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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 Reverend JOHN MICHELL, M. A.
Fellow of Queen's-College, Cambridge.

Read at several Meetings of the ROYAL SOCIETY.

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CONJECTURES

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CONJECTURES concerning the CAUSE,

AND

OBSERVATIONS upon the PHÆNOMENA,

OF

EARTHQUAKES.

INTRODUCTION.

Read Feb. 28. March 6. 13. 20. 27. 1760.

ART. 1. IT has been the general opinion of philoſophers, that earthquakes owe their origin to ſome ſudden exploſion in the internal parts of the earth. This opinion is very agreeable to the phænomena, which ſeem plainly to point out ſomething of that kind. The conjectures, however, concerning the cauſe of ſuch an exploſion, have not been yet, I think, ſufficiently ſupported by facts; nor have the more particular effects, which will ariſe from it, been traced out; and the connexion of them with the phænomena explained. To do this, is the intent of the following pages; and this we are now the better enabled to do, as the late dreadful earthquake of the

1ſt of November 1755 ſupplies us with more * facts, and thoſe better related, than any other earthquake of which we have an account.

2. That theſe concuſſions ſhould owe their origin to ſomething in the air, as it has ſometimes been imagined, ſeems very ill to correſpond with the phænomena. This, I apprehend, will ſufficiently appear, as thoſe phænomena are hereafter recounted; nor does there appear to be any ſuch certain and regular connexion between earthquakes and the ſtate of the air, when they happen, as is ſuppoſed by thoſe who hold this opinion. It is ſaid, for inſtance, that earthquakes always happen in calm ſtill weather: but that this is not always ſo, may be ſeen in an account of the † earthquakes in Sicily of 1693, where we are told, "the ſouth winds have blown very much, which ſtill "have been impetuous in the moſt ſenſible earth-"quakes, and the like has happened at other times."

3. Other examples to the ſame purpoſe we have in an account of the earthquakes that happened in New England in 1727 and 1728; the author of

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* Many of theſe facts are collected together in the 49th volume of the Philoſophical Tranſactions. The ſame are alſo to be found, with ſome additional ones, in "The Hiſtory and Philoſophy of "Earthquakes," (a work well worth the peruſal of thoſe, who are deſirous of being acquainted with this ſubject). The author of it has given us, beſides the aforeſaid facts, a very judicious abridgment of ten of the moſt conſiderable writers upon the ſubject. I have taken the greateſt part of my authorities either from this author, or the Philoſophical Tranſactions, that thoſe who would wiſh to examine them, may have an opportunity of doing it the more eaſily; ſome things only, which were not to be met with in theſe, and which yet were neceſſary to my purpoſe, I have been obliged to ſeek for elſewhere.

† See Phil. Tranſ. N° 207. or vol. ii. p. 408. Lowthorp's Abr.

which

which ſays, that he could neither obſerve any connexion between the weather and the earthquakes, nor any prognoſtic of them; for that they happened alike in all kinds of weather, at all times of the tides, and at all times of the moon *.

4. If, however, it ſhould ſtill be ſuppoſed, notwithſtanding theſe inſtances to the contrary, that there is ſome general connexion between earthquakes and the weather, at the time when they happen, yet, ſurely, it is far more probable, that the air ſhould be affected by the cauſes of earthquakes, than that the earth ſhould be affected in ſo extraordinary a manner, and to ſo great a depth; and that this,

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* See Philoſ. Tranſ. N° 409. or vol. vi. part ii. p. 202. Eames's Abridgment.—To theſe authorities, we may add the opinion of Monſ. Bertrand, who expreſſes himſelf, upon this occaſion, in the following manner. "Ariſtotle, Pliny, and "Seneca, tell us, that earthquakes are preceded by a calm and "ſerene air. This is, indeed, often the caſe, but not always. "I don't know, upon an examination of the whole, if there are "not as many exceptions to this rule, as examples that confirm "it. Some authors again have thought, that they might look on "a dark ſky, lightenings, and ſudden ſtorms, as the forerunners "of earthquakes." Then relating ſome inſtances of ſhocks that happened in calm and ſerene weather, he adds, "On the other "hand, it appears, from the examples, which we have before "related, that many earthquakes have happened at the time of "great rains, violent winds, and with a cloudy ſky; ſo that one "cannot find any certain prognoſtic of them in the ſtate of the "atmoſphere." See *Memoires Hiſtoriques et Phyſiques ſur les tremblemens de Terre, par Monſ. Bertrand, a la Haye* 1757. This author, in theſe ſenſible memoirs, has obliged the public with a circumſtantial account of all the facts he could collect, relating to the earthquakes of Switzerland, or thoſe of other places, that ſeemed to be connected with them. The whole ſeems to be done with care and fidelity, and without the leaſt attachment to any particular ſyſtem.

and

and all the other circumſtances attending theſe motions, ſhould be owing to ſome cauſe reſiding in the air.

5. Let us then, rejecting this hypotheſis, ſuppoſe, that earthquakes have their origin under ground, and we need not go far in ſearch of a cauſe, whoſe real exiſtence in nature we have certain evidence of, and which is capable of producing all the appearances of theſe extraordinary motions. The cauſe I mean is ſubterraneous fires. Theſe fires, if a large quantity of water ſhould be let out upon them ſuddenly, may produce a vapour, whoſe quantity and elaſtic force may be fully ſufficient for that purpoſe. The principal facts, from which I would prove, that theſe fires are the real cauſe of earthquakes, are as follow.

Section I.

6. *Firſt*, The ſame places are ſubject to returns of earthquakes, not only at ſmall intervals for ſome time after any conſiderable one has happened, but alſo at greater intervals of ſome ages.

7. Both theſe facts ſufficiently appear, from the accounts we have of earthquakes. The tremblings and ſhocks of the earth at * Jamaica in 1692, at * Sicily in 1693, and at * Liſbon in 1755, were repeated ſometimes at larger, and ſometimes at ſmaller intervals, for ſeveral months. The ſame thing has been obſerved in all other very violent earthquakes. At † Lima, from the 28th October 1746, to the

* See the accounts of theſe in the Philoſ. Tranſ.

† See Antonio d'Ulloa's Voyage to Peru, part ii. book i. ch. 7.

24th

24th February 1747 (the time when the account of them was ſent from thence), there had been numbered no leſs than 451 ſhocks, many of them little inferior to the firſt great one, which deſtroyed that city.

8. The returns of earthquakes alſo, in the ſame places, at larger diſtances of time, are confirmed by all hiſtory. Conſtantinople, and many parts of Aſia Minor, have ſuffered by them, in many different ages: Sicily has been ſubject to them, as far back as the remains even of fabulous hiſtory can inform us of: Liſbon did not feel the effects of them for the firſt time in 1755: Jamaica has frequently been troubled with them, ſince the Engliſh firſt ſettled there; and the Spaniards, who were there before, uſed to build their houſes of wood, and only one ſtory high, for fear of them: * Lima, Callao, and the parts adjacent, were almoſt totally deſtroyed by them twice, within the compaſs of about ſixty years, ſcarce any building being left ſtanding, and the latter being both times overflowed by the ſea: nor were theſe the only inſtances of the like kind, which have happened there; for, from the year 1582 to 1746, they have had no leſs than ſixteen very violent earthquakes, beſides an infinity of leſs conſiderable ones; and the Spaniards, at their firſt ſettling there, were told by the old inhabitants, when they ſaw them building high houſes, that they were building their own ſepulchres †.

9. *Secondly*,

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* See the place above-quoted.

† What is here ſaid, is taken from d'Ulloa's Voyage to Peru, the Hiſtory and Philoſophy of Earthquakes, the Philoſ. Tranſ. &c.

where

9. *Secondly*, Thoſe places that are in the neighbourhood of burning mountains, are always ſubject to frequent earthquakes; and the eruptions of thoſe mountains, when violent, are generally attended with them.

10. Aſia Minor and Conſtantinople may be looked upon as in the neighbourhood of Santerini. The countries alſo about * Ætna, Veſuvius, mount Hæcla, *&c.* afford us ſufficient proofs to the ſame purpoſe. But, of all the places in the known world, I ſuppoſe, no countries are ſo ſubject to earthquakes, as † Peru, Chili, and all the weſtern parts of South America; nor is there any country in the known world ſo full of volcanos: for, throughout all that long range of mountains, known by the name of the Andes, from 45 degrees ſouth latitude, to ſeveral degrees north of the line, as alſo throughout all Mexico, being about 5000 miles in extent, there is a continued chain of them ‡.

11. *Thirdly*, The motion of the earth in earthquakes is partly tremulous, and partly propagated by waves, which ſucceed one another ſometimes at larger and ſometimes at ſmaller

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where many more examples, to the ſame purpoſe, are to be met with. See alſo *Memoires ſur les tremblemens de Terre*; in which are mentioned above 130 repetitions of earthquakes, that have happened, within the compaſs of 960 years, in Switzerland.

* See many inſtances of this in vol. ii. of Lowthorp's Abr. of the Philoſ. Tranſ.

† Monſ. Bouguer ſays, that ſcarce a week paſſes without earthquakes in ſome part of Peru. See Hiſt. of Earthq. p. 205.

‡ See the Maps of theſe countries, Condamine's Voyage down the Maranon, Acoſta's Nat. Hiſt. of the Indies, *&c.*

diſtances; and this latter motion is generally propagated much farther than the former.

12. The former part of this propoſition wants no confirmation: for the proof of the latter, *viz.* the wave-like motion of the earth, we may appeal to many accounts of earthquakes: it was very remarkable in the two, which happened at Jamaica in * 1687-8 and * 1692. In an account of the former, it is ſaid, that a gentleman there ſaw the ground riſe like the ſea in a wave, as the earthquake paſſed along, and that he could diſtinguiſh the effects of it, to ſome miles diſtance, by the motion of the tops of the trees on the hills. Again, in an account of the latter, it is ſaid, "the ground heaved and ſwelled, "like a rolling ſwelling ſea," inſomuch, that people could hardly ſtand upon their legs by reaſon of it.

13. The ſame has been obſerved in the earthquakes of † New England, where it has been very remarkable. A gentleman giving an account of one, that happened there the 18th November 1755, ſays, the earth roſe in a wave, which made the tops of the trees vibrate ten feet, and that he was forced to ſupport himſelf, to avoid falling, whilſt it was paſſing.

14. The ſame alſo was obſerved at ‡ Liſbon, in the earthquake of the 1ſt November 1755, as may be

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* See Phil. Tranſ. N° 209. or vol. ii. Lowthorp's Abridgment, p. 410.

† See Philoſ. Tranſ. vol. I. p. 1, *&c.*

‡ See the accounts collected together, in the 49th volume of the Philoſ. Tranſ. or in Hiſt. and Philoſ. of Earthq. and particularly p. 315. where it is ſaid, "A moſt dreadful earthquake ſhook by "ſhort,

be plainly collected from many of the accounts that have been published concerning it, some of which affirm it expressly: and this wave-like motion was propagated to far greater distances than the other tremulous one, being perceived by the motion of waters, and the hanging branches in churches, through all Germany, amongst the Alps, in Denmark, Sweden, Norway, and all over the British isles.

15. *Fourthly*, It is observed in places, which are subject to frequent earthquakes, that they generally come to one and the same place, from the same point of the compass. I may add also, that the velocity, with which they proceed, (as far as one can collect it from the accounts of them) is the same; but the velocity of the earthquakes of different countries is very different.

16. Thus all the shocks, that succeeded the first great one at Lisbon in 1755, as well as the first itself, came from the * north-west. This is asserted by the person, who says, he was about writing a history of the earthquakes there: all the other accounts also confirm the same thing; for what some say, that they came from the north, and others, that they came

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" short, but quick vibrations, the foundations of all Lisbon;
" then, with a scarcely perceptible pause, the nature of the mo-
" tion changed, and every building was tossed like a waggon
" driven violently over rough stones, which laid in ruins almost
" every house, church, *&c.*"

For the wave-like motion at Oporto, see Phil. Trans. vol. xlix. p. 418. for the same at Gibraltar, see Hist. and Philos. of Earthq. p. 322.

* See Philos. Trans. vol. xlix. p. 410.

from

from the weſt, cannot be looked on as any reaſonable objection to this, but rather the contrary. The velocity alſo, with which they were all propagated, was the ſame, being at leaſt equal to that of ſound; for they all followed * immediately after the noiſe that preceded them, or rather the noiſe and the earthquake came together: and this velocity agrees very well with the intervals between the time when the firſt ſhock was felt at Liſbon, and the time when it was felt at other diſtant places, from the compariſon of which, it ſeems to have travelled at the rate of more than † twenty miles *per* minute.

17. An hiſtorical account of the earthquakes, which have happened in ‡ New England, ſays, that, of five conſiderable ones, three are known to have come from the ſame point of the compaſs, *viz.* the north-weſt: it is uncertain from what point the other two came, but it is ſuppoſed that they came from the ſame with the former. The ‖ velocity of theſe has been much leſs than that of the Liſbon earthquakes: this appears from the interval between the preceding noiſe, and the ſhock, as well as from the wave-like motion before-mentioned.

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* See Philoſ. Tranſ. vol. xlix. p. 414. or Hiſt. and Philoſ. of Earthq. p. 315.

† See Art. 97.

‡ See Philoſ. Tranſ. vol. l. p. 9.

‖ As in ſome earthquakes the velocity, with which they are propagated, is much leſs than in others, it is evident, that they can by no means be owing to any cauſe reſiding in the air: for any ſhock communicated to the air, muſt neceſſarily move with a velocity neither greater nor leſs than that of ſounds; that is, at the rate of about thirteen miles *per* minute.

18. All the greater earthquakes, that have been felt at * Jamaica, ſeem, by the accounts given of them, to have come from the ſea, and, paſſing by Port-Royal, to have gone northwards. The velocity of theſe alſo was far ſhort of the velocity of the Liſbon earthquakes.

19. The earthquake of † London, on the 8th of March 1750, was ſuppoſed to move from eaſt to weſt. I have been credibly informed, that the ſame thing happened in a ſlight ſhock, which was felt there in the laſt century, as the perſon, who told me this, had an opportunity of obſerving; for being, by accident, in a ſcalemaker's ſhop at the time when it happened, he found that all the ſcales vibrated from eaſt to weſt.

20. All the ſhocks that have been lately felt at Brigue in Valais, have likewiſe come from the ſame point of the compaſs, *viz.* the ſouth ‡.

21. *Fifthly*, The great Liſbon earthquake has been ſucceeded by ſeveral local ones ſince, the extent of which has been much leſs.

22. Such were the earthquakes in Switzerland; thoſe on the borders of France and Germany; thoſe in Barbary, *&c.* ‖

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* See the accounts of them in Philoſ. Tranſ. N° 209. or vol. ii. Lowthorp's Abr. p. 410, *&c.*

† See Hiſt. and Philoſ. of Earthq. p. 250. or Philoſ. Tranſ. vol. x. Martyn's Abr. Meteorology, paſſim.

‡ See Philoſ. Tranſ. vol. xlix. p. 620. The ſame has been obſerved at Smyrna alſo, ſee Philoſ. Tranſ. N° 495, or Martyn's Abr. vol. x. p. 526.

‖ See the accounts of theſe collected together in Philoſ. Tranſ. vol. xlix. or in the Hiſt. and Philoſ. of Earthq.

Sect. II.

23. How well ſoever theſe facts may agree with the ſuppoſition before laid down, That ſubterraneous fires are the cauſe of earthquakes, one doubt, however, may perhaps remain; *viz.* how it is poſſible that fires ſhould ſubſiſt, which have no communication with the outward air? In anſwer to this, I might alledge the example of green plants, which take fire by fermentation, when laid together in heaps; where the admiſſion of the outward air is ſo far from being neceſſary, that it will effectually prevent their doing ſo. But, to paſs by this, we have many inſtances more immediately to the purpoſe.

24. It can hardly be ſuppoſed, that the fires of the generality of volcanos receive any ſupply of freſh air (for this muſt effectually be prevented by that vapour, which is continually ruſhing out at all their vents), and yet they ſubſiſt, and frequently even increaſe, for many ages. Now, theſe are fires of the very ſame kind with thoſe, which I ſuppoſe to be the cauſe of earthquakes. Other facts, ſtill more expreſly to the purpoſe, are as follow:

25. In the earthquake of the 1ſt of November 1755, we are told, that both ſmoke and light flames were ſeen on the coaſt of Portugal, near Colares; and that, upon occaſion of ſome of the ſucceeding ſhocks, a ſlight ſmell of ſulphur was perceived to accompany a "fog, which came from the ſea, from the ſame "quarter, whence the ſmoke appeared *."

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* See Philoſ. Tranſ. vol. xlix. p. 414, &c.

26. In

26. In an account of an earthquake in New England, it is ſaid, that at Newbury, forty miles from Boſton, the earth opened, and threw up ſeveral cart-loads of ſand and aſhes; and that the ſand was alſo ſlightly impregnated with ſulphur, emitting a blue flame, when laid on burning coals *.

27. One of the relaters of the earthquake in Jamaica in 1692, has theſe words: "In Port-Royal, "and in many places all over the iſland, much ſulphureous combuſtible matter hath been found "(ſuppoſed to have been thrown out upon the "opening of the earth), which, upon the firſt touch "of fire, would flame and burn like a candle.

28. "St. Chriſtopher's was heretofore much "troubled with earthquakes, which, upon the eruption there of a great mountain of combuſtible matter, which ſtill continues, wholly ceaſed, and have "never been felt there ſince †."

29. Again, we are told, that, on the 20th November 1720, a burning ‡ iſland was raiſed out of the ſea, near Tercera, one of the Azores, at which place, ſeveral houſes were ſhaken down by an earthquake, which attended the eruption of it. This iſland was about three leagues in diameter, and nearly round; from whence it is manifeſt, that the quantity of pumice ſtones and melted matter, which muſt have been requiſite to form it, was amazingly great:

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* See Philoſ. Tranſ. N° 409. or vol. vi. part ii. p. 201. Eames's Abr.

† See Philoſ. Tranſ. N° 209. or vol. ii. p. 418. Lowthorp's Abr.

‡ See Philoſ. Tranſ. N° 372. or vol. vi. part ii. p. 203. Eames's Abr.

in

in all probability, it muſt have far exceeded all that has been thrown out of Ætna and Veſuvius together within the laſt two thouſand years. This may ſerve to ſatisfy us, that the fire which occaſioned all this, muſt have ſubſiſted for many years, not to ſay ages, and this without any communication with the external air. It is worth obſerving, that * ſeveral inſtances of this kind have happened amongſt the Azores. There are beſides many marks of ſubterraneous fires about theſe iſlands, ſeveral places ſending up ſmoke or flames. Theſe iſlands are alſo ſubject to violent and frequent earthquakes.

30. We have more inſtances to the ſame purpoſe, near the iſland of Santerini in the Archipelago, where there have been ſeveral little iſlands raiſed out of the ſea by a ſubmarine volcano. The eruption of one of theſe in the year 1708, with all the circumſtances that attended it, we have a very good account of in the † Philoſophical Tranſactions. It was raiſed in a place where the ſea had been formerly 100 fathoms deep, and was attended with earthquakes before it ſhewed itſelf above water, as well as after. It is reported, that the iſland of Santerini itſelf was originally raiſed out of the ſea in the ſame manner; but, be that as it will, we have certain accounts of new iſlands raiſed there, or additions made to the old ones, from time to time, for above 1900 years backwards, and there have always been earthquakes at the time of theſe eruptions.

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* See Hiſt. and Philoſ. of Earthquakes, under the titles Azores, Iſlands raiſed, &c.

† See N° 314, 317, and 332. or vol. v. part ii. p. 196. Jones's Abr.

31. An-

31. Another example of the ſame kind happened at * Manila, one of the Philippine iſlands, in the year 1750. This alſo was attended with violent earthquakes, to which that iſland, as well as the reſt of the Philippines, is very much ſubject.

32. We may add to theſe, the many inſtances of vaſt quantities of † pumice ſtones, which have been ſometimes found floating upon the ſea, at ſo great a diſtance from the ſhore, as well as from any known volcano, that there can be little doubt of their being thrown up by fires ſubſiſting under the bottom of the ocean.

33. From theſe inſtances, we may, with great probability, conclude, that the fires of volcanos produce earthquakes: I do not, however, ſuppoſe, that the earthquakes, which are frequently felt in the neighbourhood of volcanos, are owing to the fires of thoſe volcanos themſelves; for volcanos, giving paſſage to the vapours that are there formed, ſhould rather prevent them, as in the inſtance at St. Chriſtopher's, before-mentioned.

34. We alſo meet with frequent inſtances confirming the ſame thing amongſt the Andes. Antonio d'Ulloa (ſpeaking of what happens amongſt theſe mountains) ſays, "Experience ſhews us, that, upon "the freſh breaking out of any volcano, it occaſions "ſo violent a ſhock to the earth, that all the villages, "which are near it, are overthrown and deſtroyed,

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* See Philoſ. Tranſ. vol. xlix. p. 459.

† See Philoſ. Tranſ. N° 372. or vol. vi. part ii. p. 204. and N° 402. or vol. vii. part ii. p. 43. Eames's Abr.

"as

" as it happened in the caſe of the mountain * Car-
" guayraſo. This ſhock, which we may, without
" the leaſt impropriety, call an earthquake, is ſel-
" dom found to accompany the eruptions, after an
" opening is once made; or, if ſome ſmall trembling
" is perceived, it is very inconſiderable; ſo that,
" after the volcano has once found a vent, the ſhocks
" ceaſe, notwithſtanding the matter of it continues
" to be on fire." The greater earthquakes, there-
fore, ſeem rather to be occaſioned by other fires, that lie deeper in the ſame tract of country; and the eruptions of volcanos, which happen at the ſame time with earthquakes, may, with more probability, be aſcribed to thoſe earthquakes, than the earthquakes to the eruptions, whenever, at leaſt, the earthquakes are of any conſiderable extent. If this don't appear ſufficiently manifeſt at preſent, it will, perhaps, be better underſtood, by applying to the preſent purpoſe, what will be ſaid hereafter concerning local earthquakes.

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* It does not appear altogether certain, from the expreſſion made uſe of in the French tranſlation (from whence I have taken this), that Carguayraſo might not have been a volcano in former times, which is aſſerted to have been the caſe by Monſ. Condamine. It is poſſible alſo, that the ſame may be true of thoſe four mentioned in the next article; and, indeed, it is difficult to know it to be otherwiſe, in any inſtance, among the Andes, where the volcanos are generally found at inacceſſible heights. But allowing, that all theſe were only old volcanos, which broke out afreſh, yet they will ſerve at leaſt to ſwell the number of them in the ſame neighbourhood, as well as to ſhew us, that there may, very probably, be many more, which lie hid: for theſe ſhewed no marks of their exiſtence, till, by their eruption, they melted a vaſt quantity of ſnow, with which they were before covered, and which, being reduced to water, did great damage, by overflowing the country round about.

Sect. III.

35. It may be aſked, perhaps, why we ſhould ſuppoſe, that ſeveral ſubterraneous fires exiſt in the neighbourhood of volcanos? In evidence of this, we have frequent inſtances of new volcanos breaking out in the neighbourhood of old ones: Carguayraſo, juſt mentioned, may ſupply us with one example to this purpoſe; and, in the night of the 28th of October 1746, in which Lima and Callao were deſtroyed, no leſs than four * new ones burſt forth in the adjacent mountains.

36. To the ſame purpoſe, we may allege the inſtances of many volcanos lying together in the ſame tract of country: as for example, the many places, "not ſo few as forty," amongſt the Azores, which either do now or have formerly ſent forth ſmoke and flames; the many volcanos alſo amongſt the Andes, already mentioned: thus Ætna, Strombolo, and Veſuvius, I may add Solfatara too, are all in the ſame neighbourhood: and Monſ. Condamine ſays, he has traced † lavas, exactly like thoſe of Veſuvius, all the way from Florence to Naples. In ‡ Iceland alſo, we have, beſides Hæcla, not only ſeveral other volcanos, but alſo a great number of places, that ſend up ſul-

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* See d'Ulloa's Voyage to Peru, part ii. book i. chap. 7.

† See Phil. Tranſ. vol. xlix. p. 624. All theſe lavas, as well as the volcanos juſt mentioned, lie in a continued line. The ſame thing holds good in the volcanos of the Andes alſo. This is a fact I muſt deſire the reader to attend to, as it ſerves to confirm a very material doctrine, which I ſhall have occaſion to mention hereafter. See art. 44, 45, and 46.

‡ See Horrebow's Natural Hiſtory of Iceland.

phureous

phureous vapours. But the examples of this kind are ſo frequent, that there are few inſtances to be produced of ſingle volcanos, without evident marks, either that there have been others formerly in their neighbourhood, or that there are, at preſent, ſubterraneous fires near them.

37. This frequency of ſubterraneous fires, in the neighbourhood of volcanos, will appear ſtill more probable, if we conſider the internal ſtructure of the earth; and, as it will be neceſſary alſo, in order to underſtand what follows, to know a little more of this matter, than what falls under common obſervation, I ſhall endeavour to give the reader ſome account of it.

38. The earth then (as far as one can judge from the appearances), is not compoſed of heaps of matter caſually thrown together, but of regular and uniform ſtrata. Theſe ſtrata, though they frequently do not exceed a few feet, or perhaps a few inches, in thickneſs, yet often extend in length and breadth for many miles, and this without varying their thickneſs conſiderably. The ſame ſtratum alſo preſerves a uniform character throughout, though the ſtrata immediately next to each other are very often totally different. Thus, for inſtance, we ſhall have, perhaps, a ſtratum of potters clay; above that, a ſtratum of coal; then another ſtratum of ſome other kind of clay; next, a ſharp grit ſand ſtone; then clay again; next, perhaps, ſand ſtone again; and coal again above that; and it frequently happens, that none of theſe exceed a few yards in thickneſs. There are, however, many inſtances, in which the ſame kind of matter is extended to the depth of ſome

hundreds of yards; but in all theſe, a very few only excepted, the whole of each is not one continued maſs, but is again ſubdivided into a great number of thin laminæ, that ſeldom are more than one, two, or three feet thick, and frequently not ſo much.

39. Beſide the horizontal diviſion of the earth into ſtrata, theſe ſtrata are again divided and ſhattered by many perpendicular fiſſures, which are in ſome places few and narrow, but oftentimes many, and of conſiderable width. There are alſo many inſtances, where a particular ſtratum ſhall have almoſt no fiſſures at all, though the ſtrata both above and below it are conſiderably broken: this happens frequently in clay, probably on account of the ſoftneſs of it, which may have made it yield to the preſſure of the ſuperincumbent matter, and fill up thoſe fiſſures which it originally had; for we ſometimes meet with inſtances in mines, where the correſpondent fiſſures in an upper and lower ſtratum are interrupted in an intermediate ſtratum compoſed of clay, or ſome ſuch ſoft matter.

40. Though theſe fiſſures do ſometimes correſpond to one another in the upper and lower ſtrata, yet this is not generally the caſe, at leaſt not to any great diſtance: thoſe clefts, however, in which the larger veins of the ores of metals are found, are an exception to this obſervation; for they ſometimes paſs through many ſtrata, and thoſe of different kinds, to unknown depths.

41. From this conſtitution of the earth, *viz.* the want of correſpondence in the fiſſures of the upper and lower ſtrata, as well as on account of thoſe ſtrata which are little or not at all ſhattered, it will come to paſs,

paſs, that the earth cannot eaſily be ſeparated in a direction * perpendicular to the horizon, if we take any conſiderable portion of it together; but in the horizontal direction, as there is little or no adheſion between one ſtratum and another, it may be ſeparated without difficulty.

42. Thoſe fiſſures which are at ſome depth below the ſurface of the earth, are generally found full of water; but all thoſe that are below the level of the ſea, muſt always be ſo, either from the oozing of the ſea, or rather of the land waters between the ſtrata.

43. The ſtrata of the earth are frequently very much bent, being raiſed in ſome places, and depreſſed in others, and this ſometimes with a very quick aſcent or deſcent; but as theſe aſcents and deſcents, in a great meaſure, compenſate one another, if we take a large extent of country together, we may look upon the whole ſet of ſtrata, as lying nearly horizontally. What is very remarkable, however, in their ſituation, is, that from moſt, if not all, large tracts of high and mountainous countries, the ſtrata lie in a ſituation more inclined to the horizon, than the country itſelf, the † mountainous countries being generally,

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* What I ſaid before of thoſe deep clefts, in which metals are found, will not affect this concluſion; for they are conſiderably different from either perpendicular or plane ſections of earth; they are frequently interrupted by ſtrata of clay, or other ſoft matter; and they are, in moſt parts, either filled up with rubbiſh, or with ores and ſpars, that adhere as firmly to the rocks on both ſides, as if they compoſed one continued ſtratum with them.

† It ſeems very probable, from many appearances, not only that the mountainous countries are formed out of the lower ſtrata of the earth, but that ſometimes the higheſt hills in them are formed out

generally, if not always, formed out of the lower ſtrata of earth. This ſituation of the ſtrata may be not unaptly repreſented in the following manner. Let a number of leaves of paper, of ſeveral different ſorts or colours, be paſted upon one another; then bending them up together into a ridge in the middle, conceive them to be reduced again to a level ſurface, by a plane ſo paſſing through them, as to cut off all the part that had been raiſed; let the middle now be again raiſed a little, and this will be a good general repreſentation of moſt, if not of all, large tracts of mountainous countries, together with the parts adjacent, throughout the whole world *.

44. From this formation of the earth, it will follow, that we ought to meet with the ſame kinds of earths, ſtones, and minerals, appearing at the ſurface, in long narrow ſlips, and lying parallel to the greateſt riſe of any long ridges of mountains; and ſo, in fact, we find them. The Andes in South America, as it has been ſaid before, have a chain of volcanos, that extend in length above 5000 miles: theſe volcanos, in all probability, are all derived from the † ſame

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out of ſtrata ſtill lower than the reſt, which, perhaps, may always be the caſe, where they have volcanos in them. [See a repreſentation of this in the Plate, Fig. 3.] In other inſtances, however, it often happens, that the hills, to which theſe high lands ſerve as a baſe, are not only formed out of the ſtrata next above them, but they ſtand, as it were, in a diſh, as if they had depreſſed the ground, on which they reſt, by their weight.

* Fig. 1. repreſents a ſection of a ſett of ſtrata, lying in the ſituation juſt deſcribed: the ſection is ſuppoſed to be made at right angles to the length of the ridge, and perpendicular to the horizon.

† See the notes to art. 36 and 53. See alſo Fig. 3.

ſtratum. Parallel to the Andes, is the Sierra, another long ridge of mountains, that run between the Andes and the ſea; and "theſe two ridges of mountains run "within ſight of one another, and almoſt equally, "for above a thouſand leagues together *," being each, at a medium, about twenty leagues wide. The gold and ſilver mines wrought by the Spaniards, are found in a tract of country parallel to the direction of theſe, and extending through a great part of the length of them.

45. The ſame thing is found to obtain in North America alſo. The great lakes, which give riſe to the river St. Laurence, are kept up by a long ridge of mountains, that run nearly parallel to the eaſtern coaſt. In deſcending from theſe towards the ſea, the ſame ſets † of ſtrata, and in the ſame order, are generally met with throughout the greateſt part of their length.

46. In Great Britain, we have another inſtance to the ſame purpoſe, where the direction of the ridge varies about a point from due north and ſouth, lying nearly from ‡ N. by E. to S. by W. There are many more inſtances of this to be met with in the world, if we may judge from circumſtances, which make it highly probable, that it obtains in a great number of places, and in ſeveral they ſeem to put it almoſt out of doubt.

47. The reader is not to ſuppoſe, however, that, in any inſtances, the higheſt riſe of the ridge, and

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* See Acoſta's Natural Hiſtory of the Indies.

† See Lewis Evans's Map and Account of North America.

‡ Of this I could give many undoubted proofs, if it would not too far exceed the limits of my preſent deſign, and which, for that reaſon, I am obliged to omit.

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the inclination of the ſtrata from thence to the countries on each ſide, is perfectly uniform; for they have frequently very conſiderable inequalities, and theſe inequalities are ſometimes ſo great, that the ſtrata are bent for ſome ſmall diſtance, even the contrary way from the general inclination of them. This often makes it difficult to trace the appearance I have been relating, which, without a general knowlege of the foſſil bodies of a large tract of country, it is hardly poſſible to do.

48. At conſiderable diſtances from large ridges of mountains, the ſtrata, for the moſt part, aſſume a ſituation nearly level; and as the mountainous countries are generally formed out of the lower ſtrata, ſo the more level countries are generally formed out of the upper ſtrata of the earth.

49. Hence it comes to paſs, that, in countries of this kind, the ſame ſtrata are found to extend themſelves a great way, as well in breadth as in length: we have an inſtance of this in the chalky and flinty countries of England and France, which (excepting the interruption of the Channel, and the clays, ſands, *&c.* of a few counties) compoſe a tract of about three hundred miles each way.

50. Beſides the raiſing of the ſtrata in a ridge, there is another very remarkable appearance in the ſtructure of the earth, though a very common one; and this is what is uſually called by miners, the trapping down of the ſtrata; that is, the whole ſet of ſtrata on one ſide a cleft are ſunk down below the level of the correſponding ſtrata on the other ſide. If, in ſome caſes, this difference in the level of the ſtrata, on the different ſides of the cleft, ſhould be very

very conſiderable, it may have a great effect in producing ſome of the ſingularities of particular earthquakes *.

PART II.

51. IN the former part of this eſſay, I have recounted ſome of the principal appearances of earthquakes, as well as thoſe particulars in the ſtructure of the earth, upon which I ſuppoſe theſe appearances to depend. From what has been already ſaid, I think it is ſufficiently manifeſt, that, in ſome inſtances at leaſt, earthquakes are actually produced by ſubterraneous fires; it now, therefore, remains to be ſhewn, how all the appearances above-recited, as well as many other minuter circumſtances attending earthquakes, may be accounted for from the ſame cauſe.

SECT. I.

52. The returns of earthquakes in the ſame places, either at ſmall or large intervals of time, are very conſiſtent with the cauſe aſſigned: ſubterraneous fires, from their analogy to volcanos, might reaſonably be ſuppoſed to ſubſiſt for many ages, though we had not thoſe inſtances † already mentioned, which put the

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* Fig. 2. repreſents a ſection of the ſtrata trapping down after the manner juſt deſcribed. The ſection is ſuppoſed to be made perpendicularly to the horizon, and at right angles to the direction of the cleft: an inſtance of this kind, amongſt the coal miners of Mendip in Somerſetſhire, is mentioned in the Philoſ. Tranſ. See the account of it, together with a drawing, in N° 360. or Jones's Abr. vol. iv. part ii. p. 260.

† See art. 28 to 32 inclusive.

matter out of doubt. And, as it frequently happens, that volcanos rage for a time, and then are quiet again for a number of years; ſo we ſee earthquakes alſo frequently repeated for ſome ſmall time, and then ceaſing again for a long term, excepting, perhaps, now and then ſome ſlight ſhock. And this analogy between earthquakes, and the effects of volcanos, is ſo great, that I think it cannot but appear ſtriking to any one, who will read the accounts of both, and compare them together. The raging of volcanos is not one continued and uniform effect; but an effect, that is repeated at unequal intervals, and with unequal degrees of force: thus, for inſtance, we ſhall have, perhaps, two or three blaſts diſcharged from a volcano, ſucceeding one another at the interval of a few ſeconds only: ſometimes the intervals are of a quarter of an hour, an hour, a day, or perhaps ſeveral days. And as theſe intervals are very unequal, ſo is the violence of the blaſts alſo: ſometimes ſtones, *&c.* are thrown, by theſe blaſts, to the diſtance of ſome miles; at other times, perhaps, not to the diſtance of a hundred yards. The ſame difference is obſerved in the intervals and violence of the ſhocks of earthquakes, which are repeated at ſmall intervals for ſome time.

SECT. II.

53. The great frequency of earthquakes in the neighbourhood of burning mountains, is a ſtrong argument of their proceeding from a cauſe of the ſame kind: and the analogy of ſeveral volcanos lying together in the ſame tract of country, as well as new ones breaking out in the neighbourhood of old ones,

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tends greatly to confirm this opinion; but what makes it ſtill the more probable, is that peculiarity in the ſtructure of the earth, already mentioned. I obſerved before, that the ſame ſtrata are generally very extenſive, and that they commonly lie more inclining from the mountainous countries, than the countries themſelves: theſe circumſtances make it very probable, that thoſe * ſtrata of combuſtible materials, which break

* It has been imagined by ſome authors, that volcanos are produced by the pyrites of veins, and that they do not owe their origin to the matter of ſtrata. In order to prove this, it is alleged, that volcanos are generally found on the tops of mountains, and that thoſe are the places in which veins of pyrites are generally lodged. This argument being taken from obſervations that have their foundation in nature, ought not to go unanſwered. In the firſt place, then, the pyrites of veins, or fiſſures, are not found in ſufficient quantities, or extending to a ſufficient breadth, to be ſuppoſed capable of producing the fires of volcanos: it very rarely happens, that we meet with a vein or fiſſure five or ſix yards wide; and when we meet with ſuch an one, yet, perhaps, not a twentieth part of it at moſt ſhall be filled with pyrites; but the fires of volcanos, inſtead of being long and narrow, as if the matter that ſupplied them was depoſited in veins, are generally round, and of far greater breadth than veins can be ſuppoſed to be. Monſ. Bouguer ſays, that the mouth of the volcano Cotopaxi is, at this time, five or ſix hundred fathoms wide; [ſee Hiſt. and Phil. of Earthquakes, p. 195.] and the burning iſland that was raiſed out of the ſea near Tercera, as before-mentioned, was almoſt three leagues in diameter, and nearly round. [See art. 29.]

Beſides this, it is very difficult to conceive how any matters lodged in veins can ever take fire; for, excepting where the veins are extremely narrow, they are almoſt always drowned in a very great quantity of water, which has free acceſs to every part of them: neither are the pyrites of veins, by any means, ſo apt to take fire of themſelves, as thoſe of ſtrata; and if, indeed, there are any of them that will do ſo, yet they are but few in compariſon of thoſe which will not: all thoſe, which, beſide iron and ſulphur, contain copper, or arſenic, even in a very ſmall proportion, are not

break out in volcanos on the tops of the hills, are to be found at a conſiderable depth under ground in the level and low countries near them. If this ſhould be the caſe,

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at all ſubject to inflame of themſelves. On the other hand, moſt of the pyrites of ſtrata, if not all of them, have this property more or leſs. There are alſo two ſorts of ſtrata, in which pyrites are lodged in the greateſt abundance, that have the ſame property, and that frequently in as great a degree as themſelves: theſe are coals and aluminous earths, or ſhale. There are ſome kinds of both theſe, that, upon being expoſed to the external air for a few months, will take fire of themſelves, and burn. Theſe two ſorts of ſtrata are alſo near akin to each other; they are generally found to accompany each other; they are both of them generally intermixed with, or accompanied by ſtrata of iron ore; and they both of them, for the moſt part, either contain, or are lodged amongſt, the remains of vegetable bodies; and theſe remains of vegetable bodies, in the aluminous earths, are frequently either wholly, or in part, converted into pyrites, or coal, or both. Numberleſs, inſtances of this are to be met with in the aluminous ſhale of Whitby and other places.

It is very probable, that to ſome ſtratum of this kind the fires of volcanos are owing; and this ſeems to be confirmed by the ſimilarity of the materials, which are thrown up or ſublimated by the fires of volcanos, to the matter of the aluminous earths. Solfatara produces ſulphur, alum, and ſal ammoniac. The two former of theſe are very eaſily to be obtained from the aluminous earths, and, I ſuppoſe, the latter alſo; at leaſt it is procurable from the ſoot of common foſſil coals, and probably, therefore, from the ſoot of that coaly matter which is intermixed with ſuch earths.

The aluminous earths, moreover, not only have ſeveral ſtrata of iron ore lying in them, but they alſo contain a conſiderable proportion of iron in their compoſition. In correſpondence to this, we find the lavas of volcanos, and other matters thrown out from thence, frequently containing a great deal of iron, the ſmall duſt of them readily adhering to the magnet.

As to the pyrites of veins, I much doubt whether they ever contain alum, or ſal ammoniac; at leaſt they are very rarely found to contain either the one or the other.

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and if the ſame * ſtrata ſhould be on fire in any places under ſuch countries, as well as on the tops of the hills, all vapours, of whatſoever kind, raiſed from theſe fires, muſt be pent up, unleſs ſo far as they can open themſelves a paſſage between the ſtrata; whereas the vapours raiſed from volcanos find a vent, and are diſcharged in blaſts from the mouths of them. Now, if, when they find ſuch a vent, they are yet capable of ſhaking the country to the diſtance of ten or twenty miles round, what may we not expect from them, when they are confined? We may form ſome idea of the force and quantity of theſe vapours from their effects: it is no uncommon thing to ſee them throw up, at once, ſuch clouds of ſand, aſhes, and pumice ſtones, as are capable of darkening the whole air, and covering the neighbouring country with a ſhower of duſt, *&c.* to ſome miles diſtance: great ſtones alſo, of ſome tons weight, are often thrown to the diſtance of two or three miles by theſe exploſions: and Monſ. Bouguer tells us, that he met with ſtones

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* It may be aſked, perhaps, why a ſtratum liable to take fire in ſome places, ſhould not take fire throughout the whole extent of it? In anſwer to this, it may be ſaid, that the ſame ſtratum may differ a little in the richneſs of its combuſtible principles in different places; or, perhaps, the frequency of the fiſſures, either in the combuſtible ſtratum itſelf, or the ſtratum next to it, may let in ſo much water, as to prevent its taking fire, excepting in a few places; but, if this once happens, the fire will not eaſily be put out again, but it will ſpread itſelf, notwithſtanding the fiſſures that lie in its way, though they are filled with water; for the matter on fire will be, in ſome degree at leaſt, in a fluid ſtate; and, for this reaſon, it muſt neceſſarily expel the water from the fiſſures, both on account of the extenſion of its own dimenſions by the heat, and of the weight of the ſuperincumbent earth, which, preſſing it, will make it ſpread laterally.

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in South America, of eight or nine feet diameter, that had been thrown from the volcano Cotopaxi, by one of these blasts, to the distance of more than * three leagues.

54. If we suppose that these vapours, when pent up, are the cause of earthquakes, we must naturally expect, from what has been just said, that the most extensive earthquakes should take their rise from the level and low countries; but more especially from the sea, which is nothing else than waters covering such countries. Accordingly we find, that the great earthquake of the 1st November 1755, which was felt at places near three thousand miles distant from each other, took its rise from under the sea; this is manifest, from that wave which accompanied it, as shall be shewn hereafter. The same thing is to be understood of the earthquake that destroyed Lima in the year 1746, which, it has been said, was felt as far as Jamaica; and, as it was more violent than the Lisbon earthquake, so, if this be true, it must, in all probability, have been more extensive also. There have been many other very extensive earthquakes in South America: Acosta says, that they have been often known to extend themselves one, two, or three hundred, and some even five hundred leagues, along the coast. These have been generally, if not always, attended with waves from the sea; but any minuter

* See Hist. and Philos. of Earthq. p. 195. Don Antonio d'Ulloa, an author of great veracity, speaking of the same thing, says, that "the whole plain [near Latacunga] is full of large pieces of rocks, "some of them thrown from the volcano Cotopaxi, by one of its "eruptions, to the distance of five leagues." See his Voyage to Peru, part i. book vi. chap. 1.

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circumſtances accompanying them are not related. Indeed it is hardly to be expected that they ſhould be obſerved, much leſs that they ſhould be related, when they happened in a country ſo thinly inhabited, and where one may reaſonably ſuppoſe, that, in general, only the groſſer and more violent effects would be taken notice of.

SECT. III.

55. I have ſaid before, that I imagined earthquakes were cauſed by vapours raiſed from waters ſuddenly let out upon ſubterraneous fires. It is not eaſy to find any other cauſe capable of producing ſuch ſudden and violent effects, or of raiſing ſuch an amazing quantity of vapour in ſo ſmall a time. That the blaſts, diſcharged from volcanos, are always produced from this cauſe, is highly probable; that they are often ſo, cannot admit of the leaſt doubt. There can be no doubt, that conſiderable quantities of water muſt be often let out upon the fires of theſe volcanos, and whenever this happens, it will be immediately raiſed by the heat of them into a vapour, whoſe elaſtic force is capable of producing the moſt violent effects *.

56. Both

* There are many effects produced by the vapour of water, when intenſely heated, which make it probable, that the force of gunpowder is not near equal to it. The effects of an exceeding ſmall quantity of water, upon which melted metals are accidentally poured, are ſuch, as, I think, could in no wiſe be expected from the like quantity of gunpowder. Founders, if they are not careful, often experience theſe effects to their coſt. An accident of this kind happened about forty years ſince, at the caſting of two braſs cannon at Windmill-hill, Moorfields. "The "heat

56. Both the tremulous and wave-like motion obſerved in earthquakes, may be very well accounted for

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" heat of the metal of the firſt gun drove ſo much damp into the " mould of the ſecond, which was near it, that as ſoon as the " metal was let into it, it blew up with the greateſt violence, tear- " ing up the ground ſome feet deep, breaking down the furnace, " untiling the houſe, killing many ſpectators on the ſpot, with the " ſtreams of melted metal, and ſcalding many others in a moſt mi- " ſerable manner." [See the note at the end of proceſs 44th of the Engliſh tranſlation of Cramer's Art of aſſaying Metals.]

Other inſtances of the violence of vapours raiſed from water, are frequently to be met with: one of Papin's digeſters being placed between the bars of a grate, where there was a fire, was, after ſome time, burſt by the violence of the ſteam, the fire was all blown out of the grate, and a piece of the digeſter was driven againſt the leaf of a ſtrong oak table, which it broke to pieces. [See Philoſ. Tranſ. N° 454. or Martyn's Abr. vol. viii. p. 465.] The marquis of Worceſter alſo, in his Century of Inventions, tells us, that he burſt a cannon by the ſame means.

It has been ſometimes imagined, that the vapours, which occaſion earthquakes, were of the ſame kind with thoſe fulminating damps, of which we often meet with inſtances in coal mines. Now, there are ſeveral things which make it very probable, that this is not the caſe: it is true, the force of ſuch vapours is very great; we have had inſtances, where large beams of timber have been thrown to the diſtance of an hundred yards by them: [ſee Philoſ. Tranſ. N° 136. or vol. ii. p. 381. Lowthorp's Abr.] but what is this to the force of that vapour, which could throw ſtones of twenty or thirty ton weight to the diſtance of three leagues? Nor, indeed, is it at all probable, that any vapour, already in the form of a vapour, can, by ſuddenly taking fire, increaſe its dimenſions ſo much, as to produce that immenſe quantity of motion, which we obſerve in ſome earthquakes: but this is rather to be expected from ſome ſolid body, ſuch as water, which is capable of being converted, and that almoſt inſtantly, into one of the lighteſt, and perhaps one of the moſt elaſtic, vapours in the world. Air, when heated to the greateſt degree that it is capable of receiving from the hotteſt fires we can make, acquires a degree of elaſticity about five times as great as that of common air: the vapour of gun-

for from ſuch a vapour. In order to trace a little more particularly the manner in which theſe two motions

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gunpowder, whilſt it is inflamed, has alſo about five times the elaſtic force which it has when cold. [See Robins's excellent tract on Gunnery.] Now, if we ſuppoſe a fulminating damp, of any kind, to increaſe its elaſticity, when inflamed in the ſame proportion, this will be abundantly ſufficient to make it produce any effects, which we have ever ſeen produced by any of the damps of mines, &c. And, indeed, whoever carefully examines the effects, either of the damps of mines, or of thoſe fulminating damps, that are raiſed from ſome metals, when in fuſion, or when they are diſſolving in acids, will rather be inclined to think, that the force of inflamed vapours is ſo far from exceeding the proportion of five to one, that it falls conſiderably ſhort of it.

But though we ſhould ſuppoſe that this proportion holds good, where ſhall we find a place capable of containing a ſufficient quantity of ſuch a vapour, to produce the great effects of earthquakes? It will be ſaid, perhaps, in ſubterraneous caverns. To this we may anſwer, that he, who is but moderately acquainted with the ſtructure of the earth, and the materials of which it is compoſed, will be little inclined to allow of any great or extenſive caverns in it. But, though this ſhould be admitted, how can it come to paſs that theſe caverns ſhould not be filled with water? If it is alleged, that the water is expelled, as the vapour is formed, why ſhould not the vapour, as it is ſuppoſed to be the lighter, be expelled, rather than the water, by the ſame paſſages by which the water is to be expelled? But let us ſuppoſe this difficulty alſo to be got over, and the water to be removed, and we ſhall then have a gage for the denſity of the vapour; for it muſt be juſt ſufficient to make it capable of ſuſtaining a column of water, whoſe height is equal to that of the ſurface of the ſea above the bottom of the cavern, in which the vapour is ſuppoſed to be contained. Now, ſince the mean weight of earth, ſtones, &c. is not leſs than two and a half times the weight of water, this vapour muſt be increaſed to two and half times its original elaſticity, before it can, in any wiſe, raiſe the earth above it; and if we ſuppoſe it to be increaſed to five times its original elaſticity, it will then be no more than twice able to do ſo; in which caſe, ſo much vapour only can be diſcharged from the cavern, to produce an earthquake, as is equal to the

motions will be brought about, let us ſuppoſe the roof over ſome ſubterraneous fire to fall in. If this ſhould be the caſe, the earth, ſtones, &c. of which it was compoſed, would immediately ſink in the melted matter of the fire below: hence all the water contained in the fiſſures and cavities of the part falling in, would come in contact with the fire, and be almoſt inſtantly raiſed into vapour. From the firſt effort of this vapour, a cavity would be formed (between the melted matter and ſuperincumbent earth) filled with vapour only, before any motion would be perceived at the ſurface of the earth: this muſt neceſſarily happen, on account of the * compreſſibility of

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content of the cavern: and what muſt the ſize of that cavern be, which could contain vapour enough to produce the earthquake of the 1ſt of November 1755, in which an extent of earth of near three thouſand miles diameter was conſiderably moved? or how can we ſuppoſe, that the roof of ſuch a cavern, when ſo violently ſhaken, ſhould avoid falling in? eſpecially, as it is hardly to be ſuppoſed, that any inflamed vapour whatſoever ſhould be able to move the earth over theſe caverns, if they lay at any great depth, ſince the weight of leſs than three miles depth of earth is capable of retaining the inflamed vapour of gunpowder within the original dimenſions of the gunpowder itſelf; and common air, compreſſed by the ſame weight (ſuppoſing the known law of its compreſſion to hold ſo far), would be of greater denſity than water.

We may aſk ſtill farther, whence ſuch vaſt quantities of vapour ſhould be formed, or what ſources they muſt be, which would not be exhauſted (if they were not again repleniſhed) by a very few repetitions of ſuch immenſe diſcharges.

* The compreſſibility and elaſticity of the earth, are qualities which don't ſhow themſelves in any great degree in common inſtances, and therefore are not commonly attended to. On this account it is, that few people are aware of the great extent of them, or the effects that may ariſe from them, where exceeding large quantities of matter are concerned, and where the compreſ-

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of all kinds of earth, ſtones, &c. but as the compreſſion of the materials immediately over the cavity, would

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ſive force is immenſely great. The compreſſibility and elaſticity of the earth may be collected, in ſome meaſure, from the vibration of the walls of houſes, occaſioned by the paſſing of carriages in the ſtreets next to them. Another inſtance to the ſame purpoſe, may be taken from the vibrations of ſteeples, occaſioned by the ringing of bells, or by guſts of wind: not only ſpires are moved very conſiderably by this means, but even ſtrong towers will, ſometimes, be made to vibrate ſeveral inches, without any diſjointing of the mortar, or rubbing of the ſtones againſt one another. Now, it is manifeſt, that this could not happen, without a conſiderable degree of compreſſibility and elaſticity in the materials, of which they are compoſed: and if ſuch ſmall things as the weight of ſteeples, and the motion of bells in them, or a guſt of wind, are capable of producing ſuch effects, what may we not expect from the weight of great depths of earth? There are ſome circumſtances, which ſeem to make it not altogether improbable, that the form and internal ſtructure of the earth depend, in a great meaſure, upon the compreſſibility and elaſticity of it. There are ſeveral things that ſeem to argue a conſiderably greater denſity in the internal, than the external part of the earth; and why may not this greater denſity be owing to the compreſſion of the internal parts ariſing from the weight of the ſuperincumbent matter, ſince it is probable, that the matter, of which the earth is compoſed, is pretty much of the ſame kind throughout? There is a ſtill ſtronger argument for the earth's owing its form, in ſome meaſure, to the ſame cauſe; for it is found to be higher [ſee the French accounts of the meaſures of a degree of the meridian in France, Sweden, and America] at the æquator, than at the poles, in a greater proportion than it would be on account of the centrifugal force, if it was of uniform denſity; but, if we ſuppoſe the earth to be of leſs denſity in an æquatorial diameter than in the axis, the whole will then be eaſily accounted for, from the riſing of the earth a little by its elaſticity, the weight being in part taken off by the diurnal rotation: and that the earth is really a little denſer in the axis, than in the æquatorial diameter, ſeems highly probable, from the experiments of pendulums compared with aſtronomical obſervations; for the forms of the earth derived from theſe, cannot be

 reconciled

would be more than ſufficient to make them bear the weight of the ſuperincumbent matter, this compreſſion muſt be propagated on account of the elaſticity of the earth, in the ſame manner as a pulſe is propagated through the air; and again the materials immediately over the cavity, reſtoring themſelves beyond their natural bounds, a dilatation will ſucceed to the compreſſion; and theſe two following each other alternately, for ſome time, a vibratory motion will be produced at the ſurface of the earth. If theſe alternate dilatations and compreſſions ſhould ſucceed one another at very ſmall intervals, they would excite a like motion in the air, and thereby occaſion a conſiderable noiſe. The noiſe that is uſually obſerved to precede or accompany earthquakes, is probably owing partly to this cauſe, and partly to the grating of the parts of the earth together, occaſioned by that wave-like motion before-mentioned.

57. After the water, that firſt came in contact with the fire, has formed a cavity, all the reſt of the water contained in the fiſſures, immediately communicating with the hollow left by the part that fell in,

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reconciled with each other, but upon this ſuppoſition. [See Maclaurin's Fluxions, art. 681, &c.] It appears, from ſome late and accurate obſervations, that the æquatorial parts of the planet Jupiter alſo, as well as thoſe of the earth, are a little higher than they would be, if their riſe was owing to the centrifugal force, and he was of uniform denſity; but if we ſuppoſe him to be of leſs denſity in the æquatorial, than the polar regions, then the form may be ſuch as he would aſſume from the reſpective gravitation of the ſeveral parts; and any fluid like our ocean, would not overflow the polar parts, (which, upon any other ſuppoſition, it muſt neceſſarily do) but would follow his general form, as our ocean does that of the earth.

muſt

muſt run out upon the fire, the ſteam taking its place. From hence may be generated a vaſt quantity of vapour, the effects of which ſhall be conſidered preſently. This ſteam will continue to be generated, ſuppoſing the fire to be ſufficiently great, till the fiſſures before-mentioned are evacuated, or till the water begins to flow very ſlowly; when the ſteam already formed will be removed by the elaſticity of the earth, which will again ſubſide, and, preſſing upon the ſurface of the melted matter, will force it up a little way into all the clefts, by which the water might continue to flow out. By this means, all communication between the fire and the water will be prevented, excepting at theſe clefts, where the water, dripping ſlowly upon the melted matter, will gradually form a cruſt upon it, that will ſoon ſtop all farther communication in theſe places likewiſe; and the fiſſures, that had been before evacuated, will be again gradually repleniſhed by the oozing of the water between the ſtrata.

58. As a ſmall quantity of vapour almoſt inſtantly generated at ſome conſiderable depth below the ſurface of the earth, will produce a vibratory motion, ſo a very large quantity (whether it be generated almoſt inſtantly, or in any ſmall portion of time) will produce a wave-like motion. The manner in which this wave-like motion will be propagated, may, in ſome meaſure, be repreſented by the following experiment. Suppoſe a large cloth, or carpet, (ſpread upon a floor) to be raiſed at one edge, and then ſuddenly brought down again to the floor, the air under it, being by this means propelled, will paſs along, till it eſcapes at the oppoſite ſide, raiſing the

cloth

cloth in a wave all the way as it goes. In like manner, a large quantity of vapour may be conceived to raiſe the earth in a wave, as it paſſes along between the ſtrata, which it may eaſily ſeparate in an horizontal direction, there being, as I have ſaid before, little or no coheſion between one ſtratum and another. The part of the earth that is firſt raiſed, being bent from its natural form, will endeavour to reſtore itſelf by its elaſticity, and the parts next to it beginning to have their weight ſupported by the vapour, which will inſinuate itſelf under them, will be raiſed in their turn, till it either finds ſome vent, or is again condenſed by the cold into water, and by that means prevented from proceeding any farther.

59. If a large quantity of vapour ſhould continue to be generated for ſome time, ſeveral waves might be produced by it; and this would be, in ſome meaſure, the caſe, if the quantity at firſt generated was exceedingly great, though the whole of it was generated in leſs time, than whilſt the motion was propagated through the diſtance between two waves.

60. Theſe waves muſt riſe the higher, the nearer they are to the place from whence they have their ſource; but, at great diſtances from thence, they may riſe ſo little, and ſo ſlowly, as not to be perceived, but by the motions of waters, hanging branches in churches, *&c.*

61. The vibratory motion occaſioned by the firſt impulſe of the vapour, will be propagated through the ſolid parts of the earth, and therefore, it will much ſooner become too weak to be perceived, than the wave-like motion; for this latter, being occaſioned by the vapour inſinuating itſelf between the ſtrata,

ſtrata, may be propagated to very great diſtances; and even after it has ceaſed to be perceived by the the ſenſes, it may ſtill diſcover itſelf by the appearances before-mentioned.

Sect. IV.

62. All earthquakes derived from the ſame ſubterraneous fire, muſt come to the ſame place in the ſame direction; and thoſe only which are derived from different fires, will come from different points of the compaſs; but as, in all probability, it ſeldom happens that earthquakes, cauſed by different fires, affect the ſame place, we therefore find in general, that they come from the ſame quarter: it is not, however, to be ſuppoſed, that this ſhould always be the caſe, for it will, probably, ſometimes happen to be otherwiſe: and this is to be expected in ſuch places as are ſituated in the neighbourhood of ſeveral ſubterraneous fires; or where, being ſubject to the ſhocks of ſome local earthquake of ſmall extent, they now and then are affected by an earthquake, produced by ſome more diſtant, but much more conſiderable cauſe. Of this laſt caſe, we ſeem to have had ſome inſtances in the earthquake of the 1ſt of November 1755, and thoſe local ones, before-mentioned, which ſucceeded it.

63. As we may reaſonably infer from many earthquakes coming to the ſame place, from the ſame point of the compaſs, that they are all derived from the ſame cauſe, and that a permanent one; ſo we may reaſonably infer the ſame thing alſo, from their being propagated with the ſame velocity; but this argument will ſtill come with the greater force, if it be conſidered,

conſidered, that the velocity of any vapour, which inſinuates itſelf between the ſtrata of the earth, depends upon the depth of it below the ſurface; for the deeper it lies, the greater will be its * velocity. We may therefore conclude, from the ſameneſs of the velocity of the earthquakes of the ſame place, that the cauſe of them lies at the ſame depth; and from the inequality of the velocity of the earthquakes of different places, that their cauſes lie at different depths. Both theſe are perfectly conſiſtent with the ſuppoſition, that earthquakes owe their origin to ſubterraneous fires, ſince the ſtrata in which theſe ſubſiſt, may be eaſily conceived to lie at different depths in different parts of the world.

SECT. V.

64. From the ſame cauſe, we may eaſily account for thoſe local earthquakes, which ſucceed the greater and more extenſive ones. If there are many ſubterraneous fires ſubſiſting in different parts of the world, the vapour coming from one fire may very well be ſuppoſed, as it paſſes, to diſturb the roof over ſome other fire, and, by that means, occaſion earthquakes by the falling in of ſome part of it: and this may be the caſe, in ſome meaſure, even where the vapour paſſes at ſome ſmall diſtance over the fire; but it will be moſt likely to take place, where the vapour either

* The velocity of ſuch a vapour, depending intirely upon the elaſticity of the earth which is over it, will be, *cæteris paribus*, (if I am not miſtaken) in the ratio of the depth below the ſurface. This ſeems to follow from a known law of all elaſtic bodies, according to which they tend to return to their ſtate of reſt, when either dilated or compreſſed, with forces proportionable to the quantity by which they differ from their natural bounds.

paſſes

paſſes at ſome diſtance under it, or between the ſtratum, in which the fire lies, and that next above or below it.

PART III.

SECT. 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

* 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;

ginal 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

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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; B B, parts of the ſame ſtratum yet unkindled; C C, 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

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 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

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approach 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.

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.

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:

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* 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 time; 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.

† See Philoſ. Tranſ. N° 437. or Martyn's Abridgm. vol. viii. p. 689.

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 No-
" vember, the water of a fountain was greatly de-
" creaſed: on the morning of the 1ſt of November,
" it ran very muddy, and after the earthquake, it re-
" turned to its uſual ſtate, both in quantity and clear-
" neſs." The ſame author ſays, a little lower, " in
" the afternoon of the 24th, I was much apprehen-
" ſive, that the following days we ſhould have an-
" other great earthquake; for I obſerved the ſame
" prognoſtics as in the afternoon of the 31ſt October;
" that is," *&c.* " And I farther 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 agita-

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* See Philoſ. Tranſ. vol. xlix, p. 416 and 417.—or Hiſt. and Philoſ. of Earthq. p. 313.

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tion 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 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

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* See Philoſ. Tranſ. vol. xlix.—or Hiſt. and Philoſ. of Earthq. art. Lochneſs, Lochlommond, &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 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 *et* 105.]

communi-

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

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* 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. N° 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.

chiefly

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 latter 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.

SECT. 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,

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* See art. 43.
† See art. 63. the note.

"like

" like a mountain, came rolling in; and about Bel-
" lem 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 ob-
" ſerved 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 perpen-
" dicular 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 ſud-
" denly 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 farther progreſs of the communication between the fire and water, the vapour, that is

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

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

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 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

* See art. 56 to 60 incluſive.

way,

way, and produce a great wave immediately ſucceeding the previous retreat *.

Sect. 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 firſt, but by the great extenſion of the heated matter, yet, after they have once taken place,

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* 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.

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.

Sect. 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,

* See art. 43.

having

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, then, the largeſt fires are to be ſuppoſed to ſubſiſt under the ocean, it is no wonder that the

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* 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 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.]

moſt

moſt extenſive earthquakes ſhould take their riſe from thence: the great earthquake of Liſbon has been * ſhewn 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,

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* 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.

that

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.

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 ſome- " times are felt by thoſe that live in and at the foot

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* See art. 28.

† 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. N° 209. or Lowthorp's Abr. vol. ii. p. 417 and 418.

" of

" 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."

SECT. 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

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* See Phil. Tranſ. N° 209, or Lowthorp's Abr. vol. ii. p. 410.

ſhall

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 * 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

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

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 re-"mains, 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,

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* 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.]

within an extent of 120 miles long, and leſs than thirty broad, the 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 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 man-"ner, and huge maſſes of them were thrown down "into the ſubjacent vallies ‡."

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* 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.

 86. The

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 Cla-" rendon 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 moun-" tains, 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 great ſhakes continued, " bellowed out prodigious loud noiſes and echo-" ings.

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 Port-

" morant,

" morant, 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 ſup-
" poſed to be many ſtrange alterations of the like
" nature; but thoſe wild deſart 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 de-
" prived of their natural verdure *."

SECT. 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

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* See Philoſ. Tranſ. N° 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 deſart country, where at moſt half a dozen unknown ſhepherds might feel the effects of it, or perhaps only ſee it at a diſtance.

there

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 comprehended 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.

SECT. 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,

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 judgment 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

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. *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.

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* 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) 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.

Liſbon

	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 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

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* 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 exactly, 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.

not always greatly to be depended on. The times themſelves alſo are often ſo careleſly 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

* 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.

not

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 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

* 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.*]

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.

Sect. 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 be 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

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* 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.

depth

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 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 acknowleged, 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

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* 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.

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 ſhew 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 farther: ſuch, for 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.*

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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.

107. *Se-*

107. *Secondly*, Thoſe appearances which ſeemed to depend upon particular circumſtances, and of which, therefore, unleſs we had a more exact knowlege 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.

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

FINIS.

Cambridge University Library,
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Fig. 1.

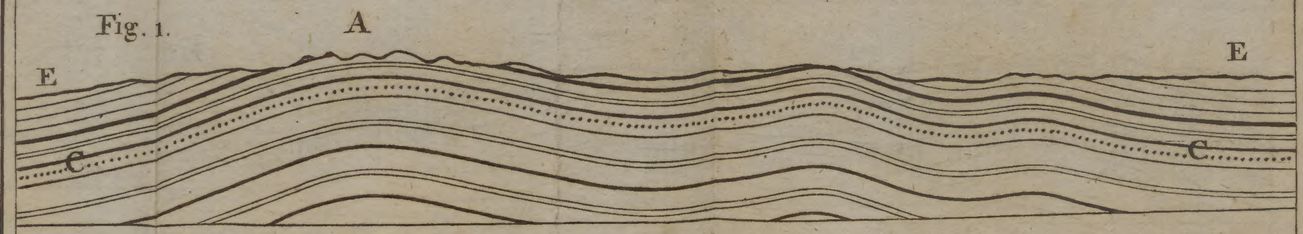


Fig. 3.

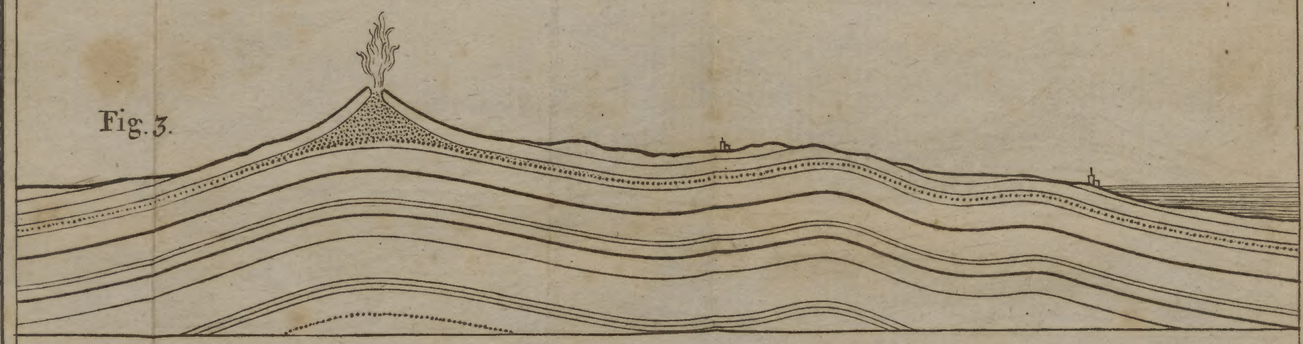


Fig. 4.

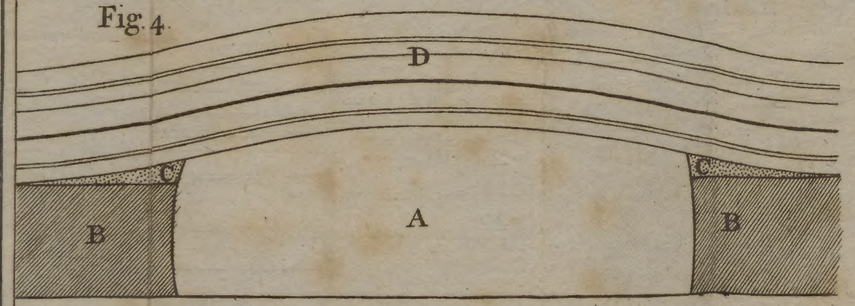
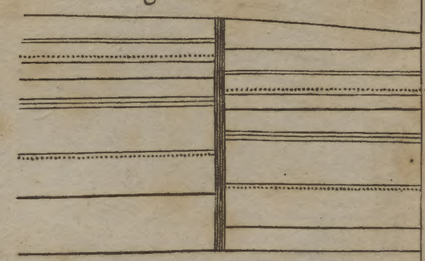


Fig. 2.

J. Mynde Sc.

p. 10 – Deviation from same point

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17. } ms
o 26 } argument and
} Mickle

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