed by two milder ones.

"26th October, 1699, severe earthquakes were felt in Lisbon, which continued intermittingly during the greater part of November.

"On the 26th of May, 1719, shortly before sunrise and during an eclipse of the moon, a fearful noise followed by an earthquake of three or four minutes' duration occurred in the southern part of Portugal. Another severe shock, on the 27th December, 1722, ruined many towns in the same part of the Kingdom.

On the 12th October, 1724, at 2.45 p.m., a very smart earthquake was felt, not only in Lisbon but all over the country; and finally the calamitous shock of the 1st November, 1755, of which the above account has been given, and which caused,

not only destruction and ruin to Lisbon, but carried desolation to many flourishing towns in its neighbourhood."

In concluding the abstract I have given of the pamphlet on the great earthquake, I may perhaps add that, since that memorable event, no extraordinary earthquake has visited Portugal beyond that of the 11th of November 1858, at 7 a.m.; the weather being at the time fine and clear. This shock, which lasted about 48 seconds, was preceded by a rumbling noise, and followed shortly after by a strong wind from the north-east. The damage done to the city of Lisbon was very trifling; but at Setubal, a town situated at the mouth of the river Sado, and distant some twelve miles from Lisbon, many houses were destroyed, and several persons were killed.

In the midst so many conflicting theories as to the origin or cause of earthquakes, it is interesting to find another obscure seismologist of the last century entertaining the very prevalent idea that earthquakes are produced by tidal action acting on the interior of the earth. This opinion, to a certain extent, coincides with one of the latest theories, which attributes the earthquakes in the Mediterranean to the melting of enormous masses of ice in the arctic regions. An event of that kind might to some extent affect the regularity of the tides, and this again, according to the view of the observer above quoted, might be the origin of serious convulsions of the soil near to the ocean. As to his hypothesis that there are periods of seismic action on the coast of Portugal occurring at equal intervals of two hundred years, it can only be founded on some such theory as that of the existence of a submarine volcano near the coast, which gets into activity every two centuries, and the explosions of which continue for several days or even months, but gradually decrease in violence until they entirely subside.

That the cause of many or most earthquakes lies under the sea, there is very little reason to doubt: in fact we know that earthquakes seldom occur very far inland, and generally pro-

duce the heaviest damage on or near the sea-coast. It is possible that enormous landslips occur under the sea, near to the land; and that these sub-marine landslips are the origin of seismic action. This, however, only future study and careful sounding in order to ascertain if frequent changes occur on the soil under the sea, will be the means of proving. The action of strong currents, in constantly undermining the soil, might produce landslips, which would not only cause a more or less violent concussion on the land in the vicinity; but might also create a tidal wave of more or less magnitude. That such landships have occurred near the coast of Portugal seems evident, from the fact that a big island existing in the time of Augustine, and mentioned in the Roman History, has disappeared, and its place is now occupied by the Berleugas Rocks, with very deep sea all round.

The landslips and avalanches in Switzerland and other mountainous regions have often produced earthquakes. Why should not landslips occurring in the submarine mountains and cliffs, where the pressure is so much greater than that of the atmosphere, produce the same effect as it does on the land above the sea, but with still more violent results?

However, this is merely a suggestion that I bring forth, leaving to others more competent than myself the task of deciding whether it can or cannot be admitted among the numerous theories on the origin or cause of earthquakes.

Discussion.

Mr. Milne, on rising, thanked the author of the paper for his valuable contribution to the historical section of Seismology. No earthquake which had ever occurred was better known or had been more written about than the Lisbon calamity of 1755. The sermons which had been written about this earthquake were exceedingly numerous, several of which, dating about 1756, he had pleasure in exhibiting. Notwithstanding all this, Mr. Pereira had acquainted them with some-

thing about the Lisbon catastrophe which they did not know before. These were the views of an anonymous author who was a spectator of the destruction. The most remarkable feature in many of the views held by this writer was that they were ahead of the time. What to most people in 1755 was a supernatural vistation were to the author whom Mr. Pereira had introduced to their notice, phenomena which might be explained by natural causes. One view he held was that shocks were more frequent at the syzygies, which is the time of spring tides. Somewhat similar views seem to have been held about the same time in Japan. In 1618, Richard Cocks says that in Japan it was thought that earthquakes were more frequent at the time of high water, the reason being that the rising tide shut air in cracks and caverns which in its endeavours to escape, shook the ground. In 1703, Georges Baglioli and Joseph Tolado suggested that there might be terrain tides produced by the action of the moon, but it was not until 1854 that this idea was discussed philosophically by M. F. Zantedeschi. The proof that earthquakes are really more frequent at certain phases of the moon than at others, is due to the labours of Professor Perrey, of Dijon. The differences in favour of certain seasons are, however, small. Thus between 1843 and 1872 Perrey found that earthquakes had been distributed as follows:—

At Syzygies	8,838
At Quadrature	8,410
At Perigee	3,290
At Apogee	3,015

In Mr. Milne's opinion these slight differences were hardly sufficient to establish a definite law. In many countries, as in Japan, the results of investigations are exactly the reverse of Perrey's result. Also with regard to earthquakes and the tide, Mr. Milne stated that he had found that there were 11 per cent. more earthquakes at low water than at high water. As to great sea waves or alteration in the level of the water in 1755 not having been produced by the same cause that pro-

duced the earthquake he was in great doubt. Great waves certainly have occurred when there have been no sensible earthquakes, but when we have earthquakes, originating in the ocean, it is only natural to conclude that there may be waves. The great difference in time between the shocks and the sea waves at the time of the Lisbon earthquake may be explained by the fact that the sea waves travel slowly and the earthwaves with great rapidity. In water the depth of the Atlantic the sea waves may have travelled at the rate of say 40 miles per hour while the earth waves may have travelled at the rate of 3 miles per second.

Taking these numbers as approximately true, then, if the Lisbon disturbances originated in the volcanic belt running north and south in the Atlantic, say at a distance of 800 miles off shore, the interval in time between the sea waves and the earth waves, must have been at least 2 hours, and in this way sea waves belonging to one disturbance may have been confused with disturbances which did not take place until 2 hours after their production.

In speaking of the destruction that occurred at Lisbon the marked deficiences in effect between that which happened in the low ground as compared with that upon the high ground had apparently been overlooked. The low ground in Lisbon, where destruction was the greatest, he was told, consisted of clay and soft material, while on the high ground where the destruction was relatively small, it was basalt or limestone.

Mr. Pereira confirmed the statement made by Mr. Milne that the greatest destruction caused by the Lisbon earthquake of 1755 was in the lower portion of the town. The so-called *Cidade Baixa* was totally ruined; whereas the buildings on the highest part of the town nearly all escaped destruction.

Dr. Kikuchi remarked that in the paper there was a statement about certain weather being premonitory of earthquakes. There is also a popular belief in Japan about dull, stifling, hot weather being a sign of earthquakes—a belief not justified by

scientific observations so far as he knew. But it is singular that there should be such an agreement (not grounded on a common *fact*, *i.e.* physical fact). Perhaps it is to be explained by a psychological fact or something of that kind. Dr. Kikuchi then said that he thought it might be interesting to some present to know that they had just missed the 33rd anniversary of the great Ansei earthquake by a day. Yesterday (2nd Oct.), (though the real date is the 2nd day of the 10th month of the 2nd year of Ansei), was held at Ekoin, near Ryogoku Bashi, a "Segaki" (a sort of public mass) for the souls of those who died by that terrible earthquake and the still more destructive fires which followed. All those bodies which were not claimed or identified were buried at Ekoin.

Prof. Sekiya said that the premonitory tremors which usually preceded the principal motion differed in their duration as observed in various destructive earthquakes. In the Lisbon earthquake of 1755 they learned from Mr. Pereira's paper that the fatal shock arrived a few minutes after the commencement. In the great Yedo earthquake of 1855, which devastated the city, the main destruction was completed with one blow. People scarcely felt any preliminary vibration. The duration of the Charlestown earthquake was nearly 40 sec.; the motion at first was moderate, but increased with great rapidity during the last 10 or 15 secs. In the Italian earthquake of Feb. 23 of the present year, the trembling began somewhat gently at first, but soon grew more and more marked, and then came a fearful shock. As to the sea waves which followed the shock of 1755, there were many similar cases in this country, and people who live near the coast in a shaky land like Japan should always keep in mind the danger of remaining near sea-shores at the time of great quakes.

The Chairman (Dr. C. G. Knott) said—The author of the pamphlet touched upon many of the points which are still subjects of discussion. Upon a few of these only I shall make any remark. The tidal phenomena, which are de-

scribed as accompaniments of the great Lisbon earthquake of 1755, are certainly very extraordinary. It would be well to search through contemporary literature for corroborative evidence; for we can hardly accept the simple statement of one man who probably got much of his information second-hand. In times of danger few people are capable of making accurate scientific observations. We have here tides described as occurring two hours later than usual on the days preceding certain of the heavy shocks. Such seeming regularity might be explained as due to temporary changes of level of the land; but the nature of the disturbance as described is too extraordinary to be accepted without reserve. The possible connection between tidal stresses and earthquakes is of necessity touched upon in rather vague terms by the author of the pamphlet. He adds, however, that he had observed that the most violent explosions are always felt at syzygies and quadratures of the moon. Observe, syzygies *and* quadratures; the very form of the statement suggests doubt. We should like to know on what special system of averages he established such a conclusion, and what range of time is expressed by the preposition "at." I am afraid there can be little true scientific basis for the conclusion.

The description of the seismic events which make up the great Lisbon earthquakes suggests a succession of explosions, probably at different centres—one might call it a train of explosions following the first shock and started by it in the seismically sensitive crust. The premonitory rumblings suggest a first origin at some distance; for when great shocks come suddenly without any previous symptoms, it is probably because of the nearness of the origin, in virtue of which the more rapidly-moving condensation wave has not time to gain appreciably upon the distortion waves. With regard to the suggestion made by Mr. Pereira that submarine landslips might be a cause of earthquakes, I should be inclined to think that such landslips were rather to be reckoned among the effects of seismic shocks. Submarine denudation plays quite an

insignificant part in the fashioning of the contour of ocean beds. There is lacking in such regions the needed variety of actions which in the case of subaërial deundation exists in the form of wind, rain, snows, frost, and running waters.

In conclusion, it is my pleasing duty to convey to Mr. Pereira the thanks of the Society for his valuable contribution to the historical side of earthquake literature.