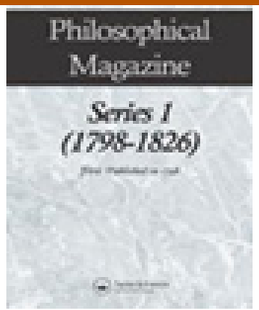

Philosophical Magazine Series 1

ISSN: 1941-5796 (Print) 1941-580x (Online) Journal homepage: http://www.tandfonline.com/loi/tphm12

LIV. Conjectures concerning the cause, and observations upon the phænomena, of earthquakes; particularly of that great earthquake of the first of November 1775, which proved so fatal to the city of Lisbon, and whose effects were felt as far as Africa, and more or less throughout almost all Europe

Rev. John Michell M.A.

To cite this article: Rev. John Michell M.A. (1818) LIV. Conjectures concerning the cause, and observations upon the phænomena, of earthquakes; particularly of that great earthquake of the first of November 1775, which proved so fatal to the city of Lisbon, and whose effects were felt as far as Africa, and more or less throughout almost all Europe , Philosophical Magazine Series 1, 52:247, 323-341, DOI: 10.1080/14786441808652061

To link to this article: http://dx.doi.org/10.1080/14786441808652061

The angle under which the shadow appears is taken in the same manner; and the moon's semidiameter : this measure :: semidiameter in miles : the length of the shadow.

As the result deduced from the above operation will always be the depth of that part of the cavity on which the extremity of the shadow falls, the difficulty of ascertaining when the shadow falls *on the bottom* may be objected to it:—this, however, may always be obviated by continuing the observations until their result becomes a maximum, which will evidently be the depth of the deepest part; or in those cavities in which prominences or bright spots appear, it may be more easily done by observing when one of these prominences (which are no doubt situated at the bottoms of their respective cavities) is in the line which forms the boundary of the shadow.

By repeated observations some idea may be formed of the interior shapes of these cavities. If from a few continued measurements the same depths are deduced, it may be concluded that the bottom is a plane surface: if they are found gradually to increase and afterwards decrease in the same proportion, that part of the interior surface will be shown either to be formed by the inclination of two planes meeting at the bottom, or to be a curve: to which of these classes it belongs may be ascertained from the nature of this increase. Any considerable irregularities in the bottom or sides will be marked by corresponding diminutions in the depth of the cavity, or length of the shadow. Whether these speculations are carried further than is sanctioned by the present state of our best instruments, remains for the determination of those who are possessed of them, and are accustomed to use them."

LIV. *Conjectures concerning the Cause, and Observations upon the Phænomena, of Earthquakes; particularly of that great Earthquake of the first of November* 1755, *which proved so fatal to the City of Lisbon, and whose Effects were felt as far as Africa, and more or less throughout almost all Europe; by the Rev.* JOHN MICHELL, *M.A. Fellow of Queen's College, Cambridge.*

[Concluded from p. 270.]

PART III.—SECTION I.

65. IN the former part of this tract, I supposed a part of the roof over some subterraneous fire to fall in: this is an event that cannot happen merely accidentally; for so long as the roof rests on the matter on fire, no part of it can fall in, unless the matter below could rise and take its place: now, it is very difficult to conceive how this should happen, unless it was to rise by

some larger passages than the ordinary fissures of the earth, which seem much too narrow for that purpose; for, besides that the melted matter cannot be supposed to have any very great degree of fluidity, it must necessarily have a hard crust formed upon it, at all the fissures, by the long continued contact of the water contained in them: these impediments seem too great to be overcome by the difference of the specific gravities of the part that is to fall in, and the melted matter, which is the only cause that can tend to make it descend; the manner therefore, in which, I suppose, this event may be brought about, is as follows:

66. The matter of which any subterraneous fire is composed, must be greatly extended * beyond its original dimensions by the heat. As this will be brought about gradually, whilst the matter spreads itself, or grows hotter, the parts over the fire will be gradually raised and bent; and this bending will, for some time, go on without any other consequence; but, as the fire continues to increase, the earth will at last begin to be raised somewhat beyond the limits of it. By this means, an annular space will be formed at the edges next to the fire, and surrounding it, a vertical section of which space, through a diameter of the fire, will be two long triangles, the shortest side or base of each lying next the fire, and the two longer sides being formed by the upper and lower strata, which will be separated for a considerable extent, proportionably to the distance through which they are raised from each other †. This space will be gradually filled with water, as it is formed, the melted matter being prevented from filling it, by its want of fluidity, as well as on account of the other circumstances, under which it is to spread itself; for the lentor and sluggishness of this kind of matter is such, that, when somewhat

* As all bodies we are acquainted with are liable to be extended by heat, there can be no doubt of its being so in this case likewise; but the matter of subterraneous fires is yet much more extended, than those bodies which are only capable of being melted into a solid glass, if we may judge of it from what we see of volcanos; for the lavas, sciari, and pumice stones, thrown out from thence, even after they are cold, are commonly of much less specific gravity, on account of their porous spongy texture, than the generality of earth, stones, &c. and they frequently are even lighter than water, which is itself lighter than any known fossil bodies, that compose strata in their natural state.

† In fig. 4. A is supposed to represent a vertical section of the matter on fire; BB, parts of the same stratum yet unkindled; CC, the two sections of the annular space, (surrounding the fire) which is supposed to be filled with water, as far as the strata are separated; D, the several sets of earth, stones, &c. lying over the fire, which are raised a little, and bent, by the expansion of the matter at A. As it is not easy to represent the things above described in their due proportions, it may not be amiss, in order to prevent the figure here given from misleading the reader, to give some random measures of the several parts, such as may probably approach towards

what cooled on the surface by the contact of the air only, it will not flow, perhaps, ten feet in a month, though in a very large body; instances of which we have in the lavas of Ætna, Vesuvius, &c. It is not to be expected then, that it should spread far, when it comes in contact with water at its edges, as soon as it is formed, and when it is, perhaps, several months in acquiring a thickness of a few inches; but it must, by degrees, form a kind of wall between the fire and the opening into the annular space before described. This wall will gradually increase in height, till it becomes too tall in proportion to its thickness, to bear any longer the pressure of the melted matter; which must necessarily happen at last, because the thickness of it will not exceed a certain limit*.

67. Besides the giving way of this wall, the fire may undermine the space containing the water, and, by that means, open a communication between them. Let us suppose one of these come to pass, and the time arrived when the partition begins to yield. If then the water had any way to escape readily, the breach would be made, and the melted matter would burst forth immediately, and flow out in large quantities at once amongst it; but as this is not the case, and it can only escape by oozing slowly between the strata, and through the fissures, the way that it came, the breach will be made gradually, from whence we may account for some appearances that have preceded great earthquakes.

towards those which are sometimes found in nature: we may suppose then the stratum B to be, perhaps, from ten or twenty to a hundred yards in thickness; the greatest height of the annular space C, next the fire, to be from four or five to ten or fifteen feet, and its greatest extent, horizontally, from ten or twenty to fifty or sixty feet; the horizontal extent of the fire at A, may be from half a mile to ten or twenty miles; [see art. 29, and the note to art. 53.] and the thickness of the superincumbent matter at D, may be from a quarter or half a mile to two or three miles; the number of the laminæ also, into which it is divided, may be many times more than those in the figure. As to the perpendicular fissures, they must be so numerous, and so small, in proportion to the other parts, that I chose rather to leave them, to be supplied by the imagination of the reader, than attempt to express them in a manner, that could give no adequate idea of them at all.

* This limit will depend upon the thickness of the matter necessary to prevent so quick a communication of the heat or cold through it, as that the water should be able to diminish the heat of the fire considerably. The thickness requisite to do this, is very different in different kinds of bodies. Metals of all kinds transmit heat and cold extremely readily; but bricks and vitrified substances (with which last we may class the matter under our present consideration) transmit them very slowly: the walls of the hottest of our furnaces, when built of bricks, and eighteen inches thick, will not transmit more heat than a living animal can bear without injury, though the fires are continued in them for ever so long a tima; probably, therefore, if we allow two feet for the thickness of the matter, cooled and rendered hard by the contact of the water, we shall not underdo it.

 68. We

68. We are told, that two or three days before an earthquake* in New England, the waters of some wells were rendered muddy, and stank intolerably: why might not this be occasioned by the waters contained in the spaces before described, which, being impregnated with sulphureous steams, were driven up, and mixed with the waters of the springs? At least, there can be no doubt, by whatsoever means it was brought about, that this phænomenon was owing to the same cause, already beginning to exert itself, which afterwards gave rise to the succeeding earthquake.

69. Something like this happened before the great Lisbon earthquake† of 1755. We are told, that at Colares, about twenty miles from thence, "in the afternoon preceding the 1st of November, the water of a fountain was greatly decreased: on the morning of the 1st of November, it ran very muddy, and after the earthquake, it returned to its usual state, both in quantity and clearness." The same author says, a little lower, "in the afternoon of the 24th, I was much apprehensive, that the following days we should have another great earthquake; for I observed the same prognostics as in the afternoon of the 31st of October; that is," &c. "And I further observed, that the water of a fountain began to be disturbed to such a degree, that in the night it ran of a yellow clay colour; and from midnight to the morning of the 25th, I felt five shocks, one of which seemed to me as violent as that of the 11th of December."

70. But the most extraordinary appearance of any that preceded this earthquake, was that of the agitation of the waters of Lochness‡, and some others of the lochs in Scotland, about half an hour before any motion was felt at Lisbon, notwithstanding the cause of all these great effects could not lie far from thence, and, I think, certainly lay to the south of Oporto. Nor is it probable, that there should be any mistake in the time, not only because the difference is too great, as well as the concurrent testimonies too many, to admit of such a solution; but because they mention another greater agitation, that happened

* See Philos. Trans. No. 437, or Martyn's Abridgem. vol. viii. p. 689.

† See Philos. Trans. vol. xlix. p. 416 and 417; or Hist. and Philos. of Earthq. p. 313.

‡ See Philos. Trans. vol. xlix.—or Hist. and Philos. of Earthq. art. *Lochness, Lochlomond*, &c. The same thing also seems to have taken place in Switzerland; for Mons. Bertrand says, that all the agitations of the waters in the lakes there, which were observed on the 1st of November 1755, happened between nine and ten in the morning; and particularly at lake Leman, he says, the agitation happened just before ten; which, allowing for the difference of longitude, must have been just before nine at Lisbon; and, consequently, if there is no mistake in the times, all these agitations preceded the earthquake, at this last place, by near three quarters of an hour. [See *Memoires sur les Tremblemens de Terre*, p. 107 & 105.]

about

about an hour and half after the former; which latter agrees with the times when the agitations of the waters were observed in England, if we allow only a proper interval for the motion to be propagated so far northward, proportionably to the time it took up in travelling from its original source near Lisbon.

71. These appearances seem to be connected with that mentioned in the preceding article, and they may both, I think, be accounted for, by supposing a considerable quantity of vapour to be raised, whilst the partition before-mentioned was beginning to give way; during which time a partial communication between the water and fire would be brought on, and that by degrees only. Hence the vapour, not being produced at once but gradually, might creep silently between the strata*, towards that quarter where the superincumbent mass of earth was lightest; and, by this means, some places very near the source of the vapour might be little, or not at all, affected by it, whilst others might be greatly affected, though they lay at a great distance; and even those places, which lay immediately over the part where the vapour was passing, might not perceive any effect, on account of the gentleness of the motion, occasioned by the small quantity of it. This might continue to be the case, till it came to some country where, the set of strata above being much thinner, the vapour would not only be hurried forward, but collected also into a much narrower compass; and therefore, raising the earth more, would produce more sensible effects; and this we ought chiefly to expect in the most mountainous countries, according to the idea before given of them†.

72. To make this something clearer, let us suppose, in fig. 1. the vapour to be passing between the strata in the dotted line C, and to go forwards, till it arrives at A: whilst, then, it passes under the deeper parts at E, it will raise the earth over it but little, as well because it will be spread broader and thinner, as because it will be more compressed by the weight of the superincumbent matter; but as it arrives towards A, not only the lat-

* Some appearances that have been observed in New England seem to confirm this, and make it probable, that a small quantity of vapour is often found to creep silently between the strata, before a general communication between the water and the fire gives rise to the greater and more sensible effects of earthquakes. See Philos. Trans. No. 462; or Martyn's Abr. vol. viii. p. 693, where we are told, that, at Newbury, a little before any noise or shock was perceived, the bricks of an hearth were observed to rise, and, falling down again, to lean another way. In the same account, it is also said, that "a few minutes before any shock came, many people could foretell it by an alteration in their stomachs:" an effect, which seems to be of the same kind with sea-sickness, and which always accompanies the wave-like motion of earthquakes, when it is so weak, as to be uncertainly distinguishable. † See art. 43.

ter part will be driven forwards with greater velocity, but the foremost will travel slower, on account of its travelling under a thinner set of strata*; and, besides this, the load being much less, it will greatly expand itself. From all these causes taken together, the wave at the surface of the earth, occasioned by the passing of the vapour under it, will not only be much higher, but also much shorter, and, consequently, the sides of it, on both these accounts, will be much more inclined to the horizon: and, moreover, because the progress of the wave will be slower, it will give more time to any waters situated on one side of it, to flow one way; and on this account also, the apparent agitation of them will be increased.

SECTION II.—73. We are told, that, in the Lisbon earthquake of 1755, "the bar [at the mouth of the Tagus] was seen dry from shore to shore; then suddenly the sea, like a mountain, came rolling in; and about Bellem castle, the water rose fifty feet almost in an instant; and, had it not been for the great bay opposite to the city, which received and spread the great flux, the low part of it must have been under water†." The same phænomena were observed to accompany the same earthquake at the island of Madeira; where we are told, that, at the city of Funchal, "the sea, which was quite calm, was observed to retire suddenly some paces; then rising with a great swell, without the least noise, and as suddenly advancing, it overflowed the shore, and entered the city. It rose full fifteen feet perpendicular above high-water mark, although the tide, which ebbs and flows there seven feet, was then at half ebb. In the northern part of the island, the inundation was more violent, the sea retiring there above one hundred paces at first, and suddenly returning, overflowed the shore, forcing open doors, breaking down the walls of several magazines and storehouses, and carrying away in its recess, a considerable quantity of grain, and some hundred pipes of wine‡."

74. Both these appearances (which have been observed to attend several other earthquakes, as well as this) seem to admit of an easy solution, supposing the cause of them to lie under the bed of the ocean; for, in the further progress of the communication between the fire and water, the vapour, that is gradually raised at first, will at last begin to raise the roof over the fire, which being supported by so light a vapour, there will now be no want of fluidity in the matter it rests upon, and the difference of specific gravity between the two, instead of being small, will be

* See art. 63, the note.

† See Hist. and Philos. of Earthq. p. 316.

‡ See Philos. Trans. vol. xlix. p. 432, &c. or Hist. and Philos. of Earthq. p. 329.

very

very great: hence, if any part of the roof gives way, it must immediately fall in, the vapour readily rising, and taking its place; and a beginning being once made, a communication will be opened with numberless clefts and fissures, that must occasion the falling in of vast quantities of matter, which, as soon as the vapour can pass round them, will want their support; then will follow the great effects* already described.

75. Now, whilst the roof is raising, the waters of the ocean, lying over it, must retreat, and flow from thence every way; this however, being brought about slowly, they will have time to retreat so gently, as to occasion no great disturbance: but as soon as some part of the roof falls in, the cold water contained in the fissures of it, mixing with the steam, will immediately produce a vacuum, in the same manner as the water injected into the cylinder of a steam-engine, and the earth subsiding, and leaving a hollow place above, the waters will flow every way towards it, and cause a retreat of the sea on all the shores round about: then presently, the waters being again converted by the contact of the fire into vapour, together with all the additional quantity, which has now an open communication with it, the earth will be raised, and the waters over it will be made to flow every way, and produce a great wave immediately succeeding the previous retreat†.

SECTION III.—76. That great quantity of water, which we have supposed to be let out upon subterraneous fires, and, by that means, to produce earthquakes, will supply us with a reason, why they observe a sort of periodical return. This water must extinguish a great portion of the burning matter, in consequence of which, it will be contracted within much narrower bounds; and though the effects before described could not take place at

* See art. 56 to 60 inclusive.

† It may, perhaps, be objected, that these phænomena may as easily be occasioned by a vapour generated under the dry land, which, by first raising the earth upon the sea-shore, would make the waters retreat; and that the return of them again, upon its subsiding into its place, might cause the subsequent wave. That this may be the case, in some instances, is not impossible, but, I believe, upon examining the particular circumstances, it will generally be found to be otherwise; and there cannot be any doubt about it, in the case of the Lisbon earthquake; for the retreat was observed to precede the wave, not only on the coast of Portugal, but also at the island of Madeira, and several other places: now, if the retreat had been caused by the raising of the earth on the coast of Portugal, the motion of the waters occasioned by this means, when propagated to Madeira, must have produced a wave there previous to the retreat, contrary to what happened; nor could the motion of the waters at Madeira be caused by the earthquake at that place, because it did not happen till above two hours after; whence it is manifest, that it must have been owing to the continuation of a motion propagated from the place, where the earthquake exerted its first efforts. And we may observe, in general, that this must always be the case, whenever the retreat does not happen till some considerable time after the earthquake.

first,

first, but by the great extension of the heated matter, yet, after they have once taken place, they may well continue to do so for some time; for the great disturbance in the first instance, by the falling in of a great part of the roof, must render the frequent communication between the fire and water not only very easy, but almost unavoidable: and this will continue to be so, till the roof is well settled, and the surface of the melted matter sufficiently cooled, after which, it may require a long time for the fire to heat it again so much, as will be necessary to make it produce the former effects. Now, as the matter has been more or less cooled, or as the combustible materials are with more or less difficulty set on fire again, as well as on account of other circumstances, the returns of these effects will be later or earlier; but though they will not, for this reason, observe any exact period, yet they will generally fall within some sort of limits, till either the matter that occasions them is consumed, (which, probably, will seldom happen in less than many ages,) or till the fires open themselves a passage, and become volcanos.

SECTION IV.—77. I have already intimated, that the most extensive earthquakes frequently take their rise from the sea. According to the description of the structure* of the earth before given, any combustible stratum must lie at greater depths in places under the ocean, than elsewhere; hence far more extensive fires may subsist there, than where the quantity of matter over them is less; for any vapour raised from such fires, having both a stronger roof over it, and being pressed by a greater weight, (beside the additional weight of the water) will not only be less at liberty to expand itself, and consequently of less bulk, but it will also be easily driven away towards the parts round about, where the superincumbent matter is less, and therefore lighter. On the other hand, any vapour raised from fires, where the superincumbent matter is lighter, finding a weaker roof over it, and being not so easily driven away under strata, that are thicker and heavier, will be very apt to break through, and open a mouth to a volcano; and it must necessarily do this long before the fires can have spread themselves sufficiently, to be near equal to those which may subsist in places that lie deeper. All this seems to be greatly confirmed by the situation of volcanos, which are almost always found on the tops of mountains †, and those often some of the highest in the world.

78. If,

* See art. 43.

† Perhaps this may supply us with a hint (if the conjecture is not thought extravagant) concerning the manner in which these mountains have been raised, and why the strata lie generally more inclining from the mountainous countries, than those countries themselves; an appearance not easily to be accounted for, but upon the supposition, that the upper parts of the earth rest

78. If, then, the largest fires are to be supposed to subsist under the ocean, it is no wonder that the most extensive earthquakes should take their rise from thence: the great earthquake of Lisbon has been shown to have done so*; and that the cause of it was also at a greater depth, than that of many others, appears from the greater velocity with which it was propagated †.

79. The great earthquake that destroyed Lima and Callao in 1746, seems also to have come from the sea; for several of the ports upon the coast were overwhelmed by a great wave, which did not arrive till four or five minutes after the earthquake began, and which was preceded by a retreat of the waters ‡, as well as that at Lisbon. Against this, it may, perhaps, be alleged, that there were four volcanos broke out suddenly §, in the neighbouring mountains, when this earthquake happened, and that the fires of these might be the occasion of it. This however, I think, is not very probable; for, to omit the argument of the wave, and previous retreat of the waters, already mentioned, it is not very likely, that more than one fire was concerned: besides, the vapour, opening itself a passage at these places, could not well be supposed, if it took its rise from thence, to spread itself far; especially towards the sea, where it is manifest, that the strata over it were of great thickness, as appears from the great velocity with which the earthquake was propagated there: the shocks also continued with equal, or nearly equal violence, for some months after the openings were made; whereas, if these fires had been the cause of them, they must immediately have ceased, upon the fires finding a vent, as it has happened in other cases ||. It is therefore much more probable, that a very large quantity of vapour, taking its rise from some far more extensive fire under the sea, spread itself from thence; and as it passed in places, where the roof over it was naturally much thinner, as well as greatly weakened by the undermining of these fires, it opened itself a passage, and burst forth.

rest upon matter, in some degree, though not perfectly fluid, and that this matter is lighter than the earth that rests upon it. This conjecture, however, will probably be thought less strange, if it be considered, that the new islands, formed about Santerini and the Azores, have some of them been raised from 200 to 300 yards, and upwards; a height which might well enough intitle them to the denomination of mountains, if they had been raised from lands not lying under the ocean. [See fig. 3.]

* See art. 54. See also art. 94 to 97 inclusive.

† See the note to art. 63.

‡ Both the wave and previous retreat have been observed in the other great earthquakes, which have happened at Lima, and in the neighbouring country. See d'Ulloa's Voyage to Peru, part ii. book i. chap. 7.

§ If these volcanos were not new ones, but only old ones which broke out afresh, [see the note to art. 34.] the argument will come with still greater force.

|| See art. 28.

80. As

80. As the most extensive earthquakes generally proceed from the lowest countries, but especially from the sea, so those of a smaller extent are generally found amongst the mountains: hence it almost always happens, that earthquakes, which are felt near the sea, if at all violent, are felt also in the higher lands; whereas there are many amongst the hills, and those very violent ones, which never extend themselves to the lower countries. Thus we are told, that, at Jamaica, "shakes* often happen in the country, not felt at Port-Royal; and sometimes are felt by those that live in and at the foot of the mountains, and by no body else." On the other hand, the earthquake that destroyed Port-Royal extended itself all over the island: and the same was observed of a smaller earthquake, that happened there in 1687–8; which latter undoubtedly came from the sea, as appears by Sir Hans Sloane's account of it †.

81. Earthquakes of small extent are also very common amongst the mountains of Peru and Chili. Antonio d'Ulloa says, "Whilst we were preparing for our departure from the mountain Chichi-Choco, there was an earthquake which was felt four leagues round about: our field tent was tossed to and fro by it, and the earth had a motion like that of waves; this earthquake, however, was one of the smallest, that commonly happen in that country." The same author tells us, in another place, that, "during his stay at the city of Quito, or in the neighbourhood of it, there were two earthquakes, violent enough to overturn some houses in the country, which buried several persons under their ruins."

SECTION V.—82. It is generally found, that earthquakes in hilly countries, are much more violent than those which happen elsewhere; and this is observed to be the case, as well when they take their rise from the lower countries, as amongst the hills themselves. This appearance being so easily to be accounted for, from the structure of the earth already described, I shall content myself with establishing the certainty of a fact, which tends so greatly to confirm it.

83. The earthquakes that have infested some of the towns in the neighbourhood of Quito, have not only been incomparably more violent than that which destroyed Lisbon, but they seem to have exceeded that also which destroyed Lima and Callao. In

* This is taken from an account of the earthquake that happened at Jamaica in the year 1692, which, as well as some others before mentioned, was attended with the wave and previous retreat. See Philos. Trans. No. 209, or Lowthorp's Abr. vol. ii. p. 417 and 418.

† See Phil. Trans. No. 209, or Lowthorp's Abr. vol. ii. p. 410.

Lisbon,

Lisbon*, many of the houses were left standing, although few of them were less than four or five stories high. At Lima also, it is only said, that "all the buildings, great and small, or at least the greatest part of them, were destroyed." Callao likewise, as it appears from the accounts we have of it, had many houses left unhurt by the earthquake, till the wave came, which overwhelmed the whole town, and threw down every thing that lay in its way. All these effects seem to be greatly short of those produced by an earthquake that happened at Latacunga, in the year 1698, when the whole town, consisting of more than six hundred houses, was entirely destroyed in less than three minutes time, a part of one only escaping; notwithstanding that the houses there are never built more than one story high, in order, if possible, to avoid these dangers. Ambato, a village about the same size as Latacunga, together with a great part of Riobamba, another town in the same neighbourhood, were also entirely destroyed by the same earthquake, and some others were either destroyed, or received considerable damage from it. At the same time, a volcano burst out suddenly in the neighbouring mountain of Carguayraso, as before-mentioned; and, "near Ambato, the earth opened itself in several places, and there yet remains, to the south of that town, a cleft of four or five feet broad, and about a league in length, lying north and south; there are also several other like clefts on the other side of the river." The city of Quito† was affected at the same time, but received no damage, though it is no more than forty-two geographical miles from Latacunga, not far from whence the greatest violence of the shock seems to have exerted itself. These towns are supposed to stand by far the highest of any in the world, being as high above the level of the sea, as the tops of some of the highest mountains in Europe; and the ground upon which Riobamba stands, wants but ninety yards‡ of being three times as high as Snowdon, the highest mountain in Wales.

84. The country upon which these towns stand, serves as a base, from whence arise another set of high lands and mountains, which are much the highest in the known world. Amongst these mountains there are no less than six volcanos, if not more, within an extent of 120 miles long, and less than thirty broad, the

* See Phil. Trans. vol. xlix. p. 403, where it is said, "of the dwelling-houses, there might be about one-fourth of them that tumbled."

† The city of Quito stands lower than the level of Riobamba, by about 500 yards perpendicular. Though it escaped this, it has lately, however, been destroyed by another violent earthquake, that happened on the 28th April 1756, of which I have not yet seen any other particulars worth notice.

‡ This is according to Antonio d'Ulloa's account; but Mons. Condamine makes it exactly three times the height of Snowdon, computing it at 1770 toises. [See his measure of a degree of the meridian.]

lowest

lowest of which exceeds the height of Riobamba by above two-thirds of a mile, and the highest by more than twice that quantity. Now, as the earthquakes have been more violent at the foot of these mountains, than in the lower lands, so they have been still more violent towards the tops of them: this is sufficiently manifest, from the many rents made in them and the rocks *, that have been broken off from them, upon such occasions: but it appears still more manifestly, and beyond all dispute, in the bursting forth of volcanos, which are almost always at the very summit of the mountains †, where they are found. In these instances, the earth, stones, &c. which lay over the fire, are generally scattered by the violence of the vapour, that breaks its way through, to the distance of some miles round about.

85. The great earthquake of the 1st of November 1755, was also more violent amongst the mountains, than at the city of Lisbon. We are told, that "the mountains of Arrabida, Estrella, Julio, Marvan, and Cintra, being some of the largest in Portugal, were impetuously shaken, as it were, from their very foundations; and most of them opened at their summits, split and rent in a wonderful manner, and huge masses of them were thrown down into the subjacent valleys ‡."

86. The same was observed at Jamaica likewise. In the earthquake that destroyed Port-Royal in 1692, we are told, that "more houses were left standing at that town than in all the island besides. It was so violent in other places, that people were violently thrown down on the ground, where they lay with their legs and arms spread out, to prevent being tumbled about by the incredible motion of the earth. It scarce left a planter's house or sugar-work standing all over the island: I think it left not a house standing at Passage Fort, and but one in all Liganee, and none in St. Iago, except a few low houses, built by the wary Spaniards. In Clarendon precinct, the earth gaped, and spouted up, with a prodigious force, great quantities of water into the air, twelve miles from the sea; and all over the island, there were abundance of openings of the earth, many thousands. But in the mountains, are said to be the most violent shakes of all; and it is a generally received opinion, that the nearer to the mountains, the greater the shake; and that the cause thereof, whatever it is, lies there. Indeed they are strangely torn and rent, especially the blue, and other highest mountains, which seem to be the greatest sufferers, and which, during the time that the

* See d'Ulloa's Voyage to Peru, part i. book vi. chap. 2.

† The only exceptions that I know of to this rule, are in those cases, where the highest part having an opening already, some fresh mouth opens itself in the side of the mountain.

‡ See Hist. and Philos. of Earthq. p. 317.

great

great shakes continued, bellowed out prodigious loud noises and echoings.

87. "Not far from Yallowes, a mountain, after having made several moves, overwhelmed a whole family, and a great part of a plantation, lying a mile off; and a large high mountain near Portmorant, near a day's journey over, is said to be quite swallowed up.

88. "In the blue mountains, from whence came those dreadful roarings, may reasonably be supposed to be many strange alterations of the like nature; but those wild desert places being very rarely, or never visited by any body, we are yet ignorant of what happened there; but whereas they used to afford a fine green prospect, now one half part of them, at least, seem to be wholly deprived of their natural verdure*."

SECTION VI.—89. I have supposed, that fires lying at the greatest depths generally produce the most extensive earthquakes. We must, however, except from this rule those cases where the depths are very great: for, as the weight of three miles perpendicular of common earth is capable of absolutely repressing the vapour of inflamed gunpowder, so we may well suppose, that there may be a quantity of earth sufficient to repress the vapour of water, and keep it within its original limits, though ever so much heated. Now, whenever this is the case, it is manifest, that it can produce no effect: or, it may happen, that though the quantity of earth may not be sufficient absolutely to repress the vapour, yet it may be so great, as to suffer it to expand but very little: in this case, an earthquake arising from it would be but of small extent; the wave-like motion would be little or none; the vibratory motion would be felt every where; and the propagation of the motion would be very quick. This last circumstance being almost the only one, by which these earthquakes can be known from those which owe their origin to shallower fires, it must be very difficult to distinguish them with certainty, as it is almost impossible to distinguish the difference of the time of their happening in different places, when the whole, perhaps, is com-

* See Philos. Trans. No. 209; or Lowthorp's Abridg. vol. ii. p. 416, &c. where there is a great deal more to the same purpose. See also Hist. and Philos. of Earthq. p. 286 and 287.

From the authorities quoted in this section, it appears, how little reason there is for the notion, that either large cities, or towns situated near the sea-coast, are more subject to violent earthquakes than others: it is not, however, much to be wondered at, that such a notion should have prevailed, after the great destruction that happened in so large and populous a city as Lisbon; since the demolition of a few ruinous houses only, in such a place, would have affected the imaginations of men more, and would have been more talked of, than the subversion of whole mountains in some wild and desert country, where at most half a dozen unknown shepherds might feel the effects of it, or perhaps only see it at a distance.

prehended

prehended within the space of two or three minutes; possibly, however, some of the earthquakes, which we have had in England, may have been of this class.

SECTION VII.—90. If we would inquire into the place of the origin of any particular earthquake, we have the following grounds to go upon.

91. *First*, The different directions, in which it arrives at several distant places: if lines be drawn in these directions, the place of their common intersection must be nearly the place sought: but this is liable to great difficulties; for there must necessarily be great uncertainty in observations, which cannot, at best, be made with any great precision, and which are generally made by minds too little at ease to be nice observers of what passes; moreover, the directions themselves may be somewhat varied, by the inequalities in the weight of the superincumbent matter, under which the vapour passes, as well as by other causes.

92. *Secondly*, We may form some judgement concerning the place of the origin of a particular earthquake, from the time of its arrival at different places; but this also is liable to great difficulties. In both these methods, however, we may come to a much greater degree of exactness, by taking a medium amongst a variety of accounts, as they are related by different observers. But,

93. *Thirdly*, We may come to the greatest degree of exactness in those cases, where earthquakes have their source from under the ocean; for, in these instances, the proportional distance of different places from that source may be very nearly ascertained, by the interval between the earthquake and the succeeding wave: and this is the more to be depended on, as people are much less likely to be mistaken in determining the time between two events, which follow one another at a small interval, than in observing the precise time of the happening of some single event.

94. Let us now, by way of example, endeavour to inquire into the situation of the cause, that gave rise to the earthquake of the 1st of November 1755, the place of which seems to have been under the ocean, somewhere between the latitudes of Lisbon and Oporto, (though probably somewhat nearer to the former) and at the distance, perhaps, of ten or fifteen leagues from the coast. For,

95. *First*, The direction, in which the earthquake arrived at Lisbon, was from the north-west; at Madeira it came from the north-east; and in England it came from the south-west; all of which perfectly agree with the place assumed*.

96. *Se-*

* All these directions together with the times when the earthquake, as well as the succeeding wave, arrived at different places, (two or three only excepted)

96. *Secondly*, The times in which the earthquake arrived at different places, agree perfectly well also with the same point. And,

97. *Thirdly*, The interval between these, and the time of the arrival of the subsequent wave, concur in confirming it. That all this might appear the better, I have subjoined the following table, assuming the point, from whence I compute, at the distance of about a degree of a great circle from Lisbon, and a degree and half from Oporto. In consequence of this supposition, I have added three minutes to the interval between the time when the shock was felt at Lisbon, and at the several other places. The first column in the table contains the names of places; the second, the distances from the assumed point, reckoned in half degrees; the third, the time that the earthquake took up in travelling to each, expressed in minutes; and the fourth contains the time in which the wave was propagated, from its source to the respective places, expressed in minutes likewise.

	Half deg.	Min.	Min.
Lisbon*	2	3	12
Oporto*	3	5	
Ayamonte	6		53
Cadiz	9	12	82
Madrid	9	11	
Gibraltar.....	11	18	
Madeira	19	25	152
Mountsbay	20		267
Plymouth	21		360
Portsmouth	23	29	
Kingsale	23		290
Swansea	24		530
The Hague	30	32	
Lochness	33	66	
Antigua	98		565
Barbadoes	101		485

98. In

excepted) are taken from the 49th volume of the Philos. Trans. and the Hist. and Philos. of Earthq. To these I must refer the reader for the particular authorities, which, as they are very numerous, I was not willing to quote at length.

* It appears, by all the accounts, that the interval between the earthquake and wave, either at Oporto or Lisbon, was not long: I have met with no account yet, however, which tells us how long it was at the former, and only one which mentions it at the latter, where it is said to have been nine minutes. [See *Memoires sur les Tremblemens de Terre*, p. 245, compared with Hist. of Earthquakes, p. 315.] These intervals, if we knew them ex-

98. In computing the times in the preceding table, allowance was made for the difference of longitude, as it is laid down in the common maps, which are not always greatly to be depended on. The times themselves also are often so carelessly observed, as well as vaguely related, that they are many of them subject to considerable errors; the concurrent testimonies, however, are so many, that there can be no doubt about the main point; and, that the errors might be as small as possible, I have not only endeavoured to select those accounts that had the greatest appearance of accuracy, but, in all cases where it was to be had, I have always taken a mean amongst them. In many of the accounts, the relaters say only between such hours, or about such an hour: of this kind were the accounts of the times of the agitation of the waters at the Hague and Lochness, which vary the most from a medium of the rest, the former erring about seven minutes in defect, and the latter about twenty minutes in excess: with regard to the latter, however, I must observe, that, from the account itself, it is probable the agitation happened sooner than eleven o'clock, which is the time mentioned. The accounts also of the time of the agitation of the waters in the northern parts of England, seem to confirm the same thing*.

99. It is observable, in the preceding table, that the times, which the wave took up in travelling, are not in the same proportion with the distances of the respective places from the supposed source of the motion: this, however, is no objection against the point assumed, since it is manifest, wherever it was, that it could not be far from Lisbon, as well because the wave arrived there so very soon after the earthquake, as because it was so great, rising, as we are told, at the distance of three miles from Lisbon, to the height of fifty or sixty feet. The true reason of this disproportion seems to be the difference in the depth of the water; for, in every instance in the above table, the time will be found to be proportionably shorter or longer, as the water through

actly, might have served, perhaps, to ascertain the distance of those two places from the original source a little more accurately; but, as the distance of neither from thence could be very great, a small difference in them would hardly sensibly affect any of the others; from which, therefore, we may draw the same general conclusions, as if they were exact.

* As the shortest way that the vapour could pass from near Lisbon to Lochness was under the ocean, possibly it might, on that account, be somewhat retarded; for the water adding to the weight of the superincumbent mass, and not to its elasticity, must produce this effect in some degree: it is probable, however, that this could make no great difference, as the motion seems to have been very little retarded in its passage from the original source to Madeira, to which place, I suppose, it must have passed under deeper seas than would be found in its road to Scotland.

which

which the wave passed was deeper or shallower*. Thus the motion of the wave to Kingsale or Mountsbay (through waters not deeper in general than 200 fathoms) was slower than that to Madeira, (where the waters are much deeper,) in the proportion of about three to five; and it was slower than that to Barbadoes, (where its course lay through the deepest part of the Atlantic ocean) nearly in the proportion of one to three: so likewise the motion of it from the Scilly islands to Swansea in Wales (where the depth gradually diminishes from about sixty or seventy fathoms to a very small matter) was still slower than that to Kingsale, in the proportion of less than one to three: the same thing is observable with regard to Plymouth also, where the wave arrived about ninety minutes later than at Mountsbay, though the difference of their distance from the first source could not, upon any supposition, be more than forty or fifty miles.

SECTION VIII.—100. If we would inquire into the depth, at which the cause lies, that occasions any particular earthquake, I know of no method of determining it, which does not require observations not yet to be had; but if such could he procured, and they were made with sufficient accuracy, I think some kind of guess might be formed concerning it: for,

101. *First,* In those instances, where the vapour discharges itself at the mouths of volcanos, (as in the case of the earthquake at Lima,) it might, perhaps, be possible for a careful observer to trace the thickness of the several strata† from thence to the place where the earthquake took its rise, or at least as far as the shore, if it took its rise from under the sea. If this could be once done in any one instance, and the velocity of such an earthquake nicely determined, we might then guess at the depth of the cause in other earthquakes, where we knew their velocity, by taking the depths‡ proportional to those velocities, which probably would answer very nearly.

102. *Secondly,* If, in any instance, it should be possible to know how much the motion of any earthquake was retarded by passing under the ocean, the depth of the ocean being known, the depth at which the vapour passed would be known also; for the velocity under the water would be to the velocity, if there had been no water, in the subduplicate ratio of the weight in

* We have an instance to this purpose in the tides, which, in deep waters, move with a velocity that would carry them round the whole earth in a single day; but as they get into shallower waters, they are greatly retarded: and we are told, that in the river of Amazons, the same tide is found running up to the tenth or twelfth day, before it is entirely spent. [See Condamine's Voyage down the Maranon.]

† This is upon the supposition, that the under strata, in ascending up the hills, come to the day in the manner before described. See art. 43, and fig. 3,

‡ See the note to art. 63.

the latter case to the weight in the former: hence allowing earth to be about two and half times the weight of water, the depth will be readily found.

103. *Thirdly*, Let us conceive the earth to be formed according to the idea before given of it, and that the same strata are at a medium of the same thickness for a very great extent, as well in those places, where several of the upper ones are wanting, as where they are not. Upon this supposition, we may discover the depth, at which the vapour passes, by comparing the several velocities of the same earthquake in places where the thicknesses* of the superincumbent mass are different. It must be acknowledged, indeed, that such observations with regard to time, as would enable us to determine these velocities, are in general much too nice to be expected: the matter, however, is not altogether desperate, as we may collect them, in some measure perhaps, from other circumstances; such, for instance, as the degree of agitation in different waters†, the proportional suddenness‡ with which the earth is lifted in different places, &c.

104. As the observations relating to the earthquake of the 1st of November 1755 are too gross, it would be in vain to attempt, by any of the foregoing methods, to determine with any certainty the depth at which the cause of it lay; but, if I might be allowed to form a random guess about it, I should suppose, (upon a comparison of all circumstances,) that it could not be much less than a mile, or a mile and half, and I think it is probable, it did not exceed three miles.

Conclusion.—105. Thus have I endeavoured to show how the principal phænomena of earthquakes may be produced, by a cause with which none, that I have seen, appear to me to be incompatible. As I have not knowingly misrepresented any fact, so neither have I designedly omitted any that appeared to affect the main question; but, that I might not unnecessarily swell what had already much exceeded the limits at first intended for it, I have omitted,

106. *First*, Those minuter appearances, which almost every reader would easily account for, from what has been said already, and which did not seem to lead to any thing further: such, for

* In order to know this difference, it will be necessary to trace the thickness of those strata, which are found in some of the places, but are wanting in others. † See art. 71 and 72.

‡ This may be known from the distance to which the mercury subsides in the barometer, upon the first raising of the earth by the vapour. I don't find that this phænomenon, which is a common attendant on earthquakes, was observed any-where, at the time of the earthquake of the 1st of November 1755, except at Amsterdam, where the mercury subsided more than an inch. See Hist. and Philos. of Earthq. p. 309.

instance,

instance, are the sudden stopping and gushing out of fountains, occasioned by the opening or contracting of fissures; the dizziness and sickness people feel, from the almost imperceptible wave-like motion, &c.

107. *Secondly*, Those appearances which seemed to depend upon particular circumstances, and of which therefore, unless we had a more exact knowledge of the countries where they happened, it would have been impossible to give any account, without having recourse to uncertain conjectures; of this kind was the greater agitation of the waters in the lakes of Switzerland, at the time of the earthquake of the 1st of November 1755, than during the earthquake of the 9th of December following*, though the houses upon the borders of them were more violently shaken by the latter. And,

108. *Lastly*, Those appearances, which only seem to have an accidental connection with earthquakes, or the causes of them; of this kind, are the effects which, in some instances perhaps, they produce on the weather; the distempers which are sometimes said to succeed them; the disturbance which, we are told, they have sometimes occasioned, during the shocks, in the direction of the magnetic needle, &c. none of which are observed to be constant attendants on earthquakes, nor do they seem materially to affect the solution given either one way or other.

LV. *Account of certain Improvements in Involution and Evolution.* *By Mr.* PETER NICHOLSON.

INVOLUTION.

I HAVE not observed in any of our treatises on Algebra, any general form for the expansion of $(a+b+c+d+e+\ \&c.)^n$, except that which would result from the theorem of Demoivre: but as this is capable of a more simple form, which does not involve the combinations of the quantities, and on which the extraction of roots in numbers entirely depends, I shall here exhibit it thus:

$$(a+b+c+d+e+\&c.)^n = a^n$$

$$(2),+\left\{ na^{n-1}b + \frac{n.n-1}{1.2}a^{n-2}b^2 + \frac{n.n-1.n-2}{1.2.3}a^{n-3}b^3 + \frac{n.n-1.n-2.n-3}{1.2.3.4}a^{n-4}b^4 + \&c. \right\}$$

$$(3),+\left\{ n(a+b)^{n-1}c + \frac{n.n-1}{1.2}(a+b)^{n-2}c^2 + \frac{n.n-1.n-2}{1.2.3}(a+b)^{n-3} c^3 + \&c. \right\}$$

* See Monsieur Bertrand's *Memoires sur les Tremblemens de Terre.*