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EIGHTEENTH-CENTURY EARTHQUAKE THEORIES:
A CASE-HISTORY INVESTIGATION INTO THE CHARACTER
OF THE STUDY OF THE EARTH IN THE ENLIGHTENMENT.

The University of Oklahoma, Ph.D., 1975
History of Science

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THE UNIVERSITY OF OKLAHOMA
GRADUATE COLLEGE

EIGHTEENTH-CENTURY EARTHQUAKE THEORIES: A CASE-HISTORY
INVESTIGATION INTO THE CHARACTER OF THE STUDY
OF THE EARTH IN THE ENLIGHTENMENT

A DISSERTATION
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degree of
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BY
JOHN GATES TAYLOR, JR.

Norman, Oklahoma

1975

EIGHTEENTH-CENTURY EARTHQUAKE THEORIES: A CASE-HISTORY
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OF THE EARTH IN THE ENLIGHTENMENT

APPROVED BY

Kenneth L. Taylor

David B. Hill

Thomas M. Smith

Jonathan W. Sanger

Sanger

DISSERTATION COMMITTEE

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BOOK ONE

INTRODUCTION AND FIRST HALF-CENTURY

EIGHTEENTH-CENTURY EARTHQUAKE THEORIES: A CASE-HISTORY
INVESTIGATION INTO THE CHARACTER OF THE STUDY
OF THE EARTH IN THE ENLIGHTENMENT

CHAPTER I

INTRODUCTION

Earthquakes have been the subject of philosophical interest since the sixth century B.C. when natural philosophers of Ionian Greece began to speculate on what causes the earth to shake. According to the Roman writer Lucius Annaeus Seneca (d. A.D. 65), Thales of Miletos (fl. 585 B.C.) believed that an agitation of the great sea on which the earth floats produces earthquakes.¹ Aristotle (384-322 B.C.) stated that Anaximenes of Miletos (fl. 6th century B.C.) thought that both drought and an excess of moisture cause the earth to break apart.² In Seneca's account, Anaximenes is cited as attributing earthquakes to the aging and wasting away of the

¹Seneca Naturales quaestiones 6. 6. 1-4. Seneca in Ten Volumes, Vol. X: Naturales quaestiones, trans. by Thomas H. Corcoran, Loeb Classical Library (Cambridge: Harvard University Press, 1972).

²Aristotle Meteorologica 2. 7. 365b7-13. The Works of Aristotle, ed. by W. D. Ross, Vol. III: Meteorologica, De mundo, De anima, Parva naturalia, De spiritu (Oxford: Clarendon Press, 1931). Meteorologica trans. by E. W. Webster.

earth, the dissolving of the land by moisture, or the action of fire and blasts of air.³

For Archelaos of Miletos, a fifth-century B.C. philosopher, air is the cause. Winds that find their way down into the caverns and internal passages of the earth are compressed as more air is added until the subterranean wind explodes from its confinement, shaking the ground.⁴ A contemporary philosopher, Anaxagoras of Klazomenae, added the power of fire, because when subsurface winds collide, a lightning-like fire is produced. This fire is able to force its way through any obstacle to reach freedom in the atmosphere.⁵

Later in the fifth century, Demokritos of Abdera cited water as a source of earthquakes. First, he explained that the underground movement of water from places where the land is saturated to places without water is one cause. And second, when more rainwater is added to already swollen reservoirs of subterranean water, the earth trembles.⁶ In another account, Seneca wrote that Demokritos listed as causes both subsurface wind and moving underground water.⁷

The working hypothesis that the movement of air in subterrestrial chambers is the origin of earthquakes formed the basis of the most elaborate theories of ancient times. The

³Seneca Naturales quaestiones 6. 10. 1-2.

⁴Ibid., 6. 12, 1-2.

⁵Ibid., 6. 9. 1.

⁶Aristotle Meteorologica 2. 7. 365b1-6.

⁷Seneca Naturales quaestiones 6. 20. 1-7.

subterranean-air idea was the subject of extensive comments by a number of philosophers. Aristotle stated that the sun and the earth's heat give rise to vapors and windy exhalations both inside the earth and on its surface.⁸ These winds cause both earthquakes and volcanoes. For one example, Aristotle cited an earthquake at Heraklea in Pontos in which the earth rose in a mound until the wind that caused it burst out of the earth, ejecting fire that was formed by the broken and agitated air.⁹

Kallisthenes (ca. 360-328 B.C.),¹⁰ Epikuros (342-270 B.C.),¹¹ Poseidonios (ca. 130-50 B.C.),¹² and Lucretius (95-55 B.C.)¹³ also included subterranean wind as a major source of earthquakes. Another proponent of the idea after Aristotle was Seneca, who stated that the force of confined air and the

⁸Aristotle Meteorologica 2. 8. 365b21-29.

⁹Ibid., 2. 8. 366b30-367a11.

¹⁰Frank Dawson Adams, The Birth and Development of the Geological Sciences (Baltimore: Williams & Wilkins Company, 1938), p. 401. (Hereinafter referred to as Geological Sciences.)

¹¹Epikuros Letter to Pythokles 105-6. Epicurus: The Extant Remains, trans. by Cyril Bailey (Hildesheim: Georg Olms Verlag, 1970). (A reprint of the Oxford, 1926 edition.)

¹²J. Beaujeu, "[Hellenistic and Roman Science:] Physics and Biology," in Ancient and Medieval Science: From the Beginnings to 1450, ed. by René Taton, trans. by A. J. Pomerans (London: Thames and Hudson, 1963), pp. 334-35.

¹³Lucretius De rerum natura 6. 535-608. Lucretius: The Way Things Are. The De rerum natura of Titus Lucretius Carus, trans. by Rolfe Humphries (Bloomington: Indiana University Press, 1968).

power of a swift-moving wind as it travels through the earth are capable of breaking any obstacle.¹⁴ While he recognized the ability of subterranean fire and water to create earthquakes, Seneca maintained that wind is the primary cause.¹⁵ Likewise, Pliny the Elder (A.D. 23-79) emphasized internal winds in his Historia naturalis.¹⁶

The basic concepts of subterranean fire, water, and air continued to be cited in the period from the first to the seventeenth centuries. Remaining most prominent was the idea that when forceful vapors become trapped underground, the earth is shaken. The only major change was the addition of astrological considerations. Conrad von Megenberg (d. 1374), for instance, thought that Mars, Jupiter, and Saturn govern the destructive action of the terrestrial vapors.¹⁷ The importance of astrology later declined, but as will be shown (in Bk. III, chap. iii), the influence of the moon, sun, and comets on the earth were being discussed centuries later.

Concerning other ideas, Georgius Agricola (1494-1555) stated that the earthquake-producing subterranean vapors were created by the action of the earth's central fire on

¹⁴Seneca Naturales quaestiones 6. 16-17.

¹⁵Ibid., 6. 20. 1-7.

¹⁶Pliny Historia naturalis 2. 81. Pliny Natural History with an English Translation in Ten Volumes, Vol. I: Libri I-II, trans. by H. Rackham, Loeb Classical Library (Cambridge: Harvard University Press, 1947).

¹⁷See the passages from Conrad von Megenberg's Buch der Natur translated in Adams, Geological Sciences, p. 404.

the waters in the earth.¹⁸ Bernard Palissy (1510-1589) attributed the cause to underground forces of fire, water, and air.¹⁹ Girolamo Cardano (1501-1576) gave as the source vapors of nitre, bitumen, and sulphur;²⁰ and Athanasius Kircher (1601-1680) presented similar views while comparing earthquakes to gunpowder explosions.²¹

In the eighteenth century the study of earthquakes continued with renewed vigor. The next century was also an active period for such studies, and work is continuing in the twentieth century to perfect a theory of earthquakes. However, as far as the history of the investigation of these earth movements is concerned, there is a major gap. From the existing secondary literature, it appears that the problem of understanding earthquakes was basically a question concentrated in two widely separated eras: in the period of ancient natural philosophy, and in the time of the development of modern seismology in the nineteenth and twentieth

¹⁸Adams, Geological Sciences, pp. 408-9, citing Agricola's De ortu et causis subterraneorum. Lib. V. (Basileae: Froben, 1546).

¹⁹Bernard Palissy, Discovrs admirables de la natvre des eavx et fonteines, tant natvralles qv' artificielles, des metaux, des sels & salines, des pierres, des terres, du feu & des emaux. Avec plvsievs avtres excellens secrets des choses naturelles. Plvs vn trait  de la marne, fort vtile & necessaire, pour ceux qui se mellent de l'agriculture. Le tovt dress  par dialogves, lesqvls sont introduits la theorique & la pratique (Paris: Chez Martin le Jeune, 1580), pp. 22-27.

²⁰Adams, Geological Sciences, p. 409.

²¹Ibid., pp. 410-11.

centuries. This is the view presented to the readers of one early study, Ferdinand de Montessus de Ballore's "Histoire de la sismologie" (1921).²²

As far as the first part of the missing piece of history is concerned, there may well have been little interest in the subject of earthquakes in the period from the first century A.D. through the Middle Ages and on into the seventeenth century, but this subject remains open for further investigation. However, the gap extends all the way to the nineteenth century. Relative to just the later segment of the missing history, Charles Davison in The Founders of Seismology (1927)²³ does present a limited view of the work of the 1700's, but he, too, concentrates his efforts on later periods.

One major deficiency in the history of earthquake studies now becomes distinct, for an important missing element is the period centered on the eighteenth century. Yet, writers have not ignored the subject entirely, because this century is one in which a major historic event affecting politics, religion, literature, and art happened to be an earthquake--the Lisbon earthquake of 1755.²⁴ But other than noting the

²²Revue des questions scientifiques, 3rd ser., XXIX (1921), 29-57, 320-50.

²³(Cambridge: University Press, 1927.)

²⁴See Suzanne Chantal, "Disaster Strikes Lisbon," Milestones of History: 100 Decisive Events in the History of Mankind (New York: W. W. Norton & Company, Inc., 1971), pp. 574-79; T. D. Kendrick, The Lisbon Earthquake (London: Methuen &

Portuguese disaster, the subject has been dismissed after outlining the contributions of Hooke, Woodward, Stukeley, and Michell. For example, in the general histories of the earth sciences, such as in Karl Alfred von Zittel's Geschichte der Geologie und Paläontologie bis Ende des 19. Jahrhunderts (1899),²⁵ in Carl Christoph Beringer's Geschichte der Geologie und des geologischen Weltbildes (1954),²⁶ in Helmut Hölder's Geologie und Paläontologie in Texten und ihrer Geschichte (1960),²⁷ or in André Cailleux's Histoire de la géologie (1961)²⁸ there are few references to eighteenth-century earthquake theories. Two of the most informative sources, Sir Archibald Geikie's The Founders of Geology (2nd ed., 1905)²⁹ and Frank Dawson Adams' The Birth and Development of the Geological Sciences (1938) go into greater detail, but again they imply that philosophical interest in the topic was limited to the isolated work of very few individuals.

If the history of the investigation of earthquakes in the Enlightenment were presented as a historical drama, and if the script were based on the secondary sources mentioned

Co., Ltd., 1956), and Kenneth Clark, The Romantic Rebellion: Romantic Versus Classic Art (New York: Harper & Row, Publishers, 1973), p. 45.

²⁵ (München: R. Oldenbourg.)

²⁶ (Stuttgart: Ferdinand Enke Verlag.)

²⁷ (München: Verlag Karl Alber.)

²⁸ (Paris: Presses Universitaires de France.)

²⁹ (London: Macmillan and Co., Limited.)

above, then the audience might see a brief one-act play by an all-English cast led by John Michell in the starring role as the heroic "father of modern seismology." The dramatic critics would see the awkwardness with which the playwright treated the character named William Stukeley. They would find the role of John Bevis overblown, while John Woodward and Robert Hooke were relegated to the much too small chorus of supporting actors.

The imaginary author of this whimsical play would find critical reviews of the inadequate plot and cast of characters already written. In the mid-1960's Rhoda Rappaport³⁰ and V. A. Eyles³¹ both called attention to the need for work in many areas of eighteenth-century geology. Included among needed studies is research into earthquake theories. Rappaport and Eyles were quite correct in calling attention to this topic, for there is much more to the story than has been suggested before.

This dissertation has two purposes. First, it is intended to fill the gap in our knowledge of the study of earthquakes in the period from the 1680's to the 1830's. A discussion of the solutions that were offered to the question of what causes the earth to shake is a necessary part of the account, for such information has not been assembled in one

³⁰"Problems and Sources in the History of Geology, 1749-1810," History of Science, III (1964), 60-78.

³¹"The History of Geology: Suggestions for Further Research," Ibid., V (1966), 77-86.

place before. Second, this monograph provides a case-history approach examining the quest for an understanding of the natural world in this one particular period. Emphasized here is the problem of how an author formed and established his theory. This is an examination into the influential thoughts and events that affected the study of the earth and the processes by which facts and ideas passed through several generations of investigators. It is in the character of this particular subject that the activity is stressed over the solution of the problem, for by the year 1800 there was simply no single answer to the question of how earthquakes are produced; in fact, more hypotheses formed the basis for specific explanations than a hundred years before.

This study examines the proliferation of general working hypotheses and detailed theories as ideas evolved through continuing efforts to improve theses in the face of contradictory evidence, or in competition with a better-developed explanation, or in response to a new interest in one particular aspect of the multi-faceted earthquake phenomenon. Some of the competing views of the earth were versions of ideas that had been discussed for ages, while new hypotheses emerged that were derived from recent investigations of the earth and its atmosphere. Thus, this dissertation surveys the activities of men of the eighteenth century as they pursued the ultimate explanation through several streams of thought.

The history is examined in a view that is broader than

the tracing of the development of a single idea from its first conception in the distant past to its acceptance by the present generation of science writers. Here is an opportunity to view the labors of scores of individuals from traditionalists who carefully altered in small steps the more accepted explanations of the day to iconoclasts who rejected subterranean air, fire, and water to produce theories based on electricity and atmospheric explosions. The subjects of this examination are, first, the working naturalists--no "heroes" here--who gathered pieces of information and contributed germinal ideas, and, second, the innovative theoreticians who introduced revolutionary new concepts, as both endeavored to account for a trembling earth.

Since previous historians have not sufficiently recognized the philosophical interest in earthquakes that was present throughout the 1700's, the first task (the subject of the next chapter) must be to account for this fascination about the shaking earth in the age called the Enlightenment.

CHAPTER II

THE INTEREST IN EARTHQUAKES IN THE EIGHTEENTH CENTURY

The eighteenth century provides the historian with many examples of the work of naturalists, natural philosophers, and other serious secular students of nature, as well as theologians, dilettantes, and educated gentlemen, all of whom possessed diverse backgrounds and interests and all of whom sought to understand the world around them. Of the subjects to be explored, the shaking earth was a topic of particular fascination and man's curiosity was heightened by several massive shocks that struck various parts of the globe. Not only did major earthquakes, such as the Lisbon or the Calabrian disasters, focus attention on investigations of this frightening phenomenon, but also certain minor shocks, like the London earthquakes of 1750 or the ones in New England five years later, stimulated local intellectual explorations into the interior regions of the earth or out into space--wherever man thought to look for the origins of earthquakes.

The London Earthquakes of 1750

Early in the afternoon of February 8, 1750 (O.S.) an earthquake struck London and Westminster. The courts of

Chancery and King's Bench adjourned from Westminster Hall in haste for fear that the building might collapse.¹ Among the first printed commentaries marking the beginning of an outpouring of literature on the subject of earthquakes that was to follow was a satirical verse by an anonymous poet.

You say, old Rufus' fabric trembl'd,
When Earth her entrails shook;
And all the able hands assembl'd,
The term-time work forsook.

'Twas wrong!--they shou'd have made a stand,
And not have left their shops:
If law's the basis of the land,
Sure lawyers are the props.²

The lawyers had little to fear, because the earthquake was not severe. The destruction was generally confined to chimneys, and no injuries were reported.³ However, earthquakes in London soon became more than the subject of a poet's jest.

Almost exactly one month later, on the morning of March 8, 1750 (O.S.), the people of London and Westminster were violently awakened by the groaning and shaking of the earth and by church bells striking spontaneously. This shock was more severe than the earlier one; some stones did

¹This account of the earthquake is based on the "Historical Chronicle," a monthly news summary assembled from various English newspapers and other sources published as a part of The Gentleman's Magazine. "Historical Chronicle, February 1750," Gentleman's Magazine, XX (February, 1750), 89. Hereinafter, the year is cited as "1750," not "1749/50."

²"To a Friend, on Hearing of the Desertion at Westminster-Hall, at the Time of the Late Earthquake," Gentleman's Magazine, XX (February, 1750), 85.

³"Historical Chronicle, February 1750," p. 89.

fall from the new spire of Westminster Abbey. And there were some injuries; for instance, a woman thrown out of bed by the shock suffered a broken arm.⁴ Horace Walpole, the Fourth Earl of Orford (1717-1797), an outspoken observer of the English scene, remarked that London was becoming so "overstocked" with earthquakes as to lower the price of such "wonderful commodities."⁵

In spite of the excitement, the March earthquake, like the one the month before, had produced a catastrophe only for the London china shops; even then, one enterprising shopkeeper made the best of the situation by doubling the price of a jar cracked by the earthquake, in consideration of its new-found rarity.⁶ Walpole's correspondent, Horace Mann (1701-1786), the English envoy in Florence, remarked that someone would probably pay the higher price and cherish the jar as highly as fortunate military officers value hats with bullet holes in them.⁷

⁴"Historical Chronicle, March 1750," Gentleman's Magazine, XX (March, 1750), 137.

⁵Letter from Horace Walpole to Horace Mann, March 11, 1750, O.S., in Horace Walpole's Correspondence with Sir Horace Mann, ed. by W. S. Lewis, Warren Hunting Smith, and George L. Lam, Vol. XX of The Yale Edition of Horace Walpole's Correspondence, ed. by W. S. Lewis (New Haven: Yale University Press, 1960), p. 130. (Hereinafter, references to this collection will be to Walpole's Correspondence.)

⁶Letter from Horace Walpole to Horace Mann, May 19, 1750, O.S., Walpole's Correspondence, XX, 155.

⁷Letter from Horace Mann to Horace Walpole, June 26, 1750, N.S., Walpole's Correspondence, XX, 158-59.

Since Londoners had suffered earthquakes one month apart and since the second shock had been more severe than the first, many were apprehensive about what might happen a month later in April. Walpole reported that on this account some people were leaving London, although they claimed it was the fine weather that drew them out into the countryside.⁸ Whatever the stated reason, in a three-day period 730 coaches were counted leaving the city,⁹ and lodgings were reported scarce in Windsor, which was outside of the area that had received the two earthquakes.¹⁰ In London, women dressed in warm "earthquake gowns"¹¹ and joined the "incredible numbers of people" who spent the night of the expected earthquake in fields and in boats on the Thames so as not to be caught inside collapsing buildings.¹² All of these precautions were unnecessary, for there was no earthquake.¹³

⁸Letter from Walpole to Mann, March 11, 1750, pp. 130-31.

⁹Letter from Horace Walpole to Horace Mann, April 2, 1750, O.S., Walpole's Correspondence, XX, 136-37.

¹⁰"Historical Chronicle, April 1750," Gentleman's Magazine, XX (April, 1750), 184.

¹¹Letter from Walpole to Mann, April 2, 1750, p. 137.

¹²"Historical Chronicle, April 1750," p. 184.

¹³However, a satire did describe an April earthquake. [Richard Bentley,] A Full and True Account of the Dreadful and Melancholly Earthquake, Which Happened between Twelve and One O'Clock in the Morning, on Thursday the Fifth Instant. With an Exact List of Such Persons as Have Hitherto

Mann remarked that since the shaking earth was a rather unusual experience for England, he was not surprised by the reaction of the English people, who "are always in extremes with regard to every thing that is new, . . ." But he was worried that such a long period of panic would "destroy the reputation the English have hitherto had of being undaunted."¹⁴ The panic that was ruining reputations had been encouraged in part by clergymen and their sermons and tracts warning of God's evident displeasure with the sinners of London. From the pulpit they proclaimed the two earthquakes as signs of a more severe judgment that was sure to come in the absence of wholesale repentance.¹⁵

While some parts of the London population panicked, while the clergy preached and prayed, and while Walpole looked on with amusement, another portion of the citizenry saw the earthquakes as a curious natural phenomenon to be studied and explained. Following the February shock, the regular meeting of the Royal Society of London was attended by an unusually large number of visitors who came to hear discussions about the earthquake.¹⁶ The Royal Society also

Been Found in the Rubbish. In a Letter from a Gentleman in Town, to His Friend in the Country (4th ed., London: Printed for Tim Tremor, 1750).

¹⁴Letter from Horace Mann to Horace Walpole, May 8, 1750, N.S., Walpole's Correspondence, XX, 147.

¹⁵See below, pp. 243-47.

¹⁶As reported by William Stukeley (1687-1765), F.R.S.,

received such a number of letters containing accounts of the two shocks and papers explaining their origins that the Society printed a 149-page supplemental issue of its Philosophical Transactions containing fifty-seven contributions.¹⁷ Several of these articles will be the subject of close examination in later chapters.

Minor shocks such as those in the London area would have gone almost unnoticed if they had occurred in regions of the world where earthquakes were common, but these two surprising events had jolted one of the world's leading cities, and the result was not a disaster but an outpouring of literature from London presses on the subject of earthquakes.¹⁸ This interest proved not to be an isolated case, for a similar response (on a proportionally smaller scale) followed a pair of earthquakes that struck part of England's American colonies.

in his diary for February 15, 1749/50, printed in Family Memoirs of the Rev. William Stukeley, M.D. and the Antiquarian and Other Correspondence of William Stukeley, Roger & Samuel Gale, etc. (3 vols.; Durham: Printed for the [Surtees] Society by Andrews & Co., and others, 1882-87), II, 370-71. (Hereinafter, references to this collection will be to Family Memoirs.)

¹⁷"Philosophical Transactions. Being an Appendix to Those for the Year 1750. Consisting of a Collection of Several Papers Laid Before the Royal Society, Concerning Several Earthquakes Felt in England, and Some Neighbouring Countries, in the Year 1750," Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 601-750.

¹⁸For another account of the London reaction to the startling events, see G. S. Rousseau, "The London Earthquakes of 1750," Cahiers d'histoire mondiale, Journal of World History, Cuadernos de historia mundial, XI (1968), 436-51.

The New England Earthquakes, 1755

On November 18, 1755, New England experienced a minor earth movement comparable in strength to the second London earthquake of 1750. The jolt, which was felt most strongly in Boston, was followed by another, but less important, shock four days later. Over the next several months, publishers Benjamin Edes (1723-1803) and John Gill (1697-1771), in their weekly Boston Gazette, or Country Journal,¹⁹ devoted considerable space to the topic of earthquakes. On the first page of the November 24, 1755 issue was printed one gentleman's personal account of the first shock; beside it was a portion of a sermon prompted by the event. Subsequent issues published advertisements for a number of homilies on the subject, reflecting the religious interest of the clergy about the quaking earth.²⁰ The same newspaper also reprinted

¹⁹Citations are to the microprint edition: The Boston Gazette, 1719-1798 (New York: Readex Microprint Corp., n.d.).

²⁰The following is a list of the sermons along with the date they were first advertised: Thomas Prince (1687-1758), An Improvement of the Doctrine of Earthquakes, Being the Works of God, and Tokens of His Just Displeasure (Nov. 24, 1755); Charles Chauncy (1705-1787), Earthquakes a Token of the Righteous Anger of God (Dec. 8, 1755); Mather Byles, Jr. (1706-1788), Divine Power and Anger Displayed in Earthquakes (Dec. 15, 1755); Jonathan Mayhew (1720-1766), The Expected Dissolution of All Things, a Motive to Universal Holiness (Dec. 15, 1755); Jonathan Mayhew, A Discourse on Rev. XV. 3d, 4th. Occasioned by the Earthquakes in November, 1755 (Jan. 26, 1756); Thomas Prentice (1702-1782), Observations Moral and Religious, on the Late Terrible Night of the Earthquake (Jan. 26, 1756); Charles Chauncy, The Earth Delivered from the Curse to Which It Is, at Present, Subjected (Feb. 2, 1756); and Thomas Foxcroft (1697-1769), The Earthquake, a Divine Visitation (Feb. 16, 1756). (Complete citations are in the "Bibliography.")

an article by "a Gentleman in Yorkshire" who examined various theories explaining the origins of earthquakes. In the end, the author (John Wesley, 1703-1791, the English evangelist) concluded that since theories of subterranean fire, air, and water proved to be unsatisfactory, earthquakes must be directly the work of God.²¹

Balancing the religious reaction was a published lecture by John Winthrop (1714-1779), Hollis Professor of Mathematics and Natural and Experimental Philosophy at Harvard College.²² A lively debate developed in the pages of the Boston Gazette between Professor Winthrop and the Reverend Thomas Prince. Winthrop emphasized natural philosophy over theological concerns, while Prince espoused the opposite point of view.²³ The Harvard professor also sent to the Royal Society of London an account of the New England earthquake.²⁴

²¹"From a Late Bristol Journal. Extract of a Letter from a Gentleman in Yorkshire," Boston Gazette, January 12, 1756, 21, recto and verso. Also see below, pp. 248-50.

²²A Lecture on Earthquakes; Read in the Chapel of Harvard-College in Cambridge, N.E. November 26th 1755. On Occasion of the Great Earthquake Which Shook New-England the Week Before (Boston: Printed and sold by Edes & Gill, 1755).

²³See the letters from Prince published in the Boston Gazette on January 26, 1756 (21, recto), and on February 23, 1756 (21, verso), and a letter from Winthrop published on March 1, 1756 (21, recto). Also see below, pp. 129-33, 256-57.

²⁴"An Account of the Earthquake Felt in New England, and the Neighbouring Parts of America, on the 18th of November 1755. In a Letter to Tho. Birch, D.D. Secret. R. S. by Mr. Professor Winthrop, of Cambridge in New England,"

The continuing concern about earthquakes by New Englanders was not due just to the trauma of having their own homes shaken by a trembling earth, for in the middle of December, 1755, news reached Boston that the city of Lisbon had been destroyed by a massive earthquake on the first day of November.²⁵ The Boston Weekly Newsletter for January 9, 1756 doubled its usual size to print a "Postscript" containing accounts of the disaster.²⁶ The Boston Gazette, the Boston Weekly Newsletter, and the Boston Evening-Post²⁷ continued for half a year to print reports, as more information about the wide-ranging shock arrived from various parts of Europe.

The Lisbon Earthquake, 1755

The London and New England earthquakes stimulated a local interest in earthquakes, but the Lisbon catastrophe generated world-wide curiosity. The first accounts reaching England reported that a hundred thousand people had been buried in the rubble of Portugal's capital city and that fires

Philosophical Transactions of the Royal Society of London, L, Pt. I (1757), 1-18.

²⁵The Boston Gazette carried the news in the December 22, 1755 issue. First accounts had arrived on the fifteenth and sixteenth when ships from Spain and Portugal brought the news.

²⁶References are from the microprint edition: The Boston Newsletter, 1704-1776 (Worcester, Mass.: Micro Research Corp., n.d.).

²⁷References are from the microprint edition: The Boston Evening Post, 1735-1775 (Worcester, Mass.: Micro Research Corp., n.d.).

were consuming what was left of the town. A village to the south of Lisbon had reportedly disappeared into the earth, the city of Madrid had also suffered damage from the shock, and at Toledo the Tagus River had risen ten feet at the time of the earthquake. The effects were not limited to the Iberian peninsula, since the sea was agitated off the coasts of the Netherlands and England, and disturbed waters were noted as far north as the Baltic Sea.²⁸ While it was first feared that the English consul in Lisbon had perished in the disaster, he did survive to write one of the first detailed accounts of the event.²⁹ His report begins another period in which printers found earthquakes a good source of business, as authors penned new accounts, chronicles, and theories explaining the shaking earth.

For a second time the Royal Society published a special issue of its Philosophical Transactions to accomodate a number of reports about earthquakes.³⁰ From Scotland to Gibraltar and from Geneva to Boston came twenty-two letters about

²⁸"Historical Chronicle, Nov. 1755," Gentleman's Magazine, XXV (November, 1755), 521.

²⁹Ibid., and "Letter from Abr. Castres, Esq; Envoy Extraordinary to the King of Portugal," Gentleman's Magazine, XXV (December, 1755), 556-58.

³⁰"An Extraordinary and Surprising Agitation of the Waters, Though Without Any Perceptible Motion of the Earth, Having Been Observed in Various Parts of This Island, Both Maritime and Inland, on the Same Day, and Chiefly About the Time, That the More Violent Commotions of Both Earth and Waters So Extensively Affected Many Very Distant Parts of the Globe; the Following Accounts, Relating to the Former, Have Been Transmitted to the Society; in Which Are Specified

the Lisbon shock and associated earthquakes. The shaking earth was no longer a local subject, for writers in Portugal, Spain, Switzerland, France, Italy, Germany, England, and America offered their ideas for explaining earthquakes, in particular the cause and propagation of the one centered off the coast of Portugal.

The decade of 1750-60 was the part of the Enlightenment during which the largest number of authors produced an extensive body of literature on earthquakes. Previous histories have recognized this by concentrating on these few years. However, what has not been recognized is that the subject of earthquakes was a popular topic of debate in other periods throughout the century.

In the eighteenth century, the production of earthquake literature was concentrated in two distinctive periods, one covering the early decades of the century, and the other spanning the period from 1750 to the mid-1780's. Of these, the latter was most significant, for it was a time during which new ideas and new information about a number of major earth movements were leading to continuing discussion, innovation, and revision of man's conception of the earth.

The first half-century was a time when theorists did not create revolutionary new hypotheses, but instead, developed and reformed ideas involving subterranean air, water,

the Times and Places When and Where They Happened," Philosophical Transactions of the Royal Society of London, XLIX, Pt. I (1755), 351-444.

and fire that had been used for centuries. The authors of the earthquake treatises did not pay homage to the ancient authorities for originating these ideas, for they had been reasserted anew in the last two decades of the seventeenth century and in the first few years of their own century. The history of this period of revision begins with a series of papers published by the Royal Society of London in 1684. Not surprisingly, the publication followed another pair of significant earthquakes; this time in Oxfordshire.³¹

³¹See Thomas Pigott, "An Account of the Earthquake That Happened at Oxford and the Parts Adjacent Sept. 17. 1683. by a Fellow of a College in That University, and the Royal Society," Philosophical Transactions of the Royal Society of London, XIII, No. 151 (1683), 311-21. A "Post-script" mentioned a more severe earthquake of October 9, 1683 (O.S.) in Oxfordshire.

CHAPTER III

THE PRELUDE TO THE STUDY OF EARTHQUAKES IN THE EIGHTEENTH CENTURY

By the year 1701 numerous explanations of earthquakes had been offered; some were over two thousand years old, but eighteenth-century authors of earthquake treatises did not often refer to ancient ideas. Instead, they cited several late seventeenth-century and early eighteenth-century theories. However, these new views of the subject relied, as they had in the past, on the idea that the forces of subterranean fire, water, and air (singly or in various combinations) are in one way or another responsible for shaking the earth. To understand the earthquake theories of the 1700's it is not necessary to return to Ancient Greece, for one needs only to turn back to England in the 1680's.

Subterranean Fires and Vapors

Martin Lister

Throughout the eighteenth century, authors cited a trio of papers on the origins of earthquakes published in 1684 by an English physician, naturalist, antiquarian, and Fellow of the Royal Society of London, Martin Lister (1638?-

1712).¹ He theorized that earthquakes are the product of the "Inflamable breath" of pyrites, a mineral primarily composed of sulphur and iron. The inflammable vapors fill natural cavities inside the earth, and when they are fired, an earthquake is produced. In the same manner, miniature earth shocks are created by exploding vapors in coal mines.² The second paper by Lister emphasized the ability of moistened pyrites to inflame themselves, and again he gave as an example mine explosions of "fire-damps."³

The author compared the burning characteristics of coal from different mining regions and the amounts of the pyrites they contain in order to show that pyrites are very long-burning substances. Having few pyrites, Scotch coal burns quickly, while coal from a particular mine in Ireland (the most pyrite-rich coal in evidence) burns red-hot for twenty-four hours without deteriorating. He explains that volcanoes, such as those in Italy, are mountains of highly sulphureous pyrites (as compared to the English variety) that were ignited at the Creation, or shortly thereafter,

¹"Three Papers of Dr. Martin Lyster, . . . ,"Philosophical Transactions of the Royal Society of London, XIII, No. 157 (1683/84), 512-19. The title of each paper varies; see notes 2, 3, and 7 below.

²"Three Papers of Dr. Martin Lyster, the First of the Nature of Earth-quakes; More Particularly of the Origine of the Matter of Them, from the Pyrites Alone," Ibid., pp. 512-15. (Hereinafter referred to as "Nature of Earth-quakes.")

³"The Second Paper of the Same Person Concerning the Spontaneous Firing of the Pyrites," Ibid., pp. 515-17.

and these burning-mountains have remained afire since that time.⁴

Italy suffers more from earthquakes than England, and the Italian examples are long-lasting and dangerous when contrasted against England's short and weak shocks. Explaining the difference in characteristics of the two types of earthquakes, Lister stated that of the two countries, Italy simply has greater supplies of the volcanic type of pyrites and larger subterranean cavities in which to confine the explosive vapors.⁵

In regards to the same comparison, he remarked that summertime lightning is an almost daily experience in Italy, which is in contrast to the relative absence of such meteors in England. The relationship is explained by the abundance of pyrite vapors in the Mediterranean state, since lightning is another manifestation of the same inflamed pyrite vapors that cause the earth to tremble. In an earthquake, the exhalations generated by pyrites are inflamed inside caverns, whereas in lightning, the vapors take fire in the atmosphere. Lister cited the vapor-like appearance of a thunderbolt, the smell of sulphur left in the air whenever lightning strikes the ground, and the accompanying noise (resembling a train of gunpowder set on fire) as evidence showing that inflamed

⁴Ibid., pp. 516-17.

⁵Lister, "Nature of Earth-quakes," pp. 514-15.

vaporous pyrites is the source.⁶ In the last of the three papers,⁷ he added further evidence associating lightning and pyrites by calling attention to the reports of pieces of iron and iron powder falling from the sky in various parts of Europe. He theorized that the iron had been "concreted" out of pyrite vapors. Furthermore, the reported magnetic properties of both lightning and pyrites formed an additional link between the two.⁸

Although the theory of lightning may seem far afield from a discussion of an earthquake treatise, a significant number of Lister's contemporaries shared and developed further his idea that earthquakes and lightning have the same cause. This theoretical combination of the two phenomena paved the way for later consideration of two very different theories: the airquake and the electrical explanations of earthquakes.⁹

Lister's work describing burning pyrites and explosive vapors as the agency responsible for shaking the earth replaced the old concepts of subterranean fire and wind. Ancient authorities for these ideas now became passé; henceforth

⁶Ibid., pp. 512, 514-15.

⁷"The Third Paper of the Same Person, Concerning Thunder and Lightning Being from the Pyrites," Philosophical Transactions of the Royal Society of London, XIII, No. 157 (1683/84), 517-19.

⁸Ibid., pp. 518-19.

⁹See below, Bk. II, chaps. i-iii.

Lister's ideas were the ones to be quoted as to the true source of the shocks, or mentioned in support of related theories involving inflammable and explosive materials in the earth, or disputed as a part of the exposition of completely different ideas.

The three papers of 1684 not only mark the renewal of a theoretical interest in the origins of earthquakes, but more specifically, many of Lister's particular comments introduced some of the topics and questions that subsequent authors now had to deal with in order to cover the subject adequately. Thus, later writers had to be specific in describing the burning or exploding materials that cause the earth to shake. Their answers had to include a solution to the problem of the existence of two species of earthquakes: the long, disastrous Italian shocks and the brief, insignificant English ones. Following Lister's example, it also became fashionable to link an explanation of lightning to an earthquake theory.

One of the characteristics of the study of the earth that will become increasingly evident is the awareness most writers had of the recent literature on the subject--a familiarity that is directly acknowledged or that is implicit in later statements. The better-informed authors were finding an audience for their explanations, and among their readers were some sufficiently impressed to borrow ideas, forms of presentation, and topics of discussion for their own treatises.

Lister and his successors were knowledgeable about recent developments in their field of study, but references to classical authorities are conspicuously few. Aristotle directly linked the winds that cause earthquakes to the origin of lightning,¹⁰ but he is not mentioned by Lister; neither did he refer to Pliny on the matter.¹¹ Preserved Smith in his work on the Enlightenment has pointed out the disinterest in the ancient authorities, as men of that age turned to examine nature through their own efforts.¹² If the writers of the late seventeenth and the eighteenth centuries were aware of the old precursors of their fundamental ideas, they did not care to make the point.¹³

Robert Plot

The next significant presentation of ideas about earthquakes appeared two years after Lister's paper, and while his influence is not specifically acknowledged, it nevertheless is indicated. In The Natural History of Stafford-shire, author Robert Plot¹⁴ (1640-1696) of Oxford, Keeper of the

¹⁰Aristotle Meteorologica 2. 9. 370a25-32.

¹¹Pliny Historia naturalis 2. 81.

¹²Preserved Smith, The Enlightenment: 1687-1776, Vol. II of A History of Modern Culture (New York: Collier Books, 1962), p. 119.

¹³Smith's analysis is valid concerning this one area of study, although there were, of course, a few minor exceptions to the rule. See below, pp. 111, 230.

¹⁴(Oxford: Printed at the Theater, 1686.)

Ashmolean Museum, combined the combustible properties of pyrites and the well-known explosive power of gunpowder into a theory of earthquakes. It is a simple process by which the land is jolted: moistened pyrites take fire spontaneously and ignite subterranean supplies of a natural gunpowder composed of a mixture of coal, sulphur, and nitre.¹⁵ He emphasized that water is the crucial ingredient necessary to set the pyrites afire by recalling the story of a Yorkshireman who stored cartloads of the mineral in a leaky barn only to have a rain set the pyrites burning like red-hot coals, destroying the barn.¹⁶

Anticipating possible objections to his explanation, Plot sought to remove some of the specific difficulties that critics might find in his basic idea. First, since air is necessary for fire, would not the subterranean materials fail to ignite deep in the earth? He replied that air is unnecessary for the fires, because it had been shown in the reports of miners that fire-damps occur only when the workers underground begin to feel the need for air, and admitting fresh air into the mine destroys fire-damps.¹⁷

¹⁵Plot, Natural History of Stafford-shire, pp. 142-44.

¹⁶Ibid., p. 142. He cited as the source of the story Henry Power (1623-1668), Experimental Philosophy in Three Books: Containing New Experiments Microscopical, Mercurial, Magnetical. With Some Deductions, and Probable Hypotheses, Raised from Them, in Avouchment and Illustration of the Now Famous Atomical Hypothesis (London: Printed by T. Roycroft for John Martin, and James Allestry, 1664), pp. 62-63.

¹⁷Plot, Natural History of Stafford-shire, p. 144.

Foreseeing another possible question, Plot recognized that in England neither fire nor smoke had been seen on the surface of the earth as indications of a subterranean explosion. But he explained that in his country there are fewer explosive minerals, and the pores of the earth are closed by the frosts of winter (the season with the most earthquakes). Thus, the limited earthquake-producing fires are smothered by their own smoke, and the fumes cannot escape to the surface. While English earthquakes present no exterior indications of underground fires and explosions, in the warmer climates to the south, great supplies of the dangerous materials combine with open pores in the earth to create shocks accompanied by eruptions of subterranean fire in the form of volcanoes.¹⁸ Through these comments Plot solved in a slightly different manner the problem pointed out by Lister regarding the difference between English and Italian earthquakes.

To forestall critics who would specifically question how Oxford could have experienced earthquakes (like the two in 1683 and the one of 1666¹⁹) in the absence of known coal

¹⁸Ibid., pp. 144-45.

¹⁹See above, p. 22, n. 31, and John Wallis, "A Relation Concerning the Late Earthquake Neer Oxford; Together with Some Observations of the Sealed Weatherglass, and the Barometer, Both upon That Phaenomenon, and in General," Philosophical Transactions of the Royal Society of London, I, No. 10 (1665/66), 166-71 (hereinafter referred to as "Earthquake Neer Oxford"), and Robert Boyle, "A Confirmation of the Former Account Touching the Late Earthquake Near Oxford, and the Concomitants Thereof," Ibid., I, No. 11 (1666), 179-81.

deposits in the area, Plot proposed that another mineral of the region called "golden Marchasit" (a type of pyrite) when combined with nitre and water is equally capable of forming the natural gunpowder responsible for earthquakes.²⁰

Robert Plot followed the pattern set by Martin Lister in at least three respects. First, he expanded his remarks on the nature of the underground burning materials and the means by which they take fire; second, he commented on the difference between English and Italian earthquakes; and, third, he answered anticipated specific criticisms.

For more than sixty years after Lister and Plot, the subject of earthquakes was not of the major interest it became after 1750. Many of the treatises were one-time affairs by people of many and varied concerns. In such cases the author gave the best exposition of his ideas; then he moved on to some other topic. For example, astronomer John Flamsteed (1646-1719) in 1693 offered a detailed explanation of earthquakes, while at the same time remarking that the presentation was his last word on the subject, for he had more pressing activities to pursue.²¹ Thus, until 1750, there was little disputation between individuals, although some authors in their writings appear to be debating with themselves or with imaginary critics.

²⁰Plot, Natural History of Stafford-shire, pp. 144, 145-46.

²¹See below, pp. 75-81.

This technique of anticipating criticisms, directly pointing out the objections that the theorist feels others might raise, and then quelling challenges before they can actually be presented is an important tactic in this early period. After 1750, in contrast, major debates (as over airquakes, over the merits of the electrical hypothesis, or on the causes of the Calabrian earthquakes²²) become much more common. The strategy of self-criticism, while effective for the initial introduction of a theory poses a problem for the historian, since it removes the opportunity to examine the process by which an author develops his views over a period of time in response to the constructive and destructive criticism.²³ Historiographically, the period up to mid-century is characterized by single attempts at an understanding of earthquakes, and the primary interest must be placed on tracing ideas as they are borrowed and altered. For the second half-century, more attention can be devoted to the investigation of the work of individuals who developed their concepts over a period of time by reacting to events and criticisms.

Martin Hartop

The time is the late seventeenth century, and the year 1750 is far away. The next article following in the tradition

²²See below, pp. 82-87, 108-22, 126-51, 202-9.

²³As in William Stukeley's electrical theory (see below, Bk. II, chap. ii).

of the presentations of Lister and Plot came by way of Naples. In 1693, Mr. Martin Hartop offered to the Royal Society of London an explanation of earthquakes based on a familiarity with Italian volcanoes and shocks (notably the 1692 earthquake in Sicily).²⁴ He wrote that earthquakes and volcanoes are caused by subterranean fires of burning nitre, sulphur, and other minerals in caverns. When these fiery substances are able to reach the surface, a volcano is formed, otherwise, the fires and vapors build up pressures in the underground chambers capable of shaking the earth. The author supported his theory by the popular notion that when volcanoes are active, Naples is free from major earth movements, while, on the other hand, the silence of the burning mountains is a threatening sign, for it means a major earthquake is again possible.²⁵

Theories linking earthquakes and volcanoes were not new, but Hartop added ideas similar to those in Lister's contribution. He hypothesized that an earthquake is created when inflamed vapors from subterranean fires (the same vapors that also cause thunder and lightning) rush through passages in the earth and create a horizontal, vibratory motion that builds in strength like a storm.²⁶

²⁴"A Letter from Mr. Martin Hartop at Naples, to the Publisher. Together with an Account of the Late Earthquake in Sicily," Philosophical Transactions of the Royal Society of London, XVII, No. 202 (1693), 827-29.

²⁵Ibid., pp. 827-28.

²⁶Ibid., pp. 828-29.

John Ray

At the same time as Hartop was writing, there appeared a more detailed presentation of similar ideas by the English naturalist John Ray (1627-1705). The explanation of Martin Lister, and perhaps those of Robert Plot and John Woodward²⁷ as well, influenced the theory of earthquakes expressed by Ray in the enlarged editions of his Miscellaneous Discourses²⁸ published in 1693 under the new title Three Physico-Theological Discourses and brought up to date ten years later.²⁹

Proceeding from the common association of volcanic eruptions and earthquakes, Ray wrote that the trembling of the

²⁷See below, pp. 40-42.

²⁸Miscellaneous Discourses Concerning the Dissolution and Changes of the World. Wherein the Primitive Chaos and Creation, the General Deluge, Fountains, Formed Stones, Sea-Shells Found in the Earth, Subterraneous Trees, Mountains, Earthquakes, Vulcanoës, the Universal Conflagration and Future State, Are Largely Discussed and Examined (London: Printed for Samuel Smith, 1692). (Hereinafter referred to as Miscellaneous Discourses.)

²⁹Three Physico-Theological Discourses, Concerning I. The Primitive Chaos, and Creation of the World. II. The General Deluge, Its Causes and Effects. III. The Dissolution of the World, and Future Conflagration. Wherein Are Largely Discussed, the Production and Use of Mountains; the Original of Fountains, of Formed Stones, and Sea-Fishes Bones and Shells Found in the Earth; the Effects of Particular Floods, and Inundations of the Sea; the Eruptions of Vulcano's; the Nature and Causes of Earthquakes: With an Historical Account of Those Two Late Remarkable Ones in Jamaica and England. With Practical Inferences (2nd ed. corrected, very much enlarged; London: Printed for Sam. Smith, 1693) and (London: Printed for William Innys, 1713). Hereinafter, references will be to the 1713 edition composed by Ray "towards the latter End of the Year 1703, or Beginning of 1704: . . ." (William Derham, "To the Reader," Ibid., p. xviii), but not published until after his death.

earth is caused by "exhalations or Steams" inflamed underground. Although he claimed to be not "fully satisfied" as to the cause of such steams or how they inflame themselves, he did refer the reader to Lister's contribution in the Philosophical Transactions.³⁰ Ray agreed with his predecessor that the vapors must contain sulphur (as indicated by the smell of sulphur in the air and water after a shock). He also thought that the steam does not require the "Touch of Fire" but "conceives Fire of itself"--perhaps by some kind of fermentation.³¹ Concerning the idea that earthquakes in England are caused by self-inflaming vapors just like the explosive fire-damps in coal mines, Ray was more cautious than Lister. In several instances of such explosions, lighted candles had been shown to have been involved, indicating that the fire-damps may not be self-igniting as had been thought.³²

The author of the Discourses agreed with "most learned Men" that thunder and lightning and earthquakes have the same cause.³³ Ray explained in some detail how lightning is created by sulphureous steams (Lister's "Breath of the Pyrites") inflamed in the clouds: since water (in a liquid or vapor form) acts on pyrites (in solid or vapor form) to

³⁰Ray, Three Physico-Theological Discourses, pp. 258-59.

³¹Ibid., p. 259.

³²Ibid., pp. 261-65.

³³Ibid., p. 258.

create heat and fire, vaporous pyrites and water mix violently inside clouds to produce lightning--the fiery steam seen escaping from a cloud. After some of the steam has escaped, the cloud is able to enclose the remaining exhalations until the force of the sulphureous steam is once again displayed. The operation continues until all of the vapor is consumed or until the cloud precipitates away. Analogously, earthquakes are created by the same process operating underground: in subterranean caverns a mixture of water and pyrites heats until there is an explosion of the vapors.³⁴

Like Robert Plot before him, Ray also anticipated possible objections to his theory and answered them. The first problem was one also noted by Plot. In an earthquake there are no signs of subterranean activity on the earth's surface --no lightning, no flames. Ray answered that the internal lightning is trapped below, since it is not powerful enough to break out. The fire from the exploding vapors travels through underground passages and eventually diffuses itself and ends up as "Fume and Ashes."³⁵ After recognizing the exception that some earthquakes had opened up the earth--still without displaying any internal fires--he explained that in such cases the subterranean fire is encased deep inside the earth underneath an impenetrable stone layer. Above this layer are cavities and less solid materials that are opened

³⁴Ibid., pp. 260-61.

³⁵Ibid., pp. 265-66.

to view by the explosive concussion of a major earthquake.³⁶

Concerning the propagation of an earthquake, Ray thought that extensive shocks have their origins deep in the earth, and as an additional factor, subterranean passages play an important role in the transmission of the tremors over large areas.³⁷ In 1692, an earthquake hit parts of England, the Netherlands, France, and areas of central Europe; Ray explained that vapors were inflamed underground in the earth's network of "Cuniculi" (otherwise referred to as "Conduits," "Caverns," and "Tunnels"³⁸). The exploding vapors traced a path from England, under the English Channel, and on through passages below much of continental Europe. The suggestion of subterranean passages was not unusual, since the volcanoes Etna, Stromboli, Vesuvius, and perhaps even Mt. Semo in Ethiopia were thought to be interconnected.³⁹

Ray called attention to another problem: if the source of earthquakes is deep below the surface of the earth and sealed off by a layer of rock, the vibrations of the land above cannot explain the thunderous noise that accompanies major earthquakes. In response, he theorized that the sound comes not from the vibrating earth but from the movement of sulphureous exhalations that are able to force their way through the earth to the surface. The sulphureous smell

³⁶Ibid., pp. 266-67.

³⁷Ibid., p. 276.

³⁸Ibid., pp. 276, 278, 279.

³⁹Ibid., pp. 278-79.

in the air after an earthquake was for Ray evidence that escaping vapors explain the thunder of earthquakes.⁴⁰

From its beginning in 1684, the particular explanation of earthquakes initiated by Lister had become quite sophisticated by Ray's time, but still the theory had not been perfected. In the family of ideas dating back to Lister, flames and lightning are trapped below, while sulphureous vapors can escape. This presents a problem: the exhalations make their way out into the atmosphere to cause lightning, shooting stars, and noises; but fires and smoke are contained within the earth. This inconsistency was not one of the several difficulties discussed. Although Plot, Ray, and other authors in writing about earthquakes in the context of much larger works could not be expected to deal with every detail, it is likely they intentionally refrained from mentioning this one problem for which they had no satisfactory solution, while still believing that the answer was there for the investigator who concentrated on the question. This brings up the point of the relative value that is placed on obviously successful ideas and on only potential discrepancies when developing a theory. Well established and fundamental facts and thoughts are given more creditability than a small annoyance that stands in the way of an otherwise pleasing conception of nature.

⁴⁰ Ibid., pp. 276-77.

The sulphureous-vapor hypothesis had been well received as an explanation of both lightning and earthquakes. The facts were clear to the students of nature: sulphureous smells were noticed in conjunction with earthquakes as well as with lightning. Thus, it appeared certain that the exhalations do rise from the earth. And there was other evidence. In England, fire and smoke were not seen in earthquakes, but such phenomena were known to be connected with the shocks through observations of the more active Italian earthquakes and volcanoes. The fires of English earthquakes are apparently contained deep underground. The popular theory for explaining both earthquakes and lightning together had too much supporting evidence to suffer from a failure to explain why, if smoke is trapped, sulphureous vapors are not. In the absence of an obvious explanation, the minor problems could be set aside for the time being, for the solution must be there.

The inconsistency just noted was a difficulty that was specific to that brand of explanations involving subterranean vapors. However, one riddle that authors such as Ray especially pointed out but could not answer involved a question that theorists of all persuasions had to confront: in earthquakes some places are shaken, while others close by are not affected at all. During one shock, Ray's own house was spared the "least Motion or Impression," while neighbors half a mile away and less had houses "considerably shaken."⁴¹ For

⁴¹Ibid., p. 277.

this puzzle, Ray could not find a satisfactory solution.

He did reach an understanding as to why English earthquakes had been generally limited to one explosion, although other places, notably Jamaica, usually experienced multiple shocks. He suggested, as Robert Plot had earlier, that while English caverns are small, the great cavities under Jamaica fill with fiery vapors, raising the earth in an effort to break free. But the chambers resist the forceful exhalations, the fire spreads through subterranean passages, the great caverns cool, and the earth subsides. The fiery steams then refill the cavities for a second explosion, a third, and still more shocks as long as the vapors remain capable of shaking the earth. Not being entirely satisfied with this explanation, Ray suspected that it might be improved upon.⁴²

Fires and Waters

John Woodward

While Marin Lister, Robert Plot, Martin Hartop, and John Ray had presented earthquake theories that by the end of the seventeenth century had revived older ideas involving the general concepts of subterranean fire and vapors, another author contemporary with these men reintroduced the idea of subterranean water as a cause of earthquakes.

John Woodward (1665-1728), an English physician and a professor at Gresham College, in his An Essay Toward a Natural

⁴²Ibid., pp. 267-68, 277.

History of the Earth (1695)⁴³ added another concept to the ideas under discussion--the effect of internal fires of the earth on subterranean waters. He theorized that the fires normally cause underground waters to rise to the surface, but if something blocks the passage way, then the accumulated waters are heated to "very great Commotions."⁴⁴ These agitated waters have the power to break the earth so as to form new passages by which the imprisoned water is free again to rise to the surface. Suddenly overflowing rivers and wells, as well as troubled seas, offer evidence of this source of earthquakes.⁴⁵ In addition, underground rivers and streams undermine parts of the land, causing it to collapse.⁴⁶

In remarking that while no region is completely free from earthquakes, certain areas are struck most often and strongly, Woodward introduced a topic that would be discussed by eighteenth-century writers. Mountainous countries are particularly subject to earthquakes, he suggested, because they contain more underground cavities in which the fires and the waters can accumulate. In addition, the solid masses of

⁴³An Essay Toward a Natural History of the Earth: and Terrestrial Bodies, Especially Minerals: as Also of the Sea, Rivers, and Springs. With an Account of the Universal Deluge: and of the Effects That It Had upon the Earth (London: Printed for Ric. Wilkin, 1695).

⁴⁴Ibid., pp. 133-34.

⁴⁵Ibid., pp. 133-37.

⁴⁶Ibid., pp. 134-35.

stone and marble imprison the subterranean forces until these become so great that the highlands are "most furiously shattered." On the other hand, areas consisting of gravel and sandy materials release the heated waters before they can accumulate to a dangerous level.⁴⁷

Another earthquake-producing force for Woodward, as it had also been for Robert Plot, was the explosive force of natural gunpowder. He specifically attributed the noise that accompanies earthquakes to the concussion of the naturally-occurring mixture of sulphur and nitre--a combination of materials that is found in the mountainous, earthquake-prone countries of Italy, Sicily, and Greece.⁴⁸

Thus, John Woodward's Essay added the force of heated subterranean water to the theories that had presented underground fires and explosive vapors as the source of earthquakes. The English encyclopedist John Harris (ca. 1666-1719) adopted Woodward's explanation in the article, "Earthquakes" in his Lexicon Technicum of 1704.⁴⁹ Compilers of later reference works continued to cite the theory, but not

⁴⁷Ibid., pp. 140-41. Later theorists were divided as to whether mountainous lands or maritime regions were most subjected to the shocks. See below, pp. 63, 162-63, 169-70.

⁴⁸Woodward, Essay Toward a Natural History of the Earth, pp. 141-42.

⁴⁹Lexicon Technicum: or, an Universal English Dictionary of Arts and Sciences: Explaining Not Only the Terms of Art, but the Arts Themselves (London: Printed for Dan. Brown and others, 1704), sig. Aaa2^r-[Aaa3^r].

to the exclusion of other explanations.⁵⁰ Furthermore, additional ideas in new directions were still being offered.

Subterranean Air Pressure

In antiquity, the most extensively discussed hypothesis was one involving subterranean wind. But in the latter part of the seventeenth century, the time in which older ideas of underground fire and water had been revitalized, a distinct concept of subterranean winds such as Aristotle or Seneca described is missing. Aspects of this type of explanation can be inferred to be present in the accounts involving explosive vapors (especially in the theories of Hartop and Ray). However, in the early eighteenth century a new thought about earthquakes was introduced, specifically featuring subterranean air pressure.

Guillaume Amontons

In 1703, Guillaume Amontons (1663-1705), a French experimental natural philosopher presented the results of his experiments and calculations indicating that a small amount of heat is capable of placing the air inside the earth--air under great pressure--into very violent commotions.⁵¹

⁵⁰See below, pp. 66-67, 137-39, 142, 150-51.

⁵¹"Que les nouvelles experiences que nous avons du poids & du ressort de l'air, nous font connoître qu'un degré de chaleur mediocre, peut réduire l'air dans un etat assez violent pour causer seul de tres-grands tremblements & bouleversements sur le globe terrestre," Histoire de l'Academie Royale des Sciences. Année MDCCIII. Avec les memoires de

Deeper and deeper into the earth the air becomes increasingly dense. Amontons calculated that at a depth of 43,528 toises (about one seventy-fourth of the earth's radius) air is compressed to the density of gold.⁵² At surface atmospheric pressures, heat produces little effect on the air, but as it is compressed, heat produces more and more disastrous results. Thus, an amount of heat that at the surface is insignificant is capable of producing catastrophes at the pressures existing deep in the earth. Add the well-known fact that nature can create great amounts of heat inside the terrestrial sphere, as volcanic fires illustrate, and Amontons had an elegantly simple theory to explain the greatest earthquakes.⁵³

The author not only had a novel explanation, but his presentation was far different from that of his predecessors and successors who tested their ideas against information about past earthquakes, who supported their cases with arguments defending what might appear at first to be weak points, and who presented additional comments explaining accompanying phenomena such as thundering noises or the absence of any evidence of subterranean fires in England. None of these ancillary discussions are in Amontons' treatise, because his assembly of facts and ideas (of which only one is controversial)

mathematique & de physique, pour la même année (Paris, 1705), Memoires, pp. 101-8.

⁵²Ibid., pp. 103-4, 106-7.

⁵³Ibid., pp. 107-8.

is persuasive in itself. His evidence can be outlined as follows: (1) there are subterranean cavities (a proposition universally accepted at this time); (2) these cavities are filled with air (a debatable point since Robert Plot had denied the presence of air, and others emphasized the existence of volcanic fires and caverns of water); (3) air pressure increases with depth; (4) the interior of the earth is hot; and (5) experiments showed that air under pressure when heated is very dangerous. If a person accepts the premise that the inner earth contains great caverns of dense air, then he can easily support Amontons' explanation of earthquakes. In this presentation references to actual earthquakes are superfluous. The theory indicates that there must be earthquakes, and the common knowledge that there are such shocks is all the supporting evidence that Amontons needed.

In certain details, such as explaining the difference in English and Italian earthquakes, or showing the variance in English and Jamaican shocks, or discussing the propagation of earthquakes, his explanation is deficient when compared to the work of his predecessors. But as far as offering a solution to the basic problem of what causes earthquakes is concerned, the Lister-Plot-Ray type of theory and Woodward's subterranean-water concept was now joined by a third major hypothesis. To the eighteenth-century student of earthquakes, the mention of subterranean fire, water, and air brought to mind the names Lister, Woodward, and Amontons rather than

the names Anaxagoras, Demokritos, and Aristotle.

The Status of Earthquake Theories at the
Beginning of the Eighteenth Century

The examination of earthquake theories from Lister to Amontons offers a preview of the investigations that were to continue through the eighteenth century. A number of explanations had been offered, using three different fundamental views of the earth. Detailed theories, as well as new working hypotheses, continued to be added in the coming decades, particularly in the last half of the century. For the period before 1750, the study of earthquakes followed in the pattern of the introductory period. Of the three principal plans for explaining the quaking earth, the one introduced by Lister received the most attention as others endeavored to perfect it. Woodward's underground-water idea continued to be recognized as a promising solution, as was Amontons' scheme. By the year 1800, none of the early hypotheses had been rejected outright, but they gradually disappeared from discussions as new ideas became the center of attention.

One of the characteristics of the prefatory period that appears in contrast to later developments is that statements of earthquake theories were short, concise, yet thorough, expositions. In the summaries of the writings of Lister, Plot, Hartop, Ray, Woodward, and Amontons, reference is made to just over forty pages of text. In contrast, the

last half of the eighteenth century saw entire books on the subject illustrated with hundreds of pages of experimental evidence, historical examples, and contemporary observations. The authors just discussed shared a common view of the phenomenon called an earthquake, and in setting forth their explanations they took little time to describe evidence that everyone knew. Later, as new questions were discussed, as theories became more complex, and as the competition between schools of thought intensified, a more detailed look at the shaking earth revealed that the phenomenon was not so simple. One explanation might describe the origins of one shock beautifully, yet it might be totally inappropriate when accounting for the next incident. As the subject became more difficult, newer, more detailed theories were offered to meet the challenge.

A person in the year 1800 who wondered about earthquakes had a problem of choosing among the many explanations that were being offered, but the choice was not much simpler a hundred years before. By 1703, early authors had devised diverse, thoughtful solutions, but there was no basis for selecting one theory over another in the absence of conclusive supporting evidence for one idea or of damaging contradictions in another. Unfortunately, no one possessed an instrument that would enable him to see pyrites in some deep cavern take fire, nor could an observer see the erosion caused by agitated subterranean waters, or view air pressure

buckle the supporting column of a great cavern. Thus, the search for the ultimate explanation continued, building on the pioneering work of the men of the late seventeenth century.

CHAPTER IV

THE FIRST HALF-CENTURY

Subterranean-Fire Theory Developments

In the last two decades of the seventeenth century, the most prominent explanations of earthquakes were based on the ideas that subterranean fires, inflammable vapors, and explosive substances are the responsible agents. In the first half of the eighteenth century, these causes continued to be examined in the effort to explain exactly how underground fires and explosions occur in nature to shake the earth.

Nicolas Lémery

In the early 1700's the foremost proponent of the subterranean-fire-and-vapors theory was the French chemist Nicolas Lémery (1645-1715), who sought to establish through a series of experiments and demonstrations the source of the fires and exhalations that are responsible for earthquakes, volcanoes, and lightning. In the Mémoires of the Académie Royale des Sciences for the year 1700,¹ he described an

¹"Explication physique & chymique des feux souterrains, des tremblemens de terre, des ouragans, des eclairs & du

experiment in which he combined equal parts of iron filings and pulverized sulphur with just enough water to form a paste. After a few hours, the substance became hot and expanded to the point of producing vapors and flames. Lémery explained that what he had created was a fermentation in which the acid-points of sulphur interact violently with the particles of iron.²

He did not describe the origins and evolution of his theory, but in its outline are recognizable the essential features of Martin Lister's presentation of 1684. In Lister's papers, natural pyrites (consisting of sulphur and iron) are cited as the source of the destructive inflammable fumes. Lémery's experiments with sulphur and iron provided, in effect, artificial pyrites to demonstrate the earth-shaking force of such a combination. In addition, Lémery followed Lister's lead in attributing to the explosive vapors the origins of volcanoes and lightning as well.

The Frenchman's contribution to Lister's conception of the earth rests on experiments and demonstrations so persuasive that an account of Lémery's work became a standard component in subsequent discussions in earthquake chronicles and encyclopedia articles, and in the theoretical writings

tonnerre," Histoire de l'Academie Royale des Sciences, année MDCC. Avec les memoires de mathematique & de physique, pour la même année (Paris, 1703), Memoires, pp. 101-10

²Ibid., pp. 102-3.

of others involved in the further development of Lister's theory.

Lémery's vivid demonstration depicted what he believed happens inside the earth. He put a quantity of iron and sulphur paste into a great pot, covered it with a cloth, and then buried it. After eight or nine hours, the ground above the pot expanded and gave forth hot, sulphureous fumes and flames in a miniature earthquake and volcano.³ He explained that in the earth the hot exhalations from the natural combination of iron and sulphur creates a sulphureous wind that travels through the earth and shakes it in seeking release from confinement. If the vapors find an opening to the surface, they exit with such violence that trees are uprooted and houses shaken. . Otherwise, if the vapors cannot escape, they assault the earth until they lose their power to do damage. In still other cases, when very abundant supplies of iron, sulphur, water, and air are available along with adequate vents to the surface, volcanoes are produced.⁴

This theory, like Lister's also accounts for the creation of lightning. Lémery explained that sulphureous winds from inside the earth escape into the atmosphere and there form clouds and storms. On taking fire the vapors appear as

³Ibid., pp. 103-4.

⁴Ibid., pp. 104-5. Unlike Plot who stated that air is not necessary for subterranean fires, Lémery wrote that underground vents provide the needed air. Ibid., p. 104.

lightning. Lightning produces thunder by its rapid movement and through being extinguished upon entering a cloud. As before, traces of sulphur in the air after a lightning storm were indicated as part of the proof that thunderbolts and earthquakes share the same cause.⁵ Offering an experimental analogy, Lémery remarked that a heated mixture of spirit of vitriol, water, and iron filings forms a sulphureous vapor that a lighted candle can explode several times repeatedly.⁶ In assembling support for his theory, the author did not always follow Lister's lead, for he omitted Lister's report of iron falling from the sky, and accounts of the fall of sulphur were rejected as doubtful.⁷

Lémery's explanation of earthquakes, usually mentioned in conjunction with a description of Lister's work on pyrites, was a well-known and respected theory during the eighteenth century, although Guillaume François Rouelle (1703-1770), another French chemist, pointed out that Lémery had used metallic iron and not the dephlogisticated iron most often found in nature. Phlogisticated iron is seen only rarely, such as in Senegal, where mineral iron has been purified by the fires of the earth.⁸ Nevertheless, the Lister-Lémery proposal

⁵Ibid., pp. 101-2, 106-7.

⁶Ibid., pp. 107-8.

⁷Ibid., pp. 106-7.

⁸Rouelle cited in the article: "Tremblemens de terre, (Hist. nat. minér. & physiq.)," by Paul Henri Thiry, Baron d'Holbach in Vol. XVI of Denis Diderot's Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers

acquired extensive support, and Rouelle's question was hardly noticed.

Sir Isaac Newton

Part of the acceptance of the theory can be attributed to the adoption of Lémery's explanation by other influential writers, including Sir Isaac Newton (1642-1727), the English mathematician. In 1718, in the thirty-first "query" of the Opticks, Newton wrote of the violent effects of a mixture of iron filings, powdered sulphur, and water. He proposed that the great quantity of sulphur in the earth ferments with other minerals, becomes inflamed, and creates sudden explosions that break caverns to shake the earth. Newton also joined Lister, Lémery, and the others who stated that the sulphureous vapors pass through the earth to the atmosphere where they form thunder and lightning, as well as storms and other fiery meteors.⁹

Scheuchzer and Cyrillus

Ideas similar to those expressed by Lister, Lémery, and Newton were used by John Gaspar Scheuchzer (or Scheutzer) (1702-1729), a young Swiss naturalist and later a physician

par une société de gens de lettres. Mis en ordre en publié par Mr. *** (Neufchâtel: Chez Samuel Faulche & Compagnie, 1765), p. 581.

⁹Sir Isaac Newton, Opticks: or a Treatise of the Reflections, Refractions, Inflections and Colours of Light (2nd ed., with additions; London: Printed for W. & J. Innys, 1718), pp. 351-55.

in England, to explain the Sicilian earthquakes of 1693, 1694, and 1717.¹⁰

Scheuchzer was not the only author to find in Italian earthquakes evidence to support the subterranean-fire-and-vapor theory. Nicolas Cyrillus (1671-1735), who taught medicine at Naples, in his investigation of the Neapolitan earthquake of 1731 offered additional proof.¹¹ An analysis of water thrown out of the earth indicated that a subterranean mixture of sulphur and iron is involved in the production of earthquakes. He observed that the ejected water weighed more than spring water from the same area, and after distillation, a residue was left containing sulphur as well as particles that were attracted by a lodestone, indicating iron in the sample.¹²

¹⁰"An Account of a Book Entituled, Dominici bottoni, de immani trinacriae terrae motu idea historico-physica, in qua non solum telluris concussiones transactae recensentur, sed novissimae anni 1717. Messanae 1718, 8^o. By J. G. Scheuchzer, M.D. R.S.S. Coll.M.L.Lic.," Philosophical Transactions of the Royal Society of London, XXXIII, No. 384 (1724), 151-58.

¹¹"Historia terraemotus Apuliam & totum ferè Neapolitanum Regnum, anno 1731, vexantis. A Nicolao Cyrillo, in Regiâ Universitate Neapolitanâ, Pr. Med. Prof. & R.S.S.," Philosophical Transactions of the Royal Society of London, XXXVIII, No. 428 (1733), 79-84. See also "An Account of an Earthquake in Apulia and Most Other Parts of the Kingdom of Naples, in the Year 1731. By Dr. Cyrillus of Naples. No. 428. p. 79. Translated from the Latin," Philosophical Transactions of the Royal Society of London, abridged ed., ed. by Charles Hutton, George Shaw, and Richard Pearson (London: C. and R. Baldwin, 1809), VII, 606-9.

¹²Cyrillus, "Historia terraemotus Apuliam," pp. 83-84, and "An Account of an Earthquake in Apulia," pp. 608-9.

Thus, over a period of over forty years (beginning in 1684 and extending into the 1730's) there developed the attractive idea that sulphur, iron, and water are the ingredients needed for creating the underground fires and explosive exhalations that were thought responsible for producing earthquakes. From its origins in the initial statements by Martin Lister, the theory, which had been elaborated by the addition of experiments and demonstrations of Nicolas Lémery, advocated by Newton, and supported through more evidence presented by Scheuchzer and Cyrillus, became the primary earthquake hypothesis of the early eighteenth century.

Le Comte de Buffon

Helping to perpetuate the subterranean-fire hypothesis was the appearance in 1749 of a theory of the earth in the first volume of the Histoire naturelle by naturalist Georges Louis Leclerc, Comte de Buffon (1707-1788).¹³ He began discussing the subject by first distinguishing between earthquakes associated with volcanoes and the non-volcanic type of shock that had been of particular interest to French and English authors.¹⁴ Tremors had long been known to accompany volcanic eruptions, lending support to the popular theory that

¹³Histoire naturelle, générale et particulière, avec la description du cabinet du roi, (Paris: De l'Imprimerie Royale, 1749). Hereinafter, citations are to the microprint edition: Landmarks of Science (New York: Readex Microprint Corp., 1969).

¹⁴Ibid., I, 526-27.

when a large quantity of burning material fails to find a natural vent, the earth is opened forceably by an earthquake, releasing a volcanic eruption. He also offered the view that if the quantity of the combustible matter is relatively small, there can be localized earthquakes without the appearance of a volcano.¹⁵

Buffon knew that the shocks in volcanic regions are limited in scope (comparable to the jolt caused by the explosion of a gunpowder magazine); for example, an eruption of Mt. Etna causes earthquakes only over a limited area.¹⁶ But the non-volcanic type of earthquake is felt over great distances: in the year 1692 the earth trembled along a path from England, through France, through the German states, and on into Hungary. To create such long-distance earthquakes, Buffon postulated that an explosion of inflammable materials, such as the fermentation of pyrites, produces a quantity of heated air in subterranean chambers. Heated compressed air is then capable of great efforts in its escape horizontally through underground tunnels and caverns. A violent wind thus passes through the earth, shaking it as far as the blast is able to travel; the amount of destruction depends on the character of the obstructions it encounters during its furious passage.¹⁷

¹⁵Ibid.

¹⁶Ibid.

¹⁷Ibid., I, 527-30.

By 1749, the subterranean-fire hypothesis in the various detailed versions related to the presentations of Lister and L  mery was one of the best-known explanations of earthquakes of the day, since the major components had appeared in London and Paris philosophical journals, in Newton's Opticks, and in Buffon's Histoire naturelle. In addition, Lister's plan and the experiments of L  mery were restated many times in encyclopedias and in earthquake chronicles.¹⁸ The idea of subterranean fires and vapors as the source of earthquakes was one that remained viable throughout the century--and not only in the form introduced by Lister and company.

Another View of Subterranean Fire:

A Note in Varen's Geography

The Lister-L  mery thesis was dominant in the first half of the century, but it was not the only one offered. Other explanations were formed in the same search into the exact cause of the subterranean fire that produces earthquakes and volcanoes. One new theory appeared in the 1730's in English translations of the Geographia generalis of Bernhard Varen (1622-1650).¹⁹ This obscure theory, located in a footnote,

¹⁸For example, see below, pp. 67, 138, 236.

¹⁹A Compleat System of General Geography: Explaining the Nature and Properties of the Earth; viz. It's Figure, Magnitude, Motions, Situation, Contents, and Division into Land and Water, Mountains, Woods, Desarts, Lakes, Rivers, &c. With Particular Accounts of the Different Appearances of the Heavens in Different Countries; the Seasons of the Year Over All the Globe; the Tides of the Sea; Bays, Capes, Islands,

could be easily ignored in a main-stream study of influential treatises, because reference to it by contemporary writers is almost unknown. But the note is of importance here in illustrating one pervading characteristic of earthquake studies of the age: the proliferation of detailed explanations through a process of synthesizing a new scheme from ideas borrowed from a variety of sources.

The addition to Varen's Geography is a compilation containing some of the views of Lister, Woodward, and Newton; but its basis is in the earlier ideas of the French natural philosopher Jacques Rohault (1620-1675). In his Traité de physique (1671)²⁰ Rohault suggested that a residue from the vapors of sulphur or bitumen coats the roofs of caverns. This covering joins with the saltpetre already found there to form an explosive, earthquake-producing substance. He

Rocks, Sand-Banks, and Shelves. The State of the Atmosphere; the Nature of Exhalations; Winds, Storms, Tornados, &c. The Origin of Springs Mineral-Waters, Burning Mountains, Mines, &c. The Uses and Making of Maps, Globes, and Sea-Charts. The Foundations of Dialling; the Art of Measuring Heights and Distances; the Art of Ship-Building, Navigation, and the Ways of Finding the Longitude at Sea. Originally Written in Latin by Bernhard Varenus, M.D. Since Improved and Illustrated by Sir Isaac Newton and Dr. Jurin; and Now Translated into English; with Additional Notes, Copper-Plates, and Alphabetical Index and Other Improvements. Particularly Useful to Students in the Universities; Travellers, Sailors, and All Those Who Desire To Be Acquainted with Mixed Mathematics, Geography, Astronomy, and Navigation. By Mr Dugdale. The Whole Revised and Corrected by Peter Shaw, M.D. (2 vols., 3rd ed., with additions; London: Printed for Stephen Austen, 1736), I, 155, n. (e). (The British Museum General Catalogue lists three Dugdale-Shaw editions between 1733 and 1736.)

²⁰(Paris: Chez le Veuve de Charles Savreux.)

described several ways by which the mixture is kindled: some parts of the crust of the inflammable materials falling to the floor of the cavern ignite as they hit, or stones striking the ground can inflame the substance through sparks as one rock hits another. Flames can come from falling stones by a grinding effect producing explosions like those in accidents in manufacturing gunpowder, or by the agitation of the air as they fall. An additional source of subterranean fire for Rohault is sulphureous vapors. Whatever the exact origins of the fire and explosion, the result may well be the collapse of a large cavern, causing the land above to subside and forming an earthquake like those that have swallowed entire towns.²¹

Later in England, Rohault's work appeared in Latin and English editions containing notes by Dr. Samuel Clarke (1675-1729) in support of Newtonian philosophy. In the third Latin edition, Clarke added footnotes concerning the Frenchman's earthquake theory.²² He thought that the best experimental

²¹Rohault, Traité de physique, pp. 247-49.

²²Jacobi Rohaulti Physica. Latine vertit, recensuit, & adnotationibus ex illustrissimi Isaaci Newtoni philosophia maximam partem haustis, amplificavit & ornavit Samuel Clarke, S.T.P. Regiae Majestati a sacris. Editio tertia, in qua annotationes sunt dimidia parte auctiores, additaeque octo tabulae aeri incisae (Londini: Impensis Jacobi Knapton, 1710), p. 413, n. * and p. 410, n. *. See also the English edition: Rohault's System of Natural Philosophy, Illustrated with Dr. Samuel Clarke's Notes, Taken Mostly Out of Sir Isaac Newton's Philosophy, trans. by John Clarke (London: Printed for James Knapton, 1723), II, 196, n. 2, and 192, n. 1.

explanation for subterranean fires was the one offered by Newton in his Opticks, but Clarke was not referring to Newton's description of an experiment like L  mery's; instead, he called attention to Newton's account of the flaming explosion that results from a mixture of sulphur, nitre, and salt of tartar.²³

Clarke's note, Rohault's ideas on the origins of earthquakes, the pyrite theory of Martin Lister, together with certain remarks by John Woodward were all combined into a footnote in Varen's Geography to form a comprehensive explanation of earthquakes. From Rohault came the idea that exhalations of sulphur and nitre create an inflammable material (like a natural gunpowder) that can be ignited by the spark of a falling rock. Lister's inflammable pyrite-vapor theory was added together with Newton's fermenting vapors to form an additional source of subterranean fires and explosions. Woodward was identified as the source of the idea that volcanoes allow the internal fires and vapors to escape, but if the subterrestrial forces cannot be released by a volcano, an earthquake shakes the earth in the effort to release the imprisoned fiery exhalations.²⁴

Although the particular version of the subterranean-fire hypothesis appearing in Varen's book was lost among the many other, more popular ideas, the example illustrates the

²³Ibid. See also Newton, Opticks, 2nd ed., pp. 353-54.

²⁴Varen, Compleat System of General Geography, p. 155, n. (e).

state of flux that earthquake theorizing was in: ideas come and go, they are combined and separated--still without providing any sort of consensus among the experts regarding the origins of earthquakes.

A New View of Subterranean Water

The most prominent explanation in the first half of the eighteenth century involved subterrestrial fires and explosive vapors. But it was not the only successful working hypothesis. The erosive effects and the violent agitations of underground rivers and bodies of water had been considered in antiquity as the cause of earthquakes, and this same view of the earth was still being discussed in the 1700's.

Under the subterranean-water hypothesis can be found theories, evidence, and arguments as persuasive as those under the banner of subterranean-fire. However, whereas in the "fiery" theories, discussions are centered on descriptions of the inflammable and effervescent materials involved, such detailed inquiries into the behavior of underground substances were unnecessary in the case of subterranean-water theories. The writings favoring this other explanation are concise statements (as the one by Woodward) that simply relate the author's certain view that the movement of water in underground rivers and stormy lakes shakes the earth. But one author did go beyond the general presentations and incorporated some of the Lister-Lémery ideas in a more detail theory.

Amedée François Frézier

Breaking from the more traditional views of the role of water in the formation of earthquakes was Amedée François Frézier (1682-1773), a French military officer, geographer, and naturalist. In 1716, he published a report of a voyage to the western coast of South America that included a novel account of the origins of earthquakes.²⁵ He agreed with his predecessors that water, by undermining the supporting structures of the earth's surface, causes portions of the land to collapse.²⁶ However, as in the case of the development of the Lister-Lémery theory over a period of decades and in the Rohault-Clarke-Newton-Lister-Woodward explanation described above, Frézier combined ideas borrowed from others with his own view of the matter to form an altered picture of the shaking earth. Straight from Lémery came the account of what happens when iron filings, sulphur, and water are mixed. But instead of emphasizing the sulphur and iron, as had the

²⁵Relation du voyage de la Mer du Sud aux côtes du Chily et du Perou, fait pendant les années 1712, 1713 & 1714 (Paris: Chez J.-G. Nyon, E. Ganeau, J. Quillau, 1716). Hereinafter, citations will be to a second, enlarged edition: Relation du voyage de la Mer du Sud aux côtes du Chily et du Perou, fait pendant les années 1712, 1713 & 1714. Dediée à S. A. R. Monseigneur le Duc d'Orleans, Regent du Royaume. Avec une réponse a la preface critique du livre intitulé Journal des observations physiques, mathematiques & botaniques du R. P. Feuillée, contre la Relation du voyage de la Mer du Sud, & une chronologie des Vicerois du Perou, depuis son etablisement jusqu' au tems de la Relation du voyage de la Mer du Sud (Paris: Chez Nyon, Didot [et] Quillau, 1732).

²⁶Ibid., pp. 189-90.

subterranean-fire-and-vapor theorists, Frézier added his personal touch by stressing the water.²⁷

The French officer reached his unique position after an examination of South American earthquakes indicated to him that Peruvian and Chilean shocks have been confined to coastal areas, while the high Cordilleras have remained comparatively little affected. On further investigation he found that it is generally true that earthquakes are more common in maritime areas. For instance, southern Italy, in the midst of the Mediterranean Sea, has received more shocks than the higher, interior areas such as the Alps. Pointing to his South American observations, Frézier explained that the sea provides the necessary water, while mines of sulphur and iron indicate the presence of the other two ingredients required for Lémery's explanation.²⁸

Specific observations further demonstrated to Frézier's satisfaction that water is the primary factor in earthquake production. During some shocks the ground was seen to flow to a lower level in the same manner as the movement of molten wax. He explained that the flowing earth was caused by the base of the land being soaked with water, allowing the topsoil to move downhill when shaken by an earthquake. In other instances when lakes were formed when the land suddenly sank, Frézier saw these simply as additional signs of the role water plays in the creation of earthquakes.²⁹

²⁷Ibid.

²⁸Ibid., p. 190.

²⁹Ibid.

Opposition to Frézier's Theory

One of the characteristics of earthquake writings in the first half of the eighteenth century was the general lack of formal criticism of opposing views by those favoring different explanations. In most cases, an author made a positive statement of his own ideas, and while he sometimes pointed out and then eliminated debatable parts of his own presentation in a technique to add further credence to his theory, he generally did not make the effort to destroy the theories he wished to supplant. In an exception to this general rule, Frézier's concept drew direct, point-by-point opposition.

In the year 1748, there appeared in London an unsigned work with a lengthy title that began: A True and Particular Relation of the Dreadful Earthquake Which Happen'd at Lima.³⁰

³⁰A True and Particular Relation of the Dreadful Earthquake Which Happen'd at Lima, the Capital of Peru, and the Neighbouring Port of Callao, on the 28th of October, 1746. With an Account Likewise of Every Thing Material That Passed There Afterwards to the End of November Following. Published at Lima by Command of the Viceroy, and Translated from the Original Spanish, by a Gentleman Who Resided Many Years in Those Countries. To Which Is Added, a Description of Callao and Lima Before Their Destruction; and of the Kingdom of Peru in General, with Its Inhabitants; Setting Forth Their Manners, Customs, Religion, Government, Commerce, &c. Interspersed with Passages of Natural History and Physiological Disquisitions; Particularly an Enquiry into the Cause of Earthquakes. The Whole Illustrated with a Map of the Country About Lima, Plans of the Road and Town of Callao, Another of Lima; and Several Cuts of the Natives, Drawn on the Spot by the Translator (London: Printed for T. Osborne, 1748). (Hereinafter referred to as True and Particular Relation.)

An unimpressed reviewer in Gentleman's Magazine³¹ pointed out that a large portion of the book consists of a description of the region based on other accounts, and it reveals very little accurate information on the Lima earthquake of 1746.³²

But one section of the work on Peru did contribute to the discussions on the causes of earthquakes by raising problems over Frézier's ideas on the role of water in earthquakes. While the French officer had emphasized the importance of water in Lémery's experiments and demonstrations, he failed to note that only a little water is required to create the fermentation--just enough to make a paste. Furthermore, too much water can bring to a halt any subterranean fire.³³

³¹"View of a Pretended Translated Account of the Late Earthquake at Lima," Gentleman's Magazine, XVIII (August, 1748), 361-62.

³²Ibid. Much of the book and even much of the title came from a work attributed to Padre Pedro Lozano, S.J. (1697-1752) that was first published in Lima (1746) and later in Mexico (1747): Individual, y verdadera relacion de la extrema ruina que padeciò la Ciudad de los Reyes Lima, capital del reyno del Perú, con el horrible temblor de tierra acaecido en ella, la noche del 28. de octubre de 1746. y de la total assolacion del presidio, y puerto del Callao, por la violenta irrupcion del mar, que ocasionò en aquella bahia ([colophon: Impresso en Lima, y por su original, de mandato del Exc^{mo}. Sr. virrey, reimpresso en Mexico por la viuda de Joseph Bernardo de Hogal. Año de 1747]). This work was translated by Henry Johnson (1698?-1760) for True and Particular Relation (pp. 131-99). [LC 6-9320] The reviewer in Gentleman's Magazine (pp. 361-62) lamented that such a work would be promoted into a second edition, but the book was also attractive to other printers, as it was reprinted in Philadelphia (Printed and sold by B. Franklin and D. Hall, 1749) and in Boston a year later (Printed and sold by D. Fowle).

³³True and Particular Relation, pp. 115-16.

Frézier's mention of lakes formed where the ground had subsided during an earthquake was considered irrelevant, because the lakes could have been created by subterrestrial waters without these waters having been involved in causing the shock itself. In addition, the author of the English report of the earthquake at Lima wrote that earthquakes are explosions that lift the surface of the earth or move it horizontally--they do not just create depressions in the earth.³⁴ Instead of subterranean waters as the cause, the anonymous author presented the usual version of Lister's theory of pyrite-vapors as the explanation of the trembling earth.³⁵

Earthquake Studies at the Half-Century Mark

In the first half of the eighteenth century, the authors of earthquake treatises continued to support and develop the ideas presented in the period from Lister to Amontons. By the year 1749, the answer to the question of what causes earthquakes was far from settled. Subterranean fire and vapors could be the cause; but which detailed version of that explanation was the correct one? The situation was not significantly different than it had been in 1728 when Ephraim Chambers (ca. 1680-1740) presented a discussion of the major earthquake theories in his Cyclopaedia³⁶ and

³⁴Ibid., pp. 116-17.

³⁵Ibid., pp. 118-26.

³⁶"Earthquake," Cyclopaedia: or, an Universal Dictionary

concluded that naturalists were not able to decide on one explanation.. Water, fire, and air all seemed reasonable causes, for the earth abounds in subterranean caverns filled with water, combustible materials, and exhalations. In particular the Cyclopaedia article described Lister's pyrite theory, L  mery's demonstrations, and Woodward's views, while giving special attention to Amontons' theory of the force of heated compressed air (a theory that until then had received relatively little attention).

The chronological division of this history of the study of earthquakes into half-centuries may appear to be an artificial device of antiquarian convenience, but it so happens that the year 1750 does see significant changes in the character of the investigation of the shaking earth. In 1749, the problem was how to choose among various detailed theories based on familiar, and easily understood ideas involving subterranean fire, vapors, and water. The next year saw the introduction of two radically different working hypotheses.

of Arts and Sciences; Containing the Definitions of the Terms, and Accounts of the Things Signify'd Thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine: the Figures, Kinds, Properties, Productions, Preparations, and Uses, of Things Natural and Artificial; the Rise, Progress, and State of Things Ecclesiastical, Civil, Military, and Commercial: with the Several Systems, Sects, Opinions, &c. among Philosophers, Divines, Mathematicians, Physicians, Antiquaries, Criticks, &c. The Whole Intended as a Course of Antient and Modern Learning. Compiled from the Best Authors, Dictionaries, Journals, Memoirs, Transactions, Ephemerides, &c, in Several Languages (2 vols.; London: Printed for James and John Knapton, and others, 1728), I, 266-68.

The accumulation of raw data and the proliferation of hypotheses and fully elaborated theories in the second half-century surpassed by far the efforts of workers in the first period. Before 1750, things had been relatively quiet as far as intellectually stimulating earthquakes went--especially in comparison to the London, Lisbon, and Calabrian shocks of the next few decades. Each event was followed by periods in which additional facts were pondered in light of old and new theories to further cloud the question of what causes the earth to tremble. Those in the eighteenth century who were curious about earthquakes were forced to try to make sense out of a mass of sometimes conflicting information, evaluating a chaotic array of dozens of detailed explanations. But out of the situation comes the opportunity to see how naturalists in the period dealt with such predicaments.

BOOK TWO
THE SECOND HALF-CENTURY

CHAPTER I

THE AIRQUAKE THEORY OF EARTHQUAKES

In the months of February and March, 1750, London and the surrounding area experienced two minor earthquakes that stimulated considerable interest in the problem of finding the cause of the shocks. One of the solutions did not rely on any of the previous explanations involving subterranean fire, water, or air pressure; for a new working hypothesis had been introduced: the "airquake" theory of earthquakes. The development of the concept provides another case-history of the work of eighteenth-century naturalists--this time as they examined the phenomenon in terms of a new cause that moved the source from within the earth and placed it in the atmosphere.

Stephen Hales

The main spokesman for the new hypothesis was the English experimental philosopher Stephen Hales (1677-1761), who in one of the articles printed in the 1750 earthquake supplement of the Philosophical Transactions,¹ reported on the

¹"Some Considerations on the Causes of Earthquakes," Philosophical Transactions of the Royal Society of London,

London earthquake of the eighth of March. It was in the early morning hours when it struck, he recalled; the heaving of his bed was followed by a "hollow, obscure, rushing Noise in the House." And then came a disturbance outside sounding like small-cannon fire. The entire event lasted about four seconds.² Hales later learned that soldiers in St. James's Park saw a black cloud and a great amount of lightning before the shock, although the weather was not stormy at the time. In the paper for the Royal Society, he wrote that earthquakes usually occur in calm weather and are generally accompanied by black clouds and other indications (such as lightning and falling stars) of inflammable, sulphureous matter in the air.³

Hales stressed the sulphureous nature of the atmosphere in earthquakes, because he had a theory requiring such conditions. He recounted an experiment he had briefly described much earlier in his Vegetable Staticks⁴ concerning a mixture

XLVI, No. 497 (1750), 669-81. The article was also published separately: Some Considerations on the Causes of Earthquakes. Which Were Read Before the Royal Society, April 5, 1750 (London: Printed for R. Manby and H. S. Cox, 1750). (Hereinafter, references will be to the Philosophical Transactions article as "On the Causes of Earthquakes.")

²Hales, "On the Causes of Earthquakes," pp. 671-72.

³Ibid., pp. 672, 676.

⁴Ibid. See Vegetable Staticks: or, an Account of Some Statical Experiments on the Sap in Vegetables: Being an Essay Towards a Natural History of Vegetation. Also, a Specimen of an Attempt to Analyse the Air, by a Great Variety of Chymio-Statical Experiments; Which Were Read at Several

of sulphureous air and pure air using a water bath technique. Aqua fortis and powdered pyrites were mixed together to produce "redish sulphureous Fumes" that became clear after a few hours. On admitting fresh air into the glass of clear sulphureous air, there instantly arose a "violent Agitation between the two Airs," creating a "redish turbid Fume." Hales compared this color to the appearance of the sky in the evenings before the March, London earthquake.⁵

Lightning had also been viewed, and the experiment described what takes place in the atmosphere to create that bright meteor. According to the author, air impregnated with sulphureous vapors from pyrites mixes with fresh air to form an agitation and effervescence that is seen as lightning--an idea Martin Lister had introduced more than half a century earlier. Hales explained further: the sulphureous fumes exhaled from the earth are mixed with fresh air from above the clouds; the clouds act as the water bath in the experiment to separate the pure air and the sulphureous air so that the two can only suddenly come together at the openings between the clouds. Thus, the airs ferment with greater violence than if they gradually mix in the atmosphere. While Hales had observed no strokes of lightning in his experiment, he thought that in nature a great quantity of vapors "acquire

Meetings Before the Royal Society (London: Printed for W. and J. Innys and T. Woodward, 1727). See "Experiment XCVI," p. 220.

⁵Hales, "On the Causes of Earthquakes," pp. 672-73.

so rapid a Velocity, as to kindle the sulphureous Vapours" and to produce flashes of light.⁶

In his experiment, as fresh air and sulphureous air were mixed and became reddish and turbid, an amount of air (nearly equal to the amount of fresh air admitted) was destroyed.⁷ This, Hales found, coincides with what is observed in conjunction with lightning, for a bolt of lightning has the ability to destroy the elasticity of the air. When it strikes an animal, the beast is killed by the destruction of air's elasticity in the lungs. As another example, lightning striking close to a house breaks windows outwards by reducing the elasticity of the air outside the house. He indicated further that when the sulphureous fumes eliminate a quantity of the elastic air, other air rushes into the evacuated place with a velocity that Denis Papin (1647-1712) had determined to be 889 miles per hour. Thus, in nature when the sulphureous vapors mix with air and destroy a portion of its elasticity, violent commotions are produced in the atmosphere.⁸

Hales theorized that sulphureous fumes are constantly being emitted through the pores of the earth--an idea supported by the observations of the so-called "falling stars"

⁶Ibid., pp. 674-75.

⁷Ibid., p. 673.

⁸Ibid., pp. 675-76. See also "A Demonstration of the Velocity Wherewith the Air Rushes into an Exhausted Receiver, Lately Produced Before the R. Society by Dr. D. Papin, Reg. Soc. S.," Philosophical Transactions of the Royal Society of London, XVI, No. 184 (1686), 193-95.

that are in reality inflamed exhalations. Long periods of hot and dry weather cause the pores of the land to open, allowing great quantities of the vapors to rise from the earth. When winds are not available to disperse the fumes, the clouds of sulphureous air explode like lightning at the surface of the globe ("Earth-Lightning") to create an earthquake.⁹

The author found observations to support his theory. First, in earthquake-plagued Jamaica the earth trembles only in calm weather, because, otherwise, winds safely blow away the dangerous vapors. Second, the London shock described at the beginning of his paper had occurred when the wind was calm and when a black, sulphureous cloud was present.¹⁰ Third, the fouling of London water wells by the earthquake was to Hales additional evidence that the sulphureous exhalations had filtered through the ground to the atmosphere.¹¹

The airquake idea was a new hypothesis; but it was not without any forebears, for in Hales's version, the theory was a significant modification of some ideas that had been discussed since the latter part of the seventeenth century. Martin Lister and his successors had identified earthquakes and lightning as coming from exploded sulphureous airs. The airquake hypothesis moved the inflammable vapors from under

⁹Hales, "On the Causes of Earthquakes," pp. 676-78.

¹⁰Ibid., pp. 676-77.

¹¹Ibid., p. 679.

the earth and placed them on the surface. The best guess is that in Hales's theory the cause was removed from its usual place in the subterranean realm for a combination of reasons. Familiarity with the most popular explanation as to the source of earthquakes, experimental work with sulphureous airs, and observations of the atmosphere at the time of a tremor all combined into the creation of a new theory. One can only conjecture as to how Hales derived his account, for he does not reveal the process by which he arrived at his conclusions.

For all practical purposes, Hales earned the credit he received for developing the airquake idea, but the attribution could have gone to someone else. It is possible that Hales may have been influenced by the previous work of another writer on the subject, for in 1750, the idea that earthquakes are caused by vapors exploding, not below, but above the surface was not new. The basic concept of airquakes was more than half a century old when Hales sent his paper to the Royal Society.

John Flamsteed

In 1693, John Flamsteed (1646-1719), the English Astronomer Royal, composed a confidential letter introducing quite a different explanation of earthquakes compared to the contemporary subterranean-fire-and-vapors theories discussed by Martin Lister and Robert Plot. Flamsteed requested that his

solution not be released for publication, for he was too busy to be bothered by questions and objections. In accordance with his wishes, it was not until 1750, long after his death, that the letter was made public through the printing of a copy in the possession of a London merchant.¹²

Even as the curiosity about earthquakes following the events of 1750 in London led to the publication of Flamsteed's letter, so the author himself had become interested enough in the subject to propose a new theory after receiving a letter describing a shock in Sicily in 1692/93. On this occasion he discussed several great earthquakes: one that jolted Jamaica in 1692, the one that affected a large area extending from southern England to central Europe in the same year, and earlier earthquakes, such as the tremor of 1601 that shook all of Europe and parts of Asia.¹³ This survey pointed out a problem that the solutions offered by Lister and Plot could not answer, for Flamsteed felt there could not be enough explosive materials or extensive, continuous cavities under all of Europe to cause wide-spread disturbances of the land.¹⁴

¹²A Letter Concerning Earthquakes, Written in the Year 1693, by the Late Celebrated Astronomer, Mr. John Flamsteed, Math. Reg. F.R.S. to a Gentleman Then Residing at Turin in Savoy, on Occasion of the Destruction of Catanea, and Many Other Cities, Towns and Villages, in Sicily, in the Year 1692 (London: Printed for A. Millar, 1750). (Hereinafter referred to as Letter Concerning Earthquakes.) Flamsteed's request for confidentiality was published in the introduction to the 1750 edition: "Advertisement," l2, verso.

¹³Flamsteed, Letter Concerning Earthquakes, pp. 1-7.

¹⁴Ibid., pp. 7-8.

After surveying the evidence, he wrote that any explanation of the quaking of the earth must account for seven different phenomena: (1) earthquakes occur in calm weather, (2) a noise is heard in the air just before (nearly simultaneously with) a shock, (3) earthquakes jolt ships at sea without disturbing the surface of the ocean, (4) in some examples large areas of the earth are affected nearly instantaneously, while in others the disturbance travels from place to place very slowly, (5) underground noises and eruptions sometimes are associated with major earth movements, (6) upper rooms of houses are disturbed more than the lower levels or the cellar, and (7) many people become dizzy and sick when the earth trembles.¹⁵

The Astronomer Royal found that he could not explain these seven facts using the idea of subterranean explosions, but he did discover that a theory postulating concussions in the atmosphere does account for earthquake phenomena.¹⁶ He based his idea on a comparison of circumstances surrounding earth shocks with similar occurrences in which the cause is known to be an explosion in the atmosphere.¹⁷ For example, great sea battles may begin during a strong wind, but after a number of broadsides have been fired, the wind becomes calm. The example explained that a concussion in the air produces the calm winds accompanying an earthquake.¹⁸ In

¹⁵Ibid., pp. 2-7.

¹⁶Ibid., p. 9.

¹⁷Ibid., pp. 10-11.

¹⁸Ibid., p. 10.

another example, he stated that when a gunpowder factory or a gunpowder magazine blows up, such a disaster is often described as causing the earth to shake, but when pressed to think about it a moment, people will admit that the earth did not move--only their homes were shaken by the concussion.¹⁹ Thus, aerial explosions explain why the lightly constructed upper stories of houses vibrate more than the lower floors, and why sailing ships experience earthquakes without the sea becoming agitated.²⁰

While Flamsteed first admitted not knowing the cause of the atmospheric explosions, later in his letter he suggested that subterranean vapors kindled under the earth (exhalations such as those from Lister's pyrites) might break out into the atmosphere, mix with "aqueous, oily, saline, nitrous and sulphureous" particles in the air, and explode.²¹

Rejecting the subterranean-fire explanations, Flamsteed wrote that only an aerial explosion is capable of spreading a shock over all of Europe in a few minutes' time. The magnitude and speed of the propagation of the earthquake depends only on the number of explosive particles in the air.²² Thus, if the air contains an abundance of the particles, there will be a fast-moving earthquake. And by suggesting that the air

¹⁹Ibid., pp. 11-12

²⁰Ibid., pp. 15-16.

²¹Ibid., pp. 12-13, 17-18. He also thought that such vapors are also responsible for the earthquake-related illnesses. Ibid., p. 13.

²²Ibid., pp. 13-14.

under certain conditions is not full of the nitrous and sulphureous matter, the theory explains slow-moving shocks such as the one that moved leisurely through the Oxford area in 1665/66.²³ As another example of how the amount of particles in the air affects the propagation of earthquakes, Flamsteed observed that the extensive earthquake of 1692 was felt only in southern England, because rains in the north had precipitated the explosive matter out of the air, leaving the northern part of the country safe from the shock.²⁴

Anticipating the possible criticism that there are no visual signs of an atmospheric explosion, he proposed that the tiny bits of nitre and sulphur when ignited produce a light too subtle to be seen. Similarly, it is not surprising that most shocks are not accompanied by a great noise, for gunpowder spread thinly on a sheet of paper explodes with little sound.²⁵ Concerning still another possible objection, Flamsteed noted that there are some examples of the earth shaking that his theory just cannot account for. In these instances, some of the great earthquakes must be actual subterranean explosions that do cause eruptions and do collapse the thin crust of the earth's surface into caverns.²⁶

²³Ibid., pp. 17-18. See Wallis, "Earthquake Near Oxford," p. 169.

²⁴Flamsteed, Letter Concerning Earthquakes, p. 17.

²⁵Ibid., pp. 14-15.

²⁶Ibid., p. 19.

Flamsteed's explanation of the creation and propagation of earthquakes was one of the best and most effective expositions in the period. However, the author, recognizing the startlingly new character of his theory, chose not to publish his explanation. When he later brought his ideas to the attention of some of his colleagues at the Royal Society, Robert Hooke (1635-1703) reacted by calling it a "nonsensical" hypothesis.²⁷ Such a reaction confirmed Flamsteed's caution in rejecting an expression of his views in a formal publication. Nevertheless, the private letter was a well-developed presentation lacking the appearance of a communication containing the speculations of a man who had entertained a brief interest in a problem, had investigated, and had arrived at a new solution. Perhaps he saw in his work some flaw or inadequacy that he felt was too much trouble for a busy man to spend any further effort on. But it is not clear what that problem might be. He went so far as to explain away such minor difficulties as the absence of a flash of light in the atmosphere. He had even added an

²⁷Robert Hooke, Diary, May 3, 1693, in R. T. Gunther, Early Science in Oxford, Vol. X: The Life and Work of Robert Hooke (Part IV). Tracts on Capillary Attraction, 1661; Diary, 1688 to 1693 (Oxford: Printed for the author [Oxford University Press], 1935), p. 336. Flamsteed should not have been too surprised with Hooke's assessment of his work, as he had been referred to earlier as "an Ignorant impudent Asse." Hooke, Diary, November 27, 1677, The Diary of Robert Hooke, M.A., M.D., F.R.S. (1672-1680). Transcribed from the Original in the Possession of the Corporation of the City of London (Guild Hall Library), edited by Henry W. Robinson and Walter Adams (London: Taylor & Francis, 1935), p. 330.

"escape clause" allowing for other theories to explain the earthquake which exhibited characteristics incompatible with those he dealt with. The problem may have been as he first stated, his inability to define the exact source or nature of the explosive materials, although he later mentioned pyrite vapors as a possible cause--an answer that was a perfectly acceptable explanation in 1693.

The question remains as to how Flamsteed arrived at his novel view. He did not directly discuss how his ideas came into being, but his writings offer some clues. First, there was the basic problem as he saw it: underground explosions are not satisfactory explanations of general earthquakes. Concerning the task of creating a replacement theory, he first claimed he assembled a list of characteristic phenomena. Next, he mentioned that he found by way of analogies that known explosions in the air (cannon fire and gunpowder concussions, for example) produce some of the same effects as earthquakes. From the new hypothesis that atmospheric (not subterranean) explosions cause the earth to shake, the explanation was worked out as to the details.

While the hypothesis of aerial explosions was created in 1693, Flamsteed's work was not well known until 1750 when Hales had also introduced his version of the idea. Later references about the subject were to Stephen Hales and not John Flamsteed.

The Airquake Debate

At mid-century, the term "earthquake" became inadequate for describing the shocks that Flamsteed and Hales said did not occur inside the terrestrial sphere. As the merits of the new hypothesis became a topic for debate, a new term, "airquake," came into limited use to describe the natural phenomenon of the atmosphere that rattles dishes, or at the other extreme, destroys towns. Compared with the discussion and development of the principal subterranean-fire theory over a period of decades by individuals in England, France, and Italy, the discussion of the airquake idea forms only a brief episode, for the debate is centered in England in the year 1750. In that year, one of the questions surrounding the philosophical discussions of the local shocks centered on the basic question of whether their source was above the earth, or in the depths below.

Much of the debate was carried in the public press. An article in the General Advertiser for March 13, 1750 (O.S.) suggested that the earthquake of that month had been caused by an explosion of combustible materials in the air or an "airquake."²⁸ The newspaper wrote that the air that winter had been filled with sulphureous exhalations because of the unusual warmth and dryness of the season and also from coal-fire vapors. The sulphureous nature of the air

²⁸ ["An Airquake Supposed,] General Advertiser, March 13," Gentleman's Magazine, XX (March, 1750), 125.

was indicated by the excessive amount of lightning and meteors that had been seen, especially just before the earthquake. The article gave as further evidence of an airquake the thunder-like sound preceeding the shock as well as the shaking of windows and beds "sideways" (contrasting the common notion that earthquake motion is a vertical movement). The paper also suggested that an airquake is not very dangerous; such events are even useful, since they serve to purify the air.²⁹

Queries in the London Gazetteer³⁰ challenged the "whimsical reflections" in the General Advertiser's article on airquakes, for the Gazetteer asked why only the area around London had been disturbed when all of England had experienced a warm and dry winter. The newspaper also questioned that the motion of windows and beds was in fact sideways as the General Advertiser reported. The critical article also pointed out that less radical theories suffice to explain the appearance of lightning and shooting stars.³¹

The General Advertiser countered with further evidence in support of the airquake hypothesis by citing an account of a fireball seen late in 1741 that appeared with a noise

²⁹Ibid.

³⁰"On This Occasion Were Publish'd in the Gazetteer the Following Queries," Gentleman's Magazine, XX (March, 1750), 125.

³¹Ibid.

like thunder, and that made the house shake as if in an earthquake.³²

Bishop George Berkeley (1685-1753) of Ireland also entered into the airquake vs. earthquake controversy.³³ He discounted the evidence presented in the General Advertiser because the same facts had been taken into consideration in conventional earthquake theories. As an example from a personal experience (Messina, 1718), the bishop found that earthquakes can have a horizontal, as well as vertical, motion. Furthermore, the state of the air and the observation of meteors that have been cited as evidence of airquakes are known to have accompanied definite earthquakes, as during one shock in Catanea. Berkeley explained that such signs in the air come from exhalations from below the earth's surface. He concluded that England had experienced an earthquake and not an airquake.³⁴

The matter was not yet settled, for the year 1750 was still young, and England had not yet received its quota of earthquakes for the season. A shock that hit areas of

³²"Gen. Advertiser, March 15. An Account of a Meteor on Dec. 31, 1741; by the Rev. Mr Wm Gostling, Minor Canon of the Cathedral Church of Canterbury; Inserted in Support of the Supposition of an Airquake in the Said Paper of the 31st. [sic, 13th]," Gentleman's Magazine, XX (March, 1750), 129.

³³"Observations by a Rt Rev. Prelate in Ireland, . . . Concerning Earthquakes," Gentleman's Magazine, XX (April, 1750), 166-68.

³⁴Ibid.

Lincolnshire on the twenty-third of August became a part of the airquake-earthquake debate. A contributor who signed his letter with the initials "E.A." offered a compromise to the partisans of both sides by attributing the new earthquake to both a subterranean wind and an atmospheric wind.³⁵ The author believed that underground fires might well cause the earth to tremble in Italy, but there had been no fires involved in the Lincolnshire shock because of the complete absence of sulphur and nitre supplies in the earth. Instead, in England the earthquake/airquake had been caused by a "rushing lateral wind" from the interior that swept over the surface of the earth. The wind had been created by an exceptionally hot and dry summer that caused the air in the earth to rush out as in an explosion of air from a bladder held over a fire.³⁶

An anonymous letter sent to the editor of Gentleman's Magazine presented another explanation that also combined aspects of the airquake and earthquake theories so as to arrive full circle from the idea that the shock is created in the atmosphere back to the older explanation of inflammable subterranean vapors as the cause.³⁷ The author of the

³⁵"Observations on the Earthquake Which Was Felt Over Most of, If Not All, the Fens of Lincolnshire, Aug. 23, 1750, about 35 Minutes Past 6 in the Morning," Gentleman's Magazine, XX (October, 1750), 456-57.

³⁶Ibid.

³⁷Letter to Mr. Urban, April 14, 1750, Gentleman's

letter theorized that the extremely cold winter of 1749 had frozen the ground to a great depth, and the pores of the earth had only recently been cleared by the earth's central heat. Newly released vapors mixed and fermented in the subterrestrial caverns to create earthquakes. The same vapors escaped into the atmosphere to produce the observed meteoric phenomena³⁸ (as Martin Lister had stated in 1684).

The discussions of the airquake theory in 1750 offers a view in a compact form the common pattern for the debates which followed during the second half of the eighteenth century. First, a new theory is presented in a very comprehensive way. Second, following the initial appearance come the "commentaries" on the question of whether or not the explanation is acceptable. As in the airquake presentations in the press, these commentaries are typically of three forms: (1) a positive statement of the theory and supporting evidence (as in the General Advertiser, March 13, 1750), (2) a critical statement in opposition to the proposed idea, combined with a statement of a replacement theory (as in Bishop Berkeley's article), or (3) a modification of the initial presentation to meet the objections of critics (as in "E.A.'s" contribution). In the end, the disputations did not settle anything. All parties agreed only to disagree.

Magazine, XX (April, 1750), 154. Sylvanus Urban was the pseudonym of the editor, Edward Cave (1691-1754).

³⁸Ibid.

After 1750, support for the hypothesis shared by Hales and Flamsteed submerged only to be revived late in the century. Critics were also silent--with the notable exception of a communication to the Royal Society by the Reverend William Borlase.³⁹ He found in the reports of miners about a 1757 earthquake in Cornwall that the earth actually trembled, and the noise of the shock came from below them and not from the atmosphere. Since thunder cannot be heard in deep mines (or in mines with extensive workings), Borlase agreed with miner J. Nantcarrow that the Cornwall earthquake could not have been heard as deep in the earth as it was if the source had been an airquake. Thus, the jolt must have been an actual shaking of the earth accompanied by a noise caused by air and vapors being released from the depths of the earth.⁴⁰

Little was heard of the airquake idea until later in the century. Dr. Edward Whitaker Gray (1748-1806), a naturalist on the staff of the British Museum, in his account of an English earthquake of 1795⁴¹ found it difficult to choose between explanations based on atmospheric or subterranean

³⁹"An Account of the Earthquake in the West Parts of Cornwall, July 15th 1757. By the Rev. William Borlase, M.A. F.R.S. Communicated by the Rev. Charles Lyttelton, LL.D. Dean of Exeter, F.R.S.," Philosophical Transactions of the Royal Society of London, L, Pt. II (1758), 499-505.

⁴⁰Ibid., pp. 503-5.

⁴¹"Account of the Earthquake Felt in Various Parts of England, November 18, 1795; with Some Observations Thereon,"

explosions because of the strong arguments in favor of both.⁴² Gray found that the earthquake of November 18, 1795 had been felt in an area of central England that had previously experienced shocks in 1750, 1777, and 1792. The observation that the tremors frequent certain locations and usually move in the same direction was for the author an argument in support of the idea that the source of earthquakes is inside the earth.⁴³ Yet he could not ignore certain atmospheric phenomena that are also commonly connected with the shocks (such as calm winds just before the event); although he pointed out that such is not always the case, for one tremor at Madeira happened during a gale-force wind.⁴⁴

Enough earthquakes were reported to be accompanied by dark clouds and lightning that some theorists were led to believe that atmospheric electricity is responsible for jolting the earth. But Gray was skeptical, because still not enough was known about the atmosphere or electricity to support that explanation. The idea was especially doubtful, since electricity is powerful only when concentrated. Its

Philosophical Transactions of the Royal Society of London, LXXXVI, Pt. II (1796), 353-81. (Hereinafter referred to as "Account of the Earthquake.")

⁴²Ibid., p. 378.

⁴³Ibid., pp. 374-75.

⁴⁴Ibid., p. 375. Gray was referring to the report: "An Account of the Earthquake Felt in the Island of Madeira, March 31, 1761: By Thomas Heberden, M.D. F.R.S. Communicated by William Heberden, M.D. F.R.S.," Philosophical Transactions of the Royal Society of London, LIII, Pt. I (1761), 155-56.

effects are limited in scope and cannot cause wide-ranging earth movements. He also stated that the instantaneity of an electric shock does not explain the examples where a tremor progresses slowly over the earth.⁴⁵

The writer wondered whether all examples have to be explained by the same cause. The recurrence of shocks in the same area, along with the common appearance of the same atmospheric phenomena, are two contradictory facts that are difficult to reconcile without resorting to "mixed causes."⁴⁶ Stephen Hales, Gray pointed out, had combined sources when he theorized that sulphureous vapors cause an atmospheric explosion, and a more up-to-date version of Hales's idea using the recent findings about inflammable gases might be able to explain earthquakes successfully.⁴⁷ In the end, Gray concluded that he would have to leave the definitive answer of the question of the origins of earthquakes to future investigators.⁴⁸

The same problem that bothered Gray also troubled Thomas Young (1773-1829) of the Royal Institution. In a lecture discussing (in part) volcanoes and earthquakes,⁴⁹ he remarked on the difficulty of reconciling all observations

⁴⁵Gray, "Account of the Earthquake," pp. 377-78.

⁴⁶Ibid., pp. 378-80.

⁴⁷Ibid., p. 380, n. *.

⁴⁸Ibid., p. 380.

⁴⁹"Lecture LVII. On Aqueous and Igneous Meteors," Course of Lectures on Natural Philosophy and the Mechanical Arts (London: Printed for Joseph Johnson, 1807), I, 706-22.

with subterrestrial causes, particularly the atmospheric conditions accompanying a shock. So as not to leave the problem without discussing a possible answer, Young ascribed earthquakes and volcanoes to one set of causes: fires formed from mixtures of sulphur, iron, and pyrites, as well as coal fires, and also the formation of steam when water reaches these conflagrations.⁵⁰

One feature of the airquake theory was its explanation of atmospheric phenomena associated with earthquakes--the dark clouds, lightning, and calm winds that had accompanied some prominent shocks. Although this theory was not accepted by many naturalists, to maintain creditability, the critics had to account for the same meteoric phenomena in their own earthquake treatises.

⁵⁰Young, "Lecture LVII," pp. 716-20. He relied extensively on Sir William Hamilton's contribution on the Calabrian earthquakes of 1783. See below, pp. 202-5.

CHAPTER II

THE ELECTRICAL THEORY OF EARTHQUAKES:

INTRODUCTION

Prior to 1750, theories for explaining earthquakes had been built from working hypotheses of subterranean fire and vapors, water, and air pressure. Following the London earthquakes, the airquake idea was added to the list, and during this same period still another explanation was developed, an electrical theory of earthquakes. It provides historians with another case-history of the study of the earth in the eighteenth century.

William Stukeley

William Stukeley (1687-1765), an English physician, clergyman, antiquary, and Fellow of the Royal Society of London, through a series of papers developed a theory that called electricity the source of earthquakes.¹ While his

¹"The Rev. W. Stukely M.D. & F.R.S. to the President, on the Causes of Earthquakes," Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 641-46. (Hereinafter referred to as "On the Causes of Earthquakes.") "The Rev. Wm. Stukeley M.D. F.R.S. to the President, Concerning the Causes of Earthquakes," Ibid., XLVI, No. 497 (1750), 657-69. (Hereinafter referred to as "Concerning the Causes of Earthquakes.") "The Philosophy of Earthquakes; by

ideas were presented first in 1750, he stated that he had always considered the cause of the shaking of the earth to be electrical in nature.

I did not enter into the common Notion of Struggles between subterraneous Winds, or Fires, Vapours, or Waters, that heav'd up the Ground, like animal Convulsions; but I always thought it was an electrical Shock, exactly of the same Nature as those, now become very familiar, in electrical Experiments.²

Stukeley had been influenced by Benjamin Franklin (1706-1790), a pioneer in the study of atmospheric electricity, and his "pretty Discourse" on the subject of lightning read at two meetings of the Royal Society in November of 1749 (O.S.).³ According to Franklin's account, as Stukeley understood it, clouds from over the sea are non-electrified,

the Rev. William Stukeley, M.D. F.R.S. &c. in a Letter to Martin Folkes, Esq; LL.D. and President of the Royal Society, &c.," Ibid., XLVI, No. 497 (1750), 731-50. (Hereinafter referred to as "Philosophy of Earthquakes.") Stukeley expanded these articles into The Philosophy of Earthquakes, Natural and Religious. Or an Inquiry into Their Cause, and Their Purpose (London: Printed for C. Corbet, 1750). (Hereinafter referred to as Philosophy of Earthquakes.) Six years later a revised edition appeared: (3rd ed.; London: Printed for A. and C. Corbett, 1756). (Hereinafter referred to as Philosophy of Earthquakes, 1756 ed.)

²Stukeley, "On the Causes of Earthquakes," p. 642.

³Ibid., p. 643. Letter from Benjamin Franklin to John Mitchell, April 29, 1749, "Observations and Suppositions Towards Forming a New Hypothesis for Explaining the Several Phaenomena of Thunder Gusts," The Papers of Benjamin Franklin, Vol. III: January 1, 1745, Through June 30, 1750, ed. by Leonard W. Labaree (New Haven: Yale University Press, 1961), pp. 365-76, and p. 376, n. 3. See also I. Bernard Cohen, "Introduction," Benjamin Franklin's Experiments: A New Edition of Franklin's Experiments and Observations on Electricity (Cambridge: Harvard University Press, 1941), pp. 80-82, 158

and those formed over land areas are electrified.⁴ When these two types of clouds come together, the "little Snap" associated with electrical experiments is created.⁵ Following the same line of thought, Stukeley theorized that the earth trembles whenever there is a similar electrical "snap" between the earth in its highly electrified state and a non-electrified cloud. The shock is probably initiated by a rain shower that serves to connect the two important elements.⁶ Stukeley was aware that there were some large presumptions built into this explanation, and he examined these in his writings, as will be shown below.⁷

The electrical hypothesis, like the airquake theory, was a new contribution to the study of earthquakes, but the

⁴In Franklin's letter of 1749, friction between salt (an electric) and water (a non-electric) collects the electric fire in sea water, the vapor of which forms electrified clouds. Stukeley misunderstood or inadvertently transposed the labeling terms. Or like Cadwallader Colden (1688-1776), an American physician who later criticized Franklin's theory, he perhaps interchanged the terms on purpose. Colden argued that sulphureous vapors from mountains and vapors from vegetation are more electrified than sea vapors, and that not all salt had proven to be an electric. See letters from James Bowdoin and Cadwallader Colden to Benjamin Franklin, both dated March 16, 1752, in The Papers of Benjamin Franklin, Vol. IV: July 1, 1750, Through June 30, 1753, ed. by Leonard W. Labaree (New Haven: Yale University Press, 1961), pp. 277-78, 278-81. For Stukeley's theory, the origin of the two types of clouds was less important than the idea that a non-electrified cloud, wherever formed, and an electrified earth are the conditions necessary for an earthquake.

⁵Stukeley, "On the Causes of Earthquakes," p. 643.

⁶Ibid., pp. 643-44.

⁷In particular see "Stukeley on Electricity," pp. 104-6.

way had been prepared by Lister, Hartop, Lémery, Ray, Newton, and others who thought that the inflammable vapors that cause earthquakes and volcanoes are also responsible for thunder and lightning. Thus, when Benjamin Franklin replaced the sulphureous-vapor explanation of lightning with an "electric-fire" theory, the stage had been set for designating electricity as the cause of earthquakes and volcanoes as well.

The Evidence

When London was jolted, Stukeley was provided with an opportunity to present his colleagues with a theory supported by evidence that was all too familiar. He noted that the shocks had been preceded by an unusually dry and warm winter, rare displays of the northern lights, and an exceptional "forwardness" or unseasonably advanced growth of vegetation--all signs that the earth in and around the capital city must have been in a remarkably great "State of Electricity." With the ground in such an electric condition, only the availability of a non-electric cloud was needed to produce an earthquake.⁸

Stukeley suggested that small tremors are more common than most Londoners think, because people without any experience with jolting earth movements have simply ignored the insignificant shocks. But he had to explain why, if the cause of earth shocks is so similar to lightning, England had not

⁸Stukeley, "On the Causes of Earthquakes," pp. 642-43.

experienced more severe shocks before. The answer was obvious: climatic conditions like those of the winter of 1749-50 had never existed before; the country had never been so strongly electrified.⁹

There were several indications that the earth had become unusually electrified by the early part of 1750. In late February all flowers, trees, and vegetables were in a state of growth as if it were in the month of April, and electrical experiments had shown that electrifying plants speeds their growth.¹⁰ Concerning another sign, the northern lights had been more frequent than usual, and one especially rare type had been seen prior to the London earthquakes.¹¹ The shock felt in Northampton later in the year had also been accompanied by a "blood-red" aurora, and all of England in 1750 had observed impressive displays of fireballs, lightning, and other meteors--further symptoms of the extraordinary electrical state of the earth and the atmosphere.¹²

For other evidence, Stukeley used ideas presented in earlier theories. Frézier had found that more devastating earthquakes generally occur in maritime regions such as Sicily,

⁹Ibid., p. 644.

¹⁰Stukeley, Philosophy of Earthquakes, pp. 18-19.

¹¹Stukeley, "On the Causes of Earthquakes," p. 642.

¹²Stukeley, "Philosophy of Earthquakes," p. 743.

Jamaica, and the western coast of South America. This is now explained as being derived from the principle that water strengthens and conducts electricity. For a more direct indication of the connection of water, electricity, and earthquakes, the author pointed out that one London shock had been centered along the Thames.¹³

An earthquake felt at sea strikes a ship so hard that sailors are frightened into thinking that their vessel has hit a rock--and yet the surface of the ocean remains calm, a fact Flamsteed thought important in demonstrating an atmospheric explosion. According to the new explanation, an electrical vibration transmitted through the water to the ship accounts for the experience.¹⁴ To explain the reports of fish leaping out of rivers and canals during earthquakes, Stukeley stated that since fish can be killed by a particular tone from a vibrating string, the similar, but less severe, vibratory motion of the water caused by electricity makes the fish sick, and they seek refuge out of the water.¹⁵

The electrical theory brings into focus other observations: by postulating that the force of an electric shock is proportional to the quantity of the solid material it affects, the theory explains why the thick walls of Westminster Hall

¹³Stukeley, "On the Causes of Earthquakes," pp. 644-45, and "Concerning the Causes of Earthquakes," pp. 665-66.

¹⁴Stukeley, Philosophy of Earthquakes, p. 23.

¹⁵Ibid.

were particularly shaken during one of the London tremors, and why such massive structures as castles were more threatened with collapse than other buildings.¹⁶

Additional support came from the information that people "of the weaker Constitutions" had suffered headaches, pains, rheumatism, and other medical disorders after London was shaken, for the same effects are produced by electrification.¹⁷

Other Earthquake Theories Criticized

Unlike most previous writers who concentrated only on stating their own views and did not bother to dispute other ideas, Stukeley set out to prove not only that his electrical hypothesis was correct, but he sought to show that a subterranean-fire hypothesis cannot be supported as a major cause of earthquakes. He attacked those who, he felt, had only added onto ancient ideas the evidence of gunpowder explosions and certain "chymical experiments" with artificial mixtures of materials that actually have no relationship to the composition of the earth's interior (a criticism expressed by Rouelle that had had no impact earlier). Furthermore, the violent explosions exhibited by demonstrations of inflammable substances are not applicable to the many earthquakes that

¹⁶Stukeley, "Concerning the Causes of Earthquakes," p. 667.

¹⁷Stukeley, "On the Causes of Earthquakes," p. 645.

shake large areas, and yet do not tear open the earth.¹⁸

He did concede that there are some subterranean cavities, and he even allowed that there can be limited fires and fermentations under the earth's surface (as volcanoes indicate). But such forces only occasionally cause earthquakes --and then only insignificant ones.¹⁹ Considering the mass of evidence Stukeley was to bring against the subterranean-fire theories, this concession was of little consolation to those who advocated the challenged hypothesis.

First, the scarcity of volcanoes, as well as the hard work of miners in tunneling through solid rock, showed that the earth is not filled with enough caverns to satisfy the requirements of previous explanations.²⁰ His remark that there are not sufficient cavities is challengable, for Lister had stated that the "earth is more or less hollow." And he supported his view by mentioning the "self-opens" that miners encounter "frequently," the examples of caverns such as Pools Hole and Oakie Hole, and the streams of water coming from under mountains.²¹ Thus, both writers display their theoretical

¹⁸Stukeley, Philosophy of Earthquakes, pp. 6-7. He did not cite Nicolas L  mery by name, nor did he mention directly the criticisms of Guillaume Fran  ois Rouelle. See above, pp. 49-52.

¹⁹Stukeley, "Concerning the Causes of Earthquakes," pp. 658-59.

²⁰Ibid.

²¹Lister, "Nature of Earth-quakes," pp. 512-13.

bias regarding the use of the available information about the nature of the subterranean realm. What Lister emphasizes, Stukeley discounts. Nevertheless, the author of the electrical theory had further difficulties to point out.

Second, he could not find any indications of enough combustible materials in England to produce earthquakes at all. Third, while the London shocks affected an area thirty miles in diameter, there had been no signs of fire, vapors, smells, or smoke coming from the ground. Fourth, even if the required inflammable substances were available, there cannot be enough air below the surface to allow them to burn. By resorting to an analogy, Stukeley offered still another reason why subterranean fires cannot cause the earth to shake: even though caverns, air, and burning minerals are present in coal mines, mine explosions do not produce earthquakes.²²

A discussion of underground water offered another focus for criticisms, while also providing positive evidence for the electrical hypothesis. Stukeley found that fountains and springs had continued to flow since the Creation--even in areas suffering from repeated shocks. If the earth movements were formed according to theories that utilize fires and explosions to jolt the earth, then the subsurface water system would have been ruined.²³ Although such explanations fail to

²²Stukeley, "Concerning the Causes of Earthquakes," pp. 658-59.

²³Ibid., pp. 659-61.

account for the survival of springs, Stukeley pointed out that in his own electrical theory (which requires only the surface of the earth to be shaken during an earthquake) the underground water system is not adversely affected. Not only are the springs not blocked, but they probably run more plentifully in the same way that electrification makes the blood circulate faster.²⁴ Springs are not damaged because the shock does not go deep into the earth, but the author still had to account for the fouled water wells in London. He explained that electricity, which finds easy passage through the wells, agitated the well water, stirred up mud, and thus polluted part of the city's water supply.²⁵

Martin Lister and Robert Plot had offered answers as to why England and northern countries experience fewer earthquakes than Italy and places to the south by claiming that the difference depends on the size of the caverns and the supplies of inflammable materials in the earth.²⁶ Stukeley thought that climate was the factor responsible. The warmer and drier weather in the southern regions is simply more favorable for creating the electrical state of the earth.²⁷

²⁴Ibid., p. 667.

²⁵Stukeley, Philosophy of Earthquakes, p. 30.

²⁶See above, pp. 25, 30.

²⁷Stukeley, "Concerning the Causes of Earthquakes," p. 668. The argument concerning climates proved to be the Achilles heel that many opponents of the electrical theory of earthquakes attacked later in the century, although when

The English electrician not only criticized theories of underground forces, but he also saw problems in the atmospheric-explosion ideas by pointing out that aerial disturbances cannot spread destruction over large areas of the earth. In addition, the clearness of the air before a shock shows that the air is free from dangerous vapors.²⁸

While the author had gone to greater lengths than his predecessors to dispute opposing views, his remarks on this aspect of the subject occupy relatively little space in his writings, since he devoted most of his attention to bringing forth positive evidence in support of his own hypothesis. And although criticisms up to this point had been rare, the 1750's mark a turning point. It became increasingly important in the second half-century in the face of intense competition not only to develop thoroughly one's own theory, but to show the inadequacies of other expositions.

Stukeley pledged to derive his conceptions from his personal experiences and from general facts about earthquakes, ignoring reports from those who emphasized the "marvelous," as in accounts of fires coming from the earth during a shock.²⁹

the idea was introduced, it appeared as merely another argument in the arsenal of evidence Stukeley had gathered in support of his theory. See below, pp. 126-27, 137.

²⁸Stukeley, Philosophy of Earthquakes, pp. 16, 22, 29-30. But he leaves the reader wondering what happened to Hales's black, sulphureous cloud.

²⁹Stukeley, "Concerning the Causes of Earthquakes," pp. 661-62.

Considering Stukeley's remarks about subterranean-fire, it is not surprising that he considered such sightings as fanciful tales. However, he did find it necessary at one point to explain the origin of "lambent Flames" seen coming from the earth as "purely the Effect of Electricity."³⁰

He was not always consistent in his statements. The author explained that earthquakes are often associated with volcanoes, because they help to place the earth into the "vibratory state and condition of electricity."³¹ However, while in 1750 Stukeley related volcanoes to the creation of earthquakes, in the 1756-edition of the Philosophy of Earthquakes he reversed the relationship by theorizing that the shocks create volcanoes by means of an "electric stroke" kindling sulphur at the summit of volcanic mountains.³²

In the process of amassing confirmative information, the writer examined the force and power of earthquakes. The London shocks had affected an area thirty miles in diameter. On applying the rules used by military engineers to determine the effects of land mines, he found that to shake an area of this size in accordance with a conventional subterranean-fire-and-explosive-vapors theory, the center of the concussion would have to be from fifteen to twenty miles below the surface of

³⁰Ibid., p. 668.

³¹Stukeley, Philosophy of Earthquakes, pp. 31-33.

³²Stukeley, Philosophy of Earthquakes, 1756 ed., Pt. III, p. 38.

the earth. The explosion would thus disrupt an area of the globe shaped like an inverted cone twenty miles deep and thirty miles in diameter. Lest the reader forget the point of his argument, Stukeley emphasized that a large portion of the interior of the earth was not actually shaken--it could not have been without altering the system of underground springs--he was only trying to gauge the forces involved in an earthquake.³³

The London example concerned a small shock. For a more impressive incident, the author referred his readers to Asia Minor in the year 17 A.D. when thirteen cities located in an area three hundred miles in diameter were destroyed. In this case, the center of the concussion would have to be two hundred miles below the surface or deeper, and every ounce of gunpowder ever made could not shake this great an area--and neither could the force of subterranean vapors. Furthermore, if an underground explosion of such a magnitude were the source of the shock, then more than the cities would have been affected: mountains would have been overturned, springs blocked, and rivers destroyed, but this did not happen.³⁴ The focus of Stukeley's arguments leads constantly to the notion that where gunpowder, subterranean fires and vapors, and even atmospheric explosions have failed, electricity

³³Stukeley, "Concerning the Causes of Earthquakes," p. 662.

³⁴Ibid., pp. 661-63.

remains the only force that can account for the great power of earthquakes to overturn entire cities without altering underground water systems. At the same time it is not so overpowering as to overturn mountains when a tremendous force is not indicated in the specific examples cited.

Stukeley on Electricity

The creator of the electrical hypothesis was less definite in his statements when it came to defining the cause of electricity, but Stukeley noted that the sources of magnetism and gravitation had not yet been discovered either.³⁵ There remained also the problem of explaining how the atmosphere and the earth are placed into the electrical state to give and receive the electricity, thus creating an earthquake.³⁶ He did comment that the interior of the planet is not shaken; instead, an earthquake is a regular vibration of the surface similar to the oscillation of a drinking glass that when rubbed on edge vibrates to the point of shattering. It is broken by means of an "electric Repulsion of Parts."³⁷ A subtle fluid called the "ethereal Fire" (obscurely defined as being like the ancient element "Fire," as well as being like Newton's "aether") is contained in all matter, and it is responsible for an "infinite" variety of phenomena ranging from the elasticity of the air to the role of making water

³⁵Stukeley, "Philosophy of Earthquakes," p. 745.

³⁶Ibid.

³⁷Ibid., p. 742.

liquid. The aethereal fire is also the "Mother of Electricity," for it produces the elastic or vibratory state of the air, water, or earth.³⁸

Stukeley's theory of electricity reflects an influence of the ideas of another investigator of electricity and its effects, John Freke (1688-1756), a London surgeon. In 1746, Freke published a letter³⁹ in which he defined electricity as a concentrated form of the universal, elemental Fire. He explained that in electrifying a glass tube, the hand rubs air between the hand and the tube, and in the glass is concentrated a quantity of the Fire, i.e. electricity.⁴⁰ In Stukeley's speculations on the subject, he recalled Stephen Hales's observation that cannon fire had been known to electrify the glass windows of the Treasury building,⁴¹ and Stukeley suggested that the cannon-fire electrified the glass by crowding the aethereal fire together.⁴²

In anticipating most of the questions that his theory might raise, the author of the new earthquake hypothesis encountered only a few problems that were as difficult to answer

³⁸Ibid., pp. 745-47.

³⁹An Essay to Shew the Cause of Electricity; and Why Some Things Are Non-electricable. In Which Is Also Consider'd Its Influence in the Blasts on Human Bodies, in the Blights on Trees, in the Damps in Mines; and as It May Affect the Sensitive Plant, &c. In a Letter to Mr. William Watson, F.R.S. (London: Printed for W. Innys, 1746).

⁴⁰Ibid., pp. 2-6.

⁴¹See below, pp. 116-17.

⁴²Stukeley, "Philosophy of Earthquakes," p. 748.

as the one about the nature of electricity. Most of his attention was concentrated in gathering an impressive array of supportive information for his explanation.

Additional Supporting Evidence

Stukeley's first two articles were written in an effort to explain the London earthquakes of February and March, 1749/50. The earthquake of September 30, 1750 (O.S.) in the Northampton area presented the author with another opportunity to demonstrate the viability of his thesis, and he addressed another contribution to the Royal Society of London.⁴³ An area of 4,000 square miles had been shaken "in one Moment," and only electricity "acknowledges no sensible Transition of Time, no Bounds."⁴⁴ The Northampton shock occurred in warm, dry, and calm weather--the same conditions necessary for good electrical experiments.⁴⁵ Since the area was experiencing a drought, the bogs in the region were dry on the surface, and, as Stukeley judged, were in the proper condition for the formation of an earth shock. The character of the ground also affirmed his contention that an earthquake affects just the surface of the earth.⁴⁶

In discussing the propagation of an earthquake over great distances, the theorist wrote that the jolt is communicated over an area proportional to the strength of the

⁴³Ibid., pp. 731-50.

⁴⁴Ibid., p. 738.

⁴⁵Ibid., p. 742.

⁴⁶Ibid., p. 740.

electrical shock. The extent of the electrified region, as well as the nature of the land in a particular location, also influences the distribution of the earth-shaking disturbance.⁴⁷

While trying to account for every related phenomenon, the author used a variety of evidence. He recounted the testimony of a deaf woman who had her hearing restored in the period before an earthquake,⁴⁸ and he called attention to the similarity of this case to one in which a person had his speech restored by electrification.⁴⁹

Airquakes and even "waterquakes" were accounted for. Stephen Hales would not have recognized what Stukeley referred to as an "air-quake," because the term in this instance was used to describe a "terrestrial thunder." This is a noise that is sounded when all conditions (except the electrical state of the ground) are prepared for a proper earthquake.⁵⁰ Concerning waterquakes, the effects of the

⁴⁷Stukeley, Philosophy of Earthquakes, p. 31.

⁴⁸Stukeley, Philosophy of Earthquakes, 1756 ed., Pt. III, p. 34. He mentioned that the woman's hearing had been restored half an hour before the earthquake, whereas the letter from which Stukeley drew his account indicated that her hearing had been restored two and a half hours before the shock. Letter from J. Austin to William Stukeley, April 30, 1751 (O.S.), in Stukeley, Family Memoirs, I, 401-2. The discrepancy may be attributed to strengthening the evidence to fit a theory, but a faulty memory or a typographical error are equally likely, because such an error is not typical of Stukeley's use of the information available to him.

⁴⁹Stukeley, Philosophy of Earthquakes, 1756 ed., Pt. III, p. 34.

⁵⁰Ibid., Pt. III, pp. 35-36.

Lisbon shock were experienced in England as a stormy disturbance of waters in lakes, rivers, and canals--activity resulting from an electrical agitation of the waters.⁵¹

Early Reactions to the Electrical Hypothesis

The immediate reaction to Stukeley's electrical theory of earthquakes in the period from 1750 to 1756 covered the spectrum of possible opinions. Horace Walpole, one of the early commentators, thought the writer had accounted for the English shocks "prettily," but then Walpole had found that electricity had become the "fashionable cause," replacing previous popular ideas such as Descartes' vortices and Newton's gravitation for explaining everything.⁵²

Stukeley vs. Massey

The most critical opposition came from one of the proponents of a version of an ancient theory of earthquakes. An article signed "W.M." in Gentleman's Magazine disagreed with Stukeley's hypothesis, and the author presented his own theoretical considerations.⁵³ In a letter to naturalist Peter Collinson (1694-1768), Stukeley defended his theory against the charges brought by the critic he identified as

⁵¹Ibid., Pt. III, pp. 36-37.

⁵²Letter from Horace Walpole to Horace Mann, May 19, 1750, O.S., Walpole's Correspondence, XX, 154.

⁵³"Observations on Dr. Stukely's Essay on Earthquakes," Gentleman's Magazine, XXI (August, 1751), 355-57. (Hereinafter referred to as "Observations on Dr. Stukely's Essay.")

an Englishman named "Massey,"⁵⁴ i.e. William Massey (1691-1764), a classical scholar. In order to effectively challenge Stukeley's explanation, Massey probably tried to gain access to the Royal Society of London through Collinson, with whom Massey had corresponded concerning classical references to natural history.⁵⁵ Stukeley's point-by-point defense may have persuaded Collinson not to carry the letter any further, and Massey's views were not printed in the Philosophical Transactions, although more than a year later his ideas reached a wide audience when they appeared in the pages of Gentleman's Magazine.

Massey's first criticism was to remark that not enough had yet been learned about the causes or effects of electricity to allow Stukeley to be making theoretical judgments. He cautioned that some supporters of electricity had already gone too far in giving electricity credit for being able to do practically anything. He cited a critical report from Abbé Jean Antoine Nollet (1700-1770), the French experimental philosopher, in disproving the claim by the Italian electrical experimenter Giovanni Francesco Pivati (1689-1764) that electricity can transmit odors and is capable of curing, or

⁵⁴Letter from Stukeley to Peter Collinson, June 28, 1750, O.S., printed in Stukeley, Family Memoirs, I, 400-1. (Hereinafter referred to as: Letter to Collinson.)

⁵⁵Norman G. Brett-James, The Life of Peter Collinson, F.R.S., F.S.A. ([London:] Edgar G. Dunstan & Co., [1926]), pp. 32-33.

of at least immediately relieving, medical problems.⁵⁶

The critic's second major point was based on his personal experience with the first London earthquake of 1750. If the electrical theory were correct, Massey believed that he should have felt his body being electrified during the shock, but all he had noticed was the ground under his feet rising and then gently falling back to its original position.⁵⁷ These first two comments constitute the two basic arguments against the electrical hypothesis that continued to be raised by the proponents of rival theories in the years to come.

Massey also sought to discredit the idea by providing accounts of earth movements for which he felt electricity could offer no explanation. In one example from the latter part of the sixteenth century, a place in Herefordshire called Marklay-hill began to rise and continued to do so, carrying plants and animals with it for more than a day and a half. He wondered how electricity, which acts instantaneously, could be responsible for such a slow motion.⁵⁸ For another example, the classical scholar reached back to Biblical times for the account of an earthquake in which a

⁵⁶Massey, "Observations on Dr. Stukely's Essay," p. 356. See also, "Conclusion of the Extract of the Abbe Nollet's Examination of Certain Phenomena in Electricity," Gentleman's Magazine, XXI (August, 1751), 349-51.

⁵⁷Massey, "Observations on Dr. Stukely's Essay," p. 357.

⁵⁸Ibid., p. 356.

mountain near Jerusalem was broken in half.⁵⁹

Instead of the electrical hypothesis, Massey preferred the "old creed" of subterranean fire, air, and water as the source of earthquakes. He placed emphasis on subterrestrial wind, since it can create the "mild" and slow movement described in the Marklay-hill incident.⁶⁰ Holding to these ideas, he would have to disagree with Stukeley's belief that the earth is not filled with many underground chambers and passages, and Massey claimed to know of many examples to the contrary. For an example (only one was given) there is a well on Lincoln heath in which the water level rises and falls relative to the height of a river ten miles away.⁶¹

The author of the article in Gentleman's Magazine also thought his own favored theory explains why the more violent shocks are centered on urban areas. He felt that cities more effectively resist the release of the imprisoned subterranean winds or vapors. As an analogous situation, Massey pointed out that stone walls that resist a lightning bolt are broken, while lightning does not affect thin and porous substances.⁶² Concerning a related topic, it was for natural

⁵⁹Ibid.

⁶⁰Ibid., pp. 355-56.

⁶¹Ibid., p. 356.

⁶²This was not an unusual analogy for Massey to be using in opposition to an electrical theory of earthquakes, since an alternative to Franklin's electrical theory of lightning had been established much earlier by earthquake theorists (for example Lister, Ray, and Lémery) who cited underground sulphureous vapors emitted into the atmosphere as the cause of lightning. See above, pp. 26, 35-36, 51-52.

reasons that the shocks struck London and not the surrounding countryside. London was not more wicked than any other town in England, and the city was not the center of Heavenly Judgments as the clergy (a group including Stukeley as one of its members) claimed. Massey did concede that earthquakes are valuable demonstrations of God's power, but he objected to the conclusion that people should turn to religion out of fear, because they should be impelled by "love and esteem."⁶³

These criticisms provided Stukeley with an early opportunity to test his theory against the views of a disciple of an opposing hypothesis. In his letter to Collinson, Stukeley answered every count of the indictment penned by Massey except the first one (that not enough was known about electricity), but this point with its reference to a 1751 article, was probably not made in the letter of 1750.

In answering the charge that he should have felt electrification during the London earthquake, the defendant stated that "innumerable" people had indeed experienced electrification. One woman in his parish had even died as a result.⁶⁴ In response to the examples, Stukeley simply exclaimed his disbelief that the earthquake that slowly elevated Marklay-hill had actually occurred. In effect, he classified it along with other "miraculous" reports, such as the sightings

⁶³Massey, "Observations on Dr. Stukely's Essay," pp. 356-57.

⁶⁴Stukeley, Letter to Collinson, p. 401.

of subterranean fire, that he vowed to ignore.⁶⁵ Concerning the breaking of a mountain, Stukeley pointed out that electricity does act forcefully against solid bodies, and it can indeed split mountains--while subterranean winds and vapors cannot.⁶⁶

He defended his statement that the earth is not filled with cavities by regarding the citation of a well on Lincoln heath as inconclusive proof that the earth contains underground passages filled with fire, air, and water. Such an example only shows that God made some subterrestrial, water-filled channels,⁶⁷ a point that Stukeley had never denied. In fact, one major part of his testimony had been to state that the shocks do not affect underground water systems.

Stukeley did not think that cities had suffered more from earthquakes than the countryside. Besides, Massey's reasoning was defective, for if earthquakes were caused by vapors, they would find easier release in the diggings and passages under cities. He, in turn, challenged Massey to explain how cities a great distance apart can experience an earth shock at the same time.⁶⁸

In his role as rector of St. George's Church, Stukeley did agree with his critic's "Charitable sentiments" that

⁶⁵Ibid., p. 400. See above, p. 101.

⁶⁶Stukeley, Letter to Collinson, pp. 400-1.

⁶⁷Ibid., p. 400.

⁶⁸Ibid., p. 401.

London was not the center of vice, and he welcomed the many who had turned to religion out of "love, gratitude and esteem." But in the end, Stukeley and Massey could not even agree on the theological and moral implications of a trembling earth: Stukeley still believed that many people would only pay attention to Heavenly Judgments.⁶⁹ Thus, with these comments the author of the electrical hypothesis defended his views from the first formal challenge from the opposition.

Thomas Barker's Comments

As advocates of an effective explanation, the electricians espousing earthquake theories were targets for destructive criticism from those defending equally cherished, but differing views of the nature of the earth. As the author of a new and not yet perfected idea, Stukeley also had the opportunity to take advantage of the insights offered by a rarer personality--the constructive critic. In a letter of 1755, Thomas Barker (1722-1809), an astronomer, called the electrical hypothesis the "most probable" solution yet devised.⁷⁰ However, he also thought that there were still some problems and inconsistencies that needed to be eliminated. For example, an electrical shock is instantaneous, yet he had personally experienced one earthquake that had lasted five

⁶⁹Ibid.

⁷⁰Letter from Thomas Barker to William Stukeley, December 23, 1755, printed in Stukeley, Family Memoirs, I, 412-15.

seconds. And the early accounts of the Lisbon disaster reported that the earth shook for some minutes.⁷¹

Another problem was about the electrification of people during an earthquake. Stukeley had responded to Massey's criticism by saying that many had felt electrification, but Barker wanted to know why everyone did not feel it as one invariable effect. He pointed out that electric shocks had knocked people to the floor, yet the electricity produced in an experimenter's workshop is weak when compared to the electrical force that must be present in an earthquake.⁷²

Barker was also troubled by inconsistencies in the meteorological phenomena associated with various earthquakes, because while Stukeley had connected the earth shocks with dry weather, the Northampton earthquake of September 30, 1750 followed a very rainy season.⁷³

Stukeley had made an impressive case for his idea, but there were still problems with it: especially the need for a more definitive announcement as to how the earth and atmosphere are placed in the earthquake-producing electrical state. The 1756 edition of the Philosophy of Earthquakes is the author's last complete statement on the subject; and for the questions that remained unanswered, it was now the task

⁷¹Ibid., p. 413.

⁷²Ibid., p. 415.

⁷³Ibid., p. 413. The editor of Stukeley's Family Memoirs added a note that there were also floods in parts of England. (Ibid., p. 413, n. 5.)

of Stukeley's followers to take up the problem of perfecting the theory.⁷⁴

Stukeley vs. Hales

In a long passage in Stukeley's diary dated "Dec., 1752,"⁷⁵ the writer showed serious concern for securing his place in history. Some people, he stated, had not received credit for their discoveries, and he wished to reassert his claim, for Stephen Hales was being praised for the electrical hypothesis.⁷⁶

And there was some basis for Stukeley to feel his recognition was being threatened, for Hales had not only developed the airquake theory, but he also joined Stukeley as one of the first to use electricity in a theory of earthquakes. According to Hales, an agitation of the "electrical aethereal Fluid" by a tremor causes the noise heard during the quaking of the earth. Since the motion of a revolving glass sphere can excite the electrical fluid to a force capable of killing animals, and since the agitation caused by cannon fire at St. James's Park had been known to electrify the windows of the nearby Treasury building, it seemed to Hales that a movement of the earth is capable of placing the

⁷⁴The history of the further development of the electrical hypothesis is examined in the next chapter.

⁷⁵Printed in Stukeley, Family Memoirs, II, 378-79. [Hereinafter referred to as Stukeley, Diary (1752).]

⁷⁶Stukeley, Diary (1752), p. 378.

electrical aethereal fluid into such a great state of excitement that it produces the "hollow rumbling Noise" heard during earthquakes.⁷⁷

He supported his idea by first remarking that in the London shocks the loudest explosion had been heard near large stone buildings topped with tall steeples. Since solid bodies were known to be conductors of the electrical fluid, Hales theorized that the noise is due to the sudden emission and expansion of the fluid into the atmosphere from such structures. The electrical effluvium in ascending from the larger body of the tower becomes strongly condensed and accelerated by the time it reaches the point of the weather vane where it is emitted into the air; thereby creating the concussion that he compared to the sound of small-cannon fire.⁷⁸

In Hales's view, the earthquake excites the electrical aethereal fluid to create the noise accompanying a shock. In other words, electricity is one effect of an earthquake. On this basis, the name Stephen Hales became linked with the electrical theory of earthquakes in the 1750's, although his ideas were superseded by those of William Stukeley who reversed Hales's cause and effect relationship: electricity is the cause of earthquakes.

⁷⁷Hales, "On the Causes of Earthquakes," pp. 679-80.

⁷⁸Ibid., pp. 680-81.

To set the record straight, Stukeley offered a historical sketch of the events leading toward his thesis.⁷⁹ He began the account with the year 1704 when he accompanied Stephen Gray (1666-1736) on visits to see the electrical experiments of Dr. John Gray (d. 1737). Stukeley mentioned Stephen Gray's own experiments and those of Jean Theophilus Desaguliers (1683-1744), and he remarked that many others had joined in the study of electricity throughout England and America. He stressed in particular Benjamin Franklin's work on lightning and electricity as well as the statements of John Freke.⁸⁰ From Franklin, Stukeley had derived the idea that earthquakes are an electrical "snap" between the electrified earth and a non-electric cloud, and Freke's Essay to Shew the Cause of Electricity influenced Stukeley's ideas on the nature of electricity.⁸¹ Freke may have been the source of the controversial part of Stukeley's theory that stated that earthquakes occur in dry weather because of the favorable conditions for the electrification of the earth. Freke had explained that electrical experiments do not work well in humid weather because "watry Particles in

⁷⁹Stukeley, *Diary*, (1752), p. 378. Stukeley intended to file this account with the Royal Society, which he called the "philosophical court of record, to register the memorials of discoveries in any of the branches of natural knowledge." Ibid.

⁸⁰Stukeley, *Diary* (1752), pp. 378-79.

⁸¹See above, pp. 92-93, 105.

the Air" keep the particles of the electric Fire from joining together.⁸²

The diarist next discussed his own contributions. He wrote that his first paper to the Royal Society was dated March 15, 1749 (O.S.), but it was not read until a week later when it received "great oppositon."⁸³ Shortly thereafter, on March twenty-ninth, he presented his second paper to the Royal Society (read a week later, on the fifth of April),⁸⁴ because, as he noted: ". . . I found that some worthy Members had not fully enter'd into my Way of Reasoning; nor with that Seriousness so awful a Subject requir'd: . . ."⁸⁵ In setting forth the chronology, Stukeley was careful to state that Hales's paper had been read after his own two presentations.⁸⁶

He had to establish the priority of his theory over that of Hales, because some "French philosophers" had credited the electrical theory of earthquakes to Hales.⁸⁷ The name of one French philosopher that could have been on

⁸²Freke, Essay to Shew the Cause of Electricity, p. 7.

⁸³Stukeley, Diary (1752), p. 379.

⁸⁴Ibid.

⁸⁵Stukeley, "Concerning the Causes of Earthquakes," p. 657.

⁸⁶Hales's paper was read on April fifth (Hales, "Considerations on the Causes of Earthquakes," p. 669), the same day Stukeley's second paper was read.

⁸⁷Stukeley, Diary (1752), p. 379.

Stukeley's mind as he wrote in his diary is that of Guillaume Mazéas (1712-1776), a Fellow of the Royal Society of London and another investigator of electricity. Mazéas in a letter to Hales (also published in the Philosophical Transactions⁸⁸) attributed the electrical theory of earthquakes to Hales, but with possible alternative credit going to Benjamin Franklin. Mazéas was uncertain as to the priority of "Considerations on the Causes of Earthquakes" over Franklin's paper on "thundergusts." There was no mention of the name William Stukeley.⁸⁹

To further settle the question of who actually originated the electrical theory of earthquakes, Stukeley showed that Hales's theory only approaches an electrical theory of earthquakes, while his own statements distinctly cite electricity as the cause.⁹⁰ His arguments are convincing, and there was no problem among later writers in giving proper credit to Stukeley as the founder of the electrical hypothesis.

After 1757, Stukeley produced no more papers on the subject, but in other portions of his diary he wrote that he

⁸⁸"Letters of the Abbé Mazeas, F.R.S. to the Rev. Stephen Hales, D.D, F.R.S. Concerning the Success of the Late Experiments in France. Translated from the French by James Parsons, M.D. F.R.S.," Philosophical Transactions of the Royal Society of London, XLVII (1752), 534-36. The letter is dated "May 20, 1750, N.S."

⁸⁹Ibid., p. 535.

⁹⁰Stukeley, Diary (1752), p. 379.

found the Royal Society secretaries prejudiced against his ideas. The diarist gave one example: in giving an account of an American earthquake, one secretary mentioned "but one imaginary chasm" in an earthquake covering 900 miles and ignored the bending of iron weather vanes--a fact that supported the electrical explanation.⁹¹ For a further sample of the bias, another secretary of the Society had neglected to read a letter sent from Lisbon favoring his hypothesis.

"Such is the present state of philosophy among us!"⁹²

Stukeley may have expressed his anger in places other than in his private papers, because a week later the correspondence from Portugal was made public (after a two-month delay). In the diary for that date Stukeley wrote: "The candid and sensible part of the society thought it was a very judicious account."⁹³

In the diary entries we see an example of a man fighting not only for an idea he believes in with a passion, but here is also a determined battle for the credit he deserved

⁹¹Stukeley, Diary, January 20, 1757, printed in Stukeley, Family Memoirs, II, 382-83.

⁹²Ibid., p. 383. The secretaries of the Royal Society at the time were Peter Davall (d. 1763) and Thomas Birch (1705-1766) and the Foreign Secretary was James Parsons (1705-1770). The Record of the Royal Society of London for the Promotion of Natural Knowledge (4th ed.; London: Printed for the Royal Society by Morrison & Gibb Ltd., Edinburgh, 1940), pp. 342-43.

⁹³Stukeley, Diary, January 27, 1757, printed in Stukeley, Family Memoirs, II, 383.

for originating and developing an impressive case for the electrical theory of earthquakes. In the end, he won his personal recognition, and in the second half of the eighteenth century, his idea maintained a prominent position among the competing concepts as others took up the banner to defend the theory against the opposition of those not yet convinced of the true nature of the earth, and to update it to explain newer earthquakes by means of the electrical hypothesis.

CHAPTER III

THE ELECTRICAL THEORY OF EARTHQUAKES:

LATER DEVELOPMENTS

Of the new ideas of the 1750's for explaining the origins of earthquakes, the electrical hypothesis was the one receiving the most attention. Authors took the early ideas of Stukeley, and other innovators, and developed them into theories that had to meet the test of the writers who critically weighed them against more established explanations.

Giovanni Battista Beccaria

One of the early investigators to shift the focus of earthquake studies to an examination of electricity was Giovanni Battista Beccaria (1716-1781), an Italian electrician. He theorized that if electricity is collected in great abundance in the earth, it then travels like a lightning bolt to a part of the earth or atmosphere that is less electrified. If the electricity encounters resisting bodies, a force is built up capable of breaking down this resistance, shaking and overturning part of the land in an earthquake.¹

¹Beccaria, Dell' elettricismo artificiale, e naturale libri due di Giambattista Beccaria (Torino: Nella Stampa di

Beccaria offered a demonstration in support of his theory: by holding two plates of glass with a metallic leaf between the glass connected to a source of electricity, the hand feels a tremor similar to the motion of an earthquake. Simply by enlarging the scale, one can imagine the effect of a vibration caused by the electrical power of a thunderbolt.² The force of the subterranean electricity is proportional to the quantity of the "vapor elettrico" and the distance it travels.³

There is a great abundance of the electric vapor in the earth--so much that the electricity seen in the atmosphere in the form of lightning is a very small fraction in comparison. Since a man-made spark of electricity can crush glass, and a thunderbolt can destroy towers, then the great quantity of electricity in the terrestrial sphere is capable of altering the earth's surface.⁴

For further indications that electricity is responsible for shaking the earth, Beccaria called attention to the incredible velocity of the earthquake shock,⁵ as well as the thunder and lightning accompanying volcanic eruptions and earthquakes.⁶

Filippo Antonio Campana, 1753), p. 227.

²Ibid., pp. 227-28.

³Ibid., p. 228.

⁴Ibid., pp. 228-29.

⁵Ibid., p. 231.

⁶Beccaria, Elettricismo atmosferico (2nd ed.; Bologna: Colle Ameno, 1758), pp. 361-62, nn. (a)-(b).

The writer also suggested that the movement of electricity in the earth can shake the land in indirect ways. Experiments show that a spark can inflame powdered sulphur; thus, the electric vapor rushing through the earth ignites materials to create great underground fires, the more traditional source of earthquakes. In addition, since a drop of water is vaporized instantly by an electric spark, then electricity can evaporate subterrestrial waters to steam in order to create another violent earthquake-producing force.⁷

Beccaria showed little interest in advancing his idea. His opinions are concentrated into relatively few remarks in one chapter of his Dell' elettricismo artificiale, while other statements appear in portions of his Elettricismo atmosferico in discussions of lightning and atmospheric electricity--quite a contrast from the nearly two hundred pages on the subject published by Stukeley.

In the same period in which Stukeley and Beccaria were working, still another electrical theory of earthquakes was offered. Andrea Bina (1724-1792), an Italian churchman interested in electrical studies, published a statement⁸ comparing the earth shock to that from a Leiden jar. He theorized that electricity causes explosions of subterranean

⁷Beccaria, Dell' elettricismo artificiale, pp. 228-30.

⁸Ragionamento sopra la cagione de' terremoti ed in particolare di quello della terra di Gualdo di Nocera nell' Umbria seguito l'a 1751 (Perugia, 1751). (Hereinafter referred to as Ragionamento.)

materials to shake the earth.⁹ However, it was Beccaria's and Stukeley's views that were discussed in the second half of the eighteenth century.

A Critic Called "Thomas"

One of the principal critics of the electrical hypothesis in the 1750's was Antoine Léonard Thomas (1732-1785), a member of the Académie Française and an author of works on various subjects often signed with just the name "Thomas." One of his essays, "Memoire sur la cause des tremblemens de terre,"¹⁰ won a prize of the Académie Royale des Sciences, Belles-Lettres, et Arts de Rouen.¹¹ Thomas agreed with electrical experimenter Petrus van Musschenbroek (1692-1761) that the study of electricity was still in its early stages of development, and problems, such as determining the nature of electricity and finding out how it is produced in the earth, prevent anyone from reasonably judging its effects.¹²

Thomas also offered specific reasons why he considered the electrical theory of earthquakes inadequate. Stukeley

⁹M. Gliozzi, "Bina, Andrea," Dizionario biografico degli Italiani, X, n.p.

¹⁰Printed in Suite de la clef, ou journal historique sur les matiers de tems [Journal de Verdun], LXXX (1756), 347-61, 426-35. (Hereinafter referred to as "Memoire.")

¹¹Mémoire sur la cause des tremblemens de terre, qui a remporté le prix Accessit au jugement de l'Académie Royale des Sciences, Belles-Lettres et Arts de Rouen le 3 août 1757, par M. Thomas (Paris: C.-A. Jombert, 1758).

¹²Thomas, "Memoire," pp. 429-30.

had theorized that the shocks occur mostly in warm and dry parts of the earth--in the conditions that favor electrical experiments. The critic agreed that humidity hinders the effects of electricity, but he pointed out that the areas shaken most often are in coastal regions (as Frézier had established), that are humid, not arid, lands.¹³ A second criticism, one that pointed to Beccaria's theory, concerned the findings of Abbé Nollet that the action of electricity is greater in rarified air. Thus, electricity cannot be expected to play a significant, earthquake-producing role inside the planet because of the presence of highly compressed air.¹⁴

The Electrical Hypothesis in America

The electrical theory in its early stages of development also had its supporters and critics in the New World.

Benjamin Franklin

One problem for the advocates of Stukeley's and Beccaria's thesis was that one of the most important electricians, and the man who had directly stimulated Stukeley's contribution--Benjamin Franklin--was not numbered among the theory's disciples. The American did not lend any support

¹³Ibid., p. 430.

¹⁴Ibid. See Nollet's Leçons de physique expérimentale (Paris: Chez Hippolyte-Louis Guérin, & Louis-François Delatour, 1764), VI, 487-88.

to the idea, and later he explained earthquakes without mentioning electricity. The paragraph in Mazéas's letter giving Franklin credit as one possible founder of the electrical theory of earthquakes was omitted in the fourth and fifth editions (1769, 1774) of Franklin's Experiments and Observations.¹⁵ Even if this indicates that he did not want to be identified with the concept,¹⁶ at least an examination of Franklin's published works and papers reveals no special interest in openly opposing those who followed Stukeley's lead.

In a letter of 1782, Franklin offered his own conjectures on the origins of earthquakes.¹⁷ It is "unlikely," he commented, that the earth is completely solid, for if it were, the land could not rise or fall; there would be no earthquakes. Instead, the interior of the earth consists of an extremely dense fluid of air surrounded by a shell that

¹⁵Experiments and Observations on Electricity, Made at Philadelphia in America, by Benjamin Franklin, L.L.D. and F.R.S. To Which Are Added, Letters and Papers on Philosophical Subjects ([4th ed.;] London: Printed for David Henry, 1769), p. 107, and (5th ed.; London: Printed for F. Newbery, 1774), p. 107. See above, p. 120.

¹⁶As suggested in a note in The Papers of Benjamin Franklin, ed. by Leonard W. Labaree, IV, 317, n. 4.

¹⁷Letter from Benjamin Franklin to Abbé Soulavie, September 22, 1782, in The Complete Works in Philosophy, Politics, and Morals, of the Late Dr. Benjamin Franklin, Now First Collected and Arranged; with Memoirs of His Early Life, Written by Himself (3 vols., 2nd ed.; London: Printed for Longman and others, n.d.), II, 117-22. (Hereinafter referred to as Letter from Franklin to Soulavie.) The letter was sent to Abbé Jean Louis Giraud Soulavie (1752-1813), a French naturalist and historian. Later, in 1788, these remarks were presented to the American Philosophical Society.

makes up the surface of the earth, and any great movement of the internal fluid causes the earth to shake. Since the expansion of the dense air when heated increases relative to greater densities, the subterranean fires may play a role in creating earthquakes (Amontons' view nearly eighty years before). The production of subterrestrial steam is also a factor.¹⁸ Franklin also suggested that the propagation of a shock over great distances is due to the effects of a wave in the subterranean aerial fluid moving through the earth.¹⁹ Electricity is not involved.

Prince vs. Winthrop²⁰

While Franklin did not favor an association of electricity and earthquakes, another influential American in the 1750's did. The Reverend Thomas Prince of Boston believed not only in God, but also in the electrical thesis. Before, in 1727, New England had been hit by a frightening earthquake.

¹⁸Letter from Franklin to Soulavie, pp. 117-18. See above, pp. 43-45.

¹⁹Letter from Franklin to Soulavie, pp. 120-21.

²⁰See above, p. 18. The Prince-Winthrop debate is one of the episodes often mentioned in accounts of science in colonial America. See the "Bibliography" for notes on books by Boorstin, Hindle, Merrill, and Stearns. Defending Prince's side of the case is "The Science of Thomas Prince" by Theodore Hornberger, New England Quarterly, IX (1936), 26-42, while a more balanced account is Eleanor M. Tilton's "Lightning-Rods and the Earthquake of 1755," Ibid., XIII (1940), 85-97 (hereinafter referred to as "Lightning-Rods"). Yet, these histories have not brought out a full account of Winthrop's view of the electrical hypothesis.

Prince and his colleagues welcomed this impetus to a renewal of faith, and printers in the area supplied copies of the many sermons on the subject.²¹ Following the 1755 shocks, Prince reprinted his sermons with additions of an account of the recent tremors and a new discussion of causes.²² A short appendix to his new Earthquakes the Works of God endorsed

²¹Prince, Earthquakes the Works of God, & Tokens of His Just Displeasure. Two Sermons on Psal. XVIII. 7. at the Particular Fast in Boston, Nov. 2. and the General Thanksgiving Nov. 9. Occasioned by the Late Dreadful Earthquake. Wherein among Other Things Is Offered a Brief Account of the Natural Causes of These Operations in the Hands of God: with a Relation of Some Late Terrible Ones in Other Parts of the World, as Well as Those That Have Been Perceived in New-England Since Its Settlement by English Inhabitants (Boston: Printed for D. Henchman, 1727). See also Smith, Enlightenment, pp. 402-3, and W. DeLoss Love, "The Terror of the Lord," chap. xx of The Fast and Thanksgiving Days of New England (Boston: Houghton, Mifflin and Company, 1895), pp. 285-95. The "Bibliography" contains a selection of some of the publications of the period to further illustrate the response to the event. See below, pp. 336-39.

²²The first sermon of 1727 was printed as Earthquakes the Works of God, and Tokens of His Just Displeasure; Being a Discourse on That Subject, Wherein Is Given a Particular Description of This Awful Event of Providence. And among Other Things, Is Offer'd a Brief Account of the Natural, Instrumental, or Secondary Causes of These Operations in the Hands of God. After Which, Our Thoughts Are Led Up to Him as Having the Highest and Principal Agency in This Stupendous Work . . . Made Public at This Time on Occasion of the Late Dreadful Earthquake, Which Happen'd on the 18th of Nov. 1755 (Boston: Printed and sold by D. Fowle and Z. Fowle, 1755); and the second homily became a part of An Improvement of the Doctrine of Earthquakes, Being the Works of God, and Tokens of His Just Displeasure. Containing an Historical Summary of the Most Remarkable Earthquakes in New-England, from the First Settlement of the English Here, as Also in Other Parts of the World Since 1666. To Which Is Added, a Letter to a Gentleman, Giving an Account of the Dreadful Earthquake Felt in Boston, New-England Nov. 18, Twenty-five Minutes Past 4 in the Morning (Boston: Printed and sold by D. Fowle and Z Fowle, 1755).

electricity as the means by which God had shaken New England. The author called attention to the increasing number of lightning rods erected in Boston, for these devices serve to collect electricity from the atmosphere and store dangerous quantities of the electric matter in the earth.²³

Professor John Winthrop of Harvard in his Lecture on Earthquakes²⁴ taught that the earth contains caverns filled with inflammable materials that when ignited produce such expansive vapors that the earth is raised as they move through the imprisoning passages.²⁵ Before printing his lecture, he added an appendix refuting Prince's ideas about electricity as the source of the 1755 disturbances in Boston by pointing out the great difficulties in using that "fashionable" cause.²⁶ In Benjamin Franklin's theory, lightning is ably explained by electricity: when clouds of dissimilar quantities of electrical fire come close together, there is a discharge between the clouds. But for the same type of theory to account for a lightning-like electrical discharge in the earth, the globe would have to be divisible into great masses capable of collecting dissimilar amounts of electricity.

²³Prince, Earthquakes the Works of God (1755), p. 23, quoted in Tilton, "Lightning-Rods," pp. 86-87.

²⁴See above, p. 18, n. 22. Citations are from the microprint edition: Early American Imprints: 1639-1800 (New York: Readex Microprint Corp., n.d.).

²⁵Winthrop, Lecture on Earthquakes, pp. 18-21, 23-24.

²⁶Ibid., pp. 32-38.

This is not the case; there cannot be an earth-shaking discharge.²⁷ Any quantity of electricity that lightning rods communicate to the earth is spread throughout the terrestrial sphere. Earthquakes are not caused in the manner described by Prince.²⁸

In a letter to the Boston Gazette, Prince replied by reaffirming his explanation of twenty-eight years before (using ideas similar to Winthrop's) and by stressing his moral arguments. He warned that those who are interested only in the "Material Instruments of Earthquakes" should be more concerned with their future, for an earthquake like the one at Lisbon might "bury them in eternal Ruin." He indicated that his recent statements as to causes were hypothetical inquiries into the possibility of God acting through electricity. While deemphasizing his remarks on electricity, he did not give up the new idea, for he added that Winthrop had not proven his statement that there cannot be any disequilibrium in the distribution of electricity in the planet.²⁹ Winthrop replied, and Prince countered with still another response.³⁰ And what was once a restrained controversy

²⁷Ibid., pp. 34-35.

²⁸Ibid., pp. 36-38.

²⁹Letter from Thomas Prince, Boston Gazette, January 26, 1756, 11, recto.

³⁰Winthrop, A Letter to the Publishers of the Boston Gazette, &c. Containing an Answer to the Rev. Mr. Prince's Letter, Inserted in Said Gazette, on the 26th of January 1756 (Boston: Printed and sold by Edes & Gill, 1756); and Letter from Thomas Prince, Boston Gazette, February 23, 1756, 11, verso.

degraded into a bitter conflict between two sensitive personalities, and the substance of the initial argument was forgotten amid the personal offense each took in the remarks of the other. Another letter from Winthrop simply called a halt to the irresolvable debate.³¹

The hypothesis introduced by Stukeley was not very successful in the British colonies, for the Americans remained partisans of the more traditional causes involving fire and vapors.³² Although electricity was a fashionable cause, as both Walpole and Winthrop had remarked, in the case of earthquakes, it proved to be a successful idea rivaling all other accounts being discussed in Europe. After the Lisbon earthquake, the electrical thesis, with its particular ability to explain how a shock can quickly cover a large area of the globe, was established as a major explanation of these natural events. But as critics emphasized, there were some questions that needed to be answered before proponents of other hypotheses abandoned their favorite theories for one by an electrician. The electrical hypothesis was in the same

³¹Letter from John Winthrop, Boston Gazette, March 1, 1756, 41, recto. Tilton ("Lightning-Rods," pp. 89-97) details the controversy.

³²Harvard professor of mathematics Samuel Williams (1743-1817) adopted Winthrop's explanation in his 1783 treatise: "Observations and Conjectures on the Earthquakes of New-England," Memoirs of the American Academy of Arts and Sciences: To the End of the Year D,DCC,LXXXIII, I (1783), 260-311. From the microprint edition: Early American Imprints: 1639-1800 (New York: Readex Microprint Corp., n.d.).

position in 1750 as Lister's pyrite theory was in 1684--an idea with a promising future awaiting clarification, illustration, and experimental demonstration.

Joseph Priestley

Joseph Priestley (1733-1804) in his 1767 study of electricity restated Stukeley's, Beccaria's, and part of Hales's thoughts on the subject, and then he combined and reformed their ideas into a new explanation of earthquakes.³³ William Stukeley received credit as the founder of the electrical hypothesis, although Priestley realized that Beccaria in his work on lightning had independently arrived at a similar idea at about the same time. The author pointed to the principal differences in the two theories: in Stukeley's the electrical activity takes place in the realm from the atmosphere to just under the earth's surface; while in Beccaria's the electricity accumulates deep in the planet, and an earthquake is caused by the passage of the electrical fluid through the earth in an effort to restore the balance in the amount of electricity in the earth and in the air.³⁴

Rather than choosing to support either version, Priestley devised his own theory by combining the two. He theorized

³³Priestley, The History and Present State of Electricity, with Original Experiments (London: Printed for J. Dodsley, and others, 1767), pp. 381-94. (Hereinafter referred to as History.)

³⁴Ibid., pp. 381, 391-92.

that during a dry season the electric matter collects on the surface of the earth (as in Stukeley's theory), and it is not able to "diffuse itself" to other areas of the globe. The electricity "may force itself" to the clouds in the upper portions of the atmosphere (Beccaria's theory), and return to the earth in a rain storm. The ground receives the "concussions" that conductors experience on giving or receiving electricity.³⁵

Adding to the evidence assembled by Stukeley, Beccaria, and Hales, Priestley found further indications linking electricity and earthquakes while carrying out an investigation of conductivity. He reported his findings in the section of his History, "Experiments on the Passage of the Electrical Explosion Over the Surface of Some Conducting Substances, Without Entering Them."³⁶ In an electrical discharge over water, the electricity passes over the surface, agitates the liquid, and produces a very loud explosion. These results recalled Stukeley's comment that in an earthquake electricity is discharged over the surface of the earth, and Priestley also recognized the resemblance of the turbulent water in the experiment to the troubled waters created by an earth shock. Furthermore, by placing his hand in the water while electricity passed over this fluid conductor, he and the others who also participated in the test felt a "sudden

³⁵Ibid., pp. 393-94.

³⁶Ibid., pp. 685-96.

concussion" like that experienced by sailors when hit by an earthquake at sea.³⁷

After postulating that the "similarity of the effect is a considerable evidence of a similarity in the cause,"³⁸ and after performing other versions of the experiment in which he sent electricity over various conductors, Priestley devised a demonstration showing the electrical nature of earthquakes. On a slab of ice he placed two three-inch sticks or "pillars" balanced on their ends, and he found that an electric discharge over the ice knocked over the stick nearest to the electrical explosion. On another part of the ice, Priestley placed a bottle with a brass ball suspended by a thread from a cork in the bottle. After the shock, the brass ball began vibrating in approximately the direction of the shock. Using more sticks and suspended balls, he repeated the effect. And in one "exceeding fine experiment" a board floating in water was used to represent the earth and sea; the electricity passing over the plank and "ocean" toppled the pillars in an imitation "earthquake."³⁹ Thus, Priestley added not only to the theoretical discussions, but he also contributed a vivid demonstration in support of the electrical theory of earthquakes. Now the subterranean-fire-and-vapors devotees with their buried pots

³⁷Ibid., p. 687.

³⁸Ibid., p. 688.

³⁹Ibid., pp. 689-90.

of sulphur and iron paste were not the only ones with an impressive exhibition-piece.

Continental Critics

Not everyone was as impressed or committed to the idea of the electrical origins of earthquakes as were Stukeley and Priestley. On the continent some ignored it, while others actively opposed it. In 1765, Baron d'Holbach in his article on the trembling earth for the Encyclopédie did not mention the electrical hypothesis, but instead he theorized that subterranean fire, heated air and steam, and the undermining effects of water are the sources of earthquakes.⁴⁰

Four years later, in the article "Tremblement de terre" of the Dictionnaire raisonné universel d'histoire naturelle, the French naturalist Jacques Christophe Valmont de Bomare⁴¹ (1731-1807) did discuss electricity and earthquakes, but only to echo the criticisms presented by Thomas. The frequency of tremors in humid regions of the earth, and also the great air pressure in the depths below make the theory unacceptable, because both conditions, humidity and dense air, hinder electrical effects.⁴² Instead of electricity, Valmont de Bomare

⁴⁰Holbach, "Tremblemens de terre," pp. 580-83.

⁴¹(édition augmentée; Yverdon: n.p., 1769), XI, 458-81. (Hereinafter referred to as Valmont de Bomare, "Tremblement de terre.")

⁴²Valmont de Bomare, "Tremblement de terre," pp. 475-76, 480.

wrote that fires created from Lémery's mixture of iron, sulphur, and water act on subterranean waters to produce the powerful effects of confined steam.⁴³

Continental Supporters

The electrical hypothesis also had its defenders on the continent, although they were less disposed to give electricity the whole credit for causing the earth to tremble. Instead, they cited electricity as a force working in combination with more traditional causes (as Beccaria and Bina had suggested earlier).

Aimé Henri Paulian

While articles in the Encyclopédie and in Valmont de Bomare's Dictionnaire did not enlist support for the electrical thesis, there were other authors of similar pieces in reference works who did find merit in the idea. The "Tremblement de terre" for the Dictionnaire de physique of Aimé Henri Paulian⁴⁴ (1722-1801), Professeur de physique at Avignon, presented the view that earth movements are caused by electricity acting in concert with other subterrestrial forces.

Paulian decided to come out in favor of the electrical theory after seeing the perfect analogy between earthquakes

⁴³Ibid., pp. 458-62.

⁴⁴Dictionnaire de physique, dédié a Monseigneur le Duc de Berry (Avignon: Chez Louis Chambeau, 1761), III, 329-42. Paulian stated that he first suggested his theory late in 1755. Ibid., p. 340.

and lightning. Lightning-like flames had been observed during earthquakes, as in the columns of fire before the shock at Palermo in 1726. Furthermore, both earthquakes and lightning are accompanied by a thunderous noise, both break obstacles in their respective paths, and both are accompanied by a characteristic sulphureous smell.⁴⁵

Turning his attention to the interior of the earth, he theorized that the planet contains great quantities of both electrical and combustible materials, as well as cavities filled with water and vapors. He explained that the movement of electricity through the earth ignites fires of sulphur and bitumen in lower caverns. Upper cavities filled with water are then heated to produce a situation analogous to a natural furnace and boiler. The heated water, air, and steam expand with a land-breaking force capable of opening chasms. After the release of steam and vapors, the earth closes, the subterranean chambers are resupplied, and another earthquake is again possible.⁴⁶ The noise that is associated with the shock of a jolting earth movement comes from

⁴⁵Paulian, "Tremblement de terre," pp. 329-31.

⁴⁶Ibid., pp. 332-33. In 1785, Paulian's analogy was carried to its limit when the article, "Mémoire sur les volcans et les tremblemens de terre; par M. C.D.L. Lieutenant-Colonel au Corps Royal du Génie," theorized in elaborate detail that earthquakes are caused by a great natural steam engine. Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. Le Comte d'Artois; Par M. l'abbé Rozier, XXVII, Pt. II (1785), 81-87.

compressed exhalations escaping into the atmosphere, as well as from vapors traveling through vast numbers of underground tunnels to create a bellowing sound like that produced by a convoluted musical instrument called a "serpent."⁴⁷

Joseph Aignan Sigaud-Lafond

Joseph Aignan Sigaud-Lafond (1730-1810), Professeur de Physique Experimentale at Bourges, in his Dictionnaire de physique of 1781 described in detail a theory of earthquakes⁴⁸ similar to the one in Paulian's Dictionnaire. Sigaud-Lafond joined with Paulian in stating that earthquakes and lightning share the same source because of the similarity of appearance, noise, destructiveness, and odor.⁴⁹ For one contemporary example he used the Lisbon earthquakes and the reports of fire coming from the earth, its horrible noise, the destruction, and the odor of subterranean substances that were thought to have caused an epidemic that had swept the area.⁵⁰

After establishing that lightning and earthquakes have a common origin, Sigaud-Lafond first explained how lightning is created: electricity travels between a cloud and the

⁴⁷Paulian, "Tremblement de terre," p. 335.

⁴⁸"Tremblement de terre," Dictionnaire de physique (Paris: Rue et Hôtel Serpente, 1781), IV, 439-58.

⁴⁹Ibid., pp. 443-44. Similarly, both Sigaud-Lafond (ibid.) and Paulian ("Tremblement de terre," p. 330) pointed out that Pliny had much earlier compared earthquakes and lightning. Pliny Historia naturalis 2. 81.

⁵⁰Sigaud-Lafond, "Tremblement de terre," pp. 444-45.

earth to reestablish the equilibrium in the quantity of electrical material in each.⁵¹ For the creation of a tremor, he postulated that below the surface are located great caverns filled with sulphureous, bituminous, and pyritic substances. Electricity may also be collected to an excess in the bowels of the earth. To restore the balance, the overabundant terrestrial electricity escapes to a deficiently electrified cloud that passes over the area. In the act of escaping, combustible materials are ignited, and the well-known effects of subterranean fire, vapors, and steam come into play to produce an earthquake as other theorists had proposed.⁵² Sigaud-Lafond joined Paulian in the belief that there are enough explosive materials in the earth to shake the entire globe at one time.⁵³

The discussion concluded with an explanation of how the four principal effects of earthquakes are produced. The fire comes from the inflamed subterrestrial substances, the noise is produced by escaping pressurized vapors, a building is destroyed when its center of gravity is suddenly moved away from its base, and finally, subterranean odors and infecting agents are responsible for the smells and epidemics that have accompanied the earth-jolting disasters.⁵⁴

⁵¹Ibid., pp. 445-46.

⁵²Ibid., pp. 447-48.

⁵³Ibid., p. 448, and Paulian, "Tremblement de terre," p. 334.

⁵⁴Sigaud-Lafond, "Tremblement de terre," pp. 450-51.

Mathurin Jacques Brisson

The Dictionnaire raisonné de physique of Mathurin Jacques Brisson⁵⁵ (1723-1806) appears at first to present a standard account of fire, vapors, and water to explain the creation of earthquakes; but in the end, the author arrived at the conclusion that the fermentation of combustible materials into fire and the subsequent violent expansion of air and water are only secondary causes. In the last two paragraphs of the lengthy article, electricity is presented as the true cause, primarily because it is the only explanation for the rapid propagation of a shock, such as the Lisbon earthquake, over great distances.⁵⁶

Brisson's article suggests that he may have been a late convert to the electrical hypothesis, but then, too, the exposition may have resulted from the practice of Dictionnaire authors of freely borrowing from previous works and adding new commentaries where needed (as best illustrated in the Sigaud-Lafond version of Paulian's earthquake article).

In summary, while Thomas, Holbach, and Valmont de Bomare discounted theories that attributed electricity as the source of earthquakes, the Dictionnaires of Paulian, Sigaud-Lafond, and Brisson all made use of the electrical thesis--in conjunction with the older theories of fire, air, and water.

⁵⁵"Tremblement de terre," (Paris: Hôtel de Thou, Rue des Poitevins, 1781), II, 663-70.

⁵⁶Brisson, "Tremblement de terre," pp. 669-70.

The English Advocates

The English, following the examples of Stukeley and Priestley, were willing to attribute earthquakes to electricity alone, and not in combination with other forces as the continental writers proposed. Carrying on the tradition was Tiberius Cavallo.

Tiberius Cavallo

Indirectly answering the criticisms of Massey, Nollet, and Thomas that electricity had been used too indiscriminately to explain a host of yet unexplained natural phenomena, electrical experimenter Tiberius Cavallo (1749-1809), the author of an extensive survey of his field of study,⁵⁷ commented that citing electricity as the cause of falling stars, water-spouts, hurricanes, and earthquakes may at first appear to be carrying a good idea to an extreme. Yet, no known laws of nature have been violated, and the electrical hypothesis forms the most plausible explanation offered.⁵⁸

He described a series of experiments in which electricity displayed the effects of an earthquake: by placing on the surface of a dry card the ends of two wires about one inch from each other and by passing an electric charge over the card, a "lucid track" became visible. By sending the

⁵⁷A Complete Treatise of Electricity in Theory and Practice; with Original Experiments (London: Printed for Edward and Charles Dilly, 1777).

⁵⁸Ibid., p. 74.

shock over writing paper in a similar experiment, the paper was torn into small pieces. Indelible tracks were left on glass when electricity was sent over its surface.⁵⁹

By placing weights on the glass between the wires, it was broken by the electrical explosion, sometimes shattered to a powder. Also in this experiment by William Henly (d. 1779), glass too thick to break was marked by prismatic colors caused by laminae of glass being separated by the shock.⁶⁰ In another example, a small representation of a town placed on a board and balanced on a piece of ivory between the two wires, the electric shock created an "earthquake" for the model town.⁶¹ The electricians had another effective demonstration.

The Encyclopaedia Britannica

The first edition of the Encyclopaedia Britannica⁶² of 1771 dismissed the subject of earthquakes in one sentence:

⁵⁹Ibid., pp. 247-48.

⁶⁰Ibid., p. 248.

⁶¹Ibid., p. 249, n. *. In still another electrical demonstration, the representation of a town was used by Carlo Barletti (d. 1800), of the university at Pavia, to show the action of electrical fire in lightning and earthquakes. Nuove sperienze elettriche secondo la teoria del Sig. Franklin e le produzioni del P. Beccaria di Carlo Barletti (Milano: Appresso Giuseppe Galeazzi R. Stampatore, 1771), pp. 38-41, Fig. 6.

⁶²Encyclopaedia Britannica; or, a Dictionary of Arts and Sciences, Compiled upon a New Plan. In Which the Different Sciences and Arts Are Digested into Distinct Treatises or Systems; and the Various Technical Terms, &c. Are Explained as They Occur in the Order of the Alphabet. By a Society of Gentlemen in Scotland (3 vols.; Edinburgh: Printed for A. Bell and C. Macfarquhar, 1771).

EARTHQUAKE, in natural history, a violent agitation or trembling of some considerable part of the earth generally attended with a terrible noise like thunder, and sometimes with an eruption of fire, water, wind, &c.⁶³

The only mention of causes was in the article, "Pneumatics," in which it was noted that explosions like fire-damps in mines make the earth shake, and the article described an experiment like the one devised by Lémery.⁶⁴

Eight years later a very detailed article appeared in the much larger second edition of the encyclopaedia. More than a dozen pages were devoted to earthquakes, and one section about ninety column-inches long discussed causes.⁶⁵ It was principally the product of the Encyclopaedia Britannica's general editor, James Tytler (1747?-1805).⁶⁶ He discussed briefly previous explanations, both ancient and contemporary,

⁶³Ibid., II, 464. This general definition was probably compiled by either printer and naturalist William Smellie (1740-1795) or publisher Colin Macfarquhar (ca. 1745-1793), the major contributors to the work. See the History of the Britannica in "Encyclopaedia," Encyclopaedia Britannica, 11th ed., IX, 377-80, and in S. Padraig Walsh, Anglo-American General Encyclopedias: A Historical Bibliography, 1703-1967 (New York: R. R. Bowker Company, 1968), pp. 44-54.

⁶⁴"Pneumatics," Encyclopaedia Britannica (1771), III, 490-91.

⁶⁵"Earthquake," Encyclopaedia Britannica, 2nd ed. (1779), IV, 2589-2603. See the "Bibliography" for the full citation. (Hereinafter referred to as Tytler, "Earthquake.")

⁶⁶Based on Tytler's extensive contributions on subjects of natural philosophy, on internal evidence relating this article to the article "Electricity" attributed to Tytler in the "Preface" of the 3rd ed. (1797, p. xv), and to additions to the article in the third edition that appeared during the period of Tytler's continued editorial direction. See Thomas Finlayson Henderson, "Tytler, James," DNB, XIX, 1379-380.

and judged them to be inadequate.⁶⁷ The encyclopedist then proceeded to present his own version of an electrical theory of earthquakes, one that avoided problems he saw in the previous attempts by Stukeley, Beccaria, and Priestley.

First, in criticizing Stukeley's theory, he stated that if the electric matter is on or near the surface of the earth, hills cannot be split into two parts by a shock. In this case the cause cannot be on the earth's surface; the source must be in the body of the planet or in the interior of the hill. The same conclusion must be reached when considering that miners working deep underground experience an earth shock more strongly than those laboring on the surface.⁶⁸

For a second problem, Stukeley's version was based on an earthquake in London that was accompanied by the weather conditions required by his theory; yet, the Lisbon shock of 1755 was more violent, and there were no signs that the earth or atmosphere were in an electric state. The earthquakes that struck Manchester in 1777 had been marked by an absence of lightning, and vegetation had been "extremely backward" not forward as it should have been in order to support Stukeley's view. On a more theoretical basis, any great difference between the electrical nature of the atmosphere and the surface of the earth should be impossible, because

⁶⁷Tytler, "Earthquake," pp. 2597-598.

⁶⁸Ibid., p. 2600.

innumerable points can draw off excessive terrestrial electricity into the air. Lightning is possible, but earthquakes are not.⁶⁹

Beccaria's explanation is not any more satisfactory, according to Tytler, because the electric matter does not travel easily through the atmosphere as compared to moist earth as a conductor. If there is an imbalance in the equilibrium in the electric fluid in the earth, the electricity should safely travel directly through the earth to the place where it is needed, rather than pass through the atmosphere.⁷⁰ Furthermore, in Beccaria's theory earthquakes should be felt only in limited areas, places where the electric fluid leaves the earth, and where it reenters.⁷¹

⁶⁹Ibid.

⁷⁰Ibid. Beccaria's brief and decentralized presentation left his ideas concerning earthquakes open to interpretation. While in the Dell' elettricismo artificale it is not definitely stated that the electric fluid has to pass through the atmosphere to reestablish the equilibrium of electricity in another part of the globe, other remarks in the context of his extensive atmospheric-electricity studies allow the interpretation first presented in Priestley's History and copied almost verbatim by Tytler (p. 2599).

For if the equilibrium of the electric matter can, by any means, be lost in the bowels of the earth; so that the best method of restoring it shall be by the fluid bursting its way into the air, and traversing several miles of the atmosphere, to come to the place where it is wanted; it may easily be imagined, that violent concussions may be given to the earth, by the sudden passage of this powerful agent.

Priestley, History, pp. 391-92.

⁷¹Tytler, "Earthquake," p. 2600.

Tytler also found Priestley's synthesis defective, because electricity is confined to the surface. And the demonstration of sending an electric discharge over a representation of the earth and sea to upset miniature "pillars" does not resemble nature, because in the natural world there are no observations of a flash of electricity. In addition, the electric explosion is barely able to upset a stick only shakily balanced on its base. While the force of electricity that man is able to create is small when compared to natural electricity, the force from a battery should be able to do more than topple such pillars.⁷²

The encyclopedist offered an alternative theory free from these objections. Stated in its simplest terms, an earthquake is caused by a discharge of overabundantly accumulated electricity from the interior of the earth.⁷³ Electricity is concentrated in the planet by means of the sun,⁷⁴ and is collected in underground moisture in the same way that electric matter from an excited globe is collected by a metal conductor. When the earth's moisture can no longer contain any more electricity, the electrical fluid is discharged into

⁷²Ibid., pp. 2600-601.

⁷³Ibid., pp. 2601-602.

⁷⁴Ibid., p. 2602. In the article "Electricity" in the section entitled "Proofs of the Identity of the Electric Fluid and Elementary Fire of Light of the Sun," Tytler sought to prove that the source of the electric fluid in the earth is the sun by showing similarities of electricity and light. Encyclopaedia Britannica, 2nd ed., IV, 2690-691. Thus, he offered an answer to a question that Stukeley had skirted. See above, pp. 104-6.

the ocean so as to continue in the effort to distribute evenly the amount of electricity found in any one part of the world. However, the transmission of electricity to other areas is resisted by the quantity of electricity already spread throughout the terrestrial sphere. As the pressure of amassing electric matter grows in the southern climes, the chance of it violently breaking out into the air increases.⁷⁵

Fortunately, there are less catastrophic outlets for accumulated electricity. Fire, which is a conductor, can release the excess by means of an active volcano. A discharge can also be made from the summits of high mountains where the atmospheric resistance is less, although volcanoes may be ignited. In the final instance, when electricity collects in the earth and cannot be sent into oceans, or out of volcanoes, or released into the thin air high in the mountains, then an earthquake occurs. As the electric fluid builds up, the pressure becomes so great that it strikes against any obstacle with great violence; even mountains are split. Steeples, trees, and other high structures do safely draw off some of the electricity, but buildings that are poor conductors are destroyed. Subterranean waters become overcharged and are ejected in great quantities.⁷⁶

⁷⁵Tytler, "Earthquake," pp. 2601-602.

⁷⁶Ibid.

Through the action of the sun, electricity is created in greater quantities in tropical regions of the earth. Since there cannot be a constant increase of electricity in one part of the globe without it being discharged elsewhere, Tytler theorized that the material is continually flowing from the equator toward the poles. Everything is peaceful so long as the electric fluid moves freely and finds a safe means of discharge. But if its progress is hindered, such as by a frost that makes the air and frozen ground non-conductors, then a part of the earth will become overcharged. The result is then an earthquake on land, or if the excess is suddenly discharged into an ocean, a hurricane occurs.⁷⁷ With these remarks, Tytler concluded his novel electrical theory of earthquakes, although he extended his comments at a later date.⁷⁸

Chambers' Cyclopaedia (1780)

The development of the electrical hypothesis did not make a discussion of the causes of earthquakes any easier for the editor of Chambers' Cyclopaedia. The 1778-84 edition⁷⁹

⁷⁷Ibid., p. 2602.

⁷⁸See below, pp. 207-9.

⁷⁹Cyclopaedia: or, an Universal Dictionary of Arts and Sciences. Containing an Explanation of the Terms, and an Account of the Several Subjects, in the Liberal and Mechanical Arts, and the Sciences, Human and Divine. Intended as a Course of Ancient and Modern Learning. By E. Chambers, F.R.S. With the Supplement, and Modern Improvements, Incorporated in One Alphabet. By Abraham Rees, D.D. (4 vols. in 8 pts., plates; Dublin: Printed by John Chambers, 1778-84).

added a presentation of the explanations of Stukeley, Beccaria, and Priestley, including related electrical experiments, alongside the comments from previous editions about subterranean fire, water, and air pressure. The conclusion remained the same: the problem of pinpointing the responsibility for shaking the earth has not been solved, since all four basic answers are reasonable.⁸⁰

In the period from the 1750's to the 1780's, the electrical theory of earthquakes continued to be developed by Britishers, such as Priestley and Tytler, who credited electricity alone as the cause of earthquakes; and by Frenchmen, like the Dictionnaire editors Paulian, Sigaud-Lafond, and Brisson, who used electricity in combination with other causes. While the hypothesis had not won general acceptance, neither had any other earthquake theory; thus, the debate continued.

Later Developments

The validity of the electrical theory was again questioned in the discussions of the Calabrian earthquakes of 1783 (see Bk. II, chap. vi), but the status of the hypothesis had not changed, as it remained one of the possible explanations. Late in the 1790's a new edition of Buffon's Histoire naturelle⁸¹ listed not two types of earthquakes as before,

⁸⁰"Earthquakes, Causes of," Ibid., II, [Pt. I] (1780), n.p.

⁸¹Histoire naturelle, générale et particulière, par Leclerc de Buffon; Nouvelle édition, accompagnée de notes,

but three: the first kind is caused by land collapsing into caverns, the second has its origins in subterranean fires, but the third adds the electrical explosions of underground lightning.⁸²

The electrical hypothesis was revitalized through new investigations into galvanic electricity. In 1800, The Philosophical Magazine received a report on Dr. Henry Moyes' work on the galvanic pile.⁸³ He had found that a galvanic series of zinc, copper, and moistened alumine gives an exceptionally strong shock. He suggested that the strata of the earth may form a galvanic pile to create the electricity responsible for earthquakes.⁸⁴

In 1815, Jean Claude de La Métherie (1743-1817), also writing on the subject of subterranean galvanic forces,

et dans laquelle les supplémens sont insérés dans le premier texte, à la place qui leur convient. L'on y a ajouté l'histoire naturelle des quadrupèdes et des oiseaux découverts depuis la mort de Buffon, celle des reptiles, des poissons, des insectes et des vers; enfin, l'histoire des plantes dont ce grand naturaliste n'a pas eu le tems de s'occuper. Ouvrage formant un cours complet d'histoire naturelle; rédigé par C. S. Sonnini, membre de plusieurs sociétés savantes, Vol. II: Théorie de la terre (Paris: Chez F. Dufart, an VII).

⁸²Ibid., pp. 443-48. (Cf. above, pp. 55-56.)

⁸³"Letter from Henry Moyes, M.D. to Maxwell Garthshore, M.D. Containing an Account of Some Interesting Experiments in Galvanic Electricity. Communicated by Dr. Garthshore," The Philosophical Magazine, Comprehending the Various Branches of Science, the Liberal Arts, Agriculture, Manufactures, and Commerce, VII, Ser. 1 (1800), 347-50.

⁸⁴Ibid., p. 348.

compared the electrical agitation of the earth's strata to the shock created by the muscles of the electric torpedo fish.⁸⁵ He also summarized the evidence favoring the electrical hypothesis. First, earthquakes are accompanied by lightning (i.e. electricity). Second, the shock often lasts less than a second (again as in an electric spark). Third, there are no surface indications of subterranean fires. And fourth, La Métherie listed the strongest evidence--the instantaneous propagation of an earthquake over great distances.⁸⁶

From the time of its introduction, electricity had been favored with the loyal support of able champions, for in its day the idea was a reasonable explanation. The arguments of La Métherie were as worthy of serious consideration in 1815 as Stukeley's were in 1750. The concept could very well have been accepted as the true account of earthquakes--if it had not been for the other ideas that were just as reasonable and as well supported by observations, experiments, demonstrations, and persuasive arguments by respected explorers of the natural world.

⁸⁵"Addition a mon mémoire. Sur les causes des commotions souterraines par l'action galvanique; par J.-C. Delamétherie," Journal de physique, de chimie, d'histoire naturelle et des arts, avec des planches en taille-douce; par J.-C. Delamétherie, LXXXI (1815), 393.

⁸⁶Ibid.

CHAPTER IV

EARTHQUAKE THEORIES FOLLOWING THE LISBON EARTHQUAKE OF 1755

The most spectacular earthquake of the eighteenth century and the event that focused world-wide attention on the study of the trembling earth was the great Lisbon disaster of November 1, 1755. While those espousing the electrical hypothesis made references to it (as they must if their theories would have any creditability), the Lisbon example was more the property of those who continued to support and develop the older ideas involving subterranean fires, vapors, and waters.

Portuguese and Spanish Authors

The Portuguese and Spanish were the ones most affected by the wide-ranging Lisbon catastrophe, and a number of accounts and explanations of the event were produced in the two countries. However, the Iberian theorists were ignored by their French, English, Swiss, and Italian counterparts. A summary of the Portuguese and Spanish writings on the subject is found in The Lisbon Earthquake by T. D. Kendrick (1956) and in the far older Historia universal dos terremotos

(1758) of Joaquim José Moreira de Mendonça, who in addition to describing the shock and forming his own theoretical conclusions, also discussed contemporary theories by Iberian authors.¹

João Antonio da Costa e Andrade (b. 1702) stated that subterranean caverns are filled with combustible materials that on being ignited produce fires and vapors that force their way to freedom and in the process shake the earth.²

Moreira de Mendonça also mentioned the Investigação das causas proximas do terremoto, succedido em Lisboa no anno de 17¹¹₁55 of José Alvares da Silva, who listed several natural causes including inflammable subterranean materials and electricity.³ José Xavier de Valadares e Sousa had written that

¹Kendrick (see above, p. 6, n. 24) relied on Moreira de Mendonça for materials in the portion of his book (pp. 56-71) that dealt with the theoretical aspects. Hereinafter, the primary Moreira de Mendonça references are indicated, and a Kendrick citation is added for additional information beyond the Historia universal dos terremotos que tem havido no mundo, de que ha noticia, desde a sua creação até o seculo presente. Com huma narraçam individual do terremoto do primeiro de novembro de 1755., e noticia verdadeira dos seus effeitos em Lisboa, todo Portugal, Algarves, e mais partes da Europa, Africa, e América, aonde se estendeu: e huma dissertação phisica sobre as causas geraes dos terremotos, seus effeitos, differenças, e prognosticos; e as particulares do ultimo (Lisboa: Na Offic. de Antonio Vicente da Silva, 1758).

²Costa e Andrade, Conversação erudita, discurso familiar conferencias asceticas, historicas, politicas, e philosophicas (Lisboa: J. da Costa Coimbra, 1756), p. 14, as cited in Moreira de Mendonça, Historia universal dos terremotos, pp. 175-76.

³Moreira de Mendonça, Historia universal dos terremotos, pp. 176-77.

the earth's central fire is responsible for earth tremors.⁴ Veríssimo Antônio de Moreira de Mendonça (d. 1756), the brother of Joaquim José, in a dissertation on the Portuguese earthquake also credited subterrestrial fire as the source of the temblor.⁵

But the author of Historia universal dos terremotos did not exactly agree with his brother's explanation. Instead, he concurred with the view of Francisco Martinez Moles, of the Universidade de Alcalá, who theorized that underground fires act on water to generate steam.⁶ For Moreira de Mendonça, the flames created by spontaneous combustion or fermentation act on the waters of the earth to produce explosive effects powerful enough to shake the ground.⁷

Juan de Zúñiga, another of the writers referred to, emphasized the force of inflammable vapors.⁸ Francisco Mariano Nifo (1719-1803)⁹ and Padre Miguel Cabrera advocated the ancient idea of subterrestrial winds as the cause.¹⁰

⁴Ibid., p. 177.

⁵Ibid., p. 178.

⁶Ibid., p. 181.

⁷Joaquim José Moreira de Mendonça presented his theory in the section, "Causas geraes do terremotos e seus effeitos," Ibid., pp. 216-32. See also Kendrick, Lisbon Earthquake, p. 70.

⁸Moreira de Mendonça, Historia universal dos terremotos, p. 182.

⁹Ibid., pp. 182-83.

¹⁰Ibid., p. 183, and Explicacion physico-mechanica de las causas del temblor de tierra, como constan de la doctrina

Moreira de Mendonça also presented the speculative ideas in the letters of the Spanish sage Benito Jerónimo Feijóo y Montenegro (1676-1764).¹¹ Feijóo first mentioned that earthquakes are created by the shrinking of the globe and the resultant cracking of the earth's crust. Later he suggested that since the Lisbon earthquake affected large areas of Europe, and since the shock had been experienced in different locations at about the same time, electricity might be the source. He suspected that electricity from deep in the earth rises and explodes inflammable vapors in underground chambers.¹²

While Portuguese and Spanish writers offered many of the same theories that their counterparts in other areas of Europe were discussing, Iberian contributions form only an aside to the principal dialogue of English and continental authors.

del principe de los philosophos Aristoteles: dada por medio de la vena cava. y sus leyes, cuyo auxilio quita el horror de sus abstractos: meditada por el R. P. Fr. Miguel Cabrera (Sevilla: Imprenta de D. Diego de S. Román y Codina en calle Colcheros, [1756]).

¹¹His letters were later published in Nuevo systema sobre la causa physica de los terremotos, explicado por los fenómenos eléctricos, y adaptado al que padeció España en primero de noviembre del año antecedente de 1755 (Puerto de Santa María: Imprenta de la Casa Real da las Cadenas, 1756). See also Moreira de Mendonça, Historia universal dos terremotos, pp. 184-86, and Kendrick, Lisbon Earthquake, pp. 61-63.

¹²Moreira de Mendonça, Historia universal dos terremotos, pp. 184-86, and Kendrick, Lisbon Earthquake, pp. 63-64.

Élie Bertrand

Several carefully elaborated theories of earthquakes appeared during the 1750's, and one of these, written following the Lisbon shock, was Memoires historiques et physiques sur les tremblemens de terre by Élie Bertrand (1712-1790),¹³ a Swiss clergyman and naturalist. At the beginning of his remarks, the author stated the guiding principle for his study: the investigator must first assemble all of the facts about the subject without regard to preconceived ideas that may prove to be misconceptions. Following his creed, Bertrand recounted a wealth of information about Swiss shocks that he had assembled from printed and manuscript chronicles as well as from various works of history and natural history. For the future, he called for every country to keep continuous and detailed records of earth tremors. This data would provide later students with the facts they need for their work of furthering knowledge about the shaking earth.¹⁴

He recognized that part of the difficulty in finding an adequate explanation of earth movements came from the great variety of phenomena associated with them and with the

¹³(La Haye: Chez Pierre Gosse, Junior, 1757.) (Hereinafter referred to as Memoires.)

¹⁴Bertrand, Memoires, pp. 21-23. The largest section of his book is the chapter "Relation chronologique des tremblemens de terre, qu'on a ressenti dans la Suisse, depuis le VI. siècle jusqu'a nos jours: . . ." (pp. 22-102), and three chapters on the Lisbon earthquake as it was felt in Switzerland (pp. 103-68).

multitude of different circumstances surrounding their appearance. The problem is compounded, the author complained, by the incomplete information about many shocks and by man's limited knowledge of the earth's inaccessible interior.¹⁵

The multiformity of the phenomenon had posed a problem for those who tried to make one cause explain every example, but for Bertrand the variety of earthquake-types is one of the important details about the subject. There are local tremors that affect only small parcels of land, and there are general ones that shake the earth over a range of a thousand miles. Some are accompanied by eruptions of dust, others of water, and still others of fire and cinders; some earth movements occur without anything being ejected at all. The ground either trembles in a regular undulatory vibration, or it is shaken by an irregular motion. Seeking one cause, considering the diverse character of earthquakes, is forcing nature, Bertrand stated, into a mold that simply does not fit. As the naturalist assembles his information, he becomes aware that several hypotheses are required, for different earthquakes have different explanations.¹⁶

Bertrand on Fire and Air Theories

One variety of the shocks comes from the earth's fire and heat, for the planet contains great quantities of

¹⁵Bertrand, Memoires, pp. 169-70.

¹⁶Ibid., pp. 171-72.

effervescent and inflammable materials: sulphur, nitre, iron, bitumen, and pyrites. Earthquake-prone countries, such as Peru and Chile, have ample supplies of all the necessary ingredients used in L  mery's experiments, and there are still other combinations of substances that produce the same explosive effects.¹⁷ The resulting fires dilate the air trapped inside the earth until it builds up enough force to break the imprisoning chamber. The severity of the shock depends on the amount of air that is released and its velocity.¹⁸ Thus, to some extent, the ancient idea of subterranean winds is valid, since the explosive movement of air can cause local shocks. But this cause is not responsible for major jolts because of the small amount of air under the surface (as indicated by the need to force air down to miners working deep in the earth).¹⁹

Bertrand discussed Stephen Hales's theory that the atmosphere sometimes becomes charged with sulphureous vapors that mix with the air to create lightning-like explosions to shake the earth. While he did not want to reject any possible source, Bertrand concluded that Hales's explanation cannot be generally true in accounting for most earthquakes, for a number of shocks have taken place after rain or windstorms have dispersed any exhalations. He suggested that

¹⁷Ibid., pp. 176-82, 185.

¹⁸Ibid., pp. 195-96.

¹⁹Ibid., pp. 196-202.

Hales may have intended it only to explain limited earthquakes that affect the surface of the earth.²⁰

The Swiss naturalist next pointed to another aspect of subterrestrial air with the astonishing force necessary to rock parts of the earth--the "élasticité de l'air"--a subject that had been explored by Robert Boyle (1627-1691), Willem Jacob van's Gravesande (1688-1742), Petrus van Musschenbroek and Abbé Jean Antoine Nollet.²¹ Bertrand was impressed by the great force of air that is released when gunpowder and fulminating powder are fired. He recounted a story about a destructive explosion in an apothecary shop that not only destroyed the store but also caused as much damage to the village as if it had suffered an earthquake.²²

Turning his remarks more directly to the subject of earthquakes and the elasticity of the air, Bertrand resurrected the concept of subterranean air pressure, a topic that had lain dormant since Guillaume Amontons' "Memoire" of more than half a century before. The atmosphere at the surface of the earth is greatly compressed by the weight of the air above. Robert Boyle had been able to rarify air 10,000 times, while Jean Théophile Desaguliers (1683-1744) had achieved a rarefaction of 30,000 times less sea-level pressure. Newton had calculated that at a height of seventy-six miles the

²⁰Ibid., pp. 190-95.

²¹Ibid., pp. 203-5.

²²Ibid., pp. 208-11.

atmosphere is nearly a million times less dense than at the level of the sea.²³ All of these experiments and calculations showed that the air at the earth's surface is greatly condensed, and implied that the subsurface atmosphere must be even more compressed--like a strong spring--and capable of an extremely violent expansion when released. Bertrand concluded that the catastrophic explosion of dense, elastic subterranean air as the result of the action of inflamed materials is a major source of earthquakes.²⁴

Antoine Léonard Thomas had also considered the highly compressed state of air inside the earth. Since he did not think that the burning substances alone are able to explain the great effects observed in earthquakes, he theorized that the flaming pyrites and other burning minerals act as the means of freeing the elasticity of the very dense air. His view was supported by the experiments of Petrus van Musschenbroek, Denis Papin, and Friedrich Hoffmann (1660-1742).²⁵

Both Thomas and Bertrand knew that water is an incompressible fluid, and thus, both added the point that the subterranean waters so effectively increase the resistance of underground structures to the force of dilated air that

²³Bertrand used the revised calculations in the fourth edition of Newton's Opticks: or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light (4th ed., corrected; London: Printed for William Innys, 1730), p. 342.

²⁴Bertrand, Memoires, pp. 205-7, 212-14, 215-17.

²⁵Thomas, "Memoire," pp. 348-50, 354.

the imprisoned air builds up greater pressures than would otherwise be possible.²⁶ Using this argument, Thomas explained why coastal areas with an abundance of subsurface water are more frequently subjected to shocks than interior land areas. The abundance of water in maritime regions helps contain the vapors until they reach such an explosive force that the earth is shaken destructively. Otherwise, in areas less supplied with water, the dilated air created by burning materials finds it easier to pass to the surface without violence.²⁷ Thus, Frézier's observation about the distribution of earthquakes over the earth has a new explanation.

Similar arguments also demonstrate why earthquakes are more common in the autumn, winter, and spring, as well as in the morning and evening hours. Thomas called these the most rainy seasons and hours, and the added moisture creates greater resistance for the interior atmosphere to overcome. The spring-of-the-air then builds to the breaking point of the confining cavern. Thomas was aware that one of the great earthquakes of ancient times occurred in the summer, but he suggested that the weather was probably humid and rainy; just as the hot climate of earthquake-ridden Peru is also very wet.²⁸

²⁶Ibid., pp. 354-56, and Bertrand, Memoires, pp. 225-26.

²⁷Thomas, "Memoire," pp. 354-56.

²⁸Ibid., pp. 357-58.

Thomas and Bertrand were in agreement as to one major source of earth tremors--the action of fire on strictly confined and highly compressed air in the earth. While in Thomas's theory subterranean water plays a significant role as a means of restricting the vapors, Bertrand went further in theorizing additional major parts for masses of underground water to play.

Bertrand on Subterranean-Water Theories

In regard to the commonly-held notion that the interior of the earth is usually filled with water, Bertrand remarked that if the movement of the waters in caverns, tunnels, and springs were accidentally blocked in their normal course by some obstacle, the accumulated waters would then build up enough force to destroy the obstruction and thereby shake the land. Earthquakes often happen during or after dry seasons, indicating that much of the earth's moisture is confined under the surface and setting the stage for moving underground waters to shake the earth.²⁹ A second way shocks are created is through a subterrestrial explosion imparting to these waters a wave-like movement. This undulatory motion was observed in earthquakes that struck Lima and Lisbon.³⁰

For a third explanation, he speculated that waters filling caverns and tunnels are disturbed whenever the earth's

²⁹Bertrand, Memoires, pp. 218-20.

³⁰Ibid., p. 220.

rotation or revolution is accelerated or retarded. Since the mass of water cannot immediately adjust to these changes, they acquire an undulatory movement, and waves striking cavern walls rock the land above. Earthquakes created in this manner are usually detected as east-to-west or west-to-east waves of the earth's surface, although the geography of the underground cavities can reflect the agitated waters so as to send the waves in other directions.³¹

Bertrand also wrote that since water when heated to a vapor increases its volume thirteen- to fourteen-thousand times, without space for expansion, steam is able to produce great earth movements.³² In listing the many roles that water plays, he pointed out again that it is one of the necessary ingredients for inflaming and effervescing pyrites as indicated by L  mery.³³

Bertrand's Theory

In the Memoires, the writer demonstrated that various subterranean forces are involved in earth-jolting activities. He agreed with Abb   Nollet that since the effects of some earthquakes appear to be greater than any one source, more than a single cause may be at work to produce a shock.³⁴

³¹Ibid., pp. 221-22.

³²Ibid., pp. 227-29.

³³Ibid., p. 223.

³⁴Ibid., pp. 231-34. See also Nollet, Le  ons de physique exp  rimentale (Paris: Chez les Fr  res Gu  rin, 1748), IV, 95-96.

In examining Bertrand's essay, two aspects of his study are most significant: first, his extensive collection of earthquake phenomena, and second, his familiarity with previous theories, particularly the recent ideas of Thomas. While the Swiss naturalist did assemble a great amount of information, his theoretical opinions were guided by borrowed ideas, and he did not rely so much on the facts alone as his introductory remarks would indicate. The idea that a variety of explanations (and in some cases multiple causes) are needed to explain the origins of earthquakes is the only concept that can be said to have been derived from the facts he had carefully gathered. The assembled data served more to illustrate the reasonableness of a variety of views about the nature of earthquakes. The information did not lead to the formulation of any revolutionary explanation, but it was valuable in impressively demonstrating that many theories together are required in the total effort of accounting for all earthquakes. Bertrand is the most prominent proponent of the multiple-cause idea--one that was very common among the continental authors, as compared to the general absence of such a concept among the English writers, especially the electricians.

Johann Gottlob Lehmann

Another commentator from the period just after the Lisbon shock who discussed earthquakes in terms of multiple

causes was Johann Gottlob Lehmann (d. 1767), a teacher of mineralogy and mining at Berlin. He was also one of the few Germans to contribute to the literature on earthquakes, although even in this instance, the original work³⁵ was less often referred to compared with the French edition³⁶ containing critical notes by the translator, Baron d'Holbach, later the Encyclopédie's authority on earthquakes.³⁷

Lehmann considered subterranean fire the most common cause of ordinary earthquakes. He gave the standard explanation,³⁸ adding that inflamed pyrites ignite coal and other materials to sustain the internal fires of the earth.³⁹ Tremors occur when the pressure of the enclosed fires and vapors becomes greater than the strength of the surrounding rocks.⁴⁰ The writer also noted briefly the increased effects

³⁵Physicalisch Gedancken von denen Ursachen derer Erdbeben und deren Fortpflantzung unter der Erden (Berlin: C. A. Lange, 1757).

³⁶Considérations physiques sur les causes des tremblemens de terre, et de leur propagation; ouvrage fondé sur la structure intérieure de la terre in Essai d'une histoire naturelle de couches de la terre, dans lequel on traite de leur formation, de leur situation, des minéraux, des métaux, & des fossiles qu'elles contiennent: avec des considérations physiques sur les causes des tremblemens de terre & de leur propagation, Vol. III of Traité de physique, d'histoire naturelle, de mineralogie et de métallurgie (Paris: Chez Jean-Thomas Hérisant, 1759). (Hereinafter referred to as Considérations physiques.)

³⁷See above, p. 52, n. 8, and p. 137.

³⁸Lehmann, Considérations physiques, pp. 426-30.

³⁹Ibid., pp. 432-34, 438-43. ⁴⁰Ibid., pp. 445-46.

of fire when water is added, especially if it is sea water, since, as chefs had long known, salt increases the heat of a cooking fire.⁴¹ At this point in the French edition, Holbach interjected a note stating that he felt Lehmann had not given enough credit to water, for when it comes into sudden contact with subterranean fires, the effect is an explosion of steam. For an example of the force involved, Holbach cited a foundry accident in which water falls on molten metal to create a concussion greater than that of gunpowder. He also added that a cook in trying to put out a grease fire with water runs the risk of setting his house ablaze.⁴²

Lehmann did cite water as a factor in dissolving earth and stone to cause parts of the land to collapse.⁴³ After fire and after the undermining efforts of water, the author listed subterrestrial air as a third source of earthquakes. The air is not only necessary for the creation and maintenance of the fires, but it is also able to split rocks by means of the great pressures found underground.⁴⁴

The remainder of his contribution consists of miscellaneous answers to some of the ancillary problems that plagued

⁴¹Ibid., p. 446.

⁴²Ibid., pp. 446-47, n. *. The foundry-accident example had been used by Thomas ("Memoire," p. 357), and it would continue to be cited by writers to illustrate the explosive power of the instant creation of steam.

⁴³Lehmann, Considérations physiques, pp. 455-57.

⁴⁴Ibid., pp. 447-49.

investigators. The noise that precedes and accompanies a shock has several possible sources: fire splitting rocks, air escaping through vents, parts of the earth's subsurface structure collapsing, or the movement of subterranean waters.⁴⁵ The ground is raised in some shocks because of the expansive force of fires and vapors; in other cases, parts of the earth sink when the supporting pillars and arches collapse.⁴⁶ The swelling and agitation of waters comes from subterranean air finding an exit under the seas, rivers, and lakes.⁴⁷

The author attacked the old question of why some places suffer more than other locations. Lister had limited earthquakes to areas possessing caverns and supplies of pyrites, Woodward had defined earthquake-prone areas as mountainous regions, and Frézier, Thomas, and Bertrand indicated that maritime regions are more likely than other areas to suffer major earthquakes.⁴⁸ Lehmann concluded that the places most affected are located on unsteady foundations composed of calcareous strata and broken rocks.⁴⁹ But Holbach pointed out that while some earthquake-susceptible places like Italy and Sicily do have a loose surface composed of the debris from volcanoes, Lehmann's view of this subject is in direct

⁴⁵Ibid., pp. 461-62.

⁴⁶Ibid., pp. 462-63.

⁴⁷Ibid.

⁴⁸See above, pp. 25, 41-42, 63, 162-63.

⁴⁹Lehmann, Considérations physiques, pp. 465-66.

opposition to one of the other principles stated in the text: the earthquake shock is strongest where the earth offers the greatest resistance to the expansive forces of fire and air (Woodward's idea). Since a porous surface of broken rock does not offer resistance, the countries suffering most, according to Holbach, are those having the most combustible materials below the surface.⁵⁰

John Michell

Both Bertrand and Lehmann, as typical continental authors, worked with a multiple-cause hypothesis. Meanwhile, in England a theorist had developed a detailed explanation using a single cause--one that has so impressed modern historians that the name John Michell has become synonymous with the study of earthquakes in the Enlightenment. Such an impressive evaluation deserves critical analysis.

In 1760, in a paper delivered to the Royal Society of London, John Michell (1724-1793), Fellow of Queen's College, Cambridge and soon to become Woodwardian Professor, presented one of the most detailed earthquake treatises of the eighteenth century.⁵¹ He felt that the idea of underground explosions

⁵⁰Ibid., pp. 444-45, n. *, pp. 465-66.

⁵¹"Conjectures Concerning the Cause, and Observations upon the Phaenomena 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," Philosophical Transactions of the Royal Society of London, LI, Pt. II (1760), 566-634. This work was also

had not been explored in sufficient detail, and since the Lisbon earthquake provided the needed additional information, it was now time to take a more extensive look at the old hypothesis.⁵²

Although Michell ignored the electrical explanation, he did begin his detailed investigation by rejecting the idea that the source of the shocks is in the atmosphere. Since the airquake theory requires explosive vapors to accumulate in the air during calm weather, the thesis fails in the face of evidence that some shocks had occurred during periods of high winds.⁵³ In his new theory the absence of a correlation in meteorological phenomena is unimportant, for earthquakes are created below the surface.⁵⁴

Michell hypothesized that the cause is subterranean fire--more specifically, the explosive creation of steam when

published separately: (London: n.p., 1760). (Hereinafter, references will be to the Philosophical Transactions edition as "Conjectures.")

⁵²Michell, "Conjectures," pp. 566-67.

⁵³Ibid., p. 567. Michell cited as one example a pair of shocks in Sicily. See "An Account of the Earthquakes in Sicilia, on the Ninth and Eleventh of January, 1692/3. Translated from an Italian Letter Wrote from Sicily by the Noble Vincentius Bonajutus, and Communicated to the Royal Society by the Learned Marcellus Malpighius, Physician to His Present Holiness," Philosophical Transactions of the Royal Society of London, XVIII, No. 207 (1693/94), 2-10.

⁵⁴Michell, "Conjectures," pp. 567-69. For any connection between earthquakes and the state of the atmosphere, the subterranean forces producing the shock are responsible for the effects observed in the air. Ibid.

large quantities of water are brought into contact with the internal fires of the earth.⁵⁵ He believed "with great probability" that the same fires that are involved in volcanoes also shake the earth.⁵⁶ The fires can be viewed as either creating volcanic eruptions (an event that is sometimes accompanied by a violent shock that is called an earthquake), or they can form a wide-spread tremor not accompanied by any evidence of volcanic activity. He stated, as had others (Woodward and Hartop, for example), that after a volcano becomes active, major shocks in its vicinity cease.⁵⁷

There are supplies of fires in certain regions of the world, and these areas are usually marked by groups of volcanoes. For instance, the Azores has at least forty of the burning mountains, and southern Italy has four of them grouped together. These regions are also the locations of frequent earthquake activity.⁵⁸

⁵⁵Michell, "Conjectures," p. 569.

⁵⁶Ibid., p. 579.

⁵⁷Ibid., pp. 577, 579-80. Michell used for an example St. Christophers, a Caribbean island that had been plagued by earthquakes until a volcanic eruption and continuing volcanic activity had resulted in a steady decline in earthquake activity. ["A Letter from a Gentleman in Jamaica, to His Friend in London, Dated July 3d. 1693,"] Letter No. 8 in "A Letter from Hans Sloane, M.D. and S.R.S. with Several Accounts of the Earthquakes in Peru October the 20th. 1687. and at Jamaica, February 19th. 1687/8. and June the 7th. 1692," Philosophical Transactions of the Royal Society of London, XVIII, No. 209 (1694), 99-100.

⁵⁸Michell, "Conjectures," pp. 581-82.

The Evidence

Michell listed five important pieces of information about earthquakes that provided supporting evidence for his subterranean-fire-and-steam theory. First, earthquakes recur at the same location after either short or long intervals of time. In South America, the city of Lima received 451 shocks in one period of about four months. The capital had experienced sixteen major jolts between 1582 and 1746, and was almost totally destroyed twice in one sixty year period.⁵⁹ The author recognized a "striking" resemblance between the repetition of volcanoes and earthquakes. He explained that the dangerous fires last for ages under the surface, causing either occasional volcanic eruptions or periodic earth movements.⁶⁰

To explain the intermittent return of earthquakes, Michell theorized that the introduction of great quantities of water extinguishes a large part of the fire and cools the molten materials. It takes an indefinite period of time for the fire to recoup its power to produce disastrous effects again. But the shocks continue to make return performances in the same places until the combustible materials are exhausted, or until they find release in an active volcano.⁶¹

His first postulate is closely tied to the second major fact: the areas suffering most from frequent earthquakes are

⁵⁹Ibid., pp. 569-70.

⁶⁰Ibid., pp. 588-89.

⁶¹Ibid., pp. 614-15.

also the regions of volcanic activity. The western coast of South America experiences more shocks than any other place, and it also has the most volcanoes.⁶² For Michell this fact demonstrates that both have the same cause, subterrestrial fires. The theory depends on Michell's picture of the stratified structure of the earth: one extensive stratum can extend from high in the mountains down to a level under continental plains, and down even deeper under the floor of the sea. Thus, the layer containing combustible materials that creates volcanoes at mountain summits is also located under lower land areas and below the ocean where major earthquakes are often centered.⁶³ Not all of a combustible stratum is on fire at the same time because of differences in the "richness" of the inflammable materials available and the variable water content of different parts of the earth at a given time.⁶⁴

The fire-bearing stratum in the mountains creates volcanoes, and the vapors erupting from a volcano are capable of shaking the land for a distance of twenty miles. But in the same layer at lower levels, the steam and vapors cannot find natural vents through the earth for safely discharging the exhalations; thus, the pressure must be released by an earth-

⁶²Ibid., p. 571.

⁶³Ibid., pp. 584-86, 589-92.

⁶⁴Ibid., p. 592, n. *.

quake. The theory explains why the greatest shocks originate below lower land areas or under the sea, and not in mountainous, volcanic regions.⁶⁵ The great jolts that destroyed Lima in 1746 and Lisbon in 1755 originated under the ocean as indicated by the great waves of water that struck both coastal cities.⁶⁶

Third, Michell pointed out that the motion of an earth movement can be "tremulous," or the shock can be propagated for miles by a sea-wave form of motion in which the ground successively rises and falls.⁶⁷ In theory, the immediate cause of an earthquake is the quick and violent effect of steam generated from water suddenly coming into contact with fire, and this idea is able to explain both the tremulous and the wave-like motions. As for the first type, he stated that if the roof over a deep cavern filled with burning materials collapses, all of the water in fissures and cavities of the earth above comes into contact with the fire, and the water almost instantly becomes steam. A new roof falls into place over the cavern, and the part of the earth overhead oscillates with dilations and compressions as the new roof adjusts to its role of supporting the weight of the land above, producing a tremulous vibration that is transmitted to the surface. The noise of rocks grating together, along with

⁶⁵Ibid., pp. 592-93.

⁶⁶Ibid., p. 593.

⁶⁷Ibid., pp. 571-72.

the effects of the vibratory motion of the ground on the atmosphere at the surface, are responsible for the noise that accompanies an earth shock.⁶⁸

The propagation of a ground wave is also due to the sudden generation of steam. The wave-like motion can be easily demonstrated, the author suggested, by raising one edge of a carpet and suddenly bringing it down to the floor. The trapped air passes along under the carpet until it exits at the other side. In the earth there is little cohesion between the horizontal layers of strata; thus, when a large quantity of steam is suddenly formed, it passes between the layers of the earth, raising and lowering the land. The wave continues until the vapors find a vent to the surface, or until the steam is condensed back into water as it reaches colder regions. If there are sufficient supplies of water, and if the fires are great enough, a large quantity of vapors continues to be generated, and several waves are produced. The ground rises most close to the steam's source, but at a distance the earth moves so imperceptibly that the passing event is noticed only by a motion of chandeliers or an otherwise inexplicable agitation of lakes and rivers.⁶⁹

Fourth, in an area that suffers frequent shocks, they always come from the same direction and at the same velocity.

⁶⁸Ibid., pp. 594-99.

⁶⁹Ibid., pp. 583-84, 599-601.

The compass bearing and speed is different for each region of the earth. For instance, the jolt that hit Lisbon came from the northwest at the velocity of sound (as indicated by the noise and the shock arriving at about the same time). In a separate case, of five earthquakes experienced in New England, at least three were known to have come from the same direction (information about the other two shocks was uncertain), and the velocity was less than in the Lisbon example because of the interval separating the time of the arrival of the noise and the instant of the disturbance.⁷⁰ To the author, the evidence indicated that a region is shaken by steam originating from one source, although in any location a rare long-distance earthquake may be felt coming from a direction different from the usual local earth movement.⁷¹

Concerning the speed with which the tremors move, Michell theorized that the velocity of the vapor traveling between strata depends on its depth below the surface--the greater the depth, the greater the velocity.⁷² Thus, earthquakes proceeding at the same rate have come from a fire-stratum at the same depth in the earth.⁷³

Fifth, Michell pointed out that the Lisbon earthquake had been succeeded by several minor, local tremors in other

⁷⁰Ibid., pp. 573-74.

⁷¹Ibid., p. 602.

⁷²The velocity depends on the elasticity of the earth and the laws governing elastic bodies.

⁷³Michell, "Conjectures," pp. 602-3, p. 603, n. *.

parts of the world.⁷⁴ He concluded that since there are subterranean fires in different regions, one shock may lead to the collapse of part of the roof over some other fire-bearing stratum, and cause minor shaking there.⁷⁵

These five facts were singled out as being supremely important, but the author had plenty of other evidence to discuss. Concerning the production of sea-waves, such as the one at Lisbon that rose to a height of fifty feet in almost an instant, Michell proposed the following scenario. The source was under the ocean floor, and the steam produced there raised the part of the earth over the fire, causing the ocean waters above to retreat from the spot, but without creating any major disturbance. Because of the first explosion of steam, part of the roof over the fire collapsed, and the cold water from fissures above mixed with the steam. The vapors condensed to create a partial vacuum, and the earth subsided, lowering the ocean floor. The sea waters then flowed toward the new depression to cause the retreat of water from the shoreline. Meanwhile, deep in the earth the water had again become steam, and the floor of the sea rose suddenly to send a great wall of water toward the land.⁷⁶

Concerning the other great catastrophe that Michell stressed, the 1746 earthquake at Lima was accompanied by the

⁷⁴Ibid., p. 575.

⁷⁵Ibid., pp. 603-4.

⁷⁶Ibid., pp. 612-14.

appearance of four new volcanoes in the mountains above the city. The theorist explained as follows: the combustible stratum under the Pacific is extensive and at a great depth, and the roof over that layer is very strong. Thus, greater steam pressures are produced, and the vapors were forced through the stratum to higher altitudes where the strength of the superincumbent earth is less. The earth opened to release the fires and vapors to create new volcanoes.⁷⁷

The author of the "Conjectures" article did concede his inability to offer a solution for the problem of how air is supplied to the underground fires, but he was certain that the fires exist. For example, an island three leagues in diameter rose out of the sea in the Azores; it had been built from more volcanic debris than had been ejected from Mt. Etna and Mt. Vesuvius in 2,000 years. Such amounts of burning materials had existed for untold ages in the earth without any possible source of outside air.⁷⁸ Michell had chosen a difficult example to illustrate the problem, for the question of air supply had been answered by Buffon who pointed to a volcano in Indonesia that was more active during storms than in calm weather. He concluded that the volcanic fires are located not far from the mountain summit so that winds promote the fires.⁷⁹

⁷⁷Ibid., pp. 615-18.

⁷⁸Ibid., pp. 576-78.

⁷⁹Buffon, Histoire naturelle (1749), I, 508.

While Michell thought the powerful and most extensive earthquakes come from the greatest depths, he noted an exception: at extreme depths, the earth is capable of repressing the violent effects of the sudden generation of steam. In this instance, only a sudden vibratory motion is felt on the surface. He thought that some of the shocks felt in England might have been of this variety.⁸⁰

He rejected the common assessment that earthquakes are more common along coastal areas. The demolition of a few houses in a heavily populated coastal city simply stimulates more excitement, and the event becomes widely known. But an entire mountain may be overturned in a deserted part of a country where only a few shepherds may ever know about the truly massive earth movement.⁸¹

The English naturalist next sought a way of finding the exact location of the source, i.e. the "focus," of an earthquake. For this determination, accurate information from different locations is needed on the time and direction of a shock. However, Michell found that such observations were often made by persons "too little at ease" to be reliable witnesses. To add another problem, differences in the structure of the earth cause variations in the propagation of a tremor. He concluded that the greatest degree of accuracy

⁸⁰Michell, "Conjectures," pp. 624-25.

⁸¹Ibid., p. 624, n. *.

in locating the source occurs in cases where the focus is under the ocean. In these instances, the interval between the earth movement and the later arrival of the sea wave is more likely to be known, because people are presumably more accurate in determining time intervals than in noting the exact moment of a single event. By knowing the direction from which the shock-wave arrived at Lisbon, at Madeira, and in England, and from knowing the difference in times of arrival of the shock and the sea-wave (taking into account the effect of a variance in the depth of the ocean on the speed of the sea-wave), Michell determined that the Lisbon earthquake came from under the ocean floor about ten to fifteen leagues from the Portuguese coast at a latitude between Lisbon and Oporto.⁸²

While Michell knew of no method for determining the depth of the source, he did offer some conjectures as to how it might be determined if more information were available. At Lima one earthquake had been accompanied by volcanic eruptions, and by assuming that both were caused by fires in the same stratum, only the depth of that layer under the sea is needed to be known to locate the depth of the source. And if the depth were known in one case, the velocity of the steam as it travels through different depths of strata could be determined to establish a general depth/velocity relationship.⁸³

⁸²Ibid., pp. 625-27, 629-30.

⁸³Ibid., pp. 631-32.

As a "random guess," he speculated that the Lisbon earthquake had its focus between one and three miles deep beneath the sea bed.⁸⁴

John Michell, the Father of
Modern Seismology?

Michell's "Conjectures" has been viewed as a special landmark in the history of the study of earthquakes. In histories of geology, from Sir Archibald Geikie's The Founders of Geology (2nd ed.) to Charles Davison's The Founders of Seismology to Frank Dawson Adams's The Birth and Development of the Geological Sciences, Michell has been pictured (to use the words of Adams) as having "freed himself from the shackles of ancient views and traditions,"⁸⁵ and as having produced (in the words of Geikie) "by far the most important contribution on this branch of science that had yet appeared in any language or country."⁸⁶ It is not surprising that these earlier promotional efforts should be followed by a reference in a recent journal to Michell as the "Father of Seismology."⁸⁷

His contribution can be placed in a more accurate perspective. John Flamsteed, Stephen Hales, and William Stukeley

⁸⁴Ibid., p. 633.

⁸⁵Adams, Geological Sciences, p. 415.

⁸⁶Geikie, Founders of Geology, p. 274.

⁸⁷Clyde L. Hardin, "The Scientific Work of the Reverend John Michell," Annals of Science, XXII, No. 1 (1966), p. 30. See also Davison, Founders of Seismology, pp. 23-24.

all had gone farther to break the "shackles of ancient views and traditions" before Michell had appeared on the scene. While Michell's article is significant, the superlatives describing his work have come from geologists who recognized in the "Conjectures" certain valued aspects of nineteenth- and twentieth-century seismological theory. These "modern" ideas include "elastic waves," traveling through the earth, and the search for a method of finding the "epicentre" of a shock.⁸⁸ But by playing the geologist-historian's own game, it can be shown that Élie Bertrand had earlier explained the wave-like motion of earthquakes,⁸⁹ and Nicolas Cyrillus, half a century before, had determined the "epicentre" of an earthquake.⁹⁰ Although the theory turned out to be wrong, according to Davison, Michell had "rendered an important service in his attempt to give a consistent theory of the origin of earthquakes, . . ."⁹¹ Michell was among very good company when it came to providing consistent explanations, because in the 1750's alone, equally well-developed theses had been presented by Stukeley, Hales, Thomas, Lehmann, and Bertrand.

⁸⁸Davison, Founders of Seismology, pp. 23-24.

⁸⁹Bertrand, Memoires, pp. 221-22. He emphasized the waves formed by undulations of subterranean water created by changes in the motions of the planet.

⁹⁰Cyrillus, "Historia terraemotus Apuliam," pp. 81-82, and "An Account of an Earthquake in Apulia," p. 607. The pattern of destruction located the focus of the 1731 earthquake.

⁹¹Davison, Founders of Seismology, p. 24.

The atmospheric-explosion and electrical theories were vital, competing explanations of earthquakes when the "Conjectures" was printed, but since the former two ideas have no modern counterparts, they have not received the attention that Michell's more familiar views have. The purpose of this critique has been neither to indict some previous writers for their opinions, nor to take away from Michell credit as the author of a thoughtful and detailed theory of earthquakes; rather, the purpose is to show that applying labels such as "Father of Seismology" is an ineffective way to approach an understanding of the study of the shaking earth in the eighteenth century.

Earthquake Theories: 1750-1760

Michell's explanation was one of a number of ideas offered to account for the origins of earthquakes. His theory is a detailed version of the subterranean-fire-and-vapors hypothesis that had been discussed previously, and the concept would continue to be developed by others later in the century. For advocates of electricity and atmospheric explosions, the Michell thesis was of little importance, for their own explanations proved to be just as ingenious, and in their own view, more effective in demonstrating the means by which the earth is jolted. Rather than solving any problems, Michell added to the difficulties by contributing still another idea that had to be considered along with a host of

others. In 1760, the answer to the question of what causes earthquakes was more clouded than ever.

The decade of the 1750's was a destructive time for earthquakes, but it was also a very productive period for those who sought to understand one of nature's major events. The English shocks at the beginning presumably stimulated the development of the airquake and electrical explanations. The Lisbon earthquake was followed by further reevaluations of the more traditional views of subterranean fire, air, and water, and it also focused interest on another phenomenon--the propagation of earthquakes over great distances.

CHAPTER V

THEORIES ON THE PROPAGATION OF EARTHQUAKES

Following the Lisbon earthquake, investigators sought to find out how a major tremor can range over an extensive area, shaking widely separated locations almost simultaneously. The 1755 shock brought into focus a question that had lain dormant since the end of the seventeenth century.

Before Lisbon

The study of the propagation of earthquakes begins in 1685 when Robert Boyle (1627-1691), the English natural philosopher, theorized that extensive earth movements are not caused by one great explosion of subterranean exhalations, but a series of concussions occur as a fire passes through "some little subterranean clefts, or channels, or hidden conveyances, from one great cavity or mine to another; . . ."¹

Boyle's contribution is only evident to those searching for such opinions, because the transmission of shocks was a topic of limited interest in the period before 1755.

¹"An Essay of the Great Effects of Even Languid and Unheeded Motion. Whereunto Is Annexed, an Experimental Discourse of Some Little Observed Causes of the Insalubrity and Salubrity of the Air and Its Effects. [Being Part of an

In 1693, Martin Hartop cited the "furious Passage" of burning vapors from one cavern to the next as the cause of long-distance earthquakes like the one that had been felt in both Ireland and England at almost the same time.² Flamsteed accounted for the phenomenon with his aerial explosion thesis.³ In 1749, Buffon attributed the propagation to an underground wind.⁴ Stukeley and the electricians relied on their particular hypothesis to account for fast and extensive earthquakes.⁵ These few explanations sample the suggestions offered in the period through mid-century. But the situation changed after the Lisbon earthquake had violently shaken the earth over large parts of the Iberian peninsula, and over much of western Europe the shock had at least created waves in lakes and rivers. This event required a more thorough explanation than had been given previously.

Nicolas Desmarest

The year following the destruction of Lisbon, Nicolas Desmarest (1725-1815), a French naturalist with a developing

Intended Natural History of the Air.]," in The Works of the Honourable Robert Boyle (New ed.; London: Printed for W. Johnston and others, 1772), V, 14.

²"Letter from Mr. Martin Hartop," pp. 828-29. See above, p. 33.

³See above, pp. 76-79.

⁴Buffon, Histoire naturelle, I, 527-30. See above, pp. 55-56.

⁵Stukeley, Philosophy of Earthquakes, 1756 ed., Pt. III, p. 3. See above, pp. 106-7.

interest in studies of the earth's structure and history, produced a 63-page booklet: Conjectures physico-mechaniques sur la propagation des secousses dans les tremblemens de terre.⁶ He opened his work with an extensive geography lesson centered on a description of the great mountain and island chains and their branches that cover the surface of the earth.⁷ These mountain groupings, according to the author, provide the means for the transmission of a shock over the globe, since an explosion in one of the chains is communicated through the mountains to distant regions.⁸

He based his theory on three main principles. The first one postulated that the vibrations of the earth are more severe at the greatest distance from the point of origin. For example, if you shake a tree, the movement of the trunk is small, but the tree branches sweep the air.⁹ The

⁶Conjectures physico-mechaniques sur la propagation des secousses dans les tremblemens de terre, et sur la disposition des lieux qui en ont ressenti les effets (n.p.: n.p., 1756). (Hereinafter referred to as Conjectures.) The work was published anonymously.

⁷Desmarest, Conjectures, pp. 5-17. Philippe Buache (1700-1773) described these mountain chains in his "Essai de géographie physique, où l'on propose des vûes générales sur l'espèce de charpente du globe, composée des chaînes de montagnes qui traversent les mers comme les terres; avec quelques considérations particulières sur les différens bassins de la mer, & sur sa configuration intérieure," Histoire de l'Académie Royale des Sciences. Année M.DCCLII. Avec les mémoires de mathématique & de physique, pour la même année, tirés des registres de cette académie (Paris, 1756), Mémoires, pp. 399-416, map.

⁸Desmarest, Conjectures, pp. 17-19.

⁹Ibid., pp. 19.

second principle: a shock is transmitted through solid and resilient bodies, i.e. the mountains.¹⁰ And the third principle stated that any motion communicated through a line of the mountainous masses is felt only at the end of the series and not in the middle of the immovable file. To explain the last two postulates, the writer visualized a row of billiard balls; the force of the first ball hitting the second is sent down the line without displacing any of them until the last ball is detached from the others with a force nearly equal to that with which the first sphere hits the second.¹¹

In nature, the line of billiard balls is a mountain chain that receives a shock and carries it over great distances. Thus, if there is a violent concussion in the body of a mountain range, the great agitation (the first principle) is transmitted by the solidity and elasticity of the mountains (the second principle), and an earthquake is produced at the end of the branches of the chain (the third principle).¹² The author added that the shock is distributed only through the main trunks and secondary arteries composed of hard, massive, and resilient rocks, and not through those that are made up of sand, clay, and earth.¹³

Desmarest described a demonstration using a string of paving stones arranged in sand. One series of stones ended

¹⁰Ibid., p. 20.

¹¹Ibid., pp. 21-22.

¹²Ibid., pp. 22-23.

¹³Ibid., pp. 23-24.

in a quantity of Lémery's sulphur and iron paste. The mixture exploded, and the shock was transmitted through the miniature mountain range.¹⁴

For an example in nature, he explained that if the source of the explosion were in the Azores or in the Canary Islands, the concussion would be sent by way of islands and mountains to Mt. Atlas, and branches would spread the shock through northern Africa. Other routes deliver the earthquake to Portugal and Spain, as well as through France, the Netherlands, and across the channel at Calais into England. Still another European branch spreads the tremors into Switzerland. An earthquake originating in the Azores would also be communicated to the New World by still another long file.¹⁵ With this description, Desmarest had just picture the earth movements associated with the Lisbon earthquake. He believed that the motion felt in France, Germany, England, and Italy was not severe, because the shock had to travel great distances and traverse a number of branches and detours.¹⁶

Desmarest also pointed out that other theories for explaining the propagation of earthquakes are not acceptable. First, there is no observable evidence of subterranean trains of inflammable materials to distribute the shock.¹⁷ Second, steam and vapors traveling through tunnels are not able to

¹⁴Ibid., p. 25.

¹⁵Ibid., pp. 28-37.

¹⁶Ibid., p. 37.

¹⁷Ibid., pp. 42-43.

spread it, because at a distance from the source, the vapors cool and are no longer capable of shaking the earth. Furthermore, if the exhalations have an escape route and are not imprisoned, there is no earthquake. Neither fires nor vapors have been seen when severe jolts have opened up the earth.¹⁸ Third, although solid bodies are electrical conductors, mountain chains do not serve as conductors of electricity.¹⁹ And since the shocks occur in calm weather, the commotions are not transmitted by a disturbance in the air.²⁰

He discussed more of the information gathered in support of his theory. To begin with, the countries having major mountain ranges, such as Syria, Italy, and Peru, suffer the most earthquakes, and the places like Antioch, Lisbon, and Lima that lie at the end of branches repeatedly receive the most violent movements of the ground.²¹ In addition, plains are generally not affected by tremors, while nearby mountainous areas are struck.²² And finally, an earthquake produces a vibration aligned in the direction of the file of mountains that transmits the shock.²³

The vibratory motion received considerable attention from the author. Some earth movements are a simple rocking action, while others are marked by an irregular vibration.

¹⁸Ibid., pp. 43-45, 48.

²⁰Ibid., p. 47.

²²Ibid., pp. 47-48.

¹⁹Ibid., pp. 57-58.

²¹Ibid., pp. 45-46.

²³Ibid., pp. 48-49.

The difference depends on the reverberation of the shock. If a part of the earth oscillates and recovers before the next jolt arrives, then only a simple rocking is felt; otherwise a very destructive isochronous movement results. Damage also occurs when tremors arrive at the same place by way of two different branches.²⁴

The direction in which the earthquake wave is transmitted is also related to its destructiveness. If it moves, for example, from north and south and a city's streets are similarly arranged, the damage will be greater than if the pattern were east to west. This is because the wave in successively traveling along a length of a wall tears it apart more easily than when it lifts an entire wall and sets it down again in one motion.²⁵

Nicolas Desmarest's Conjectures presented a comprehensive theory to explain the propagation of earthquakes, but his ideas did not go uncriticized.

Thomas

Just as the critic Thomas had pointed out difficulties with the electrical hypothesis,²⁶ he was also dissatisfied with Desmarest's explanation, for it unrealistically requires the mountain ranges to be composed of hard materials without any sand, clay, or soft substances to interrupt the continuity.

²⁴Ibid., pp. 49-50.

²⁵Ibid., pp. 50-51.

²⁶See above, pp. 126-27.

Another problem: since mountains have their bases attached to the earth as a part of one great mass, the idea that the earth tremors are sent only through the towering masses is negated. Furthermore, since intermediate locations in the chain do receive the shock of an earthquake, nature's mountains are not like a line of billiard balls.²⁷

To replace Desmarest's theory, Thomas proposed that there are veins of combustible materials to spread the fire and explosions over great distances like a train of gunpowder. The shock itself is not transmitted; only the means of inflaming stores of subterranean materials is communicated.²⁸

Bertrand

Élie Bertrand also devoted considerable attention to the question. He remarked that since earthquakes have a number of sources, then there are also several causes of their propagation. This is especially true since Desmarest's ingenious idea alone cannot explain all long-distance earthquakes, for not all tremors have followed the mountains.²⁹

After examining the evidence, Bertrand found that since a shock can travel over mountains, plains, valleys, and seas, the propagation of the shock must not depend on the surface geography of the earth, but instead, the internal structure

²⁷Thomas, "Memoire," pp. 427-28.

²⁸Ibid., pp. 360, 428-29.

²⁹Bertrand, Memoires, pp. 310-13.

of the earth is the important factor.³⁰ Strata of inflammable materials spread earthquakes--the train of gunpowder idea.³¹ He claimed for these trails of fire the capability of reaching a speed approaching the velocity of electricity.³²

Bertrand could not find a relationship between the time of travel and the distance, but he partially attributed this to insufficiently exact observations. Furthermore, the different nature, quantity, and depth of the combustible and effervescent materials, as well as the structure of the earth, the amount of underground water, and a multitude of indefinable circumstances and variables, also affect the propagation of a shock. Thus, depending on whether the conditions are favorable or not, earthquakes from the same focus can travel great distances in an hour, or the tremor may take days to reach other locations much closer.³³

In addition to his subterranean-fire theory, Bertrand stated that air under pressure is also responsible for spreading earthquakes. An explosive blast of air moves through tunnels until it loses its power. By emphasizing the pressure of the subsurface air, he explained that the shock can be distributed over a considerable portion of the earth.³⁴ Thus, he countered Desmarest's charge that the effects of steam and

³⁰Ibid., pp. 306-7.

³¹Ibid., pp. 314-15.

³²Ibid., p. 315.

³³Ibid., pp. 308-9, 316-17.

³⁴Ibid., pp. 317-19.

heated air cannot travel over long distances. The Swiss writer also stated that waves of subterranean water in canals, conduits, and reservoirs are capable of spreading the earth movements.³⁵

There remained one specific problem that theorists had to explain. Earlier, John Ray had noted that some places are jolted by an earthquake, while others nearby are not shaken.³⁶ Bertrand suggested that some locations might not receive the tremor, because the veins of pyrites and other inflammable materials bypass these areas. For an alternative explanation, some regions have great quantities of the burning substances, while other places are blessed with small amounts. The depth of the inflamed, effervescent materials is also important in determining the effects on the land above.³⁷ Thus, the author remained true to his pattern of finding multiple causes for earthquake phenomena.

The Encyclopédie

While Bertrand had been unenthusiastic about Desmarest's mountain-chain theory and had discussed alternate views, Holbach combined the ideas to theorize that the earthquake shocks follow mountain ranges--not for the reasons that Desmarest proposed--but because subterranean cavities filled with

³⁵Ibid., pp. 220-21.

³⁶See above, pp. 39-40.

³⁷Bertrand, Memoires, pp. 307-8.

inflammable materials located under the mountains spread the shock.³⁸ The same explanation was supported in the nouvelle édition of the Encyclopédie in an article by Abbé Henri Montignot (ca. 1715-179?) on the Lisbon earthquake.³⁹

Propagation Theories after Lisbon

In summary, just as there was no agreement as to the cause of earthquakes, in the discussions following the Lisbon disaster, there was no unanimity of opinion as how best to explain the propagation of major earthquakes. Various authors rose to the occasion to show that their respective hypotheses are quite adequate in accounting for the wide-spread event. The subterranean-fire enthusiasts appear less secure in their ideas, and they spent proportionally greater efforts to present their case. Meanwhile, the confident electricians presumably assumed that everyone was already well aware of the almost instantaneous transmission of an electric shock as the obvious answer to the problem of the sudden and distant

³⁸Holbach, "Tremblemens de terre," p. 582. For the same reasons, Woodward had stated that earthquakes are concentrated in mountainous areas. See above, pp. 41-42.

³⁹"Tremblemens de terre. (Phys.) La nature de cet ouvrage, & l'utilité générale qui est le principal but des nouveaux éditeurs, les engage à insérer ici la lettre que M. l'abbé Montignot, chanoine de Toul, a écrite à l'auteur du Mercure sur le tremblement de terre arrivé à Lisbonne en 1755," Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres. Mis en ordre & publié par M. Diderot; & quant à la partie mathématique, par M. d'Alembert (Geneve: Chez Pellet, Imprimeur-Libraire, 1778), XXXIV, 75-79.

propagation of a tremor. The one who worked the hardest to establish his theory was the person with the most novel hypothesis, Desmarest. He did succeed in obtaining for his mountain-chain concept an audience, and although it was not adopted as the explanation, his idea was valued enough to be borrowed (in part or in a modified form) by Bertrand, Holbach, and Montignot.

CHAPTER VI

EARTHQUAKE THEORIES AND THE CALABRIAN

EARTHQUAKES OF 1783

After the London earthquakes of 1750, both the air-quake and the electrical theories were introduced. The destruction of Lisbon was followed by further theoretical inquiries, especially from those who sought to explain the propagation of major shocks over vast areas of the earth. The last great event of the eighteenth century to stimulate additional earthquake studies was not one tremendous earth movement but a series of tremors that struck Calabria throughout the first half of the year 1783.¹

The Observers

British geologist Charles Lyell (1797-1875) in the first volume of his Principles of Geology (1830)² looked to the 1700's for reliable accounts of major alterations in the

¹The many shocks, both intense and insignificant ones, were all generally regarded as part of one event, and they were often referred to collectively as the Calabrian earthquake of 1783.

²Principles of Geology, Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation ([3 vols.]; London: John Murray, 1830-33.

earth's surface, and he found that only the investigators of the Calabrian shocks provided a full record of the effects of earthquakes.³ He cited a number of useful works such as that of Francesco Antonio Grimaldi (1741-1783), of the Naples government, who surveyed in detail the affected area and produced the Descrizione de tremuoti accaduti nelle Calabrie nel 1783.⁴ The Reale Accademia delle Scienze, e delle Belle Lettere di Napoli sent an expedition to further examine the region. Its artists recorded observations, and the published illustrations⁵ provided a number of the drawings in Lyell's book.⁶ In England, the Royal Society of London published a description by Count Francesco Ippolito.⁷

Domenico Pignataro, a Monteleone physician, kept records that included weather conditions and a classification of the strength of each shock: "violenta," "fortissima," "forte," "leggiere," or "sensibile." This information for the period of

³Ibid., I, 412.

⁴Ibid., I, 413. Grimaldi's work was published posthumously: (Napoli: G. M. Porcelli, 1784).

⁵Reproduced in Istoria de' fenomeni del tremoto avvenuto nelle Calabrie, e nel Valdemone nell' anno 1783 posta in luce dalla Reale Accademia delle Scienze, e della Belle Lettere di Napoli (Napoli: Presso G. Campo, 1784).

⁶Lyell, Principles of Geology, I, 413, passim.

⁷"Account of the Earthquake Which Happened in Calabria, March 28, 1783. In a Letter from Count Francesco Ippolito to Sir William Hamilton, Knight of the Bath, F.R.S.; Presented by Sir William Hamilton," Philosophical Transactions of the Royal Society of London, LXXIII, Pt. I (1783), 209-16.

February through August was printed⁸ at the end of Giovanni Vivenzio's Istoria e teoria de' tremuoti.⁹ The Istoria also included a "Giornale meteorologica" listing barometer and thermometer readings, wind data, as well as remarks on the general state of the weather in the region during the period of earthquakes.¹⁰ In addition, Vivenzio's book also presented a town-by-town list of fatalities and the damage done by the tremors in the early part of the year.¹¹

With the Calabrian earthquakes came an effort to devise instruments for measuring earthquakes. A Neapolitan clock-maker, D. Domenico Salsano, made a "geo-sismometro" consisting of a pendulum with brush and ink attached to the weight so as to mark the motions caused by an earth movement.¹² And Antanagio Cavalli wrote that a bowl filled with mercury will

⁸"Giornale delle scosse di tremuoto avvenute nella Calabria Ulteriore, e specialmente avvertite nella città di Monteleone," pp. 21-28.

⁹Istoria e teoria de' tremuoti in generale ed in particolare di quelli della Calabria, e di Messina del MDCCLXXXIII (Napoli: Nella Stamperia Regale, 1783). (Hereinafter referred to as Istoria.)

¹⁰"Giornale meteorologica," Ibid., pp. 29-48.

¹¹"Indice generale de' paesi di Calabria Ulteriore del loro stato, de' viventi prima de' tremuoti de' febbrajo, e marzo 1783, e di' morti per cagion delle rovine," Ibid., pp. 1-15.

¹²Salsano, "Descrizione di un geo-sismometro o sia misuraterremoto," Nouvo giornale enciclopedico, novembre 1783 (Vicenza, 1783), pp. 89-95, cited in James Dewey and Perry Byerly, "The Early History of Seismometry (to 1900)," Bulletin of the Seismological Society of America, LIX (1969), 186. (Hereinafter referred to as Dewey, "Seismometry.")

be spilled by the shock to indicate the direction and relative strength of the motion.¹³ Both instruments were reinventions. Early in the century, instrument maker Jean de Hautefeuille (1647-1724) described the bowl of mercury,¹⁴ and it was again mentioned in 1773.¹⁵ The use of a pendulum was recommended by Nicolas Cyrillus¹⁶ and Andrea Bina.¹⁷ But earthquake-indicating instruments were unimportant in the 1700's, for the severity and general orientation of an earth movement was information that could be determined by observers without special apparatus. Swinging chandeliers and spilled wine glasses were sufficient for most reporters.

The Theorists

One result of the interest shown by individuals and academies in the Calabrian earthquakes was the accumulation

¹³Lettere meteorologiche romane dell' abate Atanagio Cavalli (Roma: Stamperia Pagliarini, 1785), cited in Dewey, "Seismometry," p. 186.

¹⁴Antonio Favaro, "Contribuzioni alla storia della microsismologia," Atti del Istituto Veneto dei Scienze, Lettere ed Arti, ser. 6, II (1884), 91-103, cited in Dewey, "Seismometry," pp. 184-85.

¹⁵"Methode pour déterminer la force & la direction des tremblemens de terre, par M. Wark, Ministre à Haddington," Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. Le Comte d'Artois, par M. l'abbé Rozier, I (1773), 376. From the 1784 edition: (Paris: Au Bureau du Journal de physique).

¹⁶Cyrillus, "Historia terraemotus Apuliam," pp. 81-82, and "An Account of an Earthquake in Apulia," pp. 607-8.

¹⁷Bina, Ragionamento, p. 46, cited in Dewey, "Seismometry," p. 185.

of additional facts about the shaking earth, but of more importance here is the work of those who not only collected data but used that information to reinforce commitments to particular hypotheses or to make new attempts at determining the source of earthquakes.

Giovanni Vivenzio

Vivenzio, physician to the Neapolitan court, not only collected facts for his Istoria, he also explained that electricity through its ability to cover large areas of the earth in very short periods of time is the only reasonable source of the shocks.¹⁸ The electrical fluid accumulates in one area, and since the laws of equilibrium apply to all fluids, there must be an action to reestablish an even distribution, even though obstructions have to be broken in the process. The amount of electricity, the depths involved, and the obstacles that must be overcome determine the violence of an earthquake.¹⁹ Thus, Vivenzio established electricity as the earth-breaking force, but other authors held different views.

Sir William Hamilton

Sir William Hamilton (1730-1803), who was best known for his investigation of volcanoes,²⁰ spent twenty days on a

¹⁸Vivenzio, Istoria, pp. lxxxi-xcix.

¹⁹Ibid., pp. cviii-xciv.

²⁰See Observations on Mount Vesuvius, Mount Etna, and Other Volcanos: In a Series of Letters, Addressed to the

tour of Calabria to examine the scene and to collect the reports of various observers. In a letter to the Royal Society of London, Hamilton discussed the phenomena that had accompanied the earthquakes, and he offered an explanation for each.²¹

One example concerned the accounts of rivers drying up suddenly, only to have the waters return, overflowing their banks. Hamilton suggested that on receiving the jolt, the surface of the earth was raised, and the water disappeared into the riverbed. When the land returned to its normal level, the river waters reappeared. The overflow was caused by additional water in the ground below and around the river being forced to the surface.²²

He also explained how one piece of real estate (about a mile long and half a mile wide) planted in olive and mulberry

Royal Society, from the Honourable Sir W. Hamilton, . . . To Which Are Added, Explanatory Notes by the Author, Hitherto Unpublished (London: Printed for T. Cadell, 1772). Other editions followed in 1773 and 1774.

²¹"An Account of the Earthquakes Which Happened in Italy, from February to May 1783. By Sir William Hamilton, Knight of the Bath, F.R.S.; in a Letter to Sir Joseph Banks, Bart. P.R.S.," Philosophical Transactions of the Royal Society of London, LXXIII, Pt. I (1783), 169-208. The work was also published separately: (London: Printed by J. Nicholas, 1783). (Hereinafter, references are to the Philosophical Transactions edited as "Account.")

Hamilton returned to London not long after he had sent the letter to Banks. Horace Walpole noted his return: "He will not be quite out of his element, for we have had pigmy earthquakes, much havoc by lightning, and some very respectable meteors." (Letter from Horace Walpole to Horace Mann, August 27, 1783, Walpole's Correspondence, XXV, 427.)

²²Hamilton, "Account," p. 180.

trees was moved about a mile down a valley without even overturning many of the trees. Before the shock, the surface of the earth had probably been undermined by runoff water. The earthquake released deposits of rainwater in the hills around the land so that this water by passing under the land lifted and flowed it down the valley.²³

Concerning the reports of fires issuing from the earth, Hamilton could find no evidence of volcanic matter in the vicinity of any fissures, and he concluded that the accounts of fires must have been sightings of electrical fire.²⁴ This explanation at first suggests that the author might be an advocate of the electrical hypothesis, but he was not. For him, earthquakes are caused by the same inflammable materials that are responsible for volcanoes.²⁵ The events in Calabria were caused by either activity prefatory to the creation of a new volcanic island (since the noise accompanying the shocks came from off the coast towards Stromboli),²⁶ or the tremors resulted from volcanic fires and vapors under parts of the Italian peninsula (because the center of the earthquake destruction was within a twenty-two mile radius of Oppido).²⁷

Hamilton stated that of two towns located at an equal distance from the center of the shocks, the one at the highest

²³Ibid., pp. 171, 182-83.

²⁴Ibid., p. 194.

²⁵Ibid., p. 174.

²⁶Ibid., pp. 205-7.

²⁷Ibid.

altitude suffered less damage than the town on a lower plain or in a valley--a fact that indicated to the writer that the source is in the body of the earth and not in the mountains, as others had suggested.²⁸

Déodat Dolomieu

The difference in location upon the severity of the shock was recognized by another naturalist who examined the Calabrian earthquakes: Déodat Guy Silvain Tancredè Gratet de Dolomieu (1750-1801), a French mineralogist. His investigation report²⁹ agreed with Hamilton's in showing that some towns had been ruined, while others were little damaged.³⁰ Dolomieu explained that the disparity is due to the nature of a town's foundations. Structures built on loose ground collapse when the motion of the earth disorders the soil under them. Providing a direct contrast are the relatively safe communities built in mountainous areas on solid rock, which is able to communicate the shock uniformly. A building's foundation remains intact and resumes its original position after each oscillation.³¹

There were not many points of agreement between the Calabrian-earthquake theorists. Dolomieu began his Memoire

²⁸Ibid., p. 206.

²⁹Memoire sur les tremblemens de terre de la Calabre pendant l'année 1783 (Rome: Chez Antoine Fulgoni, 1784). (Hereinafter referred to as Memoire.)

³⁰Dolomieu, Memoire, pp. 16-17.

³¹Ibid., p. 62.

with a criticisms of the views of both Vivenzio and Hamilton. He thought that the Italian author's Istoria was more a defense of electricity than a true story of the Calabrian earthquakes.³² And although Hamilton was generally a good observer, this time he simply did not have the opportunity to examine the scene thoroughly.³³ From such comments and from the Memoire itself, Dolomieu reveals a marked emphasis towards the importance of data-gathering, a procedure that he evidently feels is primary for creating and testing a theory for explaining the shocks.

Only after first presenting the evidence does Dolomieu turn to theoretical considerations. The author could not find any supporting evidence for the electrical theory (like displays of electrical fire issuing from the earth), and on a theoretical basis he pointed out that a country surrounded by water can never find the electric fluid in disequilibrium.³⁴

He joined Hamilton in rejecting the airquake hypothesis because of the difference in the weather reported during various earthquakes. For instance, one shock struck the interior of Calabria during a period of fair weather, while Messina received a jolt during a rain storm.³⁵

Dolomieu stated that he would lay all theoretical systems aside, and from the facts alone determine the source of

³²Ibid., p. 6.

³³Ibid.

³⁴Ibid., pp. 64, 66.

³⁵Ibid., pp. 64-65.

the violent earth movements.³⁶ He found that the focus of the earthquakes had ranged from south to north beneath the Apennines. Although no volcanoes or other signs of fires had been seen in the region, he theorized that subterranean fire acting on air and water is the responsible agent. But the initial source did not have to be below Calabria, for the earthquakes probably originated under Mt. Etna in Sicily. He explained that the weather had been very rainy, and water flowed into the midst of the great volcanic fires; there they were converted into the powerful force of steam. These vapors forced their way through subterranean channels to cavities below Calabria where the destructive force met obstacles, and the earth was shaken. Dolomieu believed his theory explains all of the phenomena simply and naturally.³⁷

Tytler and the Third Britannica

By including a discussion of the Calabrian earthquakes, James Tytler added five more pages to the section on causes in his article "Earthquake" for the third edition (1797) of the Encyclopaedia Britannica.³⁸ He felt that the additional information about these shocks contributed support for his thesis. While Dolomieu and Hamilton had rejected electricity as a cause, Tytler defended his theory by first pointing out

³⁶Ibid., p. 65.

³⁷Ibid., pp. 65-67, 69.

³⁸Vol. VI, pp. 264-88. Parts 282b-287b were added for the third edition. [Hereinafter referred to as "Earthquake," (1797).]

a discrepancy in the observations discussed by the two authors. The Frenchman did not find any evidence of electric sparks, while Hamilton attributed the reports of flames coming from the earth as indications of electric fire.³⁹

Tytler also charged that Dolomieu's hypothesis was developed in the worse possible way--by arguing from things unknown to things known. Even if the sea (not just water accumulated from rains) broke into Mt. Etna, the result would be boiling water and steam issuing from the volcano itself. There would be no earthquakes in southern Italy. Furthermore, Dolomieu had not taken into consideration the fact that steam condenses and loses its power as it travels through colder, distant caverns. Any great amounts of the vapor generated will also penetrate loose earth and condense back into water.⁴⁰

The editor thought that the power of steam had been overrated, especially considering the great force that is needed to shake the earth. Through a few calculations, Tytler emphasized that before the ground can be raised an inch, the pressure of the atmosphere has to be overcome, i.e. 60,217,344,000 pounds of pressure per square mile. The Lisbon earthquake covered four million square miles, and an atmospheric pressure totaling more than 240,000 million-million

³⁹Tytler, "Earthquake," (1797), pp. 282-83. See also, Dolomieu, Memoire, p. 64, and Hamilton, "Account," p. 194.

⁴⁰Tytler, "Earthquake," (1797), p. 284.

pounds had to be overpowered. And this does not even take into account the weight of the land. Since not enough steam can be produced to prevail over this resistance, electricity remains the only possible force in nature capable of rocking the earth.⁴¹

Another argument Tytler introduced in the third Encyclopaedia Britannica concerned the idea that animals seem to be able to foretell the coming of an earthquake. Previously, Lehmann thought that beasts seek refuge before a shock, because their sensitive hearing detects the subterrestrial noise that precedes a tremor, or their sense of smell discovers subterranean vapors.⁴² Instead, Tytler proposed that birds and animals, particularly geese in water, sense some changes in the electrical state of their environment.⁴³

On the propagation of earthquakes, Tytler remarked that the same quantity of electric matter that caused the Calabrian events had also been responsible for the violent thunderstorms in Europe, as well as the volcanic eruptions in Iceland and Greenland later that year.⁴⁴ This idea was in support of his view of a circulation of electricity from regions near the equator to areas towards the poles.⁴⁵

⁴¹Ibid., p. 285.

⁴²Lehmann, Considerations physiques, pp. 464-65.

⁴³Tytler, "Earthquake," (1797), p. 284.

⁴⁴Ibid., p. 286.

⁴⁵See above, p. 150.

In retrospect, the Calabrian tremors supplied additional information about the nature of earthquakes and the conditions of the earth and atmosphere associated with the phenomenon. Yet, whether a theorist was seeking more evidence for a favored thesis, or proclaiming innocence of any theoretical bias in order to work from facts alone, the results were inconclusive, for there was still no agreement as to the source of earthquakes. Naturalists could not even agree on what caused the shocks of 1783.

CHAPTER VII

A CENTURY OF EARTHQUAKE STUDIES

Earthquake theories presented in response to the three most important shocks of the eighteenth century (London, Lisbon, and Calabria) share some of the characteristics of the work done by early Enlightenment investigators. But in other ways, the nature of the study had changed in the hundred years between Lister's remarks about pyrites following the Oxford shock of 1683 and the discussions of the Calabrian earthquakes.

After 1750, there is no one common characteristic to identify the person engaging in earthquake studies. In the time before the London event, physicians and clergymen (Lister, Woodward, and Cyrillus, for example) as part-time students of earthquakes contributed on an equal basis with those in a position to spend more of their time studying nature (Newton, L  mery, and Buffon). After mid-century, the same assortment of occupations is again present: those with formal training in medicine and those with positions in a church are common (Stukeley, Bertrand, and Vivenzio are among the prominent representatives). However, in this second

period, there emerges a different correlation of occupations and expertise. Following the early discussions of airquake and electrical theories, and after the initial flurry of activity over the Lisbon disaster, the miscellaneous commentaries by the obscure dilettantes are exhausted, and the remaining authors tend to be individuals who were now limiting the scope of their investigations into nature. Michell and Lehmann were studying the structure and character of the earth. Ideas about electricity were discussed by recognized electricians: Beccaria, Priestley, Cavallo, and Tytler.

This point should not be overemphasized, for the trend to specialization was only beginning; it is still far from the time when a molecular biologist will only talk to (or be understood by) another molecular biologist. Priestley did not restrict his activities to electricity alone, as he was an important figure in the development of pneumatic chemistry and was active in the Unitarian ministry. Of greater significance, the study of the trembling earth passes increasingly to those who spend more and more of their time examining just the earth: Lehmann, Michell, Desmarest, Dolomieu, and Hamilton. The work done on earthquakes in the period is directly related to the development of geology.¹

London and Paris were centers of learning, and much of the earthquake literature came from the two capitals. It can

¹See below, Bk. III, chaps. v, vi.

also be said that writings came from areas particularly concerned with the natural cataclysms: Iberia, the Andes, and Italy. But the works produced in the primary intellectual centers have been the ones having the greatest impact. English and French authors did not pay attention to the ideas of Portuguese and Spanish writers after the Lisbon shock. Frézier and Pierre Bouguer (see below, p. 263) did not think much of South American science. And only a few Italian authors had their contributions recognized by their colleagues to the northwest. Thus, most developments in the study of the quaking earth came whenever Englishmen or Frenchmen became interested in the subject--either by personal acquaintance with one of the startling events (as in the case of Hales and Stukeley), or in response to the inquiries initiated by others (for example, Flamsteed and various commentators).

This concentration of activity was a disadvantage to the authors whose writings have been obscured through circumstances of geography and patterns of communication. While the thoughts of Bina, Costa e Andrade, or Joaquim Moreira de Mendonça were timely, their ideas were not well known outside of their home areas, and their explanations were lost among the backwaters of science. The story of this one intellectual endeavor was being written in the Paris and London journals, and in their subscribers' books, pamphlets, and correspondence. This is where the thoughts about earthquakes were ebbing and flowing.

Whether a person became interested in earthquakes through an encounter with the phenomenon, or found out about them by way of correspondence, news sources, or learned societies, it is evident that important contributions to earthquake studies were presented following major earth movements. The shocks of 1692 in Sicily, Jamaica, and western Europe, a few tremors in Oxford, one in Naples in 1731, and another in Lima in 1746 are the most prominent examples cited in the early period, but they did not have the impact of the two London shocks that saw the emergence of the electrical and atmospheric-explosion theories. The Lisbon earthquake was the center of extensive discussions from different perspectives, most prominently the propagation question. The prolonged Calabrian example served to restore the subterranean-fire hypothesis to the forefront, although the electricians were not persuaded to abandon their view. For a third of a century after 1750, new ideas came into being, were altered, and virtually disappeared with a frequency unmatched in the previous sixty-six years.

But earthquakes do not create ideas, they serve only to stimulate curiosity. The fascination with the shaking earth led naturalists to search for explanations in many directions. Some built on old theories of volcanic fires, others looked to new forces of nature. The London shocks prompted Stukeley to set forth an idea inspired by Franklin's recent work. But Stukeley was not alone in combining thoughts of electricity

and earthquakes. The appearance of a similar hypothesis through Beccaria's investigation of atmospheric electricity reinforces the suggestion that the popularity of the new, fashionable subject made the introduction of a theory emphasizing electricity all but inevitable. The hypothesis appeared after such a chain of events that it is surprising that there was not more of a dispute for priority than confronted Stukeley. The foundation had been laid in the latter part of the seventeenth century when pyrite vapors linked earthquakes and lightning. Following the acceptance of Franklin's explanation of lightning, the stage was set for comparing the jolt of an earthquake to the electrical snap in the laboratory or the tower-splitting activities of lightning. For Beccaria, the idea was one of many being discussed, but for Stukeley, with his single-minded purpose, the hypothesis was established by a volume of evidence unmatched in its day.

The year 1750 is a dividing line marking a change in one of the characteristics of earthquake studies: with the passage of time, theories became increasingly complex--from the few pages authored by Lister for the Philosophical Transactions to the comparatively voluminous productions of Stukeley, Desmarest, Bertrand, and Lehmann (the four authors accounting for more than 600 pages of relevant materials). In part, the growth resulted from an accumulation of information and a compounding of the topics of discussion.

When one author introduced a new question and answer into his thesis, there appears in the writings that follow either corroborative agreement or a new explanation to get rid of the same difficulty. In the early period, new topics of interest can be seen passing from one person to another, from Lister to Plot to Ray. In the second half-century, the increase in volume comes more from additional evidence being transmitted between writers, and from the new importance of criticism as one of the requirements for the complete exposition of a theory.

In the early discussions, well-known earthquake lore formed a common basis from which naturalists presented their ideas; detailed examples were not very important. Flamsteed's seven general facts were selected from common knowledge. But Michell chose to discuss five characteristics derived from the more complete studies of the Lisbon and Lima catastrophes. The Calabrian investigators concentrated in the greatest depth thus far on the evidence gathered in just one series of shocks in one location. The greater the number of documented facts, the more detailed the theories became. This relationship is closely tied to the problem of the great diversity of earthquake phenomena uncovered while trying to define the "typical" earthquake.

Only rarely were generalizations alone considered sufficient for theorizing about earth movements. Support by means of examples from nature and analogous experiments were

valued parts of earthquake discourses. While it can be questioned what the models such as Lémery's buried pot of sulphur and iron paste, Priestley's pillars on a floating plank, or Desmarest's sand and paving stones proved, the effect was to provide a vivid and persuasive demonstration in miniature of the massive operations that were thought to occur in the interior of the earth. These devices became an integral part of the exposition of a number of theories, since they permit admission to the subterranean regions with the one tool that is available--man's imagination. It was the type of thing that caught the eye of earthquake chroniclers and encyclopedists who further spread accounts of the most interesting demonstrations and the ideas behind them. Lister's theory might have faded into obscurity if it were not for Lémery's memorable experiment. Nearly everyone with an interest in earthquakes was aware of the explosive paste, even if he did not care for the theory it supported. Electrical experiments were similarly successful in capturing attention.

But a theory had to have more than an intriguing exhibit piece to be acceptable. Desmarest's mountain-chain idea was not very popular, although the author had a good demonstration based on the iron and sulphur mixture. Everyone could well imagine the scene; perhaps the experimenter himself performed it only in his mind. Michell's version was important, and it was supported by only a simple wave in a carpet--and by a detailed, convincing thesis.

The demonstrations were just one part of the debate among the proponents of the various hypotheses. The chief difference separating the two periods before and after the year 1750 is the advent of intense competition among the participants. Earlier, the supporters of subterranean fire, vapors, and water theories had coexisted peacefully. These three ideas were often intertwined; thus, there was little profit in seeking to annihilate an opposing idea. This accounts for much of the gentlemanly atmosphere in earthquake discussions in the early period, as each writer presented a concise, positive statement of his own views, ignoring the discrepancies in other versions. Only Frézier's theory was found by one commentator to be so out of line as to deserve exposure to the harsh light of criticism. For another source of the quiet ambience, theorizing about earthquakes before mid-century was not a very pressing problem.

In the second half-century, the subject became important, for London had been rocked not once but twice in a short span of time, and rivalries between theorists intensified markedly. Stukeley's presentation was coolly received by some Royal Society members, and he not only had to face challenges from a new theory by Hales, he had to fight for recognition as the originator of his own theory. The English electrician also had to accept the lack of support from Franklin, as well as defend against Massey's critique. He even had to contend with the friendly, yet troubling, remarks

of Barker, a sympathizer. The airquake advocates had their own problems. Criticism was now such a part of the earthquake discussions that Thomas became a major figure, not so much for his own explanation, but for the sharp and piercing opposition to other accounts.

After the 1750's, an author could not get by with the simple statements of the late seventeenth century. He had to be precise. He had to answer the problems discussed by his predecessors, while pointing out the weaknesses in the previous solutions. He should have the support of experiments and demonstrations. And he had to be willing to fight for his ideas. The more radical the conception of nature, the harder he had to work to protect his position. The atmospheric-explosion proponents had the most difficult time in convincing others, although the question of the relationship of weather conditions and earthquakes remained a nagging problem. The electricians were the most stubborn investigators. Stukeley and Tytler maintained a watchful vigil over their hypotheses, not letting their theories go with one statement but coming back to it in new editions to add testimony and to challenge the opposition anew. The disciples of the new concepts had to guard against losing supporters to the old but still very promising explanations involving volcanic fires.

There was no shortage of ideas about the origins of earthquakes. Naturalists brought forth a number of working

hypotheses. Each explanation could be used singly and exclusively to explain all shocks (for example, Stukeley and electricity), or each could be used singly and non-exclusively to account for selected tremors (Bertrand's multiple cause idea), or various sources were combined (Sigaud-Lafond on electricity igniting subterranean fires). Furthermore, the forces were thought to work at the command of God, or according to a preordained Heavenly Plan, or they can be governed by the natural laws in operation since the Creation.²

The proliferation of earthquake hypotheses resulted from the continuing lack of general acceptance of any one theory as the explanation. The problem of finding a satisfactory solution was due, in part, to the nature of earthquakes. Seemingly capricious in character, the tremors displayed such a variety of attendant phenomena that when a theory worked well in explaining one event, the next reports might invalidate the idea. The subterranean-fire authors emphasized the shocks accompanied by volcanic eruptions, but there were examples without any signs of internal combustion. Hales developed his thesis following a shock in calm weather, but it could not stand against those that took place during gale-force winds. Astrologers found their predictions were accurate; scoffers found discrepancies. Electricians stressed tremors that were felt in widely separated locations almost

²See below, Bk. III, chap. ii.

simultaneously, while others pointed to extremely slow-moving shocks. Such were the problems of the eighteenth-century naturalists.

Plenty of information was available through earthquake chronicles, correspondence, journals, and press articles that detailed the conditions of the earth, sea, and sky before, during, and after numerous tremors. Also available were detailed annotations as to the time, direction, and the strength of shocks as determined by their relative effect on life and property, as well as by occasional use of simple instruments. The facts were at hand, enough facts to support a host of theories.

The continuing effort to gather more data tended to complicate the picture more than to clarify it; yet, several authors, specifically Dolomieu, Michell, and Bertrand, emphasized the vital need for accurate information before engaging the task of explaining earthquakes. While their stated method of operation was inductive, their works reveal the use of another approach. Dolomieu's theory of underground tunnels conveying high-pressure steam from the region of Mt. Etna is not the sort of theory that is entirely induced from the information about the Calabrian earthquakes (as Tytler pointed out). In addition, from essentially the same facts, three different explanations were proposed to account for these same events. John Michell credited the Lisbon shock as the example that provided sufficient information for the author

to determine causes, but his theory came more from his conceptualization of the earth's stratified structure. The Lisbon disaster was of value in providing the initial interest in the problem and in serving as an illustration. It was only in the case of Bertrand's multiple-theory idea that the facts themselves conceivably led to new thoughts for explaining all earthquakes, although even in this case, Bertrand's knowledge of the work of previous writers was also a key factor.

The contradiction of espousing one methodology and relying on another was a result of an effort to leave the appearance that a theory was derived through what was considered the correct and proper method for arriving at truths of natural philosophy. An idea of the personal feelings involved in these situations of self-contradiction is seen in the concluding section of Benjamin Franklin's letter to Abbé Soulavie in which he offered ideas explaining the creation of the earth and the role of earthquakes in altering the landscape. Franklin wrote:

You see I have given a loose to imagination; but I approve much more your method of philosophising, which proceeds upon actual observation, makes a collection of facts, and concludes no farther than those facts will warrant. In my present circumstances, that mode of studying the nature of the globe is out of my power, and therefore I have permitted myself to wander a little in the wilds of fancy.³

It is "in the wilds of fancy" that important ideas are sometimes found.

³Letter from Franklin to Soulavie, p. 121.

The most elusive question of all is determining how an author arrived at his explanation. The view that earthquakes have their origin in volcanic-type subterranean fires was a ready-made working hypothesis for the late seventeenth- and early eighteenth-century naturalists. The next step was for Lister, Plot, L  mery, Rohault, and others to seek a better understanding of the nature and exact source of the combustion. The evolution of this hypothesis is traceable, but where did Flamsteed get the radical idea that atmospheric explosions cause earthquakes? He only recorded that he was dissatisfied with subterrestrial forces and that he found a pleasing solution by moving the search for causes out into the atmosphere. In the case of Hales's version, it is possible to speculate that his work on sulphureous air and his experience with a London earthquake together sparked an idea. But it is also possible that he knew of Flamsteed's earlier work and found an insight from that direction. Concerning the other major theoretical innovation of the 1750's, Stukeley said that he always connected earthquakes with electricity. His statement does not reveal anything about the origins of his theory, and it is inconsistent with the emphasis placed on the theories of Franklin and Freke.

The eighteenth century ended without a clear answer to the question of what causes the earth to tremble. In the 1780's, Professor John Walker (1731-1803) of the University of Edinburgh in his lectures on geology could not decide on

a theory to explain the earthquakes that are not associated with volcanoes.⁴ Writing in the 1790's Edward Gray could not point to a satisfactory solution.⁵

In the next century, the English philosopher of science William Whewell (1794-1866) considered electrical explanations too vague, and he judged the promising idea of the earth's interior heat as still immature.⁶ In 1841, the situation had not changed, and geologist David Milne-Home (1805-1890) wrote of earthquakes and volcanoes: "there is no department of physical science, over which, unfortunately, there hangs so deep a cloud of mystery."⁷ The emphasis in the first half of the nineteenth century shifted from investigating causes to work on specialized studies: Charles Lyell concentrated on the effects of the shocks,⁸ in France, Alexis Perry (1807-1882) analyzed the periodicity of earthquakes,⁹ and Robert

⁴Lectures on Geology Including Hydrography, Mineralogy, and Meteorology with an Introduction to Biology by John Walker, Professor of Natural History and Keeper of the Museum, University of Edinburgh from 1779-1803, edited by Harold W. Scott (Chicago: University of Chicago Press, 1966), pp. 208-12.

⁵See above, pp. 87-88.

⁶Whewell, History of the Inductive Sciences (3 vols.; London: John W. Parker, 1837), III, 558.

⁷"Notices of Earthquake-Shocks in Great Britain, and Especially in Scotland, with Inferences Suggested by These Notices as to the Nature and Causes of Such Shocks. By David Milne, Esq., F.R.S.E., M.W.S., F.G.S., &c. Communicated by the Author," Edinburgh New Philosophical Journal, XXXI (1841), 92-93.

⁸See below, pp. 287-89.

⁹Davison, Founders of Seismology, pp. 47-64.

Mallet (1810-1881) carried out an examination of the dynamics of earth movements.¹⁰

Writers from the 1680's to the 1780's offered a number of answers as to the source of earthquakes. Any list of the basic hypotheses would have to contain: subterranean fire (including the many accounts of its origin in pyrites, natural gunpowder, or other combinations of materials in the earth), agitated underground water, air pressure, atmospheric explosions, electricity, and the explosive release of air, vapors, or steam. The accounts were all thoroughly presented, and, objectively, there were no strong grounds for selecting one theory over another. In the absence of overwhelming supporting evidence or any conclusively damaging contradiction, the choice had to be a subjective factor--a feeling for an idea, the thought that one answer is just more pleasing, a prettier explanation.

There was no telescope enabling the naturalist to see pyrites in some deep cavern take fire as water reaches them, nor could the observer see erosion caused by agitated subterranean rivers, or view air pressure buckle the supporting columns of a cavern. The inductivists would have welcomed such an instrument. In its absence, the difficulties were compounded as more and more theories were added to the list

¹⁰"On the Dynamics of Earthquakes; Being an Attempt to Reduce Their Observed Phenomena to Known Laws of Wave Motion in Solids and Fluids," Transactions of the Royal Irish Academy, XXI, Pt. I (1846), 51-105.

of possibilities. Although some appeared more promising than others, few could be rejected for incompetent reasoning or inappropriate use of evidence, and none (with the exception of the multiple-cause thesis) could be accepted for its total consistency in explaining all earthquakes. There were fashions in ideas (electricity certainly, and Gray's abortive attempt to revive the airquake hypothesis following developments in pneumatic chemistry is another example). In looking for the unifying idea that explains the trembling earth, the eighteenth-century naturalists did not find it. Thus, the subject of this monograph is not the solution to the problem of what causes earthquakes, but the quest.

BOOK THREE
SELECTED INVESTIGATIONS

CHAPTER I

THE EARTHQUAKE CHRONICLES

In the quest for a complete understanding of the shaking earth, investigations extended into diverse areas: assemblies of earthquake accounts, considerations of natural theology, studies of possible extraterrestrial influences, and applications of theories in the creation of techniques and devices for preventing further shocks. Naturalists also examined the role of earthquakes in general theories of the earth. These topics are discussed in the following chapters, beginning with the earthquake histories.

Both Élie Bertrand and Déodat Dolomieu especially emphasized the accumulation of facts before committing themselves by proclaiming a theory of earthquakes. Dolomieu sought out information from personal, on-the-scene observations, while Bertrand relied more on printed and manuscript accounts. Among the published materials available were what can best be described as "earthquake chronicles." These are works of varied form that ranged from chronological descriptions of innumerable tremors to brief pamphlets that detailed a few major catastrophes. A number of these histories, those stressed

here, also presented ideas explaining what makes parts of the terrestrial sphere quake.

Crouch's General History of Earthquakes

One early example is by a prolific writer Nathaniel Crouch (1632?-1725?) who published in 1694 a work with the voluminous title: The General History of Earthquakes. Being an Account of the Most Remarkable and Tremendous Earthquakes That Have Happened in Divers Part of the World, from the Creation to This Time; as They Are Recorded by Sacred and Common Authors; and Perticularly Those Latelly in Naples, Smyrna, Jamaica and Sicily. With a Description of the Famous Burning Mount, Aetna, in That Island; and a Relation of the Several Dreadful Conflagrations and Fiery Irruptions Thereof for Many Ages, Likewise the Natural and Material Causes of Earthquakes, with the Usual Signs and Prognosticks of Their Approach; and the Consequents and Effects That Have Followed Several of Them.¹ As in many of the writings of the seventeenth and eighteenth centuries, the full title page provides a remarkably complete description of a book's contents.

¹(London: Printed for N. Crouch, 1694.) The work was signed "R.B.," for Crouch usually wrote under these initials that represented his more frequent pseudonym Richard Burton. William Edward Armytage Axon, "Burton, Robert or Richard," DNB, III, 466-68. The General History of Earthquakes was reprinted in the 1730's, and citations will be to the 1734 edition: (London: Printed for A. Bettesworth and J. Hodges.) (Hereinafter referred to as General History of Earthquakes; see the "Bibliography" for the full citation.)

Concerning the theoretical aspects of this chronicle, the author divided earthquakes into four types as determined by observed effects. He described the first kind as a lateral shaking of the earth like a man shivering with an "Ague Fit," and Crouch theorized that it is caused by wind and vapors moving from place to place inside the earth. A second variety of earthquakes is created when internal winds lift the ground as if a supply of gunpowder had suddenly exploded under the surface. If the earth resists the concussion, the land falls back to its original position, but in a third type of jolt the explosion opens up the earth, sometimes causing cities to fall into the chasm. Crouch grouped into a fourth classification all shocks that change the topography of the globe by creating mountains, lakes, volcanoes, and islands.²

The writer credited his basic theory to "philosophers" (primarily meaning Aristotle) who stated that the interior of the earth is filled with air. If the action of the sun on underground moisture creates more exhalations at a time when there is no more space for them, and if the pores by which the extra air can usually escape through the surface are clogged, then the vapors have to break open parts of the earth either to create new cavities or to crack the land in order to release the air to the atmosphere.³

²Crouch, General History of Earthquakes, pp. 6-7.

³Ibid., pp. 7-8.

The General History of Earthquakes listed a variety of evidence in the form of "prognostics." For example, before an earthquake, seas become agitated even when there is no wind for creating the troubled waters. Crouch explained that the vapors in trying to flee make the first attempt under the sea, but if that fails, the land is shaken and torn, allowing the subterranean winds their freedom. Similarly, the water in wells becomes turbulent and takes on a sulphureous smell from the released exhalations. Earthquakes are also associated with volcanic eruptions, because the winds ignite brimstone. Other observations also support the theory: since the vapors affecting the quality of the atmosphere are trapped beneath the surface, the atmosphere is calm and cold before a shock. The sun also does not appear as bright as usual, for the winds that normally "purge and dissipate the gross Air" are locked underground. The long streaks of cloud seen in the sky after sunset before a tremor are formed by some of the vapors escaping from the ground.⁴

Crouch's discussions about the nature and origins of earthquakes is from Aristotle,⁵ and not from recent authorities. But the theoretical portion of the book is only a small fraction of its contents. The work is primarily a chronicle of earth movements beginning with a commentary on

⁴Ibid., pp. 8-9.

⁵Meteorologica 2. 8. 365b-368b.

Biblical events, for the author believed that while God works through natural causes to shake the earth, there are eight descriptions of shocks in the Bible that tell of God directly creating the phenomenon.⁶ Most of Crouch's book relates stories of the quaking earth from the first century A.D. to shocks as recent as a 1693 earthquake in Sicily.⁷

The volume contains a wealth of miscellaneous informations: accounts of disasters, the surrounding historical events, unusual happenings coincident with a shock, and tales of miracles. For an example of the contents, one of the shorter sections begins:

In 1560. The Election of Pope Urban VII. was signalized by an Earthquake which made Austria, Bohemia and Moravia to tremble, and was followed by an extraordinary Death; Gregory XIV. quickly succeeded and died in ten months.⁸

The passage continues by describing a 1591 example in the West Indies that lasted sixteen days to so frighten the French colonists that they believed the "Day of Judgment was come." Next Crouch mentioned the death toll in a Persian calamity, and he recorded the exact number of churches and chapels destroyed in a 1614 earthquake in the Azores. The section concluded by recounting the story of the creation of an island (more than a league and a half long) in the Azores.

⁶Crouch, General History of Earthquakes, pp. 6, 10-26. In addition, Crouch discussed "Metaphorical Earthquakes," or threats of coming Judgments, as in the many warnings in the Book of Revelations. Ibid., pp. 26-31.

⁷Ibid., pp. 33-171.

⁸Ibid., p. 60.

The island rose out of a sea that had previously been 150 fathoms deep.⁹

It is difficult to call any one section "representative," since the materials vary considerably in content. A neighboring discussion described strange meteors (referred to as six suns and five moons) that accompanied a 1627 earthquake in England and France. This particular account ended by recounting a story (from Italy) of a large bell that from a tower "fell so fitly over a Child that it inclosed him, and doing him no harm made a Bulwark for him against any other danger."¹⁰ Such proceedings make up Crouch's chronicle, a work not unique in the eighteenth century.

Zachary Grey

The decade of the 1750's was a period of concentrated study of earthquakes; it was also a period in which earthquake chronicles were produced. Following the London shocks, Zachary Grey (1688-1766), an English antiquary, assembled 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 1750.¹¹

⁹Ibid., pp. 60-61.

¹⁰Ibid., p. 64.

¹¹With an Appendix, Containing a Distinct Series of Those That Have Been Felt in England. And a Preface, Seriously Address'd to All Christians of Every Denomination. By a Gentleman of the University of Cambridge (Cambridge: Printed by J. Bentham, 1750). (Hereinafter referred to as Chronological and Historical Account.)

Like Crouch, Grey also believed God is ultimately responsible for shaking the earth, and he began his work by presenting a sermon warning the citizens of London and Westminster to repent before it was too late.¹² However, the author spent relatively little space in his text on the sermon, and most of the book is devoted to compiling a list of the great earthquakes in history. Compared to Crouch's General History of Earthquakes, Grey's work gives less attention to the anecdotal aspects of earthquake lore, and the writer concentrated on a presentation of factual summaries of various shocks. He even occasionally noted the sources of his information.

To provide a contrasting view of the approaches of the two earthquake chroniclers, compare two accounts of one event. First, Crouch wrote:

In 1660 an Earthquake happened at Paris in France and at the same time they had news that part of the Pyrenean Mountains had been overthrown some days before; They are certain Mountains that divide France, and Spain; it did great mischief there, overwhelming some Medicinal Baths, many Houses, and destroying hundreds of People, only one Church which sunk into the Caverns below was thrown up again, and stands very firm, but in another place. This was looked upon as a great Miracle, especially by the French, who have disputed with the Spaniard about this Church as standing on the Frontier Line, but now is removed near half a League within the acknowledged Limits of France.¹³

On the other hand, Grey's Chronological and Historial Account stated:

¹²Grey, Chronological and Historical Account, p. iii.

¹³Crouch, General History of Earthquakes, p. 80.

In the year 1660, in the month of June, there was a terrible Earthquake, which affected all that part of France which lies between the Cities of Bordeaux and Narbonne, and swallowed up a great mountain.¹⁴

And Grey cited as his source of information Athanasius Kircher (1602-1680) in his Mundus subterraneus.¹⁵

A small part of Grey's history was devoted to the philosophical aspects, and in a presentation reminiscent of Chambers' Cyclopaedia, he mentioned the ideas of Martin Lister and John Woodward to support the conclusion that the earth contains cavities and tunnels filled with fire, water, or air --each capable of creating earthquakes in a number of ways. The underground waters can undermine the supporting arches of caverns and cause them to collapse. But fire is the main source, since it can dilate the air and turn water into steam to create a powerful earth-shaking force.¹⁶

The Theory and History of Earthquakes

Another chronicle similar to the works of Crouch and Grey was the anonymous book The Theory and History of Earthquakes written sometime in the early 1750's.¹⁷ While its

¹⁴Grey, Chronological and Historical Account, pp. 24.

¹⁵Ibid., p. 24, n. "m." (See the "Bibliography" for the full citation of Kircher's book.)

¹⁶Ibid., pp. 2-7.

¹⁷The Theory and History of Earthquakes. Containing, I. A Rational Account of Their Causes and Effects; Illustrated by Experiments and Observations on Subterraneous Vapours, and the Manner of Making Artificial Earthquakes. II. A Particular and Authentic History of Those Which Have

purpose was to "call to repentance" and "to point out the way to mercy," as well as to give men moral support during frightful cataclysms, the author considered earthquakes as natural phenomena and not miracles requiring the "extraordinary and particular exertion of the deity." Although the tremors are created according to the laws of nature (and do not involve miracles), they are still described as being under the "guidance and direction" of God.¹⁸

The writer was familiar with the popular theories of the period. He discussed the works of Martin Lister on pyrites and Nicolas Lémery's experiments.¹⁹ He also developed further the idea of subterranean explosions by basing his ideas on the common analogy of coal-mine gas explosions. He first cited Sir James Lowther's report to the Royal Society of London. Lowther described experiments with bladders filled with coal-mine gases. He found that the vapors burn continually when emitted through a tobacco pipe and ignited by a candle.²⁰ John Maud continued the study by creating a man-

Happened in These Kingdoms, and the Most Remarkable of Those Abroad, viz. in Sicily, Jamaica, and Lima, with the Most Considerable Eruptions of Vesuvius and Aetna. III. Some Seasonable Reflections on the Two Late Earthquakes, with a Pathetic Address, on That Occasion, to the Inhabitants of London and Westminster (London: Printed for J. Newbery and others, n.d.). (Hereinafter referred to as Theory and History of Earthquakes.)

¹⁸Ibid., pp. 1-2.

¹⁹Ibid., pp. 3-10.

²⁰Ibid., p. 10, citing "An Account of the Damp Air in a Coal-Pit of Sir James Lowther, Bart. Sunk within 20 Yards of the Sea; Communicated by Him to the Royal Society,"

made coal gas by dissolving iron filings in oil of vitriol and water. This gas burned like Lowther's. After pressing most of the air out of the bladder, when Maud withdrew his hand, some of the flame was drawn into the bladder, which was then torn asunder.²¹

The author of The Theory and History of Earthquakes thought that the experiments by Lowther and Maud demonstrate that for the creation of earthquakes only iron, vitriolic acid, and water are needed. Iron and sulphur are found in nature, and these can be "annalized" into a substance like oil of vitriol. The only remaining ingredient needed--water --can simply come from an overflowing spring. Mix everything together, and the result is heat and an explosion capable of breaking the earth and producing the flames that are often visible.²² Thus, here in the 1750's was another extension of the subterranean-fire theory of Lister, Lémery, and their followers. The hypothesis was still very much alive and in competition with ideas of electricity and atmospheric explosions.

Philosophical Transactions of the Royal Society of London, XXXVIII, No. 429 (1733), 109-13.

²¹Theory and History of Earthquakes, pp. 10-12, citing "A Chemical Experiment by Mr. John Maud, Serving to Illustrate the Phenomenon of the Inflammable Air Shewn to the Royal Society by Sir James Lowther, Bart. as Described in Philosoph. Transact. Numb. 429," Philosophical Transactions of the Royal Society of London, XXXIX, No. 442 (1736), 282-85.

²²Theory and History of Earthquakes, pp. 11-12.

John Bevis

The discussion of the earthquake chronicles above has emphasized the theoretical aspects of each work, but these considerations filled only a small portion of the volumes, for the vast bulk of the books consist of a description of what happened during a number of earth movements. In other words, the earthquake chronicles tell "what," "when," and "where," along with some "how," and by relating theological considerations they even state "why" the earth shakes.

Then, in 1757 there appeared another type of book--one that chronicles not earthquakes but the explanations that had been offered. The History and Philosophy of Earthquakes,²³ a work attributed to an English physician John Bevis (or Bevans) (1693-1771), is a collection of the writings of earthquake theorists including Martin Lister, Robert Hooke, John Woodward, Nicolas Lémery, Pierre Bouguer, Buffon, John Ray, Stephen Hales, and William Stukeley.²⁴

All of the histories compiled a great amount of information--some useful, and some not so helpful. It remains a question whether author "A" relied on the evidence gathered by chronicler "B," for such direct attributions are almost

²³The History and Philosophy of Earthquakes, from the Remotest to the Present Times: Collected from the Best Writers on the Subject. With a Particular Account of the Phaenomena of the Great One of November 1st, 1755, in Various Parts of the Globe. By a Member of the Royal Academy of Berlin (London: J. Nourse, 1757).

²⁴See also Davison, Founders of Seismology, pp. 3-6.

non-existent. In one rare instance, John Michell did recognize the value of Bevis's work of providing a source by which the various theories are readily compared.²⁵

Earthquake Theories and Earthquake Chronicles

Both the theorists and the chroniclers displayed a knowledge of basic earthquake lore, for the characteristics of the phenomenon were generally known. Only a few earthquake historians, such as Grey, gave their sources of factual information, but this is a better record than that of the theoreticians. However, while the individuals who emphasized their work on hypotheses often did not indicate the secondary sources of their supporting data, they frequently gave recognition to the origins of stimulating ideas. Subterranean-fire commentators of the eighteenth century did not fail to mention Lister and L  mery. Stukeley was credited as being the originator of the electrical hypothesis (in spite of Maz  as' statement to the contrary). That the earthquake chroniclers also joined with their more theoretically inclined colleagues in mentioning the pioneering investigators, principally Lister, L  mery, and Woodward, further points out how extremely well the basic ideas about earthquakes were known in the century.

These volumes also show that speculating about causes is one aspect of telling the story of nature. All of the

²⁵Michell, "Conjectures," pp. 566-67, n. *.

chronicles discussed to at least some extent an explanation of earthquakes, although these ideas were isolated in separate sections. A favored theory was not referred to when describing the different shocks; the authors did not point out conclusive evidence, nor did they sweep unhelpful or contradictory information under the proverbial rug. Hypotheses were of interest to the chronicler, but they were not too important.

The difference between the earthquake chronicler and the earthquake theorist is a matter of degree--a balance between the task of compiling data along with some theoretical speculations, and the work of theorizing about causes, supported by as much evidence as is necessary to be convincing. Within each major classification are various gradations. Among the chronicles there are those with virtually no theories, but there is The Theory and History of Earthquakes with a significant theoretical contribution, and there is Bevis's report that is essentially all theory. On the other side, Amontons' article mentions no specific earthquake examples, while the book by Bertrand lists hundreds.

The purpose of the chronicles is difficult to both fairly and briefly characterize. Grey was an antiquarian, and Crouch was a writer of books on numerous subjects. Earthquakes was a good, popular topic for both. There is no direct evidence that the compilers were seeking to supply information on which fact-hunting naturalists, such as Bertrand

or Dolomieu, could build a theory to explain the trembling earth. One purposeful aspect of the histories that is evident appears whenever it seems as if portions of their texts were being delivered from the pulpit on a Sunday morning, warning their sinning flocks of the disasters to come. As is shown in the next chapter, theological considerations were important for the earthquake chronicler and naturalist alike.

CHAPTER II

EARTHQUAKES AND NATURAL THEOLOGY

According to eighteenth-century authors, earthquakes are caused by a natural process involving subterranean fires, vapors, air pressure, water, atmospheric explosions, or electrical discharges above or below the surface of the earth, or any number of combinations of these. Many of the writers joined clergymen and theologians in believing that the shocks are created by the Hand of God.

Earthquakes as Judgments

Nathaniel Crouch in his earthquake chronicle considered the events as calls for "Repentance and Reformation," as well as demonstrations of the "Greatness and Power of the Supreme Creator."¹ He quoted the ancient Roman philosopher Seneca:

When the World itself is shaken, and the only thing that passes for fixt and immoveable in the Universe, trembles and deceives us; Whither shall we fly for security if wheresoever we are the danger be still under our feet?²

Crouch described a natural theory of earthquakes; but he also warned that God has ultimate command over the forces of

¹Crouch, General History of Earthquakes, pp. 3, 5.

²Ibid., p. 173. (Seneca Naturales quaestiones 6. 1. 4-7.)

nature, and He may send Judgments like those described in the Bible.³ Just such a punishment struck Sicily and Italy in 1693. The usual explanations, like the idea that heavy rains and the unseasonable heat of summer created overabundant supplies of subterranean vapors, were "the guesses of shortsighted Men, for the hand of Heaven seemed visible in this terrible Devastation; . . ."⁴ God always sent signs warning of an impending Judgment: prior to the 1693 shock, horrible noises had been heard coming from Mt. Etna, and on one evening (half a year before the jolt) the sunset sky seemed to be in flames. And there were other signs: although no clouds were present, three bright rainbows appeared--two of them were of the ordinary variety, but the third was upside down. Another portent involved the statue of a revered priest in Catanea that mysteriously kept falling to the floor. The statue was upset so many times that eventually it was laid flat on the ground where it remained until the city was destroyed.⁵

The admonitions had not been heeded--much to the distress of the clergy. In 1750, after the first tremor hit

³See above, pp. 231-32.

⁴Crouch, General History of Earthquakes, p. 167.

⁵Ibid., pp. 109, 167-68. Crouch's source of information may have been An Account of the Late Terrible Earthquake in Sicily, with Most of Its Particulars. Done from the Italian Copy Printed at Rome (Dublin: Reprinted by Andrew Crook, 1693), pp. 5-6.

London, one parson overheard bets being made on whether the shock had been caused by an earthquake or by the explosion of a munitions factory. The disheartened clergyman responded: "I protest, they are such an impious set of people, that I believe if the last trumpet was to sound, they would bet puppet-show against judgment."⁶

The Bishop of London's Letter

The English clergy set out to make sure that everyone knew the true meaning of earthquakes. Thomas Sherlock (1678-1761), the Bishop of London, reacted to the events of 1750 by publishing a pastoral letter calling for repentance.⁷ Ten thousand copies were sold in two days,⁸ and contributors purchased 40,000 copies for distribution among the poor.⁹

The Lord Bishop's homily presented a clear message: after examining the history of the destruction of wicked

⁶Quoted in Letter from Horace Walpole to Horace Mann, March 11, 1750, O.S., Walpole's Correspondence, XX, 131.

⁷A Letter from the Lord Bishop of London, to the Clergy and People of London and Westminster; on Occasion of the Late Earthquakes (London: Printed for John Whiston, 1750). (Hereinafter referred to as Letter from the Lord Bishop.)

⁸Letter from Horace Walpole to Horace Mann, April 2, 1750, O.S., Walpole's Correspondence, XX, 133.

⁹From a note at the end of "Abstract of the Bp of London's Letter to the Clergy and Inhabitants of London and Westminster, &c. on Occasion of the Late Earthquakes," Gentleman's Magazine, XX (March, 1750), p. 124. The editor also noted that the "great benefactions in this age are, perhaps, as remarkable as its vices." Ibid. The letter was also distributed in the British colonies (Boston: Reprinted and sold by John Draper, 1750).

cities, London and its evil inhabitants can only expect the worst, for the first shocks provided advance notice of disasters to come.¹⁰ He lamented the blasphemy and depravity he saw around him: the sale of books ridiculing the truths of religion, the many signs of lewdness and debauchery,¹¹ and the newspaper containing fifteen advertisements for plays, operas, music, dancing, cock-fights, and prize-fights.¹² The Lord Bishop prayed that the people would be spared, and that they would find their way to repentance and salvation before it was too late.¹³

Earthquakes as "Very Moving Preachers"

The author of the Theory and History of Earthquakes was also worried that London was a center of vice and corruption, and he also urged contrition before God sent an earthquake that might be as great as any in history.¹⁴ He also tried to stir the conscience of sinners by warning of things to come:

Methinks I see the guilty wretch throw his eyes over a dismal scene of desolation, trembling with wild amazement at the gaping earth, and calling on that God for pity whom he has frequently called upon for damnation;

¹⁰Sherlock, Letter from the Lord Bishop, pp. 3-4.

¹¹Ibid., pp. 7, 9.

¹²Ibid., p. 12. The bishop was particularly concerned about the English church's image abroad: "What an Idea must it give to all the Churches abroad, of the Manner in which Lent is kept in this Protestant Country?" Ibid.

¹³Ibid., p. 22.

¹⁴Theory and History of Earthquakes, pp. 58, 60.

O what distressful looks! what shrieks! what groans! thou hast escaped from thy falling house, but canst not fly from God. See that crowd hurrying along, what a dreadful chasm opens before them; these behind know nothing of it; behold they press forward, and struggling to get foremost, drive numbers down the frightful gulph.¹⁵

The writer added that a good Christian at such a time can "justly smile amidst the most dreadful convulsions of nature," because he knows of his salvation.¹⁶ To borrow a phrase from an American author of similar vivid sermons, Cotton Mather (1663-1728), earthquakes are "very moving Preachers."¹⁷

One indication of the effectiveness of the warnings, and a symptom of a renewal of puritan sentiment among the English, was the sudden demise of the popular "masquerade." After the first shock of 1750, George II (1727-1760) refused to attend a masque in deference to such a clear Heavenly sign,¹⁸ and by the time of the April earthquake scare, the revels had to be cancelled, because no one would attend.¹⁹ However, after the capital had been "saved," the masquerades were again reinstated in time for another conservative

¹⁵Ibid., p. 61.

¹⁶Ibid., p. 62.

¹⁷Mather, The Christian Philosopher: A Collection of the Best Discoveries in Nature, with Religious Improvements (London: Printed for Eman. Matthews, 1721), p. 102. [From the facsimile edition: (Gainesville, Fla.: Scholar's Facsimiles & Reprints, 1968).] New England preachers welcomed an earthquake in 1727, for it helped move the people back to the neglected religious faith. Smith, Enlightenment, p. 402, and see below, pp. 336-38.

¹⁸As noted in William Stukeley's diary for February 10, 1749/50. Stukeley, Family Memoirs, II, 370.

¹⁹Letter from Walpole to Mann, April 2, 1750, p. 135.

reaction following the news of the Lisbon disaster. Again the entertainments were "sacrificed" to the "idol earthquake," as Horace Walpole stated it.²⁰

Fear is a powerful force. The German poet and dramatist Johann Wolfgang von Goethe (1749-1832) best described the emotional response to the Lisbon earthquake when he wrote:

Ja vielleicht hat der Dämon des Schreckens zu keiner Zeit so schnell und so mächtig seine Schauer über die Erde verbreitet.²¹

In France, Cardinal Frédéric-Jérôme de Roye de la Rochefoucauld (1701-1757) used fear to his advantage by warning Louis XV (1715-1774) of the threat of a cataclysm like the one in Portugal if he did not resume the royal Easter devotions.²²

The Clergy and the "Little Philosophers"

Nathaniel Crouch used the phrase "short-sighted Men" in referring to those who sought to find natural causes for the earthquakes that were definitely Heaven-sent. This view was not uncommon. A contemporary author, Rev. John Shower (1657-1715) in a 1693 work reprinted following the London earthquakes called references to natural causes "atheistical" and

²⁰Letter from Horace Walpole to Horace Mann, March 18, 1756, Walpole's Correspondence, XX, 539.

²¹"Indeed, perhaps the demon of fear had never spread so quickly and so extensively his terror over the earth." Goethe, Aus Meinem Leben: Dichtung und Wahrheit in Autobiographische Schriften, Erster Band, Vol. IX of Goethes Werke (Hamburg: Christian Wegner Verlag, 1955), p. 30.

²²Reported in Letter from Horace Walpole to Horace Mann, February 23, 1756, Walpole's Correspondence, XX, 530.

"profane," because God sends Judgments-by-earthquake. And it is God who determines the time, place, and amount of destruction.²³ The Bishop of London also expressed a similar view and criticized those who sought to find only natural sources as "Little Philosophers" who saw little about the way the world really works.²⁴

John Wesley

John Wesley (1703-1791), the English evangelist, provided another fundamentalist view in a 1755 article, Serious Thoughts Occasioned by the Late Earthquake at Lisbon.²⁵ In his discussion he gave a detailed account of his personal study of events at Whitson Cliffs in Yorkshire in March, 1755. Over a period of several days, great noises were heard coming from the ground, then the cliffs were split, and great stones were thrown out of the earth. In this particular case, Wesley had to reject subterranean fire and water as possible causes, because there had been no sign of either on the surface. And he had to eliminate subterranean air, because it

²³ Shower, Practical Reflections on the Earthquakes That Have Happened in Europe and America, but Chiefly in the Islands of Jamaica, England, Sicily, Malta, &c. with a Particular and Historical Account of Them, and Divers Other Earthquakes (2nd ed.; London: Cook, James, and Kingman, and others, 1750).

²⁴ Sherlock, Letter from the Lord Bishop, pp. 4-5.

²⁵ Reprinted in The Works of John Wesley (Grand Rapids, Mich.: Zondervan Publishing House, n.d.), XI, 1-13. (Hereinafter referred to as Serious Thoughts.)

cannot split rocks. Wesley also refused to accept the air-quake theory, for such an idea is "so senseless, unmechanical, unphilosophical a dream, as deserves not to be named but to be exploded."²⁶ He concluded that the cause of the Whitson Cliffs shocks had been the direct action of God, for the earthquakes, which occurred by a heavily traveled road, served as a "visible monument of His power."²⁷

The Lord also caused the Lisbon earthquakes, and those who attributed it entirely to natural forces are wrong, because the Bible reveals that God creates wind, rain, lightning, storms, and earthquakes by working through nature.²⁸ "Nay, what is nature itself, but the art of God, or God's method of acting in the material world?"²⁹ The idea of purely natural processes was "extremely uncomfortable" for Wesley. While man may pray to Heaven for deliverance from the shocks, it is futile to pray to subterranean fire, air, or water.

"O earth, earth, earth, hear the voice of thy children! Hear, O air, water, fire!" And will they hear? You know it cannot be.³⁰

But the Christian, he assured his readers, need not fear the shaking earth or the end of the world, because "the God of Love is our everlasting refuge."³¹

²⁶Wesley, Serious Thoughts, pp. 2-5.

²⁷Ibid., p. 5.

²⁸Ibid., pp. 5-6.

²⁹Ibid., pp. 6-7.

³⁰Ibid., pp. 7-8.

³¹Ibid., pp. 8, 10. Sermons of sin, judgment, and salvation were the mainstay of the Methodist. In a five year

In a later work, A Survey of the Wisdom of God in the Creation; or, a Compendium of Natural Philosophy,³² Wesley looked at the subject from a different angle, and he theorized that God creates tremors by means of subterranean fire and inflammable vapors, underground water, or electricity.³³

Samuel Davies

Wesley's counterpart in America was Rev. Samuel Davies (1724-1761). In 1756, he delivered a sermon, The Religious Improvement of the Late Earthquakes,³⁴ stating that when the everyday punishments for sin, sickness and pain, become so usual that they are regarded as common events and are no longer attributed to the Supreme Being, then the Lord has to use extraordinary means to get the attention of the people: "Famine, Sword, Pestilence, and Earthquakes."³⁵ Since the Deluge, there had not been earth movements any greater than

period, Wesley's journal recorded more than two hundred instances of members of his congregation suffering from emotional disorders ranging from hysteria and blindness to incurable insanity. See Sydney G. Dimond, The Psychology of the Methodist Revival: An Empirical & Descriptive Study (London: Oxford University Press, 1926), pp. 126-28.

³² (5 vols., new ed.; London: J. Stratford, 1809.) (Hereinafter referred to as Survey.)

³³ Wesley, Survey, V, 63-64; III, 105-6, 122-23.

³⁴ Reprinted in Sermons on Important Subjects, by the Reverend Samuel Davies, A.M., President of the College of New-Jersey (2nd ed.; New York: Dayton and Saxton, 1841), III, 176-92. The sermon was presented in Virginia on June 19, 1756. (Hereinafter referred to as Religious Improvement.)

³⁵ Davies, Religious Improvement, pp. 176-77.

the one that hit Lisbon and large parts of Europe; it had even been felt lightly in Boston. He believed that God had given the Portuguese a Judgment, and to Americans He had sent a warning to show that they are not immune from Heavenly wrath.³⁶

Concerning natural philosophy, Davies told the congregation:

There is a set of little, conceited, smattering philosophers risen among us, who think they disprove all this, by alleging that earthquakes proceed from natural causes; and therefore, it is superstitious to ascribe them to the agency of Providence.³⁷

Yet, Davies did not reject natural causes; he only added that it is God who strikes the spark that sets afire the subterrrestrial materials to create the explosions that shake the earth. The Lord established the entire process at the Creation, including the exact timing, since He knew at the beginning how his children would behave, and when they would be deserving of punishment.³⁸ Thus, God creates earthquakes without miracles or altering natural laws, although God may, of course, act directly and suspend the laws of nature so that the "interference may be more conspicuous."³⁹ Davies also believed that earthquakes demonstrate on a small scale

³⁶Ibid., pp. 177-79. Davies thought that God held America in special favor as compared to the rest of the world. Ibid., pp. 185-86.

³⁷Ibid., p. 179.

³⁸Ibid., pp. 179-80.

³⁹Ibid., p. 180.

what the Final Judgment will be like. They also show that the means for the destruction of the world is already present and waiting for the moment when all of the supplies of inflammable materials are set afire in a single moment.⁴⁰

Natural Philosophy and the Wisdom of God

While some clergymen, like Bishop Thomas Sherlock and the Reverend John Shower, regarded earthquakes as strictly the work of God and disregarded the efforts of natural philosophers to explain their existence, others, like Rev. Samuel Davies and John Wesley, adopted the idea that God creates earthquakes by means of natural processes. Still another group of churchmen and philosophers saw in earthquakes the wisdom of God and examples of His wonderful handiwork.

Rev. Jonathan Mayhew

The Reverend Jonathan Mayhew (1720-1766) of Boston in a sermon delivered following the Lisbon and New England earthquakes proclaimed that these occurrences demonstrate the greatness of God and His works.⁴¹ Natural philosophy, the

⁴⁰Ibid., pp. 186-87.

⁴¹A Discourse on Rev. XV. 3d, 4th. Occasioned by the Earthquakes in November 1755. Delivered in the West-Meeting-House, Boston, Thursday December 18, Following. In Five Parts, with an Introduction. Part I. Of the Greatness of God's Works. Part II. Of Their Marvellous and Unsearchable Nature. Part III. Of the Moral Perfections and Government of God. Part IV. Of Our Obligations to Fear, Glorify and Worship Him. Part V. Practical Reflections upon the Subject, Relative to the Occasion (Boston: Printed by Edes & Gill, 1755), pp. 12-13, 48-49.

work of observing nature and finding established rules called the laws of nature, is useful for man's physical and spiritual well-being.⁴² Yet, there remain many things in nature that have not been explained (and may never be understood): earthquakes, auroras, storms, floods, meteors, and monstrous births. Mayhew wondered how many of these anomalies in the understanding of the natural world are the means by which God reveals himself to man, or how many of these explanations are not known simply because of insufficient investigation. And even if the rules of nature become as well known as the law of gravitation, God's universe is still full of wonder, for who can say he truly comprehends a natural law without acknowledging the existence of the First Cause.⁴³

Derham, Cheyne, and Woodward

A number of the authors used earthquakes and volcanoes as demonstrations of God's wondrous plan of nature. Based on the well-known association of the two phenomena, natural theologians William Derham (1657-1735), George Cheyne (1671-1743), and John Woodward pointed out that volcanic eruptions provide a means for the release of imprisoned fires and vapors; thus, even more dreadful earthquakes than those accompanying active volcanoes are prevented.⁴⁴

⁴²Ibid., pp. 24-25.

⁴³Ibid., pp. 24-27.

⁴⁴Derham, Physico-Theology: or, a Demonstration of the Being and Attributes of God, from His Work of Creation. Being the Substance of XVI Sermons Preached in St. Mary le Bow-

Concerning the Beneficial Qualities of Earthquakes

The author of the book Theory and History of Earthquakes marveled that God creates good out of such a destructive force, and he pointed to one example: the vapors that shake the earth. They are needed in the production of minerals and the growth of vegetation. Furthermore, the winds that are created prevent the atmosphere from becoming stagnant. The subterrestrial exhalations are also responsible for the fragrance of flowers, the taste and nourishment of corn, and the healing properties of mineral waters. In short, earthquakes are a matter of life as well as death.⁴⁵

Élie Bertrand also discussed the beneficial effects by remarking that tremors are followed by periods of increased soil fertility (caused by the mixing of salts and sugars required by vegetation), and the earth movements also serve to stir and circulate the waters of the globe to prevent their "corruption." Bertrand suggested that since a fever is sometimes needed by the human body, an earthquake may be just as

Church, London, at the Honble Mr. Boyle's Lectures, in the Years 1711 and 1712. With Large Notes, and Many Curious Observations Never Before Published (London: Printed for W. Innys, 1713), pp. 68-69; Cheyne, Philosophical Principles of Religion: Natural and Reveal'd. In Two Parts. Part I. Containing the Elements of Natural Philosophy, and the Proofs of Natural Religion Arising from Them. Part II. Containing the Nature and Kinds of Infinities, Their Arithmetick and Uses: Together with the Philosophick Principles of Reveal'd Religion (2nd ed., corrected and enlarged; London: Printed for George Strahan, 1715-16), Pt. I, pp. 291-92; and Woodward, An Essay Toward a Natural History of the Earth, pp. 143-44.

⁴⁵Theory and History of Earthquakes, pp. 12-13.

necessary for the earth's health, although he admitted that more needed to be learned before he could definitely say what good uses the Lord had in mind when He created earthquakes.⁴⁶

Professor John Winthrop stated that while many people had been killed by a shaking earth, many more have benefitted, for God established the natural laws for the general good of man, although the wind that powers sailing ships and prevents the air from stagnating also wrecks ships and overturns homes. Similarly, the subterranean vapors that produce earthquakes are likely indispensable for the well-being of the planet. If it were not for a shaking and loosening of the ground, the earth would become harder and more dense (due to the action of gravity and the consumption of fluids), and the production of minerals and other substances would also be hindered. The lands around Mt. Etna and Mt. Vesuvius are especially fertile, because the shocks there help the farmer by tilling the soil below the level the plow can reach. Earthquakes, in effect, cultivate the interior of the earth for the same good purpose that a man plows his fields to produce abundant crops. The lecturer also suspected that since some of the airs given off by volcanoes are noxious, other vapors must be salutary. Likewise, subterranean waters that are directed into new paths by the earth movements may be altered beneficially.⁴⁷

⁴⁶Bertrand, Memoires, pp. 19-21.

⁴⁷Winthrop, Lecture on Earthquakes, pp. 27-31.

However, not everyone was convinced of the inherent goodness to be found in a trembling earth. François Marie Arouet de Voltaire (1694-1778) in his "Poème sur le désastre de Lisbonne"⁴⁸ questioned the truism "Tout est bien." All is not well, for it is evident that earthquakes are not providential, unless one considers the good fortune of heirs who gain possession of family estates unexpectedly, or the increased demand for masons who find plenty of work rebuilding destroyed towns.⁴⁹

Natural Philosophers and Natural Theology

Just as the clergy were divided in their views, from those who used the shocks to frighten their parishoners to repentance to those who saw earthquakes as one of God's beneficent wonders, naturalists (including those who were also churchmen) were similarly split as to their views of natural theology.

Prince and Winthrop

In the debate between Rev. Thomas Prince and Professor Winthrop,⁵⁰ it was Prince who stressed God's role in creating

⁴⁸"Poème sur le désastre de Lisbonne ou examine de cet axiome: Tout est bien," Oeuvres complète de Voltaire (Nouvelle édition; Paris: Garnier Frères, Libraires-Éditeurs, 1877), IX, 470-79.

⁴⁹Voltaire, "Préface du poème sur le désastre de Lisbonne," Ibid., IX, 463, 468.

⁵⁰See above, pp. 18, 129-33.

earthquakes, while Winthrop concentrated on natural processes. But their points of view were not all that far apart. While protesting Winthrop's emphasis on natural philosophy, Prince agreed that the tremors come from natural causes--but under God's direction as a demonstration of His dissatisfaction.⁵¹ Winthrop indicated that "the operations of nature are conducted with a view, ultimately, to moral purposes; . . ."⁵²

Bertrand and Hales

Bertrand combined in a more peaceful atmosphere the views of the debaters Prince and Winthrop. He thought that there is nothing better than earthquakes for instructing the Christian, because the more unusual an event is, the easier it is to find the Hand of God. They demonstrate that the Lord is the Master of Nature. At the Creation, God established the natural laws governing the tremors, although He retains the power to initiate events. The shocks also show that the earth is breakable; after all, it has not been made for man to live on forever.⁵³ Bertrand extended his remarks on natural theology and earthquakes in four sermons delivered in Switzerland following the Lisbon cataclysm.⁵⁴

⁵¹In addition to Prince's sermons (see above, p. 130, nn. 21, 22), see the letter from Prince printed in the Boston Gazette, January 26, 1756, 21, recto.

⁵²Winthrop, Lecture on Earthquakes, p. 29.

⁵³Bertrand, Memoires, pp. 1-2, 5-7.

⁵⁴Mémoire pour servir à l'histoire des tremblemens de

Stephen Hales also thought that most earthquakes are the result of natural causes, but "the ordinary Course of Nature is as much carried on by the Divine Agency, as the extraordinary and miraculous Events." In addition, he expressed the belief that God sometimes "changes the Order of Nature, with Design to chastise Man for his Disobedience and Follies; . . ."⁵⁵

John Ray

In contrast, John Ray's theological comments were as firmly in the fire-and-brimstone school of preaching as were the writings of Bishop Sherlock or the warnings in the Theory and History of Earthquakes. Ray believed that when a city becomes too wicked, God corrects the situation by sending a "sweeping Judgment." He felt that Heaven directly intervenes in all great events. For example, in 1692, God ordered the destruction of sinful Port Royal, Jamaica. His orders were "effected perchance by the Ministry of an Angel."⁵⁶

Charles Lyell considered it remarkable that a natural philosopher of Ray's reputation would be "courting popularity,

terre de la Suisse, principalement pour l'année MDCCLV. Avec quatre sermons prononcés à cette occasion dans l'Eglise Francoise de Berne (Vevey: Chez Chenebré, 1756). See an abstract of these sermons in Nouvelle bibliotheque germanique ou histoire litteraire de l'Allemagne, de la Suisse, & des Pays du Nord, par Mr. Samuel Formey, XIX, Pt. I (1756), 43-56.

⁵⁵Hales, "On the Causes of Earthquakes," pp. 669-70.

⁵⁶Ray, Three Physico-Theological Discourses, pp. 270-71.

by pandering to the physico-theological taste of his age."⁵⁷ It is doubtful that Ray was simply supplying a need for physico-theological materials, for Lyell's remarks apply to many writers. Ray was only more flamboyant in his professions of faith as compared to the comments of his colleagues.

William Stukeley

Stukeley did not just consider electricity as a subject of only secular interest, for as Rector of St. George's Church in Queen Square, he was obliged to contemplate his theory of earthquakes from a theological viewpoint. Since everything in nature has a moral purpose, he maintained that it was the role of the earth movements to be "Warnings and Judgments."⁵⁸ Thus, the "chastening Rod" of the Lord is directed at cities and towns, and not against uninhabited lands.⁵⁹ In 1750, God was warning the people of London.⁶⁰

Earthquakes and Natural Theology

For many during the Enlightenment, as in the ages before, a major principle of faith was that God actively participates in the world order, suspending on occasion the peace of the

⁵⁷Lyell, Principles of Geology, I, 36.

⁵⁸Stukeley, "Concerning the Causes of Earthquakes," pp. 668-69.

⁵⁹Stukeley, "On the Causes of Earthquakes," p. 645.

⁶⁰Stukeley, "Concerning the Causes of Earthquakes," pp. 668-69.

earth by causing the land to tremble and break so as to punish sinners or to warn the wicked.⁶¹ In the procession of years into the eighteenth century, this attitude was changing. Previously, man sought to find the Supreme Being in miraculous events, but in the light of reason, He was seen in the perfect order in a world of unbreakable laws. In the pulpit, terrifying sermons of sin and damnation were beginning to be replaced with discourses on natural theology; literal interpretations of the Biblical Creation became allegorical. All that happens in nature was being viewed as a product of laws; events were no longer created strictly by the wrath of God.⁶²

To characterize religious thought in relation to earthquakes with a single descriptive title such as "evangelical" or "deistic" cannot take into consideration changes in outlook through the century, and the simultaneous existence of a spectrum of opinions. While the Reverend Davies retained

⁶¹While Satan was not directly blamed for earthquakes, he was an interested observer. See A Letter of Congratulation and Advice from the Devil, to the Inhabitants of Great Britain, Particularly Those of the Two Cities of London and Westminster on Their Conduct Before and After the Late Earthquakes (London: Printed by the Fool, sold by Charon, [1750?]).

⁶²The general comments in this section are based on the literature surveyed above, as well as the following: Smith Enlightenment, chaps. xiii-xv (particularly pp. 410-12); Ernst Cassirer, The Philosophy of the Enlightenment, trans. by Fritz C. A. Koelln and James P. Pettegrove (Princeton: Princeton University Press, 1951), chap. ii (particularly pp. 47-49, 69); and Charles Coulston Gillispie, Genesis and Geology: A Study in the Relations of Scientific Thought, Natural Theology, and Social Opinion in Great Britain, 1790-1850, Harper Torchbooks (New York: Harper & Row, Publishers, 1959), chap. i.

for a sometimes vengeful God the option of revoking natural laws for special purposes, Baron d'Holbach argued that ideas of the supernatural were invented by primitive men who could only explain earthquakes and lightning by ascribing them to the acts of a powerful deity--a point of view made obsolete by the new knowledge of the natural order of things in a mechanical universe.⁶³

Theological discussions were involved in the study of earthquakes. Those who searched into the causes of the shocks took into consideration the role God plays in the creation of the tremors either by direct action, or as the source of the laws by which the earth is shaken. They saw earthquakes as Divine Punishment, or as one of the wonders produced by the Master Architect. An understanding of the Lord's participation in nature was important when it came to the task of arriving at a total comprehension of earthquakes.

⁶³Holbach, Système de la nature; ou, des loix du monde physique & du monde moral, par M. Mirabaud (Londres, 1770), cited in Smith, Enlightenment, pp. 440-41.

CHAPTER III

EXTRATERRESTRIAL CAUSES OF EARTHQUAKES

Astrological explanations had been prominent in the Middle Ages, as the earthquake-producing agents of fire, wind, and water were thought to be directed in their actions by the planets. George Sarton has suggested that satisfaction with the answers astrologers offered was a factor in the scarcity of theoretical discussions of the shaking earth in the medieval period.¹ In the eighteenth century, astrological theories were not acceptable. Instead, new and different ideas were being explored: some thought the shocks were created by explosions in the earth or in the atmosphere; others blamed electricity for the tremors, while many looked to God to find the ultimate source. Only a small number of individuals even considered the idea that the heavens influence the production of the earth shocks, for that idea came under the label "astrology," a subject denounced as nonsense.² Still, there

¹Sarton, Introduction to the History of Science, Vol. III, Pt. I: Science and Learning in the Fourteenth Century (Baltimore: Published for the Carnegie Institution of Washington by the Williams & Wilkins Company, 1947), p. 216.

²For instance, see Thomas, "Memoire," p. 431.

remained a few investigators to search for a reasonable natural cause outside the terrestrial realm.

Pierre Bouguer and the Tidal Hypothesis

One naturalist who gave serious thought to the subject was Pierre Bouguer (1698-1758), the author of the report of an Académie Royale des Sciences expedition to South America.³ He was not surprised that astrology was still in use in Peru to forecast earthquakes, because that "science vaine" exists where true natural philosophy has made little progress.⁴ In 1729, a mathematician at Lima had published predictions of the most disastrous periods for Peru, and in 1734 the forecaster claimed that his prognostications of tremors had been right 143 times.⁵ Bouguer remarked that to claim such accuracy, the astrologers in western South America had an unusual advantage in the great frequency of earth movements in that part of the world. Thus, the so-called laws of astrology appear to predict actual earthquakes some of the time, although the shocks may be so minor that only the astrologers pay attention to them.⁶

³Bouguer, La figure de la terre, déterminée par les observations faites au Pérou (Paris: n.p., 1749).

⁴Ibid., p. lxxii.

⁵Ibid. Bouguer may have been referring to the work of Marco Antonio Melli, who is also mentioned in Moreira de Mendonça's Historia universal dos terremotos, pp. 183-84.

⁶Bouguer, La figure de la terre, p. lxxv.

Omitting the patently false claims, Bouguer did consider the idea of a physical connection between heavenly bodies and earthquakes worth considering. By using the Lister-Lémery thesis of the combustion of subterranean materials when moistened, he judged that since the tides affect the amount of water that penetrates into the earth, the movement of the moon in affecting the flux and reflux of the sea has a legitimate role in influencing the occurrence of earthquakes. Through the moon's effect on tides and the tidal water's effect on earthquakes, the astrologer's work is not totally invalid when it comes to predicting shocks.⁷ The author found that the city of Lima had been destroyed on three different occasions; two of the shocks had struck after spring tides had introduced a great quantity of water into subterranean cavities.⁸

The South American astrologer in his predictions had also listed as the most foreboding time for each tremor a specific six-hour period relating the position of the earth and moon. Bouguer confirmed that this period coincides with the time of the reflux of the sea along the coast of South America; here is further evidence of a tidal influence.⁹ Alas, the great 1746 earthquake at Lima occurred with the moon in the wrong position.¹⁰

⁷Ibid., pp. lxxii-lxxiii.

⁸Ibid., pp. lxxiii-lxxiv.

⁹Ibid., pp. lxxiv-lxxv.

¹⁰Ibid., p. lxxv.

The French theorist concluded that predictions based on present-day explanations cannot be expected to be very accurate considering the complicated task involved. The location of the inflammable materials, the amounts of water available, and the variables involved in combining the two in order to form Lémery's explosive mixture are just some of the factors subject to chance--even if earthquakes are conclusively demonstrated to be tied to the movement of the moon. And it was far from certain that the tidal waters do play the important role, because four major earthquakes in Peru associated with high tides also occurred in the rainy season for South America. Rainwater might well be a contributing factor in the production of the tremors.¹¹

Other Tidal Theories

More than a century after Bouguer's comments, the idea of tidal forces of the sun and moon influencing earthquake activity was still being discussed. Francesco Zantedeschi (1797-1873), a mathematician at Padua, proposed that the shape of the earth is not constant, for it is distorted in the direction of the sun and moon. Thus, earthquakes are more common in periods of syzygies (full or new moon) and during high tides.¹² In support of his theory, a number of

¹¹Ibid., pp. lxxv-lxxvi.

¹²Zantedeschi, "De l'influence de la lune dans les tremblements de terre, et des conséquences probables qui en dérivent sur la forme ellipsoïdale de la terre, et sur les

Enlightenment authors were cited, beginning with Paduan astronomer Geminiano Montanari (1633-1687) and his reassessment of astrology.¹³ Giuseppe Toaldo, another astronomer at Padua, revived some of Bouguer's arguments by giving examples of shocks at high tide.¹⁴ One physician's account of an earthquake at Rome was another source work used by Zantedeschi.¹⁵

The author could also have mentioned Élie Bertrand, for among the numerous possible explanations discussed was the idea of the attraction of the sun and moon on the crust of the earth and on the seas.¹⁶ On a related subject, Jacques

oscillations des pendules; par M. Fr. Zantedeschi," Compte rendu des séances de l'Académie des Sciences, XXXIX (1854), 375-77. (Hereinafter referred to as "De l'influence de la lune.")

¹³L'astrologia convinta di falso col mezzo di nuove esperienze, e ragioni fisico-astronomiche, o' sia la caccia del frvgnvolò, di Geminiano Montanari (Venetia: Per F. Nicolini, 1685).

¹⁴Toaldo, Della vera influenza degli astri delle stagioni e mutazioni di tempo, saggio meteorologico . . . applicato agli usi dell' agricoltura, medicina, nautica, ec., di Giuseppe Toaldo, si aggiungono i prognostici di Arato tradotti dal Sig. A. L. Bricci, et la descrizione d'un nuovo pendolo a correzione del Ch.P. Boscovich (Padova: G. Manfrè, 1770), p. 190. Toaldo cited the evidence of Jean Baptiste Thibault de Chanvalon, Voyage a la Martinique contenant diverses observations sur la physique, l'histoire naturelle, l'agriculture, les moeurs, & les usages de cette isle, faites en 1751 & dans les années suivantes. Lu à l'Académie royale des sciences de Paris en 1761 (Paris: J. B. Bauche, 1763).

¹⁵Georgio Baglivi (1668?-1707?), "Historia romani terrae motus, anni 1703," Opera omnia medico-practica et anatomica (18th ed.; Bassani: n.p., 1737), p. 413. (See the "Bibliography" for the complete citation.) Zantedeschi, "De l'influence de la lune," pp. 376-77.

¹⁶Bertrand, Memoires, pp. 187-88.

Eugène d'Allonville, Chevalier de Louville (1671-1732), a French astronomer, had observed that the moon has an atmosphere,¹⁷ and Bertrand included his suggestion that the pressure of that atmosphere on the earth is a factor in the creation of earthquakes.¹⁸

Comets and Earthquakes

Beginning with the great comet of 1680, these strange appearances in the heavens were beginning to be no longer commonly feared as portents of doom, for there was an exhaustive effort on the part of the French philosopher and man of letters Pierre Bayle (1647-1706) to show that comets are simply an unusual natural phenomenon, having no relationship to the destinies of men.¹⁹ Superstition was on the way out, and

¹⁷Chevalier de Louville, "Remarques sur les principaux phénomènes qui ont été observés pendant cette éclipse," in "Observation faite à Londres de l'éclipse totale du soleil du 3. May 1715. nouveau stile," Historia de l'Academie Royale des Sciences. Année M.DCCXV. Avec les memoires de mathematique & de physique, pour la même année (Paris, 1718), Memoires, pp. 90-99.

¹⁸Bertrand, Memoires, pp. 187-88.

¹⁹First published under the title Lettre à M. L. A. D. C. docteur de Sorbonne. Où il est prouvé par plusieurs raisons tirées de la philosophie, & de la theologie, que les cometes ne sont point le presage d'aucun malheur. Avec plusieurs reflexions morales & politiques, & plusieurs observations historiques & la refutation de quelques erreurs populaires (Cologne: Chez Pierre Marteau, 1682) and later as Pensées diverses, écrites à un docteur de Sorbonne, à l'occasion de la comète qui parut au mois de décembre 1680 (Rotterdam: Chez Reinier Leers, 1683). See also the critical edition: Pensées diverses sur la comète, ed. by A. Prat, Société des Textes Français Modernes (2 vols.; Paris: Société Nouvelle de Librairie et d'Édition, 1911).

astronomical--not astrological--considerations were important.²⁰ However, there were still those who wondered about a possible physical connection between comets and earthquakes.

Bertrand recalled that the comet of 1682 had been associated with earth tremors. He wondered if the relationship were merely coincidental, or if there were some direct cause and effect relationship. Perhaps the pressure of the comet's atmosphere on the earth or the composition of its tail may be significant. Or maybe there is a consequential mutual attraction between the earth and comets.²¹ Bertrand was not one to reject any reasonable explanation. He also found that if the period of revolution of the comet of 1682 had been correctly determined,²² then it was also the comet of 1607, 1531-32, and 1456-57. Each of these periods was marked by destructive earthquakes. The Swiss author concluded his remarks by wondering what might happen in the years 1757-58 when the comet would next appear.²³

Investigators looked everywhere to find the true source of the shaking earth--from the center of the terrestrial sphere

²⁰Smith, Enlightenment, pp. 460-61.

²¹Bertrand, Memoires, pp. 74-75.

²²According to Edmund Halley (1656-1742), A Synopsis of the Astronomy of Comets. Translated from the Original Printed at Oxford (London: Printed for John Senex, 1705).

²³Bertrand, Memoires, p. 76. While accounts of earthquakes in the years 1755 and 1756 are common, the earthquake chronicles are comparatively quiet for the period of the return of Halley's comet.

out to the realm of the moon, sun, and comets. Theories that placed the cause of earthquakes outside of the earth and its atmosphere were not very popular with eighteenth-century writers. The only extraterrestrial influences of significant interest referred to Heavenly causes with a capital "H."

CHAPTER IV

PRACTICAL APPLICATIONS OF EARTHQUAKE THEORIES

A few individuals were not just interested in finding the source of earthquakes for the sake of understanding one aspect of the natural world, for they sought to use the knowledge to arrive at a means of preventing future disasters.

The Deep-Well Method of Earthquake Prevention

Since volcanoes were thought to act as natural safety-valves, some writers supported the idea that deep wells allow subterranean vapors to escape before they can accumulate and shake the earth. Antoine Léonard Thomas pointed out that these holes would have to extend to the depth of the subterrrestrial exhalations to be effective. The author did not have a great deal of faith in the deep-well method, because even volcanoes have proven to be weak insurance against earthquakes in Italy, Peru, Iceland, and Japan. He concluded that if one wanted to feel safe from the quaking earth, the best precaution would be not to live in a country subject to the tremors.¹

¹Thomas, "Memoire," pp. 432-34.

In the same period that Thomas's essay won a prize at Rouen, another award was presented to Monsieur Isnard of Grasse.² He also noted the benefits that can be derived from digging long shafts in earthquake-prone areas.³ Yet, the ideas of both Thomas and Isnard were not original, for there were precedents. Pliny recognized the value of such a plan,⁴ and Arnolfo di Cambio (di Lapo) (1232-1301), the first architect of the cathedral at Florence, ordered wells to be dug around the church to shelter it from harm.⁵

Henri Paulian also discussed the method. In Persia, wells dug around the city of Tauris (Tabriz) in 1721 may have been instrumental in protecting the area from shocks, although Paulian admitted that the preventive measures had been in place only forty years. The subterranean forces may not have had enough time since the last shock to renew their power to create another disaster. Nevertheless, he urged the Lisbon government to adopt the same precautions that had been put into effect at Tauris.⁶

²Mémoire sur les tremblemens de terre, qui a remporté le prix de physique au jugement de l'Académie des Sciences, Belles-lettres et Arts de Rouen, le 3 août 1757, par M. Isnard (Paris: Vve. David jeune, 1758).

³Adams, Geological Sciences, p. 413.

⁴Pliny, Historia naturalis 2. 84.

⁵According to the Cronica of Giovanni Villani (ca. 1276-1348); cited in Adams, Geological Sciences, p. 413.

⁶Paulian, "Tremblement de terre," pp. 338-39.

Pierre Bertholon's Device

In the late 1770's, the principal proponent of safeguards was Pierre Bertholon (1741-1800), a French cleric, physician, and member of numerous French academies, who promoted his ideas in an article for the revised edition of the Encyclopédie⁷ and in a detailed journal presentation.⁸ He first demonstrated the need for protection from an unstable earth; there was no place that seemed safe.⁹ Although France was relatively free from the shocks, nine tremors had been counted between 1733 and 1778.¹⁰ The author concluded his chronicle with a phrase borrowed from Seneca: "On ne doit pas être surpris que la terre tremble, mais qu'elle subsiste."¹¹

⁷"Tremblement de terre. (para-tremblement de terre, ou préservateur des tremblemens de terre.)," Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres. Mis en ordre & publié par M. Diderot; & quant à la partie mathématique, par M. d'Alembert (nouv. éd.; Geneve: Chez Pellet, Imprimeur-Libraire, 1778), XXXIV, 79-81.

⁸"Mémoire sur un para-tremblement de terre, & un para-volcan," Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. le Comte d'Artois; Par M. l'abbé Rozier, XIV, Pt. II (1779), 111-12. (Hereinafter, citations to Bertholon will be to this article as "Mémoire.")

⁹He recounted some of the recent shocks in Lima, Lisbon, Baghdad, Smyrna, Tripoli, Peking, and other places around the globe. Bertholon, "Mémoire," pp. 113-14.

¹⁰Ibid., pp. 114-15.

¹¹Ibid., p. 114. ("One should not be surprised that the earth trembles, but that it subsists.")

After a great deal of effort (according to his own evaluation) in trying to find some means of protection against earthquakes, Bertholon arrived at a solution derived from the electrical hypothesis. In his synthesized version of the idea, when there exists a disequilibrium between the amount of the electrical material in the earth and in the atmosphere, an even distribution is reestablished through an effort similar to lightning. Electricity breaks out of the earth with a destructive force determined by the quantity of electricity that is required to restore equilibrium, the depths involved, and the resistance of obstacles to its passage.¹²

Since one of Bertholon's earlier journal articles demonstrated that lightning rods offer protection from thunderbolts,¹³ he proposed that a similar device would mean freedom from earthquakes. Great iron bars with sharp points on both ends sunk deep into the earth will transmit any overabundant electricity from the earth and discharge it harmlessly into the atmosphere.¹⁴ He urged that these earthquake-rods be placed around Naples, Lisbon, Cadiz, Seville, Peking, Lima

¹²Ibid., pp. 116-17.

¹³"Mémoire dans lequel on donne un nouveau moyen de se préserver du tonnerre, après avoir prouvé que la foudre s'élève souvent de la terre," Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées à Mgr. le Comte d'Artois; par M. l'abbé Rozier, X (1777), 179-96. (From the nouv. éd., Paris: Rue et Hôtel Serpente, 1782.)

¹⁴Bertholon, "Mémoire," pp. 117-18.

Quito, Mt. Vesuvius, Mt. Etna, and other troubled areas to prevent any further earthquake and volcanic activity.¹⁵

In a demonstration to show the effectiveness of his device, Bertholon constructed small houses out of cardboard to represent a town. By sending an electrical discharge through the model, the houses were overturned. And since electricity also ignites volcanoes, he also built a miniature mountain (filled with inflammable substances and light materials) that ejected fire and debris when jolted by electricity. His metal rods were put into place; this time the "town" was saved--there were no shocks, and the "mountain" remained tranquil.¹⁶

Bertholon knew of the deep wells at Tauris, but he suggested that they worked not by releasing imprisoned vapors, but by helping the electrical fluid escape. He emphasized that his metal bars as true conductors are a more effective and sure means of transmitting any excessive electricity from inside the earth out into the atmosphere. For governments worried about the high cost of such an installation, Bertholon pointed out that the cost is less than the price of replacing sumptuous palaces that might be ruined in the next earthquake. He added that the government of Naples was definitely interested in his apparatus, and he urged the monarchs of Portugal and Spain to adopt the scheme.¹⁷

¹⁵Ibid., p. 119.

¹⁶Ibid.

¹⁷Ibid., pp. 120-21.

The article on earthquakes in Sigaud-Lafond's Dictionnaire de physique also urged the implementation of Bertholon's plan, although for a different reason than its inventor gave. While Bertholon considered electricity to be the immediate cause of the tremors. Sigaud-Lafond believed that the device would work by enabling the electrical fluid to safely leave the earth without igniting and exploding the inflammable and effervescent materials that are really responsible for shaking the earth.¹⁸

Man Versus Earthquakes

In general, only a very small portion of the eighteenth-century earthquake-writers held the notion that knowledge of causes enables man to devise a means of preventing disasters. The difficulty of implementing the deep-well method and the uncertainty of its usefulness doomed it to only occasional and inconclusive trials. Nature's counterpart, the volcano, was not foolproof protection, for sometimes this "remedy" was found to be more destructive than threatening earthquakes.

The electricians held greater hopes for finding a preventative, and the idea of a lightning rod for earthquakes was an intriguing, but expensive, one. Seeing the absence of agreement among the naturalists as to the cause of earth shocks, governments would be very cautious, for surrounding a city the size of London, Lisbon, or Naples with the iron

¹⁸Sigaud-Lafond, "Tremblement de terre," pp. 453-54.

rods would be an expensive proposition. Even if the electrical hypothesis were the correct one, there was no absolute guarantee of success, since the device's predecessor, the lightning rod, had been found not to work infallibly.¹⁹

Nothing came of Bertholon's idea, but then, too, the efficacy of prayer and repentance, an age-old remedy, was also being questioned.

Most felt that not much can be done about preventing earthquakes. If they cannot be stopped, the next alternative would be to run away from them by removing populations and valuables from the scene of an impending catastrophe. But men of the Enlightenment held even less hope for predicting violent earth movements. Nathaniel Crouch's "prognostics" (turbulent water, or high, thin clouds) were too general to predict anything but false alarms. Knowing that subsurface causes are hidden where there is no way to monitor the processes, naturalists could not realistically hope to master the problem of forecasting shocks. As Bouguer admitted, there were just too many variables involved in the creation of earthquakes, and in the case of multiple-causes explanations,

¹⁹Lightning rods had not proven to be foolproof when installed at the British government's munitions stores at Purfleet, although they had been added at the recommendation of a Royal Society committee. See "A Report of the Committee Appointed by the Royal Society, to Consider of a Method for Securing the Powder Magazines at Purfleet," Philosophical Transactions of the Royal Society of London, LXIII, Pt. I (1773), 42-48; and "Sundry Papers Relative to an Accident for from Lightning at Purfleet, May 15, 1777," Ibid., LXVIII, Pt. I (1778), 232-317.

like Bertrand's theory, the problem was compounded even more. Attempts at predictions were left the province of the astrologers.²⁰

By the end of the eighteenth century, useful devices for preventing earth tremors were, for all practical purposes, unavailable, and an effective warning system was still needed. These are two very minor aspects of earthquake studies in the 1700's. Many investigators (those discussed in the next chapter) were interested in much more important topics, such as the question of what effects earthquakes have in altering the face of the earth.

²⁰See above, pp. 231, 263, 265.

CHAPTER V

ON THE LAND-ALTERING EFFECTS OF EARTHQUAKES

The ancient historian Herodotos (ca. 480-ca. 425 B.C.) told of an earthquake opening the gorge that released the landlocked Thessalian sea.¹ The Greek geographer Strabo (ca. 58 B.C.-ca. A.D. 24) remarked that Sicily had been detached from the Italian peninsula by a great earthquake, although volcanoes by releasing fire, water, and wind from beneath the surface now limit the activity of earth movements.² Renaissance authors cited earthquakes as one force that has been altering the topography of the earth since the Creation.³ One continuing investigation into the natural world has concerned the role earthquakes play in changing the appearance

¹Herodotos History of the Greek and Persian War 7. 129. Trans. by George Rawlinson, ed. by W. G. Forrest in The Great Histories, ed. by Hugh R. Trevor-Roper (New York: Washington Square Press, 1963).

²Strabo Geographia 6. 1. 6. c258. The Geography of Strabo, Vol. III, trans. by Horace Leonard Jones, Loeb Classical Library (Cambridge: Harvard University Press, 1954).

³Sister Suzanne Kelly, "Theories of the Earth in Renaissance Cosmologies," Toward a History of Geology, ed. by Cecil J. Schneer, Proceedings of the New Hampshire Inter-Disciplinary Conference on the History of Geology, September 7-12, 1967 (Cambridge, Mass.: M.I.T. Press, 1969), pp. 214-15.

of the planet. In the eighteenth century, just as there was no agreement as to causes, there was no consensus as to the consequences of the shocks as an earth-sculpting force in raising or tearing down mountains, in separating land masses, or in creating new islands.

Robert Hooke

The boundaries in time for the discussions here begin in the year 1668 with the Lectures and Discourses of Earthquakes by Robert Hooke,⁴ a series of papers presented to the Royal Society of London in which the author held that since the Creation, the earth has experienced changes that produced land where seas once existed and replaced continents with oceans. Mountains became valleys; valleys became mountains.⁵ These changes explain how sea shells came to be located on mountain summits, for the tallest peaks were once under the sea, later to be raised to their present positions. For Hooke, earthquakes are the sources of these alterations.⁶

⁴Lectures and Discourses of Earthquakes, and Subterraneous Eruptions. Explicating the Causes of the Rugged and Uneven Face of the Earth; and What Reasons May Be Given for the Frequent Finding of Shells and Other Sea and Land Petrified Substances, Scattered Over the Whole Terrestrial Superficies, in The Posthumous Works of Robert Hooke, M.D. S.R.S. Geom. Prof. Gresh. &c. Containing His Cutlerian Lectures, and Other Discourses, Read at the Meetings of the Illustrious Royal Society, ed. by Richard Waller (London: Published by Richard Waller, Printed by Sam. Smith and Benj. Walford, 1705), pp. [277]-450. (Hereinafter referred to as Lectures and Discourses.)

⁵Ibid., pp. 297-98.

⁶Ibid., pp. 291, 298.

He divided "earthquakes," a term he defined broadly as the force that shapes the appearance of the terrestrial sphere, into four types. The first includes earthquakes that elevate parts of the land to create islands, to raise mountains, and to form volcanoes. The second classification consists of those that lower the surface of the earth to form lakes and to increase the depth of the sea. "Subversions, Conversions, and Transpositions" make up the third grouping. The final list is comprised of the various operations that affect the character of the surface, including liquefaction, baking, calcination, petrification, and distillation.⁷

In additional discourses of the 1690's, Hooke theorized that the earth is altered through the action of subterranean fires and explosive vapors, but he did not give a detailed account of the materials or the process involved.⁸ He did say that since earthquakes are common near the sea, salty water may help produce fermentations in conjunction with sulphureous minerals to create an explosive mixture.⁹ Parts of the earth are raised by the expansive power of subterrestrial fires, while other parcels of land collapse into caverns created by these same fires.¹⁰

He rejected the explanation that sea shells and other marine fossils were placed on the mountain heights during

⁷Ibid., pp. 298-99.

⁸Ibid., pp. 424-25.

⁹Ibid., p. 421.

¹⁰Ibid., pp. 424-25, 305.

the Biblical Flood, because forty days and nights had not been long enough to account for the number of mature shells and the amount of sand found in the highlands.¹¹ Instead, Hooke remarked that mountains like the Alps and Andes were lifted out of the sea by earthquakes. Since subterranean fires are subject to decay (just as volcanoes become extinct from the lack of burning materials), he suggested that earth movements must have been more common in the past. Mountain-building is not seen in the present, because the fires and vapors have been exhausted, or at least they are not as powerful as they once were. Or, perhaps, the materials have been transformed into substances incapable of fueling the fires.¹²

Rudolf Erich Raspe and Hooke's Theory

Hooke's ideas were neglected until Rudolf Erich Raspe (1737-1794) of the Royal Library at Hanover rediscovered the Lectures and Discourses while pursuing an interest fostered by the Lisbon earthquake. He was convinced as to the correctness of Hooke's system for explaining the observed structure of the earth, and in 1763, he defended Hooke's thesis by publishing a new presentation based on the latest information, emphasizing contemporary accounts of the creation of new islands.¹³ However, just as Hooke's ideas had received little

¹¹Ibid., p. 341.

¹²Ibid., pp. 326, 425-27.

¹³Specimen historiae naturalis globi terraquei, praecipue de novis e mari natis insulis, et ex his exactius descriptis & observatis, ulterius confirmandâ, Hookiana telluris hypothese,

attention, Raspe's revival met the same fate. Charles Lyell later remarked that he was as surprised that Raspe's work had been ignored as Raspe had found it incredible that the Lectures and Discourses had been neglected.¹⁴

Antonio Lazzaro Moro

In 1740, another investigator Antonio Lazzaro Moro (1687-1740) presented his view as to how marine fossils came to be found in the mountains.¹⁵ After discussing observations regarding the rise of a new island near Santorini in 1707 and the creation of Monte Nuovo in 1538 near Naples, and after proposing the idea that shells found above the sea came originally from the sea, Moro postulated that lands containing marine remains were elevated out of the sea by subterranean fires.¹⁶

Moro's work benefitted from the contributions of a commentator, Giuseppe Cirillo Generelli, who elaborated on Moro's

de origine montium et corporum petrefactorum. Cum figuris aeneis (Amstelodami & Lipsiae: Sumptibus J. Schreuder & P. Mortier, 1763). See the introduction by Audrey Notvik Iversen and Albert V. Carozzi in their facsimile edition and translation of the work: An Introduction to the Natural History of the Terrestrial Sphere Principally Concerning New Islands Born from the Sea and Hooke's Hypothesis of the Earth on the Origin of Mountains and Petrified Bodies To Be Further Established from Accurate Descriptions and Observations (New York: Hafner Publishing Company, 1970), pp. xviii, xx, and chaps. ii and iv of the book. (Hereinafter referred to as Specimen and Introduction, respectively.)

¹⁴Lyell, Principles of Geology, I, 52.

¹⁵Moro, De' crostacei e degli altri marini corpi che si truovano su' monti (Venezia: Appresso Stafano Monti, 1740).

¹⁶Ibid., pp. 214-20, 230-32.

book in a dissertazione of 1757.¹⁷ Lyell stressed Generelli's explanation of the natural changes in the earth's surface in an introductory history for his Principles of Geology. For a solution to the problem that the contemporary earth movements are very weak compared to those that must have dramatically reshaped the surface, Generelli simply denied the premise. In his view, the great number of earthquakes and eruptions of volcanoes that have been recorded, as well as the innumerable occurrences that have been lost in the history of the last six thousand years, are responsible for the earth's present appearance.¹⁸

Other Points of View

A number of authors discussed the action of earthquakes in bringing about topographic changes.

John Ray

John Ray, in his Miscellaneous Discourses, stated that on the Third Day, God separated the land from the waters, and the writer concluded that this had been accomplished directly by God, or by the Lord through secondary causes, i.e. earthquakes.¹⁹ Subterranean fires and winds have a power sufficient

¹⁷Generelli, Dissertazioni de crostacei e di altre produzioni marini che sono ne monti (Milano, 1757).

¹⁸Generelli's theory as described in Lyell, Principles of Geology, I, 43-46.

¹⁹Ray, Miscellaneous Discourses, pp. 152-53.

to raise land above the waters, as had been indicated by an Andean earthquake in 1646 that had altered a large part of the mountain range.²⁰ He further stated that if at the Creation mountains and volcanoes were elevated, then there must have been proportionally great cavities under the peaks supported by vaults and pillars. Some of these supports collapsed to create hollows and valleys. Ray theorized that on the Third Day as the land rose, the waters filled the cavities and valleys to form the earth in which the depth of the sea is proportional to the height of the mountains.²¹

Hollmann and Bošković

Rudolf Erich Raspe called attention to the ideas of Samuel Christian Hollmann (1696-1787), the director of the Königliche Sozietät der Wissenschaften of Göttingen. He remarked that the earth had once been covered with water, but earthquakes caused large areas of the land to fall into caverns so as to allow the oceans to withdraw from the higher elevations.²²

Charles Lyell pointed out that Rudjer Josip Bošković (1711-1787), a Yugoslav natural philosopher, attributed to

²⁰Ibid., pp. 153, 155-56.

²¹Ibid., pp. 156-59.

²²Raspe, Specimen, pp. 144-46 (Introduction, pp. 76-77) citing: "De corporum marinorum, aliorumque peregrinorum, in terra continente origine. Commentatio Samuelis Christiani Hollmanni," Commentarii Societatis Regiae Scientiarum Göttingensis, III (1753), 285-374. (From the facsimile edition: Nendeln, Liechtenstein: Kraus Reprint, 1972.)

earthquakes the responsibility of raising and collapsing parts of the surface. He joined Hooke in thinking that the earth-altering force had been greater in the past.²³

Buffon

In contrast, Buffon disagreed with those who believed that subterranean fires and earthquakes had formed the Alps and other ranges. The force necessary to raise a mountain is so great that it would also lead to a disordering of much of the globe. For evidence of his view, he called attention to an earthquake in the second decade of the first Century A.D. that destroyed a significant portion of the known world; yet, the shock did not raise a single mountain. By comparison, a jolt sufficiently powerful to make a mountain must at the same time create havoc throughout the rest of the terrestrial sphere. Instead, the peaks were formed in the sea, and they appeared as global waters receded.²⁴

Benjamin Franklin

Franklin also discussed earth movements in terms of their significance in shaping the planet. He imagined that in the beginning the earth was only a great mixture of particles. As soon as gravity was established by "almighty fiat," the matter assembled to create a spinning earth consisting of

²³Bošković's ideas cited in Lyell, Principles of Geology, I, 53-54.

²⁴Buffon, Histoire naturelle, I, 523-25.

a dense fluid surrounded by a shell of the "first earth." Because of its rotation, the new planet formed an imperfect sphere having a larger diameter through the equator than through the poles. Franklin speculated that the axis changed, causing the internal fluid to break the shell, and the earth's irregular surface appeared.²⁵

By having the new equator where the old poles were formerly, the waters of the old equatorial regions were then lowered, while the old polar regions flooded. This accounts for the tropical fossils found in the higher altitudes of Europe.²⁶ The hot or soft iron in the earth, he theorized, created a great magnet as the iron cooled in the presence of a magnetic fluid in space. Thus, due to the permanent magnetism of the earth, the axis can no longer shift to create any more great changes in the appearance of the land; alterations are limited to those formed by waves in the subterranean fluid and to the explosive force of steam, the present sources of earthquakes.²⁷ His theory offered a novel solution to the problem Hooke had introduced a century before.²⁸ Franklin admitted that in these "reveries" he had given free

²⁵Letter from Franklin to Soulavie, pp. 118-19.

²⁶Ibid., p. 120.

²⁷Ibid., pp. 119-20. See above, pp. 128-29.

²⁸Hooke had also offered queries concerning changes in the earth's rotation, gravitation, and magnetism. Lectures and Discourses, pp. 321-22, 346-49.

rein to his imagination, and he hoped that they would be at least useful in suggesting new studies or better ideas.²⁹

James Hutton

Scottish geologist James Hutton (1726-1797) in his "Theory of the Earth"³⁰ postulated that changes in the surface occur through slow processes that are still continuing. The strata presently making up the continents were formed below the sea from the waste products of lands that were worn away and carried to the oceans. By means of subterranean heat and the pressure of water and earth above, the deposits of the sea bottom were consolidated to form basalt and granite, and then these were raised to their present level by the expansive force of subterrestrial heat (the same force involved in volcanoes).³¹

The Work of Charles Lyell

For Lyell the theories of Hooke, Raspe, Ray, Moro, Generelli, Hutton, and others had not fully explained the

²⁹Letter from Franklin to Soulavie, p. 121.

³⁰"Theory of the Earth; or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe," Transactions of the Royal Society of Edinburgh, I, Pt. II (1788), 209-304.

³¹Ibid. and Hutton, Abstract of a Dissertation Read in the Royal Society of Edinburgh, upon the Seventh of March, and Fourth of April, M,DCC,LXXXV, Concerning the System of the Earth, Its Duration, and Stability (1785), facsimile edition printed in James Hutton's System of the Earth, 1785; Theory of the Earth, 1788; Observations on Granite, 1794; Together with Playfair's Biography of Hutton, Contributions

function of earthquakes in sculpting the earth, although the various ideas are valuable contributions to a "perfect system."³² He considered the shocks not as instruments of death, but as beneficial--in fact, "essential to the stability of the system" by repairing the worn earth and making it suitable for its terrestrial and aquatic inhabitants.³³ The action of water and subterranean heat are "antagonist forces:" the water works towards smoothing the globe, while the opposing igneous agencies raise and collapse parts of the land.³⁴

Lyell connected the origins of earthquakes with the source of volcanoes, because eruptions of the burning mountains are often preceded by shocks, and because the two phenomena occur mostly in the same regions. In addition, both recur at the same location at varying intervals and continue active for different periods of time separated by terms of tranquility (Michell's points). Lyell concluded that the same forces that raise lava to great heights can exert enough hydrostatic pressures to move enormous masses of earth.³⁵

He theorized that there are a large number of great, deep cavities containing molten lava. Water reaching the

to the History of Geology, Vol. V ([Darien, Conn.:] Hafner Publishing Company, 1970). See also Lyell, Principles of Geology, I, 61-64.

³²Lyell, Principles of Geology, I, 64.

³³Ibid., I, 479.

³⁴Ibid., I, 474.

³⁵Ibid., I, 463.

molten rock is transformed into steam. This steam, along with other gases, forces the lava through the ducts of volcanoes. The great weight of the lava causes such large pressures against the chamber, ducts, and fissures that earthquakes are created in several ways: by folding the surrounding strata, by raising the roof over the cavern of lava, or by land subsiding when the vapors condense and the lava cools.³⁶

By means of a summary of shocks from the period of about the last 140 years,³⁷ Lyell challenged those who had suggested that the earth-altering effects had declined. He estimated that from the accounts he had assembled, some 100,000 square miles of land had been raised several feet, and an equal area had been lowered.³⁸

The study of earthquakes throughout the eighteenth century presented nineteenth-century geologists with useful ideas when it came to investigating topographical alterations of the earth, and the collection of specific information also proved useful to Lyell in helping to demonstrate the viability of the ancient idea that earthquakes significantly alter the face of earth. Thus, the study of earthquakes in the Enlightenment plays an important part in the history of the development of geology.³⁹

³⁶Ibid., I, 466-67.

³⁷Ibid., I, 399-449.

³⁸Ibid., I, 478.

³⁹See also the following chapter.

CHAPTER VI

EARTHQUAKE STUDIES AND HISTORY

Men of the Enlightenment investigated earthquakes from several viewpoints. In addition to the naturalists who examined the processes of nature, there were chroniclers, theologians, astrologers, and inventors of safety devices whose work dealt with peripheral aspects of understanding and coping with the natural world. Research into this subject provides a compact field of view in which to examine the character of the scientific enterprise pertaining to studies of the earth in the eighteenth century. But it must be remembered that inquiries about earth tremors were only one small part of a continuing examination of nature. Naturalists did much more than just gather data and develop hypotheses about earthquakes, for only in the study of the earth itself, individuals were examining rocks and fossils, the structure of mountains, and the layering of the earth. And all of these areas of interest came together in the basic problem of accounting for the origins of plains, mountains, and seas, as well as the task of explaining the current operations of nature in altering the face of the earth.

The study of the trembling earth was open to anyone, and he could work in the manner that best fitted his opportunities and interests. The diversity of backgrounds and activities of participants points out one of the characteristics of the study of the earth in the age: the absence of rigid specialization. Anyone, from an antiquarian to a theologian could profitably work to satisfy a curiosity about the earth, acquiring expertise as he proceeded. While building on the information and ideas of his predecessors, he passed on his own thoughts and the facts he gleaned from correspondence, literature searches, or field observations.

Given this open invitation, many contributed to the critical examination of earthquakes, although some of the parts played were so small that only a single reference has saved a name from being lost to history. For instance, Mr. J. Nantcarrow, a miner in Cornwall, mentioned a piece of information based on his working experience that was transmitted to the Royal Society of London in a letter on the subject of earthquakes.¹ His was a small addition to the store of relevant facts. At the other end of the scale, John Michell is primarily known for his detailed earthquake theory; the same holds true for William Stukeley. The names of a number of the contributors--Newton, Franklin, Priestley, Hales, Buffon--are today very well known, not for their thoughts on earthquakes,

¹See above, p. 87.

but for their writings on subjects such as optics, electricity, chemistry, or natural history.

The many-faceted subject offered topics of interest to almost anyone. There was even a choice among three types of earthquakes to discuss. Those interested in volcanoes could work on the well-known tremors that accompany eruptions. For the majority, an earthquake referred to the current shocks and those of historical record that knocked people from their feet and destroyed a few houses, or that occasionally overturned an entire city. Sometimes even mountains and islands were raised or fractured. These events were the ones that received the greatest attention in the century of studies ending after the series of Calabrian tremors.

Simultaneously, authors were also considering the possibility of a third variety of earthquakes, the ones of the distant past that had not just altered a mountain or two, but had built entire mountain ranges. These most ancient shocks bent and broke the formerly horizontal strata to create the disordered face of the globe. Later, in what has been called the "Heroic Age," which corresponds here from the period of the Calabrian studies to Lyell's Principles of Geology, the two main earthquake topics came together under the idea that there is no difference in the magnitude of earth movements in the past and present: the doctrine of uniformitarianism.²

²The general comments on the history of geology in this chapter are from the primary sources cited above and other

James Hutton and his popularizer John Playfair (1748-1819) promoted the idea that the geologist can only work with causes presently in evidence. To speculate any further as to the forces of the creation is a violation of the inductive philosophy. Hutton would only discuss the operations in nature that are constantly repairing the never-ending erosion of the land. In debate with catastrophists, Lyell argued that there were no world-wide floods or volcanic disasters, because the forces of nature in the past have been as they are now. The effects of wind, water, plants, animals, earthquakes, and volcanoes combine over a vast time scale to raise and lower the land, and to alter the appearance of the earth.

A characteristic of previous hypotheses that uniformitarians criticized was the excessive speculation about the creation of the earth and the formation of the land that is found in the writings of Ray, Woodward, William Whiston (1667-1753), Thomas Burnet (1635-1715), and others, as well as in the later views of catastrophists such as Georges Léopold Chrétien Frédéric Dagobert, Baron Cuvier (1769-1832), William

works in A Source Book in Geology: 1400-1900, ed. by Kirtley F. Mather and Shirley L. Mason (Cambridge: Harvard University Press, 1970), and from secondary sources, principally Adams, Geological Sciences; Geikie, Founders of Geology; Gillispie, Genesis and Geology; John C. Greene, The Death of Adam: Evolution and Its Impact on Western Thought (Ames, Iowa: Iowa State University Press, 1959); and V. A. Eyles, "The Extent of Geological Knowledge in the Eighteenth Century, and the Methods by Which It Was Diffused," Toward a History of Geology, ed. by Cecil J. Schneer (Cambridge, Mass.: M.I.T. Press), pp. 159-83.

Buckland (1784-1856), and Adam Sedgwick (1785-1873). Part of the difficulty came from the problem of reconciling geology and the Bible. Setting this aside, the task of accounting for earthquakes, both cataclysmic and minor, was necessarily one of the more conjectural of the early earth studies.

The theorists knew that the mechanisms that were being considered as possible causes were hidden from direct examination. Those who considered geological activities to have been much greater in the past were blocked by the one-way procession of time. Men investigating recent shocks could not actually peer into the depths to see hellish fires, dense vapors, troubled oceans, or subterranean lightning bolts, nor could they see subtle flashes of the hypothesized atmospheric explosions. Still, the mind of man took the available information about the earth and came up with a number of reasonable explanations. Through analogies, experiments, demonstrations, and active imaginations, various writers described what they believed to be the mechanisms responsible for altering and shaking the earth.

As the century progressed, the inductive spirit became increasingly prominent, and authors discussed fact-gathering as being important in the creation of their ideas about the natural world. The amount of information collected concerning the Lisbon earthquake pales in comparison with the assembly of data by the Calabrian-earthquake investigators. Bertrand, chief among the chroniclers, amassed printed and

manuscript accounts, while later inquirers in the 1780's relied more on field trips and interviews. Franklin apologized for his reveries, for the inductive method was the valued way of arriving at the truth. Dolomieu disguised the origins of his idea (derived by intuitive stroke or whatever source) in a cloak of inductivism. Before this type of explanation became fashionable, there had been no shortage of ideas about how earthquakes might be created.

The subterranean-fire idea had been a popular explanation of earthquakes in the first half-century, but in the early 1750's it briefly faded from discussions as the electrical hypothesis and the airquake interpretations were the topics of immediate discussion. The venerable thesis was revived in the hands of Michell, Hamilton, and Dolomieu. The strength of the vulcanist position in the debate over a theory of the earth also helped keep the corresponding earthquake thesis from becoming a dead issue. Otherwise, the much talked about electrical theory might have become even more prominent; then, the volcanic-fires account would have gone the way of underground-water accounts and have gradually disappeared.

Subterranean-water was a simple and reasonable explanation. Springs flowing from the earth and caverns with deep pools provided the evidence that the planet's interior is filled with waters so that underground ocean waves shake the land. The picture was too simple for the theory's own good; it could be stated in a few sentences and then be forgotten,

for there were no issues keeping people thinking about it and coming up with further evidence and refinements. You either believed the explanation, or you did not. In contrast, subterranean-fire was not so simple, and writings just to define the source of the conflagration kept it constantly before naturalists in the early period. The subsurface fires as a part of theories of the earth in the second half-century kept the hypothesis fresh in the minds of investigators who could still reject it, but they could hardly ignore it. The underground-water thesis died as much from a lack of attention as it did from internal difficulties.³

The subject of this dissertation has been an examination of the character of the earth sciences in the eighteenth century through a study of one problem, the origin and nature of earthquakes. This history has traced ideas as they have appeared and disappeared, and as they have been developed by proponents and blocked by opponents. It has examined the interactions of the persons who were searching into questions about earthquakes, and how they are influenced by information, criticism, current topics of interest, developments in other disciplines, or trends in modes of presentation. The investigation of the trembling earth in the Enlightenment cannot be pictured as the futile preoccupation of a few individuals who

³In addition, reports of eruptions of water did not make for as vivid a spectacle as volcanic eruptions--not an insignificant factor in keeping one idea alive, while allowing the other to fade away.

only contributed speculations of no lasting significance, for while no commonly agreed on explanation for the shocks was found, the quest is of interest to the historian of science. Also, the search for causes and the data gathered did play a role in the development of a science through the formation and acceptance of the uniformitarian principle--one of the important concepts in the history of geology.

BIBLIOGRAPHY

PART ONE: PRIMARY SOURCES CITED

"Abstract of the Bp of London's Letter to the Clergy and Inhabitants of London and Westminster, &c. on Occasion of the Late Earthquakes." Gentleman's Magazine, XX (March, 1750), 123-24.

An Account of the Late Terrible Earthquake in Sicily, with Most of Its Particulars. Done from the Italian Copy Printed at Rome. Dublin: Reprinted by Andrew Crook, 1693.

Agricola, Georgius. Georgii Agricolae. De ortu & causis subterraneorum. Lib. V. De natura eorum quae effluunt et terra. Lib. IIII. De natura fossilium. Lib X. De veteribus & nouis metallis. Lib. II. Bermannus, sive de re metallica dialogus. Interpretatio germanica vocum rei metallica, addito indice foecundissimo. Basileae: Froben, 1546.

["An Airquake Supposed,] General Advertiser, March 13." Gentleman's Magazine, XX (March, 1750), 125.

Amontons, Guillaume. "Que les nouvelles experiences que nous avons du poids & du ressort de l'air, nous font connoître qu'un degré de chaleur mediocre, peut réduire l'air dans un état assez violent pour causer seul de tres-grands tremblements & bouleversements sur le globe terrestre." Histoire de l'Academie Royale des Sciences. Année MDCCIII. Avec les memoires de mathematique & de physique, pour la même année (Paris, 1705), Memoires, pp. 101-8.

Aristotle. The Works of Aristotle. Edited by W. D. Ross. Vol. III: Meteorologica, [translated] by E. W. Webster, De mundo, by E. S. Forster, De anima, by J. A. Smith, Parva naturalia, by J. I. Beare and G. R. T. Ross, De spiritu, by J. F. Dobson. Oxford: Clarendon Press, 1931.

Austin, J. Letter from J. Austin to William Stukeley, April 30, 1751, O.S. Family Memoires of the Rev. William Stukeley, M.D. and the Antiquarian and Other Correspondence of

William Stukeley, Roger & Samuel Gale, etc. Vol. I. Durham: Published for the [Surtees] Society by Andrews & Co., and others, 1882, pp. 401-2.

Baglivi, Georgio. "Historia romani terrae motus, anni 1703." Opera omnia medico-practica et anatomica. Editio XVIII. Cui praeter dissertationes, aliosque tractatus anteactis editionibus adjunctos, item ejusdem Georgii Baglivi canones de medicina solidorum, dissertatio de progressionem Romani terraemotus, de systemate & usu motus solidorum in corpore animato, de vegetatione lapidum, & analogismo circulationis maris ad circulationem sanguinis; accesserunt item nunnulae aliae additiones per loca ut jacent . . . una cum indicibus aereisque tabulis nec non Joannis Dominici Santorini opuscula IV; de structura & motu fibrae; de nutritione animali; de haemorrhoidibus; & de catamenils. Bassani: n.p., 1737.

Barker, Thomas. Letter from Thomas Barker to William Stukeley, December 23, 1755. Family Memoires of the Rev. William Stukeley, M.D. and the Antiquarian and Other Correspondence of William Stukeley, Roger & Samuel Gale, etc. Vol. I. Durham: Printed for the [Surtees] Society by Andrews & Co., and others, 1882, pp. 412-15.

Barletti, Carlo. Nuove sperienze elettriche secondo la teoria del Sig. Fránklin et le produzioni del P. Beccaria di Carlo Barletti. Milano: Appresso Giuseppe Galeazzi R. Stampatore, 1771.

Bayle, Pierre. Lettre à M. L. A. D. C. docteur de Sorbonne. Où il est prouvé par plusieurs raisons tirées de la philosophie, & de la theologie que les comètes ne sont point le presage d'aucun malheur. Avec plusieurs reflexions morales & politiques, & plusieurs observations historiques & la refutation de quelques erreurs populaires. Cologne: Chez Pierre Marteau, 1682.

. Pensées diverses, écrites à un docteur de Sorbonne, à l'occasion de la comète qui parut au mois de décembre 1680. Rotterdam: Chez Reinier Leers, 1683.

. Pensées diverses sur la comète. Edited by A. Prat. Société des Textes Français Modernes. 2 vols. Édition critique. Paris: Société Nouvelle de Librairie et d'Édition, 1911.

Beccaria, Giovanni Battista. Dell' elettricismo artificiale, e naturale libri due di Giambatista Beccaria. Torino: Nella Stampa di Filippo Antonio Campana, 1753.

. Elettricismo atmosferico. 2nd ed. Bologna: Colle Ameno, 1758.

[Bentley, Richard.] A Full and True Account of the Dreadful and Melancholly Earthquake, Which Happened Between Twelve and One O'Clock in the Morning, on Thursday the Fifth Instant. With an Exact List of Such Persons as Have Hitherto Been Found in the Rubbish. In a Letter from a Gentleman in Town, to His Friend in the Country. 4th ed. London: Printed for Tim Tremor, 1750.

[Berkeley, George.] "Observations by a Rt Rev. Prelate in Ireland, . . . Concerning Earthquakes." Gentleman's Magazine, XX (April, 1750), 166-68.

Bertholon, Pierre. "Mémoire dans lequel on donne un nouveau moyen de se préserver du tonnerre, après avoir prouvé que la foudre s'élève souvent de la terre." Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. le Comte d'Artois; Par M. l'abbé Rozier, X, Pt. II (1777), 179-96. Nouvelle édition. Paris: Rue et Hôtel Serpente, 1782.

. "Mémoire sur un para-tremblement de terre, & un para-volcan." Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. le Comte d'Artois; Par M. l'abbé Rozier, XIV, Pt. II (1779), 111-21.

. "Tremblement de terre. (para-tremblement de terre, ou préservateur des tremblemens de terre.)." Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres. Mis en ordre & publié par M. Diderot; & quant à la partie mathématique, par M. d'Alembert. Vol. XXXIV. Nouvelle édition. Geneve: Chez Pellet, Imprimeur-Libraire, 1778.

Bertrand, Élie. Mémoire pour servir à l'histoire des tremblemens de terre de la Suisse, principalement pour l'année MDCCLV. Avec quatre sermons prononcés à cette occasion dans l'Eglise François de Berne. Vevey: Chez Chenebré, 1756.

. "Memoire pour servir à l'histoire des tremblemens de terre de la Suisse, principalement pour l'année MDCCLV. Avec quatre sermons prononcés à cette occasion dans l'Eglise François de Berne, par Mr. Elie Bertrand, M. D. S. E. Membre des Académies de Berlin, Gottingue, Leipzig & Mayence. A Vevey chez Chenebré 1756. 8. 220.

pages." Nouvelle bibliotheque germanique ou histoire litteraire de l'Allemagne, de la Suisse, & des Pays du Nord, par Mr. Samuel Formey, XIX, Pt. I (1756), 43-56.

. Memoires historiques et physiques sur les trem-
blemens de terre. La Haye: Chez Pierre Gosse, Junior, 1757.

[Bevis, John.] The History and Philosophy of Earthquakes, from the Remotest to the Present Times: Collected from the Best Writers on the Subject. With a Particular Account of the Phaenomena of the Great One of November 1st, 1755, in Various Parts of the Globe. By a Member of the Royal Academy of Berlin. London: J. Nourse, 1757.

Bina, Andrea. Ragionamento sopra la cagione de' terremoti ed in particolare di quello della terra di Gualdo di Nocera nell' Umbria seguito l'a 1751. Perugia, 1751.

Bonajutus, Vincentius. "An Account of the Earthquakes in Sicilia, on the Ninth and Eleventh of January, 1692/3. Translated from an Italian Letter Wrote from Sicily by the Noble Vincentius Bonajutus, and Communicated to the Royal Society by the Learned Marcellus Malpighius, Physician to His Present Holiness." Philosophical Transactions of the Royal Society of London, XVIII, No. 207 (1693/94), 2-10.

Borlase, William. "An Account of the Earthquake in the West Parts of Cornwall, July 15th 1757. By the Rev. William Borlase, M.A. F.R.S. Communicated by the Rev. Charles Lyttelton, LL.D. Dean of Exeter, F.R.S." Philosophical Transactions of the Royal Society of London, L, Pt. II (1758), 499-505.

The Boston Evening Post, 1735-1775. Microprint edition. Worcester, Mass.: Micro Research Corp., n.d.

The Boston Gazette, 1719-1798. Microprint edition. New York: Readex Microprint Corp., n.d.

The Boston Newsletter, 1704-1776. Microprint edition. Worcester, Mass.: Micro Research Corp., n.d.

Bouguer, Pierre. La figure de la terre, déterminée par les observations faites au Pérou. Paris: n.p., 1749.

Bowdoin, James. Letter from James Bowdoin to Benjamin Franklin, March 16, 1752. The Papers of Benjamin Franklin. Vol. IV: July 1, 1750, Through June 30, 1753. Edited

by Leonard W. Labaree. New Haven: Yale University Press, 1961, pp. 277-78.

Boyle, Robert. "A Confirmation of the Former Account Touching the Late Earthquake Near Oxford, and the Concomitants Thereof." Philosophical Transactions of the Royal Society of London, I, No. 11 (1666), 179-81.

_____. "An Essay of the Great Effects of Even Languid and Unheeded Motion. Whereunto Is Annexed, an Experimental Discourse of Some Little Observed Causes of the Insalubrity and Salubrity of the Air and Its Effects. [Being part of an Intended Natural History of the Air.]" The Works of the Honourable Robert Boyle. Vol. V. New edition. London: Printed for W. Johnston and others, 1772.

Brisson, Mathurin Jacques. "Tremblement de terre." Dictionnaire raisonné de physique. Vol. II. Paris: Hôtel de Thou, Rue des Poitevins, 1781.

Buache, Philippe. "Essai de géographie physique, où l'on propose des vûes générales sur l'espèce de charpente du globe, composée des chaînes de montagnes qui traversent les mers comme les terres; avec quelques considérations particulières sur les différens bassins de la mer, & sur sa configuration intérieure." Histoire de l'Académie Royale des Sciences. Année M.DCCLII. Avec les mémoires de mathématique & de physique, pour la même année, tirés des registres de cette académie (Paris, 1756), Mémoires, pp. 399-416, map.

Buffon, Georges Louis Leclerc, Comte de. Histoire naturelle, générale et particulière, avec la description du cabinet du roi. Vol. I. Paris: De l'Imprimerie Royale, 1749. Microprint ed. Landmarks of Science. New York: Readex Microprint Corp., 1969.

Contents: De la manière d'étudier et de traiter l'histoire naturelle, Histoire et théorie de la terre.

_____. Histoire naturelle, générale et particulière, par Leclerc de Buffon; nouvelle édition, accompagnée de notes, et dans laquelle les supplémens sont insérés dans le premier texte, à la place qui leur convient. L'on y a ajouté l'histoire naturelle des quadrupèdes et des oiseaux découverts depuis la mort de Buffon, celle des reptiles, des poissons, des insectes et des vers; enfin, l'histoire des plantes dont ce grand naturaliste n'a pas eu le tems de s'occuper. Ouvrage formant un cours complet d'histoire naturelle: rédigé par C. S. Sonnini, membre de plusieurs sociétés savantes.

Vol. II: Théorie de la terre. Paris: Chez F. Dufart, an VII.

Byles, Mather, Jr. Divine Power and Anger Displayed in Earthquakes. A Sermon Occasioned by the Late Earthquake, in New-England, November 18th, 1755. And Preached the Next Lord's-Day, at Point Shirley. Boston: Printed and sold by S. Kneeland, 1755.

Cabrera, Miguel. Explicacion physico-mechanica de las causas del temblor de tierra, como constan de la doctrina del principe de los philosophos Aristoteles: dada por medio de la vena cava. y sus leyes, cuyo auxilio quita el horror de sus abstractos: meditada por el R. P. Fr. Miguel Cabrera. Sevilla: Imprenta de D. Diego de S. Román y Codina en calle Colcheros, [1756.]

Castres, Abraham. "Letter from Abr. Castres, Esq; Envoy Extraordinary to the King of Portugal." Gentleman's Magazine, XXV (December, 1755), 556-58.

Cavalli, Atanagio. Lettere meteorologiche romane dell' abate Antanagio Cavalli. Roma: Stamperia Pagliarini, 1785.

Cavallo, Tiberius. A Compete Treatise of Electricity in Theory and Practice; with Original Experiments. London: Printed for Edward and Charles Dilly, 1777.

Chambers, Ephraim. Cyclopaedia: or, an Universal Dictionary of Arts and Sciences. Containing an Explanation of the Terms, and an Account of the Several Subjects, in the Liberal and Mechanical Arts, and the Sciences, Human and Divine. Intended as a Course of Ancient and Modern Learning. By E. Chambers, F.R.S. With the Supplement, and Modern Improvements, Incorporated in One Alphabet. By Abraham Rees, D.D. 4 vols. in 8 pts. Dublin: Printed by John Chambers, 1778-84.

. "Earthquake." Cyclopaedia: or, an Universal Dictionary of Arts and Sciences; Containing the Definitions of the Terms, and Accounts of the Things Signify'd Thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine: the Figures, Kinds, Properties, Productions, Preparations, and Uses, of Things Natural and Artificial; the Rise, Progress, and State of Things Ecclesiastical, Civil, Military, and Commercial: with the Several Systems, Sects, Opinions, &c. among Philosophers, Divines, Mathematicians, Physicians, Antiquaries, Criticks, &c. The Whole Intended as a Course of Antient and Modern Learning. Compiled from the Best Authors, Dictionaries,

Journals, Memoirs, Transactions, Ephemerides, &c, in Several Languages. Vol. I. London: Printed for James and John Knapton, and others, 1728.

"Earthquakes, Causes of." Cyclopaedia: or, an Universal Dictionary of Arts and Sciences. Containing an Explanation of the Terms, and an Account of the Several Subjects, in the Liberal and Mechanical Arts, and the Sciences, Human and Divine. Intended as a Course of Ancient and Modern Learning. By E. Chambers, F.R.S. With the Supplement, and Modern Improvements, Incorporated in One Alphabet. By Abraham Rees, D.D. Vol. II, [Pt. I]. Dublin: Printed by John Chambers, 1780.

Chanvalon, Jean Baptiste Thibault de. Voyage a la Martinique contenant diverses observations sur la physique, l'histoire naturelle, l'agriculture, les moeurs, & les usages de cette isle, faites en 1751 & dans les années suivantes. Lu à l'Académie royale des sciences de Paris en 1761. Paris: J. B. Bauche, 1763.

Chauncy, Charles. The Earth Delivered from the Curse to Which It Is, at Present, Subjected. A Sermon Occasioned by the Late Earthquakes in Spain and Portugal, as Well as New-England; and Preached at Boston-Thursday-Lecture, January 22, 1756. Boston: Printed and sold by Edes & Gill, 1756.

Earthquakes a Token of the Righteous Anger of God. A Sermon Preached at the Old-Brick-Meeting-House in Boston, the Lord's-Day after the Terrible Earthquake, Which Suddenly Awoke Us Out of Our Sleep in the Morning of the 18th of November, 1755. To Which Is Added an Appendix; Giving a Summary Account of the Late Earthquake. Boston: Printed and sold by Edes and Gill, 1755.

Cheyne, George. Philosophical Principles of Religion: Natural and Reveal'd. In Two Parts. Part I. Containing the Elements of Natural Philosophy, and the Proofs of Natural Religion Arising from Them. Part II. Containing the Nature and Kinds of Infinities, Their Arithmetick and Uses: Together with the Philosophick Principles of Reveal'd Religion. 2nd ed., corrected and enlarged. London: Printed for George Strahan, 1715-16.

Colden, Cadwallader. Letter from Cadwallader Colden to Benjamin Franklin, March 16, 1752. The Papers of Benjamin Franklin. Vol. IV: July 1, 1750, Through June 30, 1753. Edited by Leonard W. Labaree. New Haven: Yale University Press, 1961, pp. 278-81.

Costa e Andrade, João Antonio. Conversação erudita, discurso familiar conferencias asceticas, historicas, politicas, e philosophicas. Lisboa: J. da Coasta Coimbra, 1756.

[Crouch, Nathaniel.] The General History of Earthquakes. Being an Account of the Most Remarkable and Tremendous Earthquakes That Have Happened in Divers Parts of the World, from the Creation to This Time; as They Are Recorded by Sacred and Common Authors; and Perticularly Those Lately in Naples, Smyrna, Jamaica and Sicily. With a Description of the Famous Burning Mount, Aetna, in That Island; and a Relation of the Several Dreadful Conflagrations and Fiery Irruptions Thereof for Many Ages. Likewise the Natural and Material Causes of Earthquakes, with the Usual Signs and Prognosticks of Their Approach; and the Consequents and Effects That Have Followed Several of Them. By R. B. London: Printed for N. Crouch, 1694.

. The General History of Earthquakes: Being an Account of the Most Remarkable and Tremendous Earthquakes That Have Happened in Divers Parts of the World, from the Creation to This Time; as They Are Recorded by Sacred and Common Authors; and Particularly Those Lately in Naples, Smyrna, Jamaica and Sicily. With a Description of the Famous Burning Mount, Aetna, in That Island; and the Relation of the Several Dreadful Conflagrations and Fiery Irruptions Thereof for Many Ages. Likewise the Natural and Material Causes of Earthquakes, with the Usual Signs and Prognosticks of Their Approach; and the Consequences and Effects That Have Followed Several of Them. By R. B. London: Printed for A. Bettesworth and J. Hodges, 1734.

Cyrillus, Nicolaus. "An Account of an Earthquake in Apulia and Most Other Parts of the Kingdom of Naples, in the Year 1731. By Dr. Cyrillus of Naples. No. 428. p. 79. Translated from the Latin." Philosophical Transactions of the Royal Society of London. Edited by Charles Hutton, George Shaw, and Richard Pearson. Vol. VII. Abridged edition. London: C. and R. Baldwin, 1809, pp. 606-9.

. "Historia terraemotus Apuliam & totum ferè Neapolitanum Regnum, anno 1731, vexantis. A Nicolao Cyrillo, in Regiâ Universitate Neapolitanâ, Pr. Med. Prof. & R.S.S." Philosophical Transactions of the Royal Society of London, XXXVIII, No. 428 (1733), 79-84.

Davies, Samuel. The Religious Improvement of the Late Earthquakes. Sermons on Important Subjects, by the Reverend

Samuel Davies, A.M., President of the College of New-Jersey. Vol. III. 2nd ed. New York: Dayton and Saxton, 1841.

Derham, William. Physico-Theology: or, a Demonstration of the Being and Attributes of God, from His Works of Creation. Being the Substance of XVI Sermons Preached in St. Mary le Bow-Church, London at the Hon^{ble} Mr. Boyle's Lectures, in the Years 1711 and 1712. With Large Notes, and Many Curious Observations Never Before Published. London: Printed for W. Innys, 1713.

[Desmarest, Nicolas.] Conjectures physico-mechaniques sur la propagation des secousses dans les tremblemens de terre, et sur la disposition des lieux qui en ont ressenti les effets. n.p.: n.p., 1756.

Dolomieu, Déodat Guy Silvain Tancred Gratet de. Memoire sur les tremblemens de terre de la Calabre pendant l'année 1783. Rome: Chez Antoine Fulgoni, 1784.

"Earthquake." Encyclopaedia Britannica; or a Dictionary of Arts and Sciences, Compiled upon a New Plan. In Which the Different Sciences and Arts Are Digested into Distinct Treatises or Systems; and the Various Technical Terms, &c. Are Explained as They Occur in the Order of the Alphabet. By a Society of Gentlemen in Scotland. Vol. II. Edinburgh: Printed for A. Bell and C. Macfarquhar, 1771.

Encyclopaedia Britannica; or, a Dictionary of Arts and Sciences, Compiled upon a New Plan. In Which the Different Sciences and Arts Are Digested into Distinct Treatises or Systems; and the Various Technical Terms, &c. Are Explained as They Occur in the Order of the Alphabet. By a Society of Gentlemen in Scotland. 3 vols. Printed for A. Bell and C. Macfarquhar, 1771.

Encyclopaedia Britannica; or, a Dictionary of Arts, Sciences, and Miscellaneous Literature; Constructed on a Plan, by Which the Different Sciences and Arts Are Digested into the Form of Distinct Treatises or Systems, Comprehending the History, Theory, and Practice, of Each, According to the Latest Discoveries and Improvements; and Full Explanations Given of the Various Detached Parts of Knowledge, Whether Relating to Natural and Artificial Objects, or to Matters Ecclesiastical, Civil, Military, Commercial, &c. Including Elucidations of the Most Important Topics Relative to Religion, Morals, Manners, and the Oeconomy of Life: Together with a Description of All the Countries, Cities, Principal

Mountains, Seas, Rivers, &c. Throughout the World; a General History, Ancient and Modern, of the Different Empires, Kingdoms, and States; and an Account of the Lives of the Most Eminent Persons in Every Nation, from the Earliest Ages Down to the Present Times. Compiled from the Writings of the Best Authors, in Several Languages; the Most Approved Dictionaries, as Well of General Sciences as of Its Particular Branches; the Transactions, Journals, and Memoirs of Learned Societies, Both at Home and Abroad; the MS. Lectures of Eminent Professors on Different Sciences; and a Variety of Original Materials, Furnished by an Extensive Correspondence. 18 vols. 3rd ed. Edinburgh: Printed for A. Bell and C. Macfarquhar, 1797.

Encyclopaedia Britannica; or, a Dictionary of Arts, Sciences, &c. on a Plan Entirely New: by Which, the Different Sciences and Arts Are Digested into the Form of Distinct Treatises or Systems, Comprehending the History, Theory, and Practice, of Each, According to the Latest Discoveries and Improvements; and Full Explanations Given of the Various Detached Parts of Knowledge, Whether Relating to Nature and Artificial Objects, or to Matters Ecclesiastical, Civil, Military, Commercial, &c. Together with a Description of All the Countries, Cities, Principal Mountains, Seas, Rivers, &c. Throughout the World; a General History, Ancient and Modern, of the Different Empires, Kingdoms, and States; and an Account of the Lives of the Most Eminent Persons in Every Nation, from the Earliest Ages Down to the Present Times. The Whole Compiled from the Writings of the Best Authors, in Several Languages; the Most Approved Dictionaries, as Well of General Sciences as of Particular Branches; the Transactions, Journals, and Memoirs of Learned Societies, Both at Home and Abroad; the MS. Lectures of Eminent Professors on Different Sciences; and a Variety of Original Materials, Furnished by an Extensive Correspondence. 10 vols. 2nd ed. Edinburgh: Printed for J. Balfour and Co., and others, 1778-83.

Epikuros. Epicurus: The Extant Remains. Translated by Cyril Bailey. Hildesheim: Georg Olms Verlag, 1970.
A reprint of the Oxford, 1926 edition.

"An Extraordinary and Surprising Agitation of the Waters, Though Without Any Perceptible Motion of the Earth, Having Been Observed in Various Parts of This Island, Both Maritime and Inland, on the Same Day, and Chiefly About the Time, That the More Violent Commotions of Both Earth and Waters So Extensively Affected Many Very Distant Parts of the Globe; the Following Accounts,

Relating to the Former, Have Been Transmitted to the Society; in Which Are Specified the Times and Places When and Where They Happened." Philosophical Transactions of the Royal Society of London, XLIX, Pt. I (1755), 351-444.

Feijóo y Montenegro, Benito Jerónimo. Nuevo systema sobre la causa physica de los terremotos, explicado por los fenómenos eléctricos, y adaptado al que padeció España en primero de noviembre del año antecedente de 1755. Puerto de Santa Maria: Imprenta de la Casa Real da las Cadenas, 1756.

Flamsteed, John. A Letter Concerning Earthquakes, Written in the Year 1693, by the Late Celebrated Astronomer, Mr. John Flamsteed, Math. Reg. F.R.S. to a Gentleman Then Residing at Turin in Savoy, on Occasion of the Destruction of Catanea, and Many Other Cities, Towns and Villages, in Sicily, in the Year 1692. London: Printed for A. Millar, 1750.

Foxcroft, Thomas. The Earthquake, a Divine Visitation. A Sermon Preached to the Old Church in Boston, January 8. 1756, Being a Day of Publick Humiliation & Prayer, Throughout the Province of the Massachusetts-Bay in New-England: upon Occasion of the Repeated Shock of an Earthquake on This Continent, and the Very Destructive Earthquake and Inundations in Divers Parts of Europe, All in the Month of November Last. Boston: Printed and sold by S. Kneeland, 1756.

Franklin, Benjamin. Experiments and Observations on Electricity, Made at Philadelphia in America, by Benjamin Franklin, L.L.D. and F.R.S. To Which Are Added, Letters and Papers on Philosophical Subjects. [4th ed.] London: Printed for David Henry, 1769.

_____. Experiments and Observations on Electricity, Made at Philadelphia in America, by Benjamin Franklin, L.L.D. and F.R.S. To Which Are Added, Letters and Papers on Philosophical Subjects. 5th ed. London: Printed for F. Newbery, 1774.

_____. Letter from Benjamin Franklin to Abbé Soulavie, September 22, 1782. The Complete Works in Philosophy, Politics, and Morals, of the Late Dr. Benjamin Franklin, Now First Collected and Arranged; with Memoirs of His Early Life, Written by Himself. Vol. II. 2nd ed. London: Printed for Longman and others, n.d.

_____. Letter from Benjamin Franklin to John Mitchell,

April 29, 1749. "Observations and Suppositions Towards Forming a New Hypothesis for Explaining the Several Phaenomena of Thunder Gusts." The Papers of Benjamin Franklin. Vol. III: January 1, 1745, Through June 30, 1750. Edited by Leonard W. Labaree. New Haven: Yale University Press, 1961, pp. 365-76.

. The Papers of Benjamin Franklin. Edited by Leonard W. Labaree. New Haven: Yale University Press, 1959--.

Freke, John. An Essay to Shew the Cause of Electricity; and Why Some Things Are Non-electricable. In Which Is Also Consider'd Its Influence in the Blasts on Human Bodies, in the Blights on Trees, in the Damps in Mines; and as It May Affect the Sensitive Plant, &c. In a Letter to Mr. William Watson, F.R.S. London: Printed for W. Innys, 1746.

Frézier, Amedée François. Relation du voyage de la Mer du Sud aux côtes du Chily et du Perou, fait pendant les années 1712, 1713 & 1714. Paris: Chez J.-G. Nyon, E. Ganeau, J. Quillau, 1716.

. Relation du voyage de la Mer du Sud aux côtes du Chily et du Perou, fait pendant les années 1712, 1713 & 1714. Dediée à S. A. R. Monseigneur le Duc d'Orleans, Regent du Royaume. Avec une réponse a la preface critique du livre intitulé, Journal des observations physiques, mathematiques & botaniques du R. P. Feuillée, contre la Relation du voyage de la Mer du Sud, & une chronologie des Vicerois du Perou, depuis son établissement jusqu' au tems de la Relation du voyage de la Mer du Sud. Paris: Chez Nyon, Didot [et] Quillau, 1732.

"Gen. Advertiser, March 15. An Account of a Meteor on Dec. 31, 1741; by the Rev. Mr Wm Gostling, Minor Canon of the Cathedral Church of Canterbury; Inserted in Support of the Supposition of an Airquake in the Said Paper of the 31st. [sic, 13th]." Gentleman's Magazine, XX (March, 1750), 129.

Generelli, Giuseppe Cirillo. Dissertazione de crostacei e di altre produzioni marini che sono ne monti. Raccolta Milanese dell' anno 1757. Milano, 1757.

"Giornale meteorologico." Giovanni Vivenzio. Istoria e teoria de' tremuoti in generale ed in particolare di quelli della Calabria, e di Messina del MDCCCLXXXIII. Napoli: Nella Stamperia Regale, 1783.

Goethe, Johann Wolfgang von. Aus Meinem Leben: Dictung und Wahrheit. Autobiographische Schriften, Erster Band. Vol. IX of Goethes Werke. Hamburg: Christian Wegner Verlag, 1955.

Gray, Edward Whitaker. "Account of the Earthquake Felt in Various Parts of England, November 18, 1795; with Some Observations Thereon." Philosophical Transactions of the Royal Society of London, LXXXVI, Pt. II (1796), 353-81.

[Grey, Zachary.] 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 Address'd to All Christians of Every Denomination. By a Gentleman of the University of Cambridge. Cambridge: Printed by J. Bentham, 1750.

Grimaldi, Francesco Antonio. Descrizione de tremuoti accaduti nelle Calabrie nel 1783, opera postuma di Francesco Antonio Grimaldi. Napoli: G. M. Porcelli, 1784.

Hales, Stephen. "Some Considerations on the Causes of Earthquakes." Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 669-81.

Some Considerations on the Causes of Earthquakes. Which Were Read Before the Royal Society, April 5, 1750. London: Printed for R. Manby and H. S. Cox, 1750.

Vegetable Staticks: or, an Account of Some Statical Experiments on the Sap in Vegetables: Being an Essay Towards a Natural History of Vegetation. Also, a Specimen of an Attempt to Analyse the Air, by a Great Variety of Chymio-Statical Experiments; Which Were Read at Several Meetings Before the Royal Society. London: Printed for W. and J. Innys and T. Woodward, 1727.

Halley, Edmund. A Synopsis of the Astronomy of Comets. Translated from the Original Printed at Oxford. London: Printed for John Senex, 1705.

Hamilton, Sir William. "An Account of the Earthquakes Which Happened in Italy, from February to May 1783. By Sir William Hamilton, Knight of the Bath, F.R.S.; in a Letter to Sir Joseph Banks, Bart. P.R.S." Philosophical

Transactions of the Royal Society of London, LXXIII, Pt. I (1783), 169-208.

. An Account of the Earthquakes Which Happened in Italy, from February to May 1783. Read at the Royal Society, July 3, 1783. London: Printed by J. Nicholas, 1783.

. Observations on Mount Vesuvius, Mount Etna, and Other Volcanos: in a Series of Letters, Addressed to the Royal Society, from the Honourable Sir W. Hamilton, K.B. F.R.S. His Majesty's Envoy Extraordinary and Plenipotentiary at the Court of Naples. To Which Are Added, Explanatory Notes by the Author, Hitherto Unpublished. London: Printed for T. Cadell, 1772.

A second edition (1773) and a "new edition" (1774) were also published by Cadell under the same title.

Harris, John. "Earthquakes." Lexicon Technicum: or, an Universal English Dictionary of Arts and Sciences: Explaining Not Only the Terms of Arts, but the Arts Themselves. London: Printed for Dan. Brown and others, 1704.

Hartop, Martin. "A Letter from Mr. Martin Hartop at Naples, to the Publisher. Together with an Account of the Late Earthquake in Sicily." Philosophical Transactions of the Royal Society of London, XVII, No. 202 (1693), 827-29.

Heberden, Thomas. "An Account of the Earthquake Felt in the Island of Madeira, March 31, 1761: by Thomas Heberden, M.D. F.R.S. Communicated by William Heberden, M.D. F.R.S." Philosophical Transactions of the Royal Society of London, LII, Pt. I (1761), 155-56.

Herodotos. History of the Greek and Persian War. Translated by George Rawlinson. Edited by W. G. Forrest. The Great Histories. Edited by Hugh R. Trevor-Roper. New York: Washington Square Press, 1963.

"Historical Chronicle, April 1750." Gentleman's Magazine, XX (April, 1750), 184-87.

"Historical Chronicle, February 1750." Gentleman's Magazine, XX (February, 1750), 88-91.

"Historical Chronicle, March 1750." Gentleman's Magazine, XX (March, 1750), 136-38.

"Historical Chronicle, Nov. 1755." Gentleman's Magazine, XXV (November, 1755), 519-21.

Holbach, Paul Henri Thiry, Baron d'. Système de la nature; ou, des loix du monde physique & du monde moral par M. Mirabaud. Londres, 1770.

_____. "Tremblemens de terre, (Hist. nat. minér. & physiq.)." Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres. Mis en ordre et publié par M. ***. Vol. XVI. Neufchâtel: Chez Samuel Faulche & Compagnie, 1765.

_____. "Tremblemens de terre, (Hist. nat. minér. & physiq.)." Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres. Mis en ordre & publié par M. Diderot; & quant à la partie mathématique, par M. d'Alembert. Vol. XXXIV. Nouvelle édition. Geneve: Chez Pellet, Imprimeur-Libraire, 1778.

Hollmann, Samuel Christian. "De corporum marinorum, aliorumque peregrinorum, in terra continente origine. Commentatio Samuelis Christiani Hollmanni." Commentarii Societatis Regiae Scientiarum Gottingensis, III (1753), 285-375. Facsimile edition. Nendeln, Liechtenstein: Kraus Reprint, 1972.

Hooke, Robert. The Diary of Robert Hooke, M.A., M.D., F.R.S. (1672-1680). Transcribed from the Original in the Possession of the Corporation of the City of London (Guild Hall Library). Edited by Henry W. Robinson and Walter Adams. London: Taylor & Francis, 1935.

_____. Diary, 1688 to 1693. R. T. Gunther. Early Science in Oxford. Vol. X: The Life and Work of Robert Hooke (Part IV). Tracts on Capillary Attraction, 1661; Diary, 1688 to 1693. Oxford: Printed for the author [Oxford University Press], 1935.

_____. Lectures and Discourses of Earthquakes, and Subterraneous Eruptions. Explicating the Causes of the Rugged and Uneven Face of the Earth; and What Reasons May Be Given for the Frequent Finding of Shells and Other Sea and Land Petrified Substances, Scattered Over the Whole Terrestrial Superficies. The Posthumous Works of Robert Hooke, M.D. S.R.S. Geom. Prof. Gresh. &c. Containing His Cutlerian Lectures, and Other Discourses, Read at the Meetings of the Illustrious Royal Society. Edited by Richard Waller. London: Published by Richard Waller, printed by Sam. Smith and Benj. Walford, 1705.

[Hutton, James.] Abstract of a Dissertation Read in the Royal

Society of Edinburgh, upon the Seventh of March, and Fourth of April, M,DCC,LXXXV, Concerning the System of the Earth, Its Duration, and Stability. Facsimile edition. James Hutton's System of the Earth, 1785; Theory of the Earth, 1788; Observations on Granite, 1794; Together with Playfair's Biography of Hutton. Contributions to the History of Geology, Vol. V. [Darien, Conn.:] Hafner Publishing Company, 1970.

_____. "Theory of the Earth; or an Investigation of the Laws Observable in the Composition, Dissolution, and Restoration of Land upon the Globe." Transactions of the Royal Society of Edinburgh, I, Pt. II (1788), 209-304.

"Indice generale de' paesi di Calabria Ulteriore del loro stato, de' viventi prima de' tremuoti de' febbrajo, e marzo 1783, e di' morti per cagion delle rovine." Giovanni Vivenzio. Istoria e teoria de' tremuoti in generale ed in particolare di quelli della Calabria, e di Messina del MDCCLXXXIII. Napoli: Nella Stamperia Regale, 1783.

Ippolito, Francesco. "Account of the Earthquake Which Happened in Calabria, March 28, 1783. In a Letter from Count Francesco Ippolito to Sir William Hamilton, Knight of the Bath, F.R.S.; Presented by Sir William Hamilton." Philosophical Transactions of the Royal Society of London, LXXIII, Pt. I (1783), 209-16.

Isnard, _____. Mémoire sur les tremblemens de terre, qui a remporté le prix de physique au jugement de l'Académie des Sciences, Belles-lettres et Arts de Rouen, le 3 août 1757, par M. Isnard. Paris: Vve David jeune, 1758.

Kircher, Athanasius. Mundus subterraneus, in XII libros digestus; quo divinum subterrestris mundi opificium, mira ergasteriorum naturae in eo distributio, verbo παντάουρον protei regnum, universae denique naturae majestas & divitiae summa rerum varietate exponuntur. Abditorum effectuum causae acri indagini inquisitae demonstrantur; cognitae per artis & naturae conjugium ad humanae vitae necessarium usum vario experimentorum apparatu, necnon novo modo, & ratione applicantur. Amstelodami: Apud Joannem Janssonium & Elizeum Weyerstraten, 1665.

La Métherie, Jean Claude de. "Addition a mon mémoire. Sur les causes des commotions souterraines par l'action galvanique; par J.-C. Delamétherie." Journal de physique, de chimie, d'histoire naturelle et des arts,

avec des planches en taille-douce; par J.-C. Delametherie, LXXXI (1815), 393.

Lehmann, Johann Gottlob. Considérations physiques sur les causes des tremblemens de terre, et de leur propagation; ouvrage fondé sur la structure intérieure de la terre. Essai d'une histoire naturelle de couches de la terre, dans lequel on traite de leur formation, de leur situation, des minéraux, des métaux, & des fossiles qu'elles contiennent: avec des considérations physiques sur les causes des tremblemens de terre & de leur propagation. Vol. III of Traités de physique, d'histoire naturelle, de mineralogie et de métallurgie. [Translated by Paul Henri Thiry, Baron d'Holbach.] Paris: Chez Jean-Thomas Hérissant, 1759.

_____. Physicalische Gedancken von denen Ursachen derer Erdbeben und deren Fortpflanzung unter der Erden. Berlin: C. A. Lange, 1757.

Lémery, Nicolas. "Explication physique & chymique des feux souterrains, des tremblemens de terre, des ouragans, des eclairs & du tonnerre." Histoire de l'Academie Royale des Sciences, année MDCC. Avec les memoires de mathematique & de physique, pour la même année (Paris, 1703), Memoires, pp. 101-10.

["A Letter from a Gentleman in Jamaica, to His Friend in London, Dated July 3d. 1693."] Letter No. 8 in "A Letter from Hans Sloane, M.D. and S.R.S. with Several Accounts of the Earthquakes in Peru October the 20th. 1687. and at Jamaica, February 19th. 1687/8. and June the 7th. 1692." Philosophical Transactions of the Royal Society of London, XVIII, No. 209 (1694), 89-100.

A Letter of Congratulation and Advice from the Devil, to the Inhabitants of Great Britain, Particularly Those of the Two Cities of London and Westminster on Their Conduct Before and After the Late Earthquakes. London: Printed by the Fool; sold by Charon, [1750?].

Letter to Mr. Urban [Edward Cave], April 14, 1750." Gentleman's Magazine, XX (April, 1750), 154.

Lister, Martin. "The Second Paper of the Same Person Concerning the Spontaneous Firing of the Pyrites." Philosophical Transactions of the Royal Society of London, XIII, No. 157 (1683/84), 515-17.

_____. "The Third Paper of the Same Person, Concerning Thunder and Lightning Being from the Pyrites." Philo-

sophical Transactions of the Royal Society of London, XIII, No. 157 (1683/84), 517-19.

_____. "Three Papers of Dr. Martin Lyster, the First of the Nature of Earth-quakes; More Particularly of the Origine of the Matter of Them, from the Pyrites Alone." Philosophical Transactions of the Royal Society of London, XIII, No. 157 (1683/84), 512-15.

Louville, Jacques Eugène d'Allonville, Chevalier de. "Remarques sur les principaux phénomènes qui ont été observés pendant cette eclipse." "Observation faite a Londres de l'eclipse totale du soleil du 3. May 1715. nouveau stile." Histoire de l'Academie Royale des Sciences. Année M.DCCXV. Avec les memoires de mathématique & de physique, pour la même année (Paris, 1718), Memoires, pp. 90-99.

Lowther, Sir James. "An Account of the Damp Air in a Coal-Pit of Sir James Lowther, Bart. Sunk within 20 Yards of the Sea; Communicated by Him to the Royal Society." Philosophical Transactions of the Royal Society of London, XXXVIII, No. 429 (1733), 109-13.

[Lozano, Pedro (?)] Individual, y verdadera relacion de la extrema ruina que padeciò la Ciudad de los Reyes Lima, capital del reyno del Perú, con el horrible temblor de tierra acaecido en ella, la noche del 28. de octubre de 1746. y de la total assolacion del presidio, y puerto del Callao, por la violenta irrupcion del mar, que ocasionò en aquella bahia. [colophon: Impresso en Lima, y por su original, de mandato del Excmo. Sr. virrey, reimpresso en Mexico por la viuda de Joseph Bernardo de Hogal. Año de 1747.]

Lucretius. Lucretius: The Way Things Are. The De rerum natura of Titus Lucretius Carus. Translated by Rolfe Humphries. Bloomington: Indiana University Press, 1968.

Lyell, Charles. Principles of Geology, Being an Attempt to Explain the Former Changes of the Earth's Surface, by Reference to Causes Now in Operation. 3 vols. London: John Murray, 1730-33.

Mallet, Robert. "On the Dynamics of Earthquakes; Being an Attempt to Reduce Their Observed Phenomena to Known Laws of Wave Motion in Solids and Fluids." Transactions of the Royal Irish Academy, XXI, Pt. I (1846), 51-105.

Mann, Sir Horace. Horace Walpole's Correspondence with Sir Horace Mann. Edited by W. S. Lewis, Warren Hunting Smith, and George L. Lam. Vol. XX of The Yale Edition of Horace Walpole's Correspondence, Edited by W. S. Lewis. New Haven: Yale University Press, 1960.

Letters from Mann to Walpole cited: June 26, 1750, N.S. (pp. 158-59) and May 8, 1750, N.S. (pp. 146-49).

[Massey, William.] "Observations on Dr. Stukeley's Essay on Earthquakes." Gentleman's Magazine, XXI (August, 1751), 355-57.

Mather, Cotton. The Christian Philosopher: A Collection of the Best Discoveries in Nature, with Religious Improvements. London: Printed for Eman. Matthews, 1721. Facsimile edition. Gainesville, Fla.: Scholar's Facsimiles & Reprints, 1968.

Maud, John. "A Chemical Experiment by Mr. John Maud, Serving to Illustrate the Phenomenon of the Inflammable Air Shewn to the Royal Society by Sir James Lowther, Bart. as Described in Philosoph. Transact. Numb. 429." Philosophical Transactions of the Royal Society of London, XXXIX, No. 442 (1736), 282-85.

Mayhew, Jonathan. A Discourse on Rev. XV. 3d, 4th. Occasioned by the Earthquakes in November 1755. Delivered in the West-Meeting-House, Boston, Thursday December 18, Following. In Five Parts, with an Introduction. Part I. Of the Greatness of God's Works. Part II. Of Their Marvellous and Unsearchable Nature. Part III. Of the Moral Perfections and Government of God. Part IV. Of Our Obligation to Fear, Glorify and Worship Him. Part V. Practical Reflections upon the Subject, Relative to the Occasion. Boston: Printed by Edes & Gill, 1755.

_____. The Expected Dissolution of All Things, a Motive to Universal Holiness. Two Sermons Preached in Boston, N.E. on the Lord's Day, Nov. 23, 1755; Occasioned by the Earthquakes, Which Happened on the Tuesday Morning and Saturday Evening Preceding. With an Appendix Containing a More Particular Account of These Earthquakes, Than Has Yet Been Published Among Us. Boston: Printed and sold by Edes & Gill and by R. Draper, 1755.

Mazéas, Guillaume. "Letters of the Abbé Mazeas, F.R.S. to the Rev. Stephen Hales, D.D, F.R.S. Concerning the Success of the Late Experiments in France. Translated from the French by James Parsons, M.D. F.R.S." Philosophical Transactions of the Royal Society of London, XLVII (1752), 534-36.

"Mémoire sur les volcans et les tremblemens de terre; par M. C. D. L. Lieutenant-Colonel au Corps Royal du Génie." Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. Le Comte d'Artois; Par M. l'abbé Rozier, XXVII, Pt. II (1785), 81-87.

Michell, John. "Conjectures Concerning the Cause, and Observations upon the Phaenomena 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." Philosophical Transactions of the Royal Society of London, LI, Pt. II (1760), 566-634.

. Conjectures Concerning the Cause, and Observations upon the Phaenomena 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. London: n.p., 1760.

Milne [-Home], David. "Notices of Earthquake-Shocks in Great Britain, and Especially in Scotland, with Inferences Suggested by These Notices as to [the Nature and the] Causes of Such Shocks. By David Milne, Esq., F.R.S.E. M.W.S., F.G.S., &c. Communicated by the Author." Edinburgh New Philosophical Journal, XXXI (1841), 92-122, 259-309; XXXII (1842), 106-27, 362-78; XXXIII (1842), 372-88; XXXIV (1843), 85-106.

Montanari, Geminiano. L'astrologia convinta di falso col mezzo di nuove esperienze, e ragioni fisico-astronomiche, o' sia la caccia del frvgnvolò, di Geminiano Montanari. Venetia: Per F. Nicolini, 1685.

Montignot, Henri. "Tremblemens de terre. (Phys.) La nature de cet ouvrage, & l'utilité générale qui est le principal but des nouveaux éditeurs, les engage à insérer ici la lettre que M. l'abbé Montignot, chanoine de Toul, a écrite à l'auteur du Mercure sur le tremblement de terre arrivé à Lisbonne en 1755." Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres. Mis en ordre & publié par M. Diderot; & quant à la partie mathématique, par M. d'Alembert. Vol. XXXIV. Nouvelle édition. Geneve: Chez Pellet, Imprimeur-Libraire, 1778.

Moreira de Mendonça, Joaquim José. Historia universal dos terremotos, que tem havido no mundo, de que ha noticia,

desde a sua creação até o seculo presente. Com huma narraçam individual do terremoto do primeiro de novembro de 1755., e noticia verdadeira dos seus effeitos em Lisboa, todo Portugal, Algarves, e mais partes da Europa, Africa, e América, aonde se estendeu: e huma dissertação phisica sobre as causas geraes dos terremotos, seus effeitos, differenças, e prognosticos; e as particulares do ultimo. Lisboa: Na Offic. de Antonio Vicente da Silva, 1758.

Moro, Antonio Lazzaro. De' crostacei e degli altri marini corpi che si truovano su' monti libri due di Anton-Lazzaro Moro. Venezia: Appresso Stefano Monti, 1740.

Moyes, Henry. "Letter from Henry Moyes, M.D. to Maxwell Garthshore, M.D. Containing an Account of Some Interesting Experiments in Galvanic Electricity. Communicated by Dr. Garthshore." The Philosophical Magazine: Comprehending the Various Branches of Science, the Liberal Arts, Agriculture, Manufactures, and Commerce, VII, Ser. I (1800), 347-50.

Newton, Sir Isaac. Opticks: or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light. 2nd ed., with additions. London: Printed for W. & J. Innys, 1718.

. Opticks: or, a Treatise of the Reflections, Refractions, Inflections and Colours of Light. 4th ed., corrected. London: Printed for William Innys, 1730.

Nollet, Jean Antoine. "Conclusion of the Extract of the Abbe Nollet's Examination of Certain Phenomena in Electricity." Gentleman's Magazine, XXI (August, 1751), 349-51.

. Leçons de physique expérimentale. Vol. IV. Paris: Chez les Freres Guérin, 1748.

. Leçons de physique expérimentale. Vol. VI. Paris: Chez Hippolyte-Louis Guérin, & Louis-François Delatour, 1764.

"Observations on the Earthquake Which Was Felt Over Most of, If Not All, the Fens of Lincolnshire, Aug. 23, 1750, about 35 Minutes Past 6 in the Morning." Gentleman's Magazine, XX (October, 1750), 456-57.

"On This Occasion Were Publish'd in the Gazetteer the Following Queries." Gentleman's Magazine, XX (March, 1750), 125.

Palissy, Bernard. Discovrs admirables, de la natvre des eavx et fontaines, tant natvralles qv' artificielles, des metaux, des sels & salines, des pierres, des terres, du feu & des emaux. Avec plvsievr avtres excellens secrets des choses naturelles. Plvs vn traité de la marne, fort vtile & necessaire, pour ceux qui se mellent de l'agriculture. Le tovt dressé par dialogves, esqvls sont introduits la theorique & la pratique. Paris: Chez Martin le Jeune, 1580.

Papin, Denis. "A Demonstration of the Velocity Wherewith the Air Rushes into an Exhausted Receiver, Lately Produced before the R. Society by Dr. D. Papin, Reg. Soc. S." Philosophical Transactions of the Royal Society of London, XVI, No. 184 (1686), 193-95.

Paulian, Aimé Henri. "Tremblement de terre." Dictionnaire de physique, dédié a Monseigneur le Duc de Berry. Vol. III. Avignon: Chez Louis Chambeau, 1761.

"Philosophical Transactions. Being an Appendix to Those for the Year 1750. Consisting of a Collection of Several Papers Laid Before the Royal Society, Concerning Several Earthquakes Felt in England, and Some Neighbouring Countries, in the Year 1750." Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 601-750.

[Pignataro, Domenico.] "Giornale delle scosse di tremuoto avvenute nella Calabria Ulteriore, e specialmente avvertite nella città di Monteleone." Giovanni Vivenzio. Istoria e teoria de' tremuoti in generale ed in particolare di quelli della Calabria, e di Messina del MDCCCLXXXIII. Napoli: Nella Stamperia Regale, 1783.

Pigott, Thomas. "An Account of the Earthquake That Happened at Oxford and the Parts Adjacent Sept. 17. 1683. by a Fellow of a College in That University, and the Royal Society." Philosophical Transactions of the Royal Society of London, XIII, No. 151 (1683), 311-21.

Pliny. Natural History with an English Translation in Ten Volumes. Vol. I: Libri I-II. Translated by H. Rackham. Loeb Classical Library. Cambridge: Harvard University Press, 1947.

Plot, Robert. The Natural History of Stafford-shire. Oxford: Printed at the Theater, 1686.

"Pneumatics." Encyclopaedia Britannica; or, a Dictionary of Arts and Sciences, Compiled upon a New Plan. In Which

the Different Sciences and Arts Are Digested into Distinct Treatises or Systems; and the Various Technical Terms, &c. Are Explained as They Occur in the Order of the Alphabet. By a Society of Gentlemen in Scotland. Vol. III. Edinburgh: Printed for A. Bell and C. Macfarquhar, 1771.

Power, Henry. Experimental Philosophy in Three Books: Containing New Experiments Microscopical, Mercurial, Magnetical. With Some Deductions, and Probably Hypotheses, Raised from Them, in Avouchment and Illustration of the Now Famous Atomical Hypothesis. London: Printed by T. Roycroft for John Martin, and James Allestry, 1664.

Prentice, Thomas. Observations Moral and Religious, on the Late Terrible Night of the Earthquake. A Sermon Preached at the Thursday Lecture in Boston, January 1st. 1756. Boston: Printed and sold by S. Kneeland, for D. Henchman, in Cornhill, 1756.

Priestley, Joseph. The History and Present State of Electricity, with Original Experiments. London: Printed for J. Dodsley and others, 1767.

Prince, Thomas. Earthquakes the Works of God, and Tokens of His Just Displeasure; Being a Discourse on That Subject, Wherein Is Given a Particular Description of This Awful Event of Providence. And among Other Things, Is Offer'd a Brief Account of the Natural, Instrumental, or Secondary Causes of These Operations in the Hands of God. After Which, Our Thoughts Are Led Up to Him as Having the Highest and Principal Agency in This Stupendous Work . . . Made Public at This Time on Occasion of the Late Dreadful Earthquake, Which Happen'd on the 18th of Nov. 1755. Boston: Printed and sold by D. Fowle and Z. Fowle, 1755.

. Earthquakes the Works of God, & Tokens of His Just Displeasure. Two Sermons on Psal. XVIII. 7. at the Particular Fast in Boston, Nov. 2. and the General Thanksgiving Nov. 9. Occasioned by the Late Dreadful Earthquake. Wherein Among Other Things, Is Offered a Brief Account of the Natural Causes of These Operations in the Hands of God: with a Relation of Some Late Terrible Ones in Other Parts of the World, as Well as Those That Have Been Perceived in New-England Since It's Settlement by English Inhabitants. Boston: Printed for D. Henchman, 1727.

. An Improvement of the Doctrine of Earthquakes,

Being the Works of God, and Tokens of His Just Dis-
pleasure. Containing an Historical Summary of the Most
Remarkable Earthquakes in New-England, from the First
Settlement of the English Here, as Also in Other Parts
of the World Since 1666. To Which Is Added, a Letter
to a Gentleman, Giving an Account of the Dreadful Earth-
quake Felt in Boston, New-England Nov. 18, Twenty-five
Minutes Past 4 in the Morning. Boston: Printed and
 sold by D. Fowle and Z. Fowle, 1755.

_____. Letter from Thomas Prince. Boston Gazette, or
Country Journal, February 23, 1756, 21, verso. Micro-
 print edition. The Boston Gazette, 1719-1798. New
 York: Readex Microprint Corp., n.d.

_____. Letter from Thomas Prince. Boston Gazette, or
Country Journal, January 26, 1756, 21, recto. Micro-
 print edition. The Boston Gazette, 1719-1798. New
 York: Readex Microprint Corp., n.d.

Raspe, Rudolf Erich. An Introduction to the Natural History
of the Terrestrial Sphere Principally Concerning New
Islands Born from the Sea and Hooke's Hypothesis of
the Earth on the Origin of Mountains and Petrified
Bodies To Be Further Established from Accurate Descrip-
tions and Observations. Translated by Audrey Notvik
 Iversen and Albert V. Carozzi. New York: Hafner Pub-
 lishing Company, 1970.

_____. Specimen historiae naturalis globi terraquei,
praecipue de novis e mari natis insulis, et ex his ex-
actius descriptis & observatis, ulterius confirmanda,
Hookiana telluris hypothesi, de origine montium et cor-
porum petrefactorum. Cum figuris aeneis. Amstelodami
 & Lipsiae: Sumptibus J. Schreuder & P. Mortier, 1763.

Ray, John. Miscellaneous Discourses Concerning the Dissolu-
tion and Changes of the World. Wherein the Primitive
Chaos and Creation, the General Deluge, Fountains,
Formed Stones, Sea-Shells Found in the Earth, Subter-
ranean Trees, Mountains, Earthquakes, Vulcanoës, the
Universal Conflagration and Future State, Are Largely
Discussed and Examined. London: Printed for Samuel
 Smith, 1692.

_____. Three Physico-Theological Discourses, Concerning
I. The Primitive Chaos, and Creation of the World.
II. The General Deluge, Its Causes and Effects. III.
The Dissolution of the World, and Future Conflagration.
Wherein Are Largely Discussed, the Production and Use
of Mountains; the Original of Fountains, of Formed

Stones, and Sea Fishes Bones and Shells Found in the Earth; the Effects of Particular Floods, and Inundations of the Sea; the Eruptions of Vulcano's; the Nature and Causes of Earthquakes: with an Historical Account of Those Two Late Remarkable Ones in Jamaica and England. With Practical Inferences. 2nd ed., corrected, very much enlarged. London: Printed for Sam. Smith, 1693.

. Three Physico-Theological Discourses, Concerning
I. The Primitive Chaos, and Creation of the World.
II. The General Deluge, Its Causes and Effects. III.
The Dissolution of the World, and Future Conflagration.
Wherein Are Largely Discussed, the Production and Use
of Mountains; the Original of Fountains, of Formed
Stones, and Sea-Fishes Bones and Shells Found in the
Earth; the Effects of Particular Floods, and Inunda-
tions of the Sea; the Eruptions of Vulcano's; the Na-
ture and Causes of Earthquakes. Also an Historical
Account of Those Two Late Remarkable Ones in Jamaica
and England. With Practical Inferences. London:
Printed for William Innys, 1713.

Reale Accademia delle Scienze, Naples. Istoria de' fenomeni
del tremoto avvenuto nelle Calabrie, e nel Valdemone
nell' anno 1783 posta in luce dalla Reale Accademia
delle Scienze, e delle Belle Lettere di Napoli. Napoli:
Presso G. Campo, 1784.

"A Report of the Committee Appointed by the Royal Society, to
Consider of a Method for Securing the Powder Magazines
at Purfleet." Philosophical Transactions of the Royal
Society of London, LXIII, Pt. I (1773), 42-48.

Rohault, Jacques. Jacobi Rohaulti Physica. Latinè vertit,
recensuit, & adnotationibus ex illustrissimè Isaaci
Newtoni philosophiā maximam partem haustis, amplificavit
& ornavit Samuel Clarke, S.T.P. Regiae Majestati à
sacris. Editio tertia, in quā annotationes sunt dimidiā
parte auctiores, additaeque octo tabulae aeri incisae.
Londini: Impensis Jacobi Knapton, 1710.

. Rohault's System of Natural Philosophy, Illustrat-
ed with Dr. Samuel Clarke's Notes, Taken Mostly Out of
Sir Isaac Newton's Philosophy. Translated by John
Clarke. 2 vols. London: Printed for James Knapton,
1723.

. Traité de physique. Paris: Chez le Veuve de
Charles Savreux, 1671.

Salsano, D. Domenico. "Descrizione di un geo-sismometro o sia misuraterremoto." Nouvo giornale enciclopedico, novembre 1783. Vicenza, 1783.

Scheuchzer, John Gaspar. "An Account of a Book Entituled, Dominici bottoni, de immani trinacriae terrae motu idea historico-physica, in qua non solum telluris concussiones transactae recensentur, sed novissimae anni 1717. Messanae 1718, 8^o. By J. G. Scheuchzer, M.D. R.S.S. Coll.M.L.Lic." Philosophical Transactions of the Royal Society of London, XXXIII, No. 384 (1724), 151-58.

Seneca. Seneca in Ten Volumes. Vol. X: Naturales quaestiones. Translated by Thomas H. Corcoran. Loeb Classical Library. Cambridge: Harvard University Press, 1972.

[Sherlock, Thomas.] "Abstract of the Bp of London's Letter to the Clergy and Inhabitants of London and Westminster, &c. on Occasion of the Late Earthquakes." Gentleman's Magazine, XX (March, 1750), 123-24.

_____. A Letter from the Lord Bishop of London, to the Clergy and People of London and Westminster; on Occasion of the Late Earthquakes. London: Printed for John Whiston, 1750.

_____. A Letter from the Lord Bishop of London, to the Clergy and People of London and Westminster; on Occasion of the Late Earthquakes. Boston: Reprinted and sold by John Draper, 1750.

Shower, John. Practical Reflections on the Earthquakes That Have Happened in Europe and America, but Chiefly in the Islands of Jamaica, England, Sicily, Malta, &c. with a Particular and Historical Account of Them, and Divers Other Earthquakes. 2nd ed. London: Cook, James, and Kingman, and others, 1750.

_____. Practical Reflections on the Late Earthquakes in Jamaica, England, and Sicily, Malta, &c. anno 1692. With a Particular, Historical Account of Those, and Divers Other Earthquakes. London: Printed for J. Salusbury, 1693.

Sigaud-Lafond, Joseph Aignan. "Tremblement de terre." Dictionnaire de physique. Vol. IV. Paris: Rue et Hôtel Serpente, 1781.

Strabo. The Geography of Strabo. Vol. III. Translated by Horace Leonard Jones. Loeb Classical Library. Cambridge: Harvard University Press, 1954.

Stukeley, William. Family Memoirs of the Rev. William Stukeley, M.D. and the Antiquarian and Other Correspondence of William Stukeley, Roger & Samuel Gale, etc. 3 vols. Durham: Published for the [Surtees] Society by Andrews & Co., and others, 1882-87.

Stukeley's writings cited: Letter to Peter Collinson, June 28, 1750, O.S. (I, 400-1); Diary, February 10, 1749/50 (II, 370); Diary, February 15, 1749/50 (II, 370-71); Diary, Dec. 1752 (II, 378-79); Diary, January 20, 1757 (II, 382-83); Diary, January 27, 1757 (II, 383).

_____. "The Philosophy of Earthquakes; by the Rev. William Stukeley, M.D. F.R.S. &c. in a Letter to Martin Folkes, Esq; LL.D. and President of the Royal Society, &c." Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 731-50.

_____. The Philosophy of Earthquakes, Natural and Religious. Or an Inquiry into Their Cause, and Their Purpose. London: Printed for C. Corbet, 1750.

_____. The Philosophy of Earthquakes, Natural and Religious. Or an Inquiry into Their Cause, and Their Purpose. 3rd ed. London: Printed for A. and C. Corbett, 1756.

_____. "The Rev. Wm. Stukeley M.D. F.R.S. to the President, Concerning the Causes of Earthquakes." Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 657-69.

_____. "The Rev. W. Stukely M.D. & F.R.S. to the President, on the Causes of Earthquakes." Philosophical Transactions of the Royal Society of London, XLVI, No. 497 (1750), 641-46.

"Sundry Papers Relative to an Accident from Lightning at Purfleet, May 15, 1777." Philosophical Transactions of the Royal Society of London, LXVIII, Pt. I (1778), 232-317.

The Theory and History of Earthquakes. Containing, I. A Rational Account of Their Causes and Effects; Illustrated by Experiments and Observations on Subterraneous Vapours, and the Manner of Making Artificial Earthquakes. II. A Particular and Authentic History of Those Which Have Happened in These Kingdoms, and the Most Remarkable of Those Abroad, viz. in Sicily, Jamaica, and Lima, with the Most Considerable Eruptions of Vesuvius and Aetna. III. Some Seasonable Reflections

on the Two Late Earthquakes, with a Pathetic Address, on That Occasion, to the Inhabitants of London and Westminster. London: Printed for J. Newbery and others, [1750?].

Thomas, [Antoine Léonard.] "Memoire sur la cause des tremblemens de terre." Suite de la clef, ou journal historique sur les matiers de tems [Journal de Verdun], LXXX (1756), 347-61, 426-35.

. Mémoire sur la cause des tremblemens de terre, qui a remporté le prix Accessit au jugement de l'Académie Royale des Sciences, Belles-lettres et Arts de Rouen le 3 août 1757, par M. Thomas. Paris: C.-A. Jombert, 1758.

"To a Friend, on Hearing of the Desertion at Westminster-Hall, at the Time of the Late Earthquake." Gentleman's Magazine, XX (February, 1750), 85.

Toaldo, Giuseppe. Della vera influenza degli astri delle stagioni e mutazioni di tempo, saggio meteorologico . . . applicato agli usi dell' agricoltura, medicina, nautica, ec., di Giuseppe Toaldo, si aggiungono i prognostici di Arato tradotti dal Sig. A. L. Bricci, et la descrizione d'un nuovo pendolo a correzione del Ch. P. Boscovich. Padova: G. Manfrè, 1770.

A True and Particular Relation of the Dreadful Earthquake Which Happen'd at Lima, the Capital of Peru, and the Neighbouring Port of Callao, on the 28th of October, 1746. With an Account Likewise of Every Thing Material That Passed There Afterwards to the End of November Following. Published at Lima by Command of the Viceroy, and Translated from the Original Spanish, by a Gentleman Who Resided Many Years in Those Countries. To Which Is Added, a Description of Callao and Lima Before Their Destruction; and of the Kingdom of Peru in General, with Its Inhabitants; Setting Forth Their Manners, Customs, Religion, Government, Commerce, &c. Interspersed with Passages of Natural History and Physiological Disquisitions; Particularly an Enquiry into the Cause of Earthquakes. The Whole Illustrated with a Map of the Country About Lima, Plans of the Road and Town of Callao, Another of Lima; and Several Cuts of the Natives, Drawn on the Spot by the Translator. London: Printed for T. Osborne, 1748.

A True and Particular Relation of the Dreadful Earthquake, Which Happen'd at Lima, the Capital of Peru, and the Neighbouring Port of Callao, on the 28th of October,

1746. With an Account Likewise of Everything Material That Passed There Afterwards to the End of November Following. Published at Lima by Command of the Viceroy, and Translated from the Original Spanish, by a Gentleman Who Resided Many Years in Those Countries. Philadelphia: Reprinted and sold by B. Franklin and D. Hall, 1749.

A True and Particular Relation of the Dreadful Earthquake, Which Happen'd at Lima, the Capital of Peru, and the Neighbouring Port of Callao, on the 28th of October, 1746. With an Account Likewise of Everything Material That Passed There Afterwards to the End of November Following. Published at Lima by Command of the Viceroy, and Translated from the Original Spanish, by a Gentleman Who Resided Many Years in Those Countries. Boston: Printed and sold by D. Fowle, [1750].

[Tytler, James.] "Earthquake." Encyclopaedia Britannica. 2nd ed. (1779). Vol. IV.

_____. "Earthquake." Encyclopaedia Britannica. 3rd ed. (1797). Vol. VI.

_____. "Electricity." Encyclopaedia Britannica. 2nd ed. (1779). Vol. IV.

Valmont de Bomare, Jacques Christophe. "Tremblement de terre." Dictionnaire raisonné universel d'histoire naturelle. Vol. XI. Edition augmentée. Yverdon: n.p., 1769.

Varen, Bernhard. A Compleat System of General Geography: Explaining the Nature and Properties of the Earth; viz. It's Figure, Magnitude, Motions, Situation, Contents, and Division into Land and Water, Mountains, Woods, Desarts, Lakes, Rivers, &c. With Particular Accounts of the Different Appearances of the Heavens in Different Countries; the Seasons of the Year Over All the Globe; the Tides of the Sea; Bays, Capes, Islands, Rocks, Sand-Banks, and Shelves. The State of the Atmosphere; the Nature of Exhalations; Winds, Storms, Tornados, &c. The Origin of Springs Mineral-Waters, Burning Mountains, Mines, &c. The Uses and Making of Maps, Globes, and Sea-Charts. The Foundations of Dialling; the Art of Measuring Heights and Distances; the Art of Ship-Building, Navigation, and the Ways of Finding the Longitude at Sea. Originally Written in Latin by Bernhard Varenius, M.D. Since Improved and Illustrated by Sir Isaac Newton and Dr. Jurin; and Now Translated into English; with Additional Notes, Copper-Plates,

an Alphabetical Index and Other Improvements. Particularly Useful to Students in the Universities; Travelers, Sailors, and All Those Who Desire To Be Acquainted with Mixed Mathematics, Geography, Astronomy, and Navigation. By Mr Dugdale. The Whole Revised and Corrected by Peter Shaw, M.D. 2 vols. 3rd ed., with additions. London: Printed for Stephen Austen, 1736.

"View of a Pretended Translated Account of the Late Earthquake at Lima." Gentleman's Magazine, XVIII (August, 1748), 361-62.

Vivenzio, Giovanni. Istoria e teoria de' tremuoti in generale ed in particolare di quelli della Calabria, e di Messina del MDCCLXXXIII. Napoli: Nella Stamperia Regale, 1783.

Voltaire, François Marie Arouet de. "Poème sur le désastre de Lisbonne ou examen de cet axiome: Tout est bien." Oeuvres complète de Voltaire. Vol. IX. Nouvelle édition. Paris: Garnier Frères, Libraires-Éditeurs, 1877.

_____. "Préface du poème sur le désastre de Lisbonne." Oeuvres complete de Voltaire. Vol. IX. Nouvelle édition. Paris: Garnier Frères, Libraires-Éditeurs, 1877.

Walker, John. Lectures on Geology Including Hydrography, Mineralogy, and Meteorology with an Introduction to Biology by John Walker, Professor of Natural History and Keeper of the Museum, University of Edinburgh from 1779-1803. Edited by Harold W. Scott. Chicago: University of Chicago Press, 1966.

Wallis, John. "A Relation Concerning the Late Earthquake Neer Oxford; Together with Some Observations of the Sealed Weatherglass, and the Barometer, Both upon That Phaenomenon, and in General." Philosophical Transactions of the Royal Society of London, I, No. 10 (1665/66), 166-71.

Walpole, Horace. Horace Walpole's Correspondence with Sir Horace Mann. Edited by W. S. Lewis, Warren Hunting Smith, and George L. Lam. Vol. XX of The Yale Edition of Horace Walpole's Correspondence. Edited by W. S. Lewis. New Haven: Yale University Press, 1960.

Letters from Walpole to Mann cited: March 11, 1750, O.S. (pp. 130-32); April 2, 1750, O.S. (pp. 133-42); May 19, 1750, O.S. (pp. 154-57); February 23, 1756 (pp. 529-35); March 18, 1756 (pp. 537-39).

- _____. Horace Walpole's Correspondence with Sir Horace Mann and Sir Horace Mann the Younger. Edited by W. S. Lewis, Warren Hunting Smith, George L. Lam, with the assistance of Edwine M. Martz. Vol. XXV of The Yale Edition of Horace Walpole's Correspondence. Edited by W. S. Lewis. New Haven: Yale University Press, 1971.
Letter from Walpole to Mann cited: August 27, 1783 (pp. 426-28).
- Wark, _____. "Methode pour déterminer la force & la direction des tremblemens de terre, par M. Wark, Ministre à Haddington." Observations sur la physique, sur l'histoire naturelle et sur les arts, avec des planches en taille-douce, dédiées a Mgr. le Comte d'Artois, par M. l'abbé Rozier, I (1773), 376. Paris: Au Bureau du Journal de physique, 1784.
- [Wesley, John.] "From a Late Bristol Journal. Extract of a Letter from a Gentleman in Yorkshire." Boston Gazette, or Country Journal, January 12, 1756, 11, recto and verso. Microprint edition. The Boston Gazette, 1719-1798. New York: Readex Microprint Corp., n.d.
- _____. Serious Thoughts Occasioned by the Late Earthquake at Lisbon. The Works of John Wesley. Vol. XI. Grand Rapids, Mich.: Zondervan Publishing House, n.d.
- _____. A Survey of the Wisdom of God in the Creation; or a Compendium of Natural Philosophy. 5 vols. New edition, revised and corrected. London: Printed and sold by J. Stratford, 1809.
- Whewell, William. History of the Inductive Sciences. 3 vols. London: John W. Parker, 1837.
- Williams, Samuel. "Observations and Conjectures on the Earthquakes of New-England." Memoirs of the American Academy of Arts and Sciences: To the End of the Year M,DCC,LXXXIII, I (1783), 260-311. Microprint edition. Early American Imprints: 1639-1800. New York: Readex Microprint Corp., n.d.
- Winthrop, John. "An Account of the Earthquake Felt in New England, and the Neighbouring Parts of America, on the 18th of November 1755. In a Letter to Tho. Birch, D.D. Secret. R. S. by Mr. Professor Winthrop, of Cambridge in New England." Philosophical Transactions of the Royal Society of London, L, Pt. I (1757), 1-18.
- _____. A Lecture on Earthquakes; Read in the Chapel of Harvard-College in Cambridge, N.E. November 26th 1755.

On Occasion of the Great Earthquake Which Shook New-England the Week Before. Boston: Printed and sold by Edes & Gill, 1755. Microprint edition. Early American Imprints: 1639-1800. New York: Readex Microprint Corp., n.d.

_____. Letter from John Winthrop. Boston Gazette, or Country Journal, March 1, 1756, 21, recto. Microprint edition. The Boston Gazette, 1719-1798. New York: Readex Microprint Corp., n.d.

_____. A Letter to the Publishers of the Boston Gazette, &c. Containing an Answer to the Rev. Mr. Prince's Letter, Inserted in Said Gazette, on the 26th of January 1756. Boston: Printed and sold by Edes & Gill, 1756.

Woodward, John. An Essay Toward a Natural History of the Earth: and Terrestrial Bodies, Especially Minerals: as Also of the Sea, Rivers, and Springs. With an Account of the Universal Deluge: and of the Effects That It Had upon the Earth. London: Printed for Ric. Wilkin, 1695.

Young, Thomas. "Lecture LVII. On Aqueous and Igneous Meteors." Course of Lectures on Natural Philosophy and the Mechanical Arts. Vol. I. London: Printed for Joseph Johnson, 1807.

Zantedeschi, Francesco. "De l'influence de la lune dans les tremblements de terre, et des conséquences probables qui en dérivent sur la forme ellipsoïdale de la terre, et sur les oscillations des pendules; par M. Fr. Zantedeschi." Compte rendu des séances de l'Académie des Sciences, XXXIX (1854), 375-77.

PART TWO: SECONDARY SOURCES CITED

Adams, Frank Dawson. The Birth and Development of the Geological Sciences. Baltimore: Williams & Wilkins Company, 1938.

Andrews, William D. "The Literature of the 1727 New England Earthquake." Early American Literature, VII (1973), 281-94.

Axon, William Edward Armytage. "Burton, Robert or Richard." Dictionary of National Biography. Vol. III.

Beaujeu, J. "[Hellenistic and Roman Science:] Physics and

- Biology." Ancient and Medieval Science: From the Beginnings to 1450. Edited by René Taton. Translated by A. J. Pomerans. London: Thames and Hudson, 1963.
- Beringer, Carl Christoph. Geschichte der Geologie und des geologischen Weltbildes. Stuttgart: Ferdinand Enke Verlag, 1954.
- Boorstin, Daniel J. The Americans: The Colonial Experience. New York: Random House, 1958.
The Prince-Winthrop debate is discussed on p. 258.
- Brett-James, Norman G. The Life of Peter Collinson, F.R.S., F.S.A. [London:] Edgar G. Dunstan & Co., [1926]
- Cailleux, André. Histoire de la géologie. Paris: Presses Universitaires de France, 1961.
- Cassirer, Ernst. The Philosophy of the Enlightenment. Translated by Fritz C. A. Koelln and James P. Pettegrove. Princeton: Princeton University Press, 1951.
- Chantal, Suzanne. "Disaster Strikes Lisbon." Milestones of History: 100 Decisive Events in the History of Mankind. New York: W. W. Norton & Company, Inc., 1971.
- Clark, Kenneth. The Romantic Rebellion: Romantic Versus Classic Art. New York: Harper & Row, Publishers, 1973.
- Cohen, I. Bernard. "Introduction." Benjamin Franklin's Experiments: A New Edition of Franklin's Experiments and Observations on Electricity. Cambridge: Harvard University Press, 1941.
- Davison, Charles. The Founders of Seismology. Cambridge: At the University Press, 1927.
- Dewey, James, and Byerly, Perry. "The Early History of Seismometry (to 1900)." Bulletin of the Seismological Society of America, LIX (1969), 183-227.
- Dimond, Sydney G. The Psychology of the Methodist Revival: An Empirical & Descriptive Study. London: Oxford University Press, 1926.
- Early American Imprints: 1639-1800. New York: Readex Microprint Corp., n.d.
- "Encyclopaedia." Encyclopaedia Britannica. 11th ed. Vol. IX.
- Eyles, V. A. "The Extent of Geological Knowledge in the Eighteenth Century, and the Methods by Which It Was

Diffused." Toward a History of Geology. Edited by Cecil J. Schneer. Proceedings of the New Hampshire Inter-Disciplinary Conference on the History of Geology, September 7-12, 1967. Cambridge, Mass.: M.I.T. Press, 1969.

_____. "The History of Geology: Suggestions for Further Research." History of Science, V (1966), 77-86.

Favaro, Antonio. "Contribuzioni alla storia della micro-sismologia." Atti del Istituto Veneto dei Scienze, Lettere ed Arti, ser. 6, II (1884), 91-103.

Geikie, Sir Archibald. The Founders of Geology. 2nd ed. London: Macmillan and Co., Limited, 1905.

Gillispie, Charles Coulston. Genesis and Geology: A Study in the Relations of Scientific Thought, Natural Theology, and Social Opinion in Great Britain, 1790-1850. Harper Torchbooks. New York: Harper & Row, Publishers, 1959.

Gliozzi, M. "Bina, Andrea." Dizionario biografico degli Italiani. Vol. X.

Greene, John C. The Death of Adam: Evolution and Its Impact on Western Thought. Ames, Iowa: Iowa State University Press, 1959.

Hardin, Clyde L. "The Scientific Work of the Reverend John Michell." Annals of Science, XXII, No. 1 (1966), 27-47.

Henderson, Thomas Finlayson. "Tytler, James." Dictionary of National Biography. Vol. XIX.

Hindle, Brooke. Pursuit of Science in Revolutionary America, 1735-1789. Published for the Institute of Early American History and Culture, Williamsburg, Virginia. Chapel Hill: University of North Carolina, 1956.
American earthquakes are discussed on pp. 94-96.

Hölder, Helmut. Geologie und Paläontologie in Texten und ihrer Geschichte. München: Verlag Karl Alber, 1960.

Hornberger, Theodore. "The Science of Thomas Prince." New England Quarterly, IX (1936), 26-42.

Kelly, Suzanne, Sister. "Theories of the Earth in Renaissance Cosmologies." Toward a History of Geology. Edited by Cecil J. Schneer. Proceedings of the New Hampshire Inter-Disciplinary Conference on the History of Geology, September 7-12, 1967. Cambridge, Mass.: M.I.T. Press, 1969.

- Kendrick, T. D. The Lisbon Earthquake. London: Methuen & Co., Ltd., 1956.
- Love, W. DeLoss. The Fast and Thanksgiving Days of New England. Boston: Houghton, Mifflin and Company, 1895.
The earthquakes of 1727 and 1755 are discussed in chap. xx: "The Terror of the Lord" (pp. 285-95).
- Mather, Kirtley F., and Mason, Shirley L., editors. A Source Book in Geology, 1400-1900. Source Books in the History of the Sciences. Cambridge: Harvard University Press, 1970.
- Merrill, George P. The First Hundred Years of American Geology. New Haven: Yale University Press, 1924.
Winthrop's lecture on earthquakes is examined on pp. 7-9.
- Montessus de Ballore, Ferdinand de. "Histoire de la sismologie." Revue des questions scientifiques, 3rd ser., XXIX (1921), 29-57, 320-50.
- Rappaport, Rhoda. "Problems and Sources in the History of Geology, 1749-1810." History of Science, III (1964), 60-78.
- Rousseau, G. S. "The London Earthquakes of 1750." Cahiers d'histoire mondiale, Journal of World History, Cuadernos de historia mundial, XI (1968), 436-51.
- Royal Society of London. The Record of the Royal Society of London for the Promotion of Natural Knowledge. 4th ed. London: Printed for the Royal Society by Morrison & Gibb, Ltd., Edinburgh, 1940.
- Sarton, George. Introduction to the History of Science. Vol. III, Pt. I: Science and Learning in the Fourteenth Century. Baltimore: Published for the Carnegie Institution of Washington by The Williams & Wilkins Company, 1947.
- Smith, Preserved. The Enlightenment: 1687-1776. Vol. II of A History of Modern Culture. New York: Collier Books, 1962.
- Stearns, Raymond Phineas. Science in the British Colonies of America. Urbana, Ill.: University of Illinois Press, 1970.
The author comments on the Prince-Winthrop debate on pp. 649-50.

Tilton, Eleanor M. "Lightning-Rods and the Earthquake of 1755." New England Quarterly, XIII (1949), 85-97.

Walsh, S. Padraig. Anglo-American General Encyclopedias: A Historical Bibliography, 1703-1967. New York: R. R. Bowker Company, 1968.

Zittel, Karl Alfred von. Geschichte der Geologie und Paläontologie bis Ende des 19. Jahrhunderts. München: R. Oldenbourg, 1899.

PART THREE: SELECTED BIBLIOGRAPHY OF ADDITIONAL SOURCES

The secondary literature on eighteenth-century earthquake studies is limited, but writings on related topics are more plentiful. For background material on the general history of the period, for related investigations in the history of geology, and for recent biographical studies, the following selective bibliography provides a further survey of sources.

Becker, Carl L. The Heavenly City of the Eighteenth-Century Philosophers. New Haven: Yale University Press, 1932.

Besterman, Theodore. Voltaire. New York: Harcourt, Brace and World, 1969.

_____. "Voltaire and the Lisbon Earthquake." Voltaire Essays, and Another. London: Oxford University Press, 1962.

Brinton, Crane. A Decade of Revolution, 1789-1799. The Rise of Modern Europe Series. Edited by William L. Langer. Harper Torchbooks. New York: Harper & Row, Publishers, 1963.

Carozzi, Albert V. "Robert Hooke, Rudolf Erich Raspe, and the Concept of 'Earthquakes.'" Isis, LXI (1970), 85-91.

Davison, Charles. A History of British Earthquakes. Cambridge:

At the University Press, 1924.
A modern earthquake chronicle.

Dorn, Walter L. Competition for Empire, 1740-1763. The Rise of Modern Europe Series. Edited by William L. Langer. Harper Torchbooks. New York: Harper & Row, Publishers, 1963.

Dott, R. H., Jr. "James Hutton and the Concept of a Dynamic Earth." Toward a History of Geology. Edited by Cecil J. Schneer. Proceedings of the New Hampshire Inter-Disciplinary Conference on the History of Geology, September 7-12, 1967. Cambridge, Mass.: M.I.T. Press, 1969.

Eyles, V. A. "John Woodward, F.R.S. (1665-1728), Physician and Geologist." Nature, CCVI (1965), 868-70.

Gentleman's Magazine. Vols. I-LXX (1731-1800).
This periodical is useful in providing a continuous chronicle of the world's earthquakes.

Gerland, G. "Robert Boyle als Erdbebenforscher." Beitrage zur Geophysik; Zeitschrift für physikalische Erdkunde, IV (1900), 108.

Gershoy, Leo. From Despotism to Revolution, 1763-1789. The Rise of Modern Europe Series. Edited by William L. Langer. Harper Torchbooks. New York: Harper & Row, Publishers, 1963.

Gliozzi, Mario. "Giambattista Beccaria nella storia dell'elettricità." Archeion, XVII (1935), 15-47.

Guédon, Jean-Claude. "Protestantisme et Chimie: Le Milieu Intellectuel de Nicolas Lémery." Isis, LXV (1974), 212-28.

Kiernan, Colm. Science and the Enlightenment in Eighteenth-Century France. Studies on Voltaire and the Eighteenth Century, No. 59. Geneve: Institut et Musée Voltaire, 1968.

Lively, Jack, ed. The Enlightenment. Problems and Perspectives in History. Edited by H. F. Kearney. New York: Barnes & Noble, Inc., 1966.

Lough, John. Essays on the Encyclopédie of Diderot and d'Alembert. London: Oxford University Press, 1968.

Oldroyd, David R. "Robert Hooke's Methodology of Science as

Exemplified in His Discourse of Earthquakes." British Journal for the History of Science, VI (1972), 109-30.

Pace, A. "Beccaria, Giambattista." Dizionario biografico degli Italiani. Vol. VII.

Piggott, Stuart. William Stukeley: An Eighteenth Century Antiquary. Oxford: Clarendon Press, 1950.

The biography of an antiquary, not an electrician.

Roberts, Penfield. The Quest for Security, 1715-1740. The Rise of Modern Europe Series. Edited by William L. Langer. Harper Torchbooks. New York: Harper & Row, Publishers, 1963.

Schofield, Robert E. "John Wesley and Science in 18th Century England." Isis, XLIV (1953), 331-40.

Sleep, Mark C. W. "Sir William Hamilton (1730-1803): His Work and Influence in Geology." Annals of Science, XXV (1969), 319-38.

Taylor, Kenneth L. "Nicolas Desmarest and Geology in the Eighteenth Century." Toward a History of Geology. Edited by Cecil J. Schneer. Proceedings of the New Hampshire Inter-Disciplinary Conference on the History of Geology, September 7-12, 1967. Cambridge, Mass.: M.I.T. Press, 1969.

Topazio, Virgil W. "D'Holbach, Man of Science." Rice University Studies, LIII, No. 4 (1967), 63-68.

Willey, Basil. The Eighteenth Century Background: Studies on the Idea of Nature in the Thought of the Period. New York: Columbia University Press, 1941.

Wilson, Leonard G. Charles Lyell, the Years to 1841: The Revolution in Geology. New Haven: Yale University Press, 1972.

Wolf, John B. The Emergence of the Great Powers, 1685-1715. The Rise of Modern Europe Series. Edited by William L. Langer. Harper Torchbooks. New York: Harper & Row, Publishers, 1962.

Earthquake Literature in America

The following is an additional sampling of the writings on earthquakes produced in America (see above, pp. 17-19;

p. 130, n. 21; and p. 246, n. 17). The literature primarily consists of sermons and also letters to the Royal Society of London describing various shocks in the New England colonies. Charles Evans' American Bibliography (see below, p. 340) lists more than thirty works concerning earthquakes for the years 1727 through 1756 in addition to the more than a dozen books, pamphlets, and homilies on the tremors of the 1750's already mentioned above. Most of the works cited are available in the Early American Imprints microprint series. See also: William D. Andrews, "The Literature of the 1727 New England Earthquake," Early American Literature, VII (1973), 281-94.

Sermons of 1727-28

Colman, Benjamin. The Judgments of Providence in the Hand of Christ: His Voice to Us in the Terrible Earthquake. And, the Earth Devoured by the Curse. In Four Sermons. Boston: Printed by J. Phillips and T. Hancock, 1727.

Cotton, John. God's Awful Determination Against a People, That Will Not Obey His Voice. . . . A Sermon Preach'd . . . in Boston, February 8. 1728. after Repeated Shocks of the Earthquake. Boston: Printed by Gamaliel Rogers, for Samuel Gerrish, and Thomas Hancock, 1728.

Foxcroft, Thomas. The Voice of the Lord, from the Deep Places of the Earth. A Sermon Preached in Boston, in the Audience of the General Court, at the Opening of the Sessions, November 23, 1727. Boston: Printed for S. Gerrish, 1727.

Mather, Cotton. Boanerges. A Short Essay to Preserve and Strengthen the Good Impressions Produced by Earthquakes on the Minds of People That Have Been Awakened with Them. With Some Views of What Is To Be Further and Quickly Look'd for. Address'd unto the Whole People of New-England, Who Have Been Terrified with the Late Earthquakes; and More Especially the Towns That Have Had a More Singular Share in the Terrors of Them. With an Historical Appendix, Giving an Account of All the

Observable Occurrences of the Present Year; More Especially the Earthquakes That Have Been in Europe and the West Indies. Boston: Printed for S. Kneeland, 1727.

. The Terror of the Lord. Some Account of the Earthquake That Shook New-England, in the Night, Between the 29 and 30 of October. 1727. With a Speech, Made unto the Inhabitants of Boston, Who Assembled the Next Morning, for the Proper Exercises of Religion, or So Uncommon, and So Tremendous an Occasion. Boston: Printed by T. Fleet for S. Kneeland, 1727.

Sewall, Joseph. Repentance the Sure Way to Escape Destruction. Two Sermons on Jrr. 18. 7. 8. Preach'd December 21st, on a Publick Fast Occasioned by the Earthquake, the Night after the Lord's Day Octob. 29th. And on the Lord's-Day December 24th. 1727. Published with Some Enlargement. Boston: Printed for D. Henchman, 1727.

Letters to the Royal Society

Colden, Cadwallader. "An Account of the Earthquake Felt in New York, Novem. 18, 1755, in a Letter from Cadwallader Colden, Esq; to Mr Peter Collinson, F.R.S." Philosophical Transactions of the Royal Society of London, XLIX, Pt. I (1755), 443.

Colman, Benjamin. "Part of a Letter from the Reverend Mr. Benjamin Colman, of Boston in New England, to the late Bishop of Peterborough; giving an Account of the Late Earthquake Which Happened There. Communicated by Dr. Jurin, R.S.S. &c." Philosophical Transactions of the Royal Society of London, XXVI, No. 409 (1729), 124-27.

Dudley, Paul. "An Account of the Several Earthquakes Which Have Happen'd in New-England, Since the First Settlement of the English in That Country, Especially of the Last, Which Happen'd on Octob. 29, 1727. Communicated to the Royal Society by Paul Dudley, Esq. F.R.S. in a Letter to the Secretary." Philosophical Transactions of the Royal Society of London, XXXIX, No. 437 (1735), 63-73.

Hyde, John. "An Account of the Earthquake Felt at Boston in New-England, Novem. 18, 1755. Communicated by John Hyde, Esq; F.R.S." Philosophical Transactions of the Royal Society of London, XLIX, Pt. I (1755), 439-42.

Lewis, Richard. "A Letter from Mr Richard Lewis, at Annapolis

in Maryland, to Mr. Collinson, F.R.S. Containing the Account of a Remarkable Generation of Insects; of an Earthquake; and of an Explosion in the Air." Philosophical Transactions of the Royal Society of London, XXXVIII, No. 429 (1733), 119-21.

Mather, Cotton. "An Extract of Several Letters from Cotton Mather, D.D. to John Woodward, M.D. and Richard Waller, Esq; S. R. Secr." Philosophical Transactions of the Royal Society of London, XXIX, No. 338 (1714), 62-71.

General Biographical Sources

Biographie universelle, ancienne et moderne. 52 vols. Paris: Chez Michaud Frères, 1811-28.

The Dictionary of National Biography. 22 vols. London: Oxford University Press, 1937-38.

Dictionary of Scientific Biography. Charles Coulston Gillispie, editor-in-chief. New York: Charles Scribner's Sons, 1970--.

Dizionario biografico degli Italiani. Roma: Istituto della Enciclopedia Italiana, 1960--.

Nouvelle biographie générale depuis les temps les plus reculés jusqu'à nos jours. 46 vols. Paris: Firmin Didot Frères, 1855-66.

Poggendorff, J. C. Biographisch-Literarisches Handwörterbuch zur Geschichte der Exakten Wissenschaften enthaltend Nachweisungen über Lebensverhältnisse und Leistungen von Mathematikern, Astronomen, Physikern, Chemikern, Mineralogen, Geologen usw. aller Völker und Zeiten Gesammelt von J. C. Poggendorff. 2 vols. Leipzig: Verlag von Johann Ambrosius Barth, 1863. Lithograph edition. Ann Arbor, Mich.: Edwards Brothers, Inc., 1945.

Bibliographic Sources

British Museum General Catalogue of Printed Books. 263 vols. Photo-lithographic edition to 1955. London: Published by the Trustees of the British Museum, 1965-66.

A Catalog of Books Represented by Library of Congress Printed Cards Issued to July 31, 1942. 167 vols. Ann Arbor, Mich.: Edwards Brothers, Incorporated, 1942-46.

Catalogue général des livres imprimés de la Bibliothèque Nationale. Paris: Paul Catin, and others, 1924--.

Evans, Charles. American Bibliography by Charles Evans. A Chronological Dictionary of All Books, Pamphlets and Periodical Publications Printed in the United States of America from the Genesis of Printing in 1639 Down to and Including the Year 1820 with Bibliographical and Biographical Notes. Vol. I: 1639-1729. Vol. II: 1730-1750. Vol. III: 1751-1764. New York: Peter Smith, 1941.

The National Union Catalog, Pre-1956 Imprints. London: Mansell, 1968--.