CHAPTER I

BEFORE MICHELL

1. I have supposed the birth of seismology to date from the middle of the eighteenth century, from the time when those who studied earthquakes drew their illustrations from contemporary records and no longer from the writings of Aristotle, Seneca or Pliny. From this point of view, the first Founder of Seismology would be John Michell (*c.* 1724–93), at one time Woodwardian professor of geology at Cambridge. Much of the material used in his memoir on earthquakes (1760) was, however, derived from two volumes, both published in 1757—*The History and Philosophy of Earthquakes* and Bertrand's *Mémoires Historiques et Physiques sur les Tremblemens de Terre*. I have therefore chosen these books as my starting-point, and they form the subject of the present chapter.

The other limit of my survey is less definite. It seemed clear that living writers should be excluded, and this rule, with one or two exceptions, has been followed. On the whole, I have confined myself to the history of seismology before its latest and most interesting development, so that, roughly, the period adopted may be said to end with the nineteenth century. The three chapters on Montessus (1851–1923), Milne (1850–1913) and Omori (1868–1923), however, naturally carry on the history for some years further; and, in the eighth chapter, a slight account is given of the foundation of the Seismological Society of America and of some recent work in the United States.

2. Two events, or series of events, led up to, if they did not suggest, Michell's great memoir, which forms the subject of the next chapter. The first was the remarkable group of earthquakes in England during the year 1750, the second the destructive Lisbon earthquake of 1755. In the "year of earthquakes," as the former year was called at the time, there were five strong shocks in this country, on 19 Feb. and 19 Mar. (N.S.) in London and the home counties, on 29 Mar. in Portsmouth and the Isle of Wight,

on 13 Apr. in the north-west of England and the north-east of Wales, and on 11 Oct. in Northamptonshire and the surrounding counties. So great was the interest excited by them that, before the end of the year, nearly fifty articles were communicated to the Royal Society, in which the shocks were described or the causes and philosophy of earthquakes considered*.

To these shocks we are indebted for some of our earliest catalogues of earthquakes. Lists of British earthquakes appeared anonymously in the *London Magazine* and the *Gentleman's Magazine* for March 1750, the former recording 48 earthquakes and the latter 24. Later in the year, a third and more important catalogue was issued as a pamphlet—"*A Chronological and Historical Account of the most memorable Earthquakes that have happened in the World, from the beginning of the Christian Period to the present year* 1750; with an Appendix, containing a distinct series of those that have been felt in England, and a Preface, seriously addressed to all Christians of every Denomination." Though it was published anonymously as "By a Gentleman of the University of Cambridge," its author is known to have been the Rev. Zachary Grey (1688–1766), an antiquary of wide reading†. The main part of the pamphlet (pp. 8–44, 75–78) contains accounts of 61 destructive earthquakes, 14 of which occurred in China, Japan, Peru, etc. In the Appendix (pp. 45–74) are described 41 earthquakes felt in England from 974 to 1750.

Five years later, on 1 Nov. 1755, the city of Lisbon was destroyed by one of the greatest of recorded earthquakes. The curious seiches observed in our lakes and pools, the sea-waves that swept our southern coasts, and reported observations of the shock itself in various parts of England formed the subjects of many letters communicated to the Royal Society during November and the following months, 25 of them referring to observations in this country and 20 to those made in foreign lands‡.

* *Phil. Trans.* 1750, pp. 601–750.

† *Dict. Nat. Biog.* vol. 23, 1890, pp. 218–219. *A farther Account of memorable Earthquakes to the present Year* 1756 (Cambridge, 38 pp.), by the same author, describes some earthquakes, most of which had escaped his notice in 1750, as well as some letters on the Lisbon earthquake of 1755.

‡ *Phil. Trans.* vol. 49, 1756, pp. 351–444. Four other letters printed with the above refer to subsequent earthquakes.

JOHN BEVIS and *THE HISTORY AND PHILOSOPHY OF EARTHQUAKES*

3. The interest aroused by the Lisbon earthquake is responsible for the publication in 1757 of a remarkable volume on *The History and Philosophy of Earthquakes** by "A Member of the Royal Academy of Berlin." This is a collection of ten memoirs, some of them abridged, containing "the sentiments of the best naturalists as to their causes," in which, as the editor says, "he has retained entirely the facts, arguments and conclusions of the authors...without ever presuming to criticise any hypothesis, much less to obtrude one of his own." At the present time, the chapter of greatest value is one in which he has collected accounts of the Lisbon earthquake from the *Philosophical Transactions* and other "literary and authentic vouchers," arranging them under the places in alphabetical order.

After the lapse of more than a century and a half, it would have been difficult to discover the identity of the anonymous editor who has performed his task so skilfully. It is, however, revealed by Thomas Young (1773–1829) in what is the earliest attempt to compile a bibliography of seismology†. Young gives a list of 120 works on earthquakes, and among them occurs the entry (p. 492):

Bevis' history and philosophy of earthquakes.

John Bevis or Bevans (1693–1771) was educated at Christ Church, Oxford, where he studied medicine as a profession and optics and astronomy for pleasure. Some time before 1730, he settled in London as a physician. In 1738, he removed to Stoke Newington and there built himself an observatory in which he laboured so incessantly in taking star-transits that within seven years he had prepared his *Uranographia Britannica* or chart of the heavens in 52 plates‡. He also discovered independently the great comet of 1744. In 1750, he was elected a member of the Berlin Academy of Sciences. "He was of a mild and benevolent dis-

* London, 1757, 351 pp.
† *Lectures on Natural Philosophy*, etc. vol. 2, 1807, pp. 490–493.
‡ Owing to the failure of his publishers, this work was lost for many years. It was published, long after Bevis' death, in 1818.

position and lively temperament..., and is said to have, from modesty, concealed his authorship of several creditable works,"* including apparently *The History and Philosophy of Earthquakes*†. He must have been gratified to find three years later that the time spent on it had not been wasted. "I have taken," says Michell, "the greatest part of my authorities either from this author or the Philosophical Transactions" and *The History and Philosophy of Earthquakes* he regards as "a work well worth the perusal of those who are desirous of being acquainted with this subject."‡

4. In his choice of the ten "most considerable writers on the subject," Bevis showed much discretion. They were all then, and with perhaps two or three exceptions are still, well known. Johann Christoforus Sturmius (1635–1703) was professor of physics and mathematics at Altdorff in Germany; Martin Lister (*c.* 1638–1712), zoologist and physician, was apparently the first to suggest the construction of geological maps§; Robert Hooke (1635–1702), a man of "more than common, if not wonderful, sagacity in diving into the most hidden secrets of Nature," delivered his "discourses of earthquakes" before the Royal Society from 1667 to 1697, though, as Mallet says, they are "a sort of system of physical geology" rather than a discussion of earthquake-phenomena; John Woodward (1665–1728), the founder of the Woodwardian professorship at Cambridge, wrote *An Essay towards a Natural History of the Earth* (1695)—a work that passed through several editions and may still be read with interest; Nicolas Lemery (1645–1715) was the author of a *Cours de Chymie* that was often reprinted; Pierre Bouguer (1698–1758) spent ten years from 1735 with de la Condamine in Peru measuring a degree of the meridian near the equator; George Louis Leclerc, Comte de Buffon (1707–88), a man "of handsome person and noble presence, endowed with many of the external gifts of nature, and rejoicing in the social advantages of high

* *Dict. Nat. Biog.* vol. 4, 1885, pp. 451–452.
† A footnote on pp. 212–213, added to Buffon's text, is signed "J.B."
‡ *Phil. Trans.* vol. 51, 1761, p. 566 n.
§ Visitors to Westminster Abbey will recall the simple inscription to his little daughter "Jane Lister dear Childe."

rank and large possessions," was perhaps the most widely known of all through his encyclopaedic *Histoire Naturelle*; John Ray (1627–1705) was "the father of natural history in this country"; Stephen Hales (1677–1761) was valued both in France and England as a botanist, physiologist and inventor; and, lastly, William Stukeley (1687–1765), "a learned but honest man," won a reputation as an antiquary which has lasted to the present day*.

5. From an historical point of view, the articles collected by Bevis are useful in enabling us to estimate the knowledge of the phenomena and causes of earthquakes in the middle of the eighteenth century. The principal phenomena were clearly summarised, especially by Sturmius, Buffon and Stukeley. It was known, for instance, that, though there is hardly any country in the world that has not at one time or another been shaken by earthquakes, yet mountainous countries near the sea are exposed to the most violent, and places near volcanoes, to the most frequent, shocks; while flat, marshy, inland countries are seldom shaken, at any rate by "original" earthquakes. Buffon divides earthquakes into two classes. "One of them is occasioned by the action of subterraneous fires and explosions of volcanoes, and these are felt but to small distances, and at the time the volcanoes are raging or before their first eruption." Earthquakes of the other kind are "very different as to their effects and probably their causes too." They "are felt to vast distances and shake a long stretch of ground without the intermediation of any new

* The following are the works from which Bevis made his selection of articles:

1. Sturmius, J. C. *De Terrae-Motibus*, etc. Altdorff, 1670. 32 pp.
2. Lister, M. *Phil. Trans.* vol. 13, 1683, pp. 512–519.
3. Hooke, R. *Posthumous Works*, 1705, pp. 277–450.
4. Woodward, J. *An Essay towards a Natural History of the Earth*, etc. 3rd ed. 1723, pp. 149–160.
5. Lemery, N. Paris, *Ac. Sci. Hist. Mém.* année 1750, 1753, pp. 101–110.
6. Bouguer, P. *La Figure de la Terre*, 1749, pp. lxiv–lxxviii.
7. Buffon, G. L. L. *Histoire Naturelle*, 2nd ed. 1750, vol. 1, pp. 502–535.
8. Ray, J. *Three Physico-Theological Discourses* (second discourse, Consequences of the Deluge), 3rd ed. 1713, pp. 289–291, 294.
9. Hales, S. *Phil. Trans.* vol. 46, 1752, pp. 669–681.
10. Stukeley, W. *The philosophy of earthquakes*, a pamphlet of 139 pp. 3rd ed. 1756, based on three articles in *Phil. Trans.* vol. 46, 1752, pp. 641–645, 657–669, 731–750.

volcano or eruption." Earthquakes occur at all seasons, by night as well as by day, and under all varieties of constellations indifferently. After a very severe earthquake, such another as a rule only succeeds it after a long interval of time. The movement is sometimes a horizontal trembling, occasionally upwards (succussion). Its duration may be exceedingly short, not more than a few seconds, or may extend over whole days or "even months and years by fits." A hollow thundering noise precedes or accompanies the shock; but sometimes it is heard without any perceptible motion of the earth. In some earthquakes, torrents of water flow from fissures in the ground; in others, rivers, fountains and lakes have vanished. The surface of the earth may be raised above, or sunk below, its original level, and, in the former case, new islands may appear, though it seems probable, from the examples given, that the phenomena of earthquakes were not always kept clearly distinct from those of volcanoes.

With this accurate knowledge of earthquake-phenomena there are mingled many conceptions that can only be described as based on insufficient evidence. It is said that earthquakes are preceded and accompanied by strong winds, by fireballs and meteors, and by a continually clouded sun; that they usually occur in calm weather with a black cloud or when rain follows a great drought; and that they are succeeded by pestilences, contagious diseases and famines. Stukeley remarks that "earthquakes generally happen to great towns and cities; and more particularly to those that are situated on the sea, bays, and great rivers," or, rather more definitely as he writes in his first paper, that "the chastening rod is directed to towns and cities, where are inhabitants, the objects of its monition; not to bare cliffs and an uninhabited beach."*

6. If, with our far wider knowledge of the structure of the earth, we have much to learn as to the origin of earthquakes, it is not surprising that the solution of so complex a problem should have escaped our predecessors in the eighteenth century. They naturally connected volcanic and earthquake phenomena and

* *Phil. Trans.* vol. 46, 1752, p. 645.

assigned them to the same cause. If Woodward in 1695 could refer earthquakes to some accidental obstruction of a subterranean fire, and Stukeley to electricity, "a sort of soul to matter,"* the remaining writers, with the exception of Ray, who is silent on the question, are unanimous in favour of an explosive origin. While the accounts naturally differ in detail, the fullest is that given by Buffon.

As already noted (art. 5), Buffon divides earthquakes into two classes. The first he refers at once to volcanic explosions. As to the cause of the second kind, "it must be remembered," he says, "that all substances which are inflammable and capable of explosion do, like powder, at the instant of their inflammation, generate a great quantity of air; that air thus generated by fire is in a state of exceeding great rarefaction, and, from its circumstance of compression within the bowels of the earth, must produce most violent effects. Suppose now that at a considerable depth, as a hundred or two hundred fathoms, there should happen to be pyrites and other sulphureous matters, and that, through the fermentation excited by the filtration of waters or by any other means, they come to ignite....These matters taking flame will produce a great quantity of air, whose spring compressed in a small space, as that of a cavern, will not only shake the ground about it, but will attempt all ways of escaping and being at liberty. The passages which offer are the cavities and trenches formed by subterraneous waters and rivulets; the rarefied air will be precipitated with violence into every passage that is open to it and form a furious wind, the noise whereof will be heard on the earth's surface accompanied with shocks and tremors."†

7. It is interesting to notice how the various phenomena of earthquakes are explained on this theory. As the passages traversed by the gases are elongated, the tremors will also be

* "If a non-electric cloud discharges its contents upon any part of the earth, when in a high electrified state, an earthquake must necessarily ensue. The snap made upon the contact of many miles compass of solid earth, is that horrible uncouth noise, which we hear upon an earthquake; and the shock is the earthquake itself." (*Hist. and Phil.* p. 260.)

† *Hist. and Phil.* pp. 232–233; *Histoire Naturelle*, 2nd ed. 1750, vol. 1, pp. 528–529.

propagated lengthwise. "If this sulphureous blast be kept continually confined so as not to be able to extricate itself through any aperture, the earthquake lasts a considerable time and with strong plunges till its motion is become languid." The direction in which the shock is felt, horizontally, vertically or obliquely, depends on that of the underground passages, "just as in guns the force of the powder is directed in the same way that the piece is planted." "If an huge bulk of earth be forced up obliquely through the incumbent sea, so as not to drop back into the submarine cavern, but to rest on the solid bottom near the aperture, with its top above the surface of the sea, a new island will be formed." At the same time, much of the sea will be absorbed into the abyss below, and to this must be ascribed "the sea's instantaneous receding from the shore during an earthquake,... it being sucked into the new gulph below." Buffon, however, considers that the motion of the sea "arises solely from the shock communicated to its water by the explosion," forgetting that, in such a case, there should be a sea-wave with every strong submarine earthquake. The distribution of earthquakes is connected with that of the inflammable matter underground. Mountains are "obnoxious to shocks" because of the redundancy of inflammable substances beneath them. England is so little troubled with earthquakes and Italy so greatly because of the paucity of pyrites in the one and its abundance in the other. Lastly, according to Sturmius, "Honoratus Faber illustrates this doctrine by a variety of artificial earthquakes, as he calls them, confining gunpowder (a mixture of nitre, sulphur and charcoal) in pits, and setting fire to it by a train"*—surely the earliest of a long series of seismic experiments†.

ÉLIE BERTRAND and the *MÉMOIRES HISTORIQUES ET PHYSIQUES SUR LES TREMBLEMENS DE TERRE*

8. The same year (1757) saw the publication, not only of the *History and Philosophy of Earthquakes*, but also of a remarkable little volume by Élie Bertrand (1712–*c.* 1790), a Swiss naturalist

* Honoré, or Honorato, Fabri (*c.* 1607–88), *Physica, id est, Scientia Rerum Corpearum*, vol. 3, 1670, pp. 286–287.

† *Hist. and Phil.* pp. 26, 38, 40, 43, 62, 187, 233, 236.

and geologist, pastor at Berne, and member of the Academies of Berlin, Göttingen, Leipzig, etc.* About this time, writers on earthquakes were more intent on discussing their origin than on studying their phenomena, and Bertrand follows the prevailing custom so far as to devote more than half his volume to the "philosophy of earthquakes." Fortunately, however, he also held that the earthquakes of every country should be studied with care, and his memoirs on those observed in Switzerland possess a lasting value.

That Bertrand's book was esteemed in his own day is clear from the use that Michell makes of it in this memoir written three years later. "This author," he remarks, "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."†

9. The volume contains eight memoirs on the history of earthquakes in general and on those of Switzerland in particular. They thus fall naturally into two groups. In the more valuable section on the earthquake-phenomena of Switzerland (memoirs II–V), the longest memoir is a chronological account of the earthquakes felt in Switzerland from A.D. 563 to 1754 (pp. 22–102). The total number of earthquakes described is 155, of which 28 occurred in the sixteenth century, 62 in the seventeenth, and 31 in the eighteenth. Bertrand notices how irregularly the earthquakes are distributed over the country, the cantons most disturbed being those of Glaris, Basel and Bern, and portions of Valais, Vaud and Zurich. The fourth memoir (pp. 117–142) is one of our earliest detailed accounts of a strong earthquake—that of 9 Dec. 1755; while the fifth (pp. 143–168) deals with earthquakes observed in the Haut-Valais in 1755–56. In the third memoir (pp. 103–116) are collected the observations on the effects of the Lisbon earthquake in Switzerland—the seiches

* *Mémoires Historiques et Physiques sur les Tremblemens de Terre*, La Haye, 1757, 328 pp.

† *Phil. Trans.* vol. 51, 1761, p. 568 n.

produced in the lakes and the disturbance of many springs. It is a useful companion to the last chapter of *The History and Philosophy of Earthquakes*.

10. There is little need to refer in detail to Bertrand's clearly expressed views on the cause of earthquakes (pp. 1–21, 169–237, 300–326), for they are almost the same as those of Buffon described above (art. 5). Pyrites and pyritous materials occur, in greater or less quantity, in every place. When moistened, they become warm, ferment, and sometimes even take fire. The interior air thus dilated but confined in subterranean channels and caverns impinges on any obstacles that obstruct its free dilatation, and so gives rise to earthquakes. And the reason why certain parts of Switzerland are more subject than others to earthquakes is that they are more cavernous and contain more mineral springs and beds of sulphur. This Bertrand considers the most probable explanation, but he admits that it is by no means a complete one. There are phenomena that it is difficult so to explain—such, for instance, as the great extent of the area disturbed by the Lisbon and other destructive earthquakes, the high velocity with which the movement travels, and the regularity in the nature and direction of the undulations. Every movement due to a fermentation or a sudden inflammation must, he realises, be communicated successively, and must be confused, tumultuous, without order or direction.

11. The phenomena of earthquakes—the touchstone of his theory—are fully described by Bertrand (pp. 238–299), more fully than by Sturmius and Stukeley (art. 5). He notices that earthquakes often occur closely together, sometimes only a few minutes or even a few seconds apart, and that these returns are governed by no periodic law. The sound frequently precedes the shock, but by an interval too brief to act as a prognostic. That which accompanies the shock he likens to the fall of a load, an explosion such as that of a cannon, a rolling like that of thunder. The noises, he holds, are the effects of different causes, one of them being the collision of the solid parts of the interior. Bertrand was one of the first, if not the first, to realise the rapid propagation of the earthquake-motion. With regard to the time of