Zeitschrift: Archives des sciences et compte rendu des séances de la Société
Herausgeber: Société de Physique et d'Histoire Naturelle de Genève
Band: 48 (1995)
Heft: 3: Archives des Sciences

Artikel: Saussure's manuscript oration on earthquakes and electricity (1784) : influenced by William Stukeley and Benjamin Franklin

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DOI: https://doi.org/10.5169/seals-740257

Archs Sci. Genève	Vol. 48	Fasc. 3	pp. 209-237	Décembre 1995

SAUSSURE'S MANUSCRIPT ORATION ON EARTHQUAKES AND ELECTRICITY (1784) INFLUENCED BY WILLIAM STUKELEY AND BENJAMIN FRANKLIN

BY

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(Ms reçu le 21.8.1995, accepté le 12.10.1995)

ABSTRACT

Horace-Bénédict de Saussure's manuscript oration on earthquakes and electricity (1784) influenced by William Stukeley and Benjamin Franklin.- The concept of atmospheric electricity as the major cause of widespread destructive earthquakes was first presented in 1750 by William Stukeley after hearing a paper by Benjamin Franklin on electric storms read at the Royal Society in 1749. Although Stukeley garbled Franklin's ideas, he nevertheless derived a plausible explanation. This or similar ideas lasted for a long time because the newly-discovered electricity appeared the most likely mechanism to explain the high velocity of propagation of earthquakes over entire continents and oceans. Saussure, 34 years later, in his oration, proposed an expanded concept of electricity-- as understood at the time-- for the major cause of earthquakes. Saussure had for many years considered earthquakes responsible for mountain building. However, by the end of 1784, a few months after delivering this oration, Saussure discovered the fundamental concept of horizontal thrusting (*refoulements*) as the mechanism for building the Alps and other mountains and from then on deemphasized earthquakes as orogenic agents.

Key-words: earthquakes, horizontal and vertical seismic waves, electricity, lightning, mountain building, Alps.

INTRODUCTION

The unpublished works of Horace-Bénédict de Saussure (1740-1799), preserved at the Public and University Library of Geneva, contain the manuscripts of four orations in Latin which the young professor of philosophy had presented as a featured speaker at some of the commencement exercises of the University or Academy (*Promotions académiques*) in June at the end of the academic year. We have previously published the transcript of the original Latin text and an annotated translation into English of three orations dealing respectively in 1764 with the features and origin of glaciers (CAROZZI & NEWMAN, 1995), in 1770 with the origin of coal (CAROZZI & NEWMAN, 1993), in 1774 with mountain building (CAROZZI & NEWMAN, 1990). We are presenting here a

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similar study of the last oration of 1784 on earthquakes and electricity. This oration is of particular interest because it is the only written statement in the opus of Saussure which clearly stated his views on a possible genetic relationship between atmospheric electricity — a field he had thoroughly studied — and earthquakes, a process which he considered for many years responsible for mountain building.

SAUSSURE'S INTEREST IN ELECTRICITY

Saussure's interest in electricity and particularly in atmospheric electricity began in 1774 when his research emphasis changed from botany to a wider study of Alpine atmospheric physical processes, never to be eliminated even by geological investigations.

The first tangible expression of Saussure's interest in electricity was expressed in 1766 in his *Dissertatio physica de electricitate*. This work was in fact the doctoral thesis of his deceased student Amédée Lullin which contained a large proportion of Saussure's own ideas. It was common practice at that time to publish the thesis of a student under the professor's name. In this work, Saussure demonstrated that Franklin's theoretical views on electricity were superior to those of Abbé Jean Antoine Nollet, particularly with respect to the electric nature of lightning and the property of metallic bodies terminating with a point to attract and dissipate electricity. Like Franklin, Saussure was inclined to attribute more importance to electricity than to heat in controlling meteorological phenomena.

During Saussure's "Grand Tour," both scientists met in London in 1768 (FRESHFIELD, 1920, p. 119) and conversed at length on electric problems. Upon his return home, Saussure put immediately to practical use some of Franklin's ideas on the identity of electricity and lightning, and attached in 1771 an elaborate lightning rod to the wall of his house at the Tertasse in Geneva. This apparatus, potentially dangerous to his neighbors, made them very unhappy and so worried that he was compelled to write on November 21 of that same year a nine-page pamphlet entitled "*Exposition abrégée de l'utilité des conducteurs électriques*" in an attempt to justify his action and placate criticisms. The pamphlet shows Saussure's outstanding capacity of explaining in simple terms a rather complex scientific subject. The booklet was available free of charge to interested persons at the "*Bureau d'Avis*" of the city. Such gentle and genuine concern of Saussure for the information and welfare of the general public was well along the lines of his philosophy as an educational, social, and political reformer (CAROZZI, 1976).

All the explanations, reasonings, and justifications presented in the pamphlet seemed however not to have completely calmed the public because five years later Saussure moved his lightning rod and set it on top of his house, thus decreasing as much as possible the assumed potential danger to others.

A study of Saussure's main work *Voyages dans les Alpes...* (1779-1796) demonstrates his meticulous and pioneer work in all aspects of atmospheric electricity including the use of a portable electrometer of his own invention (1784). He made observations and experiments on electricity in almost all of his travels, for instance, on the Môle (1766 and again in 1785), the Brévent (1767), the Talèfre glacier (1767), the top of Mont-Blanc (1787), and at the scientific camp of the Col du Géant (1788). To these observations should be added Saussure's unusual paper entitled "*Description des effets électriques du tonnerre, observés à Naples dans la maison de Mylord Tilney*" (1773), a byproduct of his trip to Southern Italy and Sicily.

The concluding sentences of the chapter "*Nouvelles recherches sur l'électricité atmosphérique*" in his *Voyages...* (Vol. II, 1786, § 836) are characteristic of Saussure's scientific and philosophical belief in the great future open to studies on the nature, techniques of measurements, and general significance of atmospheric electricity and its relationships with other physical processes of the atmosphere.

WILLIAM STUKELEY - ATMOSPHERIC ELECTRICITY AS THE MAJOR CAUSE OF EARTHQUAKES

During the second half of the 18th century Western Europe was the site of many violent earthquakes among which were those of Lisbon in 1755 and of Calabria and Sicily in 1783. Many of the published accounts were reviewed by ADAMS (1938, pp. 411-425).

The spring of 1750 witnessed a series of strong earthquakes which involved both sides of the English Channel and arose so much interest in England that the Royal Society of London published an appendix to its Philosophical Transactions of 1750 consisting of 150 pages and containing 57 articles on the sole subject of earthquakes. This supplement was entitled "Philosophical Transactions being an Appendix to those of 1750 consisting of a collection of several papers laid before the *Royal Society* concerning several *Earthquakes* in *England* and some neighbouring Countries, in the Year 1750." [Vol. 46, 1749-1750, No. 497, pp. 601-750].

Among these papers, providing numerous observations and some interpretations of the causes of earthquakes, the Reverend William Stukeley (1687-1765) wrote three articles (1750, 1750a, 1750b) in which he stands out as being the first to advocate atmospheric electricity as the major cause of earthquakes. Saussure integrated some of Stukeley's ideas in a broader and improved interpretation: his oration of 1784 analyzed below.

Stukeley quickly combined his three articles in a more elaborate pamphlet (1750c) entitled "*The philosophy of earthquakes, natural and religious or an inquiry into their cause, and their purpose*" (Fig.1). Subsequently, he wrote another more expanded version (1756) following the Lisbon earthquake. Indeed, in the middle of the 18th century, electricity was being discovered with its mysterious and instantaneous effects displayed on a large scale by atmospheric phenomena and experimentally on a small scale in the laboratories. It is the extreme rapidity of propagation of destructive earthquakes over extensive areas which made these phenomena comparable to electric shocks potentially related to the spectacular displays of atmospheric electricity.

Stukeley's five papers are somewhat repetitive as he kept adding to his original comments on the earthquakes of March 8 and 18,1750, which involved an area of about

THE

PHILOSOPHY

OF

EARTHQUAKES,

NATURAL and RELIGIOUS.

OR

An Inquiry into their Cauſe, and their Purpoſe.

O Vitæ philoſophia dux, virtutum indagatrix, expultrixque vitii! Cicero.

By *WILLIAM STUKELEY*, M. D. Rector of St. *George's*, *Queen-Square*: Fellow of the College of Phyſicians and Royal Society:

The SECOND EDITION.
To which is added, PART II. on the ſame Subject.

LONDON:
Printed for C. CORBET over-againſt St. *Dunſtan's* Church, *Fleetſtreet*.

MDCCL.

FIG. 1.

Title page of W. Stukeley's first pamphlet on the philosophy of earthquakes, London, 1750. Rare Book Room, University of Illinois at Urbana-Champaign.

30 miles around London, additional descriptions of other subsequent earthquakes apparently in agreement with his interpretation which remained unchanged through time.

The major points of Stukeley's theory may be summarized as follows. The existence inside the earth of vapors, fermentations, inflammable substances, hot springs as well as active volcanoes is accepted and some smaller earthquakes may result from them, but they are rare both in time and space. Indeed, a deep-seated force acting instantly over a surface of at least 30 miles in diameter would destroy the system of underground water veins, strongly disturb the landscape, flatten mountains, whereas in fact earthquakes destroy only cities but scarcely affect elsewhere the surface of the earth. Such a force would act as an inverted cone with its focus 15 to 20 miles at depth in the solid earth, a situation impossible to conceive particularly in the case of earthquakes like those of Asia Minor which involved areas of more than 300 miles in diameter and would place the focus 200 miles deep in the ground.

The two earthquakes of March 1750 were typically preceded by the following phenomena: unusually dry and warm winter without rain; uncommon frequency of northern and southern lights (*auroras*); extraordinary forwardness of vegetation (experiments show that electrifying plants quickens their growth); flashes of lightning and fire balls with sulfurous smell during the previous night; shorts gusts of thunder and lightning with rain showers immediately before the shocks. All these features indicated that the earth was in a high state of electricity, beyond what has ever been in human memory. After having heard a paper of Benjamin Franklin read before the Royal Society on November 16, 1749 (scheduled to be published in 1750), STUKELEY (1750, p. 643) derived the idea that atmospheric electricity was the major cause of earthquakes under particular circumstances of the earth being highly electrified to be discussed in detail below.

Stukeley added that slight earthquakes can happen often when the earth is lightly electrified. In general, earthquakes are not so frequent in England and northern regions because they lack the required dry and warm climate. Furthermore, water strengthens and conveys the force of electricity, as in electrical experiments, explaining why the strongest shocks are always felt in maritime towns or along rivers.

Stukeley finally argued in favor of the theory that electricity was also at the origin of sicknesses, pains in joints, rheumatisms, hysteric and nervous disorders, headaches, colics and the like that many weak people feel for several days after earthquakes. Finally, talking as a Christian philosopher, Stukeley considered earthquakes as divine warnings and judgments operating through natural causes with their major actions (the finger of God) directed toward maritime towns and cities, abounding with wealth and luxury with their associated evils.

STUKELEY'S GARBLED VERSION OF FRANKLIN'S IDEAS

Franklin's influential paper read in 1749 was published only in 1751 by P. Collinson (FRANKLIN, 1751) after a series of complicated events discussed in detail by COHEN (1941, pp. 81-96).

All three versions of Stukeley's concept, apparently derived from his hearing of Franklin's paper, are essentially the same. They all show in the first paragraph an inversion of Franklin's statement on the properties of clouds raised from the ocean and from land and a confusion of the terms "electric and non-electric" for "electrified and non-electrified." This confusion continued throughout Stukeley's text. Furthermore, in his last paper (1756) he did not pay attention to Franklin's statement of 1751 that electric and non-electric had become obsolete terms and should be replaced by conductor and non-conductor (see COHEN, 1941, pp. 245-249, 323-327). This situation seems to indicate that Stukeley never read Franklin's papers when they became available. He relied for his concept only on what he heard or wanted to hear at the Royal Society on November 16, 1749, and he kept repeating it unchanged for seven years.

Among Stukeley's three versions we are giving below the first and clearest one (STUKELEY, 1750, p. 643) with the corrections derived from Franklin's paper of 1751 given in italics between square brackets:

"We had lately a very pretty Discourse read here, from Mr. *Franklyn* of *Philadelphia*, [read November 16, 1749] concerning Thundergusts, Lights, and like Meteors. He well solves them by the Touch of Clouds, rais'd from the Sea (which are Non-electrics) [*read: which are electrified*], and of clouds rais'd from Exhalations of the Land (which are electrify'd) [*read: which are non-electrified*]: That little Snap, which we hear, in our electrical Experiments, when produc'd by a thousand Miles Compass of Clouds, and that re-echoed from Cloud to Cloud, the Extent of the Firmament, makes that Thunder, which affrightens us.

From the same Principle I infer, that if a non-electric Cloud [*read: non-electrified cloud*] discharges its Contents [*rain*] upon any Part of the Earth, when in a high-electrify'd State, an Earthquake must necessarily ensue. As a Shock of the electric Tube in the human Body, so the Shock of many miles Compass of solid Earth, must needs be an Earthquake; and that Snap, from the Contact, be the horrible uncough Noise thereof."

A few lines below (p.644) he added:" ... a little before the Earthquake, a large black Cloud suddenly cover'd the Hemisphere; which probably occasion'd the Shock, by Discharge of a Shower."

In his first pamphlet (STUKELEY, 1750c, Part I, p. 25) the relation of the earthquake of March 18 received from Portsmouth and the Isle of Wight, mentioned that "...the Day was warm and serene; but upon a gentle shower falling in the evening, the earthquake came. Here we have reason to apprehend the electrified state of the earth, and the touch of the non-electric [*read: non-electrified*]: which caused the earthquake.

The learned Dr. *Childrey* [antiquary and astrologer, 1623-1670] observes, treating on this subject, that earthquakes happen upon rain; a sudden shower of rain in the time of great drought."

In summary, setting the record straight, Stukeley believed that the situation conducive to an earthquake consists, in a period of great drought, of a non-electrified cloud discharging its content of water, namely a rain shower, and establishing contact (since water is a conductor) with a highly electrified earth. Indeed, the electric fluid rushes violently from a highly concentrated medium ("positive" or "plus" in the sense of Franklin) to a less concentrated medium ("negative" or "minus"), the result being the vibration of the earthquake.

What did Franklin write? Among the numerous English editions of Franklin's work, we have chosen the fourth (FRANKLIN, 1769) which for our purpose is identical to the fifth of 1774 (see COHEN, 1941), both being the most complete versions personally supervised by Franklin. The paper (pp. 39-42) is entitled "*Letter V. containing observations and suppositions toward forming a new Hypothesis, for explaining the several phaenomena of Thunder-Gusts.*" It is dated Philadelphia, April 29, 1749. An asterisk following the title states "Thunder-gusts are sudden storms of thunder and lightning, which are frequently of short duration, but sometimes produce mischievous effects."

The following statements paraphrased from Franklin pertain to Stukeleys concept:

Section 26. Clouds formed by vapors raised from land have little electric fire.

Section 27. Clouds formed from vapors raised from the sea have both fires [heat and electrical], particularly a great quantity of the electrical.

Section 32. If an electrified cloud coming from the sea, meets in the air [case of a country devoid of mountains] a cloud raised from the land, and therefore not electrified; the first will flash its fire into the latter, and thereby both clouds shall be made suddenly to deposit water.

Section 36. When a great number of clouds from the sea meet a number of clouds raised from the land, the electrical flashes appear to strike in different parts; and as the clouds are jostled and mixed by the winds, or brought near by electrical attraction, they continue to give and receive flash after flash till the electrical fire is equally diffused.

Our understanding is that according to Franklin, in his perfectly clear style, clouds raised from the sea are highly electrified and those raised from the land are weakly electrified or not, flashing of fire therefore goes from the former to the latter.

Stukeley's garbled version of Franklin's ideas raises doubts about his scientific knowledge in physics and electricity. According to the DICTIONARY OF NATIONAL BIOGRAPHY (1917), Stukeley took a degree of M.B. (bachelor of medicine) in 1708 at Bennet (Corpus Christi) College, Cambridge. Stephen Hales of the Royal Society and Dr. John Gray of Canterbury were among his botanical associates and he made a large addition to RAY (1660) "*Catalogus Plantarum circa Cantabrigiam...*". He continued his studies in anatomy and medicine and went into medical practice in 1710. On March 20, 1718, he became a fellow of the Royal Society. He took an M.D. degree at Cambridge (1719) and was admitted to the College of Physicians in 1720.

Stukeley combined his medical practice with extensive antiquarian expeditions all over Great Britain, publishing many papers and a book on Stonehenge in 1740. His antiquarian research on which he wrote as much as in medicine has been highly criticized for imaginary statements and fanciful conjectures by contemporary authorities such as Edward Gibbon and others. Yet he was well known to the Earl of Pembroke, the Earl of Winchilsea, all the "virtuosos" of London, and had "a particular friendship" with Sir Isaac Newton.

Encouraged by Archbishop Wake to take orders, he was ordained in 1729, was given the "living" of All Saints at Stamford, then in 1739 of Somerby-by-Grantham. In 1747 he accepted from the Duke of Montagu the rectory of St. George-the-Martyr in Queen Square, a fashionable district of London, a position he held until his death in 1765. Stukely was considered an unconventional clergyman. Some of his close friends described him as a learned and honest man, but also a strange combination of "simplicity, drollery, absurdity, ingenuity, superstition, and antiquarianism," others said that he was "very fanciful" and "a mighty conceived man."

From the above data we can infer that his scientific knowledge, particularly in physics and electricity, was rather limited and that he probably became a fellow of the Royal Society by influence more than by recognition. He was unquestionably a clergyman of great reputation among the high society of London. However, he took advantage both of the novelty of the discovery of electricity and of the earthquakes of 1750 not only to become an expert in that field but also to preach on earthquakes with the warning that they represented divine judgments of the evils brought about by riches in society. Relying on a paper just presented by an authority such as Franklin, but apparently without understanding it fully, he was nevertheless clever enough to devise a simple plausible hypothesis on the electrical origin of earthquakes. However, is not the beginning of his second article in the Transaction of the Royal Society (STUKELEY, 1750a, p. 657) symptomatic of his degree of scientific knowledge? He wrote :" When I had the Honour last *Thursday* to lay my Thoughts upon it [earthquake] before the Society, 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: Therefore I judg'd it necessary to treat upon it in a more diffusive manner; and with some further Considerations relating to that Argument." Our implication is that his worthy listeners were not fully convinced of his scientific ideas.

An effective publicist, Stukeley developed his approach for 16 years taking advantage of all available opportunities, such as the Lisbon earthquake of 1755. Apparently, nobody in those days bothered to verify the sources of such a convincing preacher and author. It seems ironic that he even presented a copy of his 1756 pamphlet to Franklin with the longhand inscription " To Benjamin Franklin Esq. Father of Electricity. The Author." (COHEN, 1941, p. 91).

SAUSSURE ON EARTHQUAKES AS A MAJOR CAUSE OF ALPINE OROGENIC EVENTS (1778)

A detailed study based mainly on manuscript field notes of the evolution of Saussure's ideas on orogenic processes which led to the formation of the Alps was presented elsewhere (CAROZZI, 1989). A brief summary will suffice for the purpose of this paper.

In 1774 (see *Voyages...*, Vol. II, 1786, § 219), Saussure was interpreting the uplifting and folding of the Alps as the results of an internal cause such as fire or the

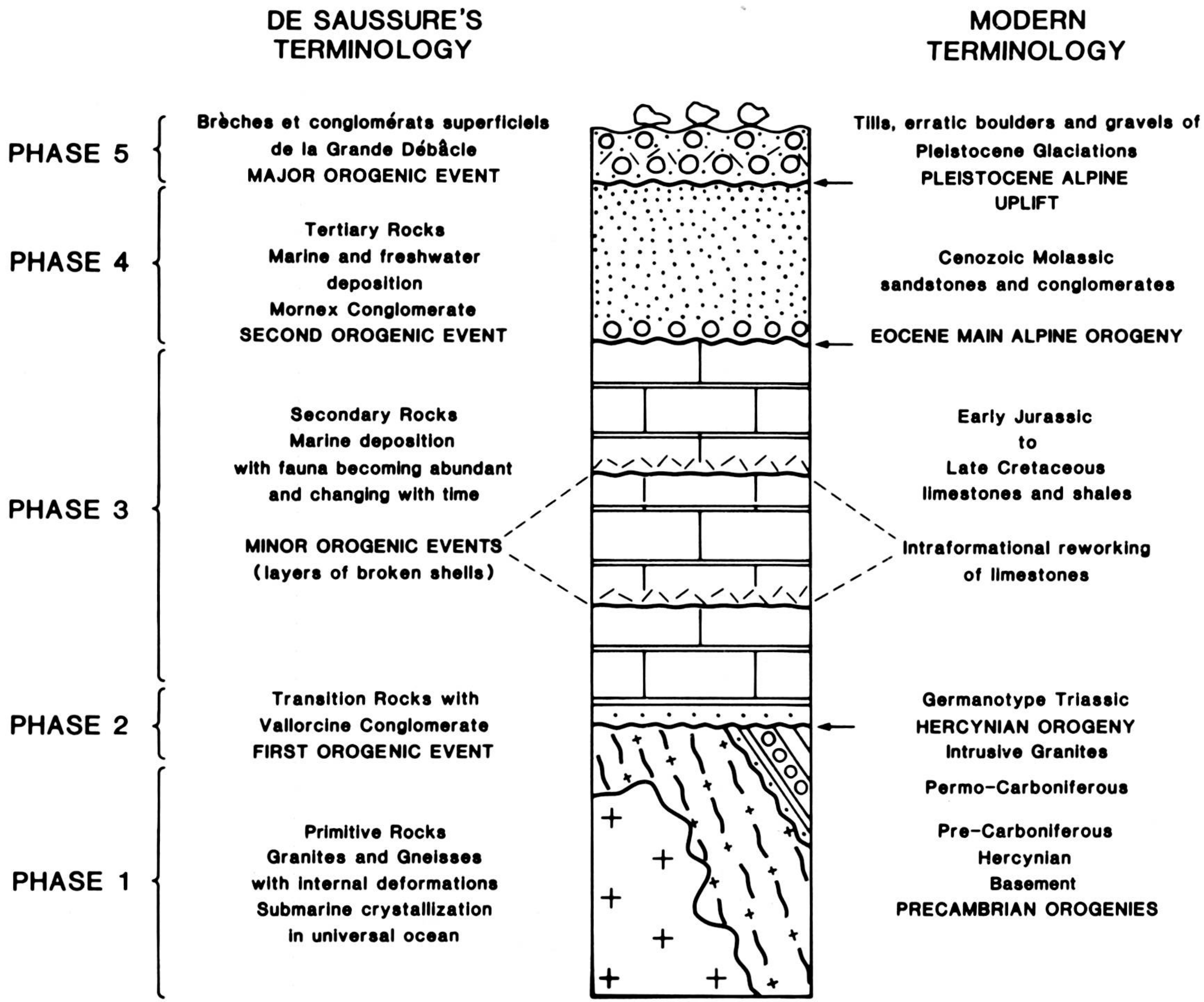

FIG. 2.

Comparison between Saussure's terminology and the modern terminology of major stratigraphic subdivisions and orogenic phases of the Alps.

explosion of elastic fluids. This was obviously a violent and instantaneous process followed by the retreat of the universal ocean. In 1779, (*Voyages...*, Vol. I, 1779, § 243) he wrote for the first time that the final orogenic phase of the Alps was a succession of two seismic shocks. The surface of the earth underwent a first violent shock [*secousse extraordinaire*] which fragmented some earlier rocks and deposited them on the seafloor as conglomerates and breccias overlain by sandstones. The second shock, more powerful than the first, dislocated and fragmented entire mountains and led to the engulfing of ocean waters in the cavities of the crust and to the dispersal by the *grande débâcle* of huge boulders found in front of the Alps (erratic boulders of the Pleistocene glaciation not understood at the time).

Furthermore, Saussure had also recognized in 1778 conglomerates at two other critical locations or *jonctions* as he called them in the stratigraphic column of the Alps: between Primitive and Secondary rocks (Vallorcine conglomerate) and between Secondary and Tertiary rocks (Mornex conglomerate). For their origin he also assumed extensive earthquakes [*secousses du globe*] as stated in *Voyages...* (Vol. I, 1779, § 594-596) obviously followed by related débâcles which were not, however, specifically mentioned. Also in 1778, Saussure completed the picture of Alpine orogenic events by reporting the occurrence in the middle of secondary limestones of layers of broken and redeposited shells [*coquilles concassées*], as evidence of minor seismic shocks which broke shells on the seafloor (reported in *Voyages...*, Vol. IV, 1796, § 2303).

In summary, by 1778 Saussure was considering at least three major seismic-orogenic events in the history of the formation of the Alps (Fig. 2). These earthquakes, possibly of worldwide nature, increased in intensity with time until the final folding and uplifting of the Alps because the extent and thickness of their corresponding conglomerates also increased in the same direction. Saussure's acceptance, at the time, of electricity as the major cause of earthquakes is developed in his oration of 1784.

ORIGINAL LATIN TEXT OF SAUSSURE'S ORATION ON EARTHQUAKES AND ELECTRICITY (1784)

Notes on Sources

The manuscript of this oration is in Saussure's handwriting and bears the title "*Oratio 1784. Discours aux promotions*" (SAUSSURE, 1784). In the absence of an original subject title, it is designated here for convenience as "Oration on earthquakes and electricity." It is a heavily corrected first draft of 17 pages (19 x 25 cm), written only in a single column on the left side of the page. The right side was intentionally left for marginalia sometimes written in pencil and therefore very difficult to decipher and furthermore often uncoded to the main text (Fig. 3). This manuscript was obviously neither recopied in final form nor handed over to a professional copyist. Saussure's fourth and last oration was written two years before resigning his professorship at the Academy (January 1786). His major concerns at the time were both the final editing of

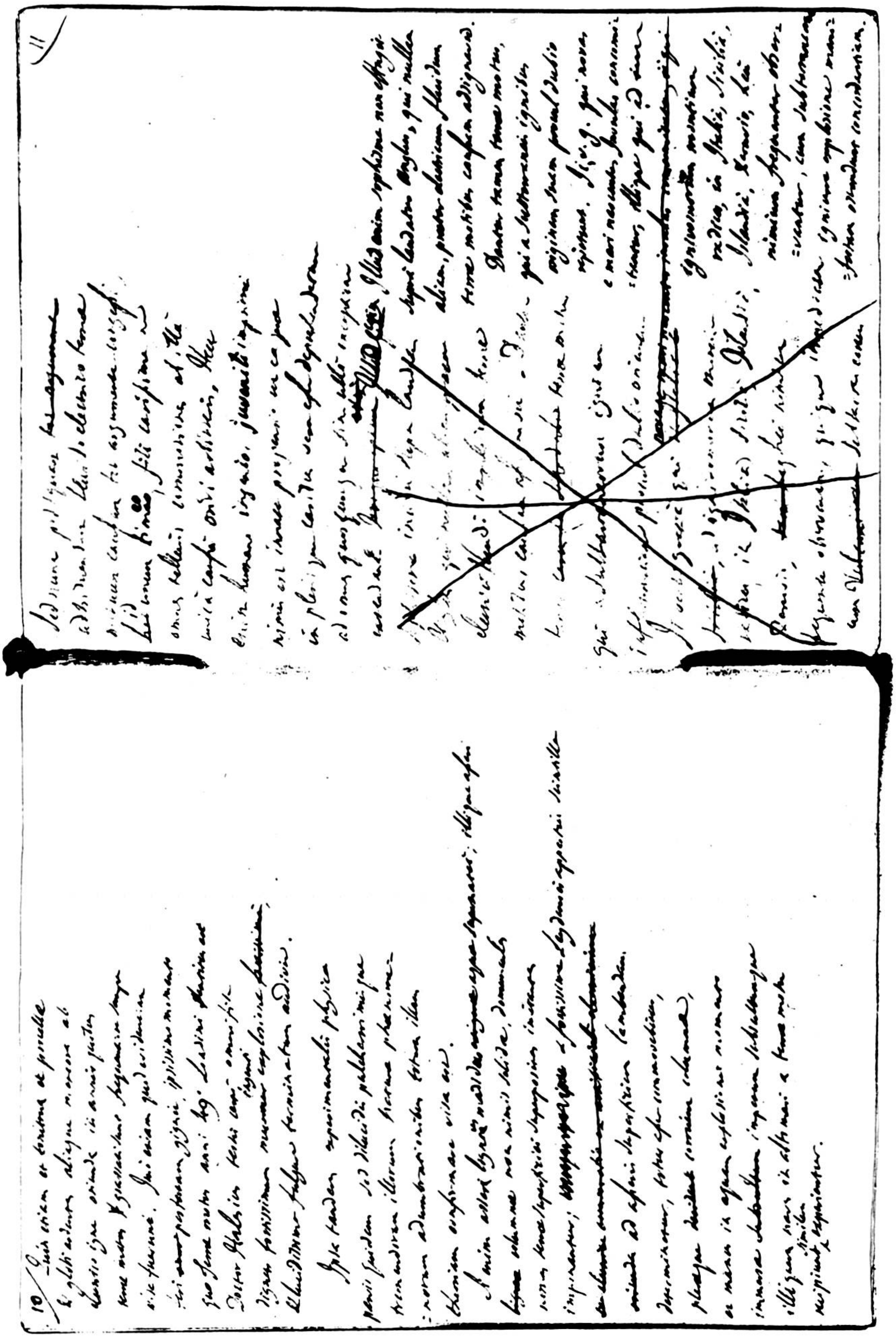

FIG. 3.

Pages 10 and 11 of Saussure's manuscript of Oration on earthquakes and electricity (1784) showing its heavily corrected first draft condition (B.P.U., Genève, Archives Saussure, Ms 59/13).

volume II of the *Voyages...* which appeared April 4, 1786 and the preparation of his famous ascent of Mont-Blanc in the summer of 1787. Obviously no time was left for further elaboration of the oration or even to give it a formal title.

Notes on Style

This oration like the preceding ones is written in the form of a dialog reminiscent of a class exercise typical of a philosophy course in which a coached student asks an important question which generates a lengthy and erudite reply by the professor. However, the question is not asked as previously by an anonymous student but by Saussure's son Théodore who was 17 years old at the time, a student at the Academy and obviously attending his father's classes. The first draft and highly corrected manuscript raises the question if the lecture was in fact delivered in this form. The attribution of what might have seemed divine vengeance for Sabbath-breaking to the shock of the Lisbon earthquake, and the unbridled confidence in the possibilities of science which marks the conclusion of the lecture, might perhaps have been a little strong for some tastes.

This oration exhibits very little of the author's customary bravura, unless we are to take the sentences describing the confluence of earthly and celestial phenomena in the mightiest earthquakes as offering a hint which might later have been worked up in more dramatic fashion. There are no quotations from the Classical authors either overt or implied of the kind that so brilliantly adorn, for example, the youthful lecture on glaciers of 1764 (see Carozzi & Newman, 1995). There is no great attention to prose rhythm. There are even occasional lapses (*sciscitare, sentiti*). Possibly Saussure no longer felt the need to impress the audience with his knowledge of the Classics and the time had come for discussing pure science by itself.

Nevertheless the lecture retains its interest, both human and scientific. At the outset, and with the aid of judicious reminders throughout, we are made aware that the professor is addressing his own son and hoped-for heir in matters scientific. Indeed, the allusion to a boyish and enthusiastic speaker on balloons seems to have been marked by him for excision as perhaps too personal for the public occasion for which his remarks were intended. We also hear of youthful impatience with the proper scientific skepticism which withholds assent to a universal theory until every instance has been examined.

The admiration of Saussure the scientist for the ingenious hypothesis of the Englishman Stukeley continues to provide evidence of the influence exercised by England on the Continent (not least in France) in so many areas of commercial, political and scientific thought during the eighteenth century. By contrast, the "central fire" of certain unnamed ancient thinkers and the "systems" of Buffon and Descartes are treated with scant respect, and relegated to the status of ancient Greek or Roman mythology. There is perhaps something of the 18th century rationalist in the author's already mentioned remark that the blow striking the merchant ship loading cargo on a holy day in harbor at Copenhagen was not in fact a punishment sent by divine wrath, but rather the shock of the famous earthquake which destroyed Lisbon. Voltaire's anti-religious piece on this event is well known. Was even the hint of this perhaps strong stuff for the divines who would be in the professor's audience? Yet de Saussure tries to offset this, not by any pious comments of a religious nature, but by his strong public-spirited endorsement of lightning-conductors, though with some reserve about their efficacy in preventing earthquakes. We also hear of the intrepid explorer who did not hesitate to climb Etna in his younger days (see *De Montium Origine* 1764 *in* CAROZZI & NEWMAN, 1990). The Indians (native South Americans) who are able to predict earthquakes by weather signs add an exotic touch appropriate to those days of vast colonial struggles by European powers to seize and extend their mastery of the new continents. De Saussure is always aware of the vast and awe-inspiring majesty of the universe, of its immense processes and energies deployed over eons of unimaginable time. The *fluidum electricum*, described by him as "that unexpected and most powerful servant of Nature," shows how far science in the latter part of the century was progressing. As a scientist, Saussure is aware that his own hesitant explanations and theories may be soon refuted or confirmed. Yet, with true humility, the professor concludes by eagerly anticipating the future triumphs of rational (logical and mathematical) enquiry, for which he can see nothing to be impossible, and hoping for his own son's contribution to it. The whole thus ends on an intimate note of both familial and scholarly dedication.

Quaestio

Quam suave est mihi, Philosophiae limen ingredienti, publicorum privatorumque studiorum ducem, in te, Pater carissime, simul intueri. Quapropter, in ipso hoc limine vix consistens, Philosophiae studiosi partes agere, teque, quaestionibus meis domi respondere consuetum, hic etiam publice interrogare vehementer concupivi.

Iamque parata erat quaestio; cum enim in construendis vibrandisque aerostaticis machinis non mediocrem industriam ostenderim, famamque non ita tenuem comparaverim, mirandarum illarum machinarum theoriam, et directionem et usus a te sciscitari iam moliebar, cum puerum Oratorem hoc ipso de argumento disserentem nec puerili tantum aspectu machinas illas considerantem, sed audaciori etiam volatu in Physicorum, Philosophorumque sphaeram sese attollentem, omniaque mea dubia docte resolventem audivi. [In a marginal note, Saussure seems to have wanted to replace the reference to "puerum Oratorem" with the following paragraph. He did not however delete anything in his main text].

Sed hoc argumentum omnibus in colloquiis omnibus in eruditis diariis agitatum. Omnes quam possibile de illo cogitationes iam vulgatas perpensasque, tam crebro audivi ut delicatissimi palatii iam fere reingestum evaserit illudque coram hac erudita panegyri proprie mirandum.

Quo igitur me convertam, ut aliquid minus tritum et ad eventus anni proxime elapsi aliquatenus tamen pertinens a te, Pater carissime, possimus audire? En! contrario gressu procedam, cumque caelestia itinera iam vulgatiora videantur, cumque primus occupans Caelos invaserit, ad Inferos ego descendam, teque rogabo; ut in intima Telluris viscera mecum penetrans, omnia commonstres quae recentiora Physicorum conamina de terrae motuum causis patefecere; unde si generalia referas principia, quae ad intelligendas terribiles illas Magnae Graeciae nuperas calamitates inservire possint, te gratam Ornatissimo Auditorio operam navaturum confido.

Oratio

Non mihi minus quam tibi, fili carissime, grata est duplex, immo et triplex quae me tibi coniungit patris privatique simul et publici institutoris, relatio. Illeque ardor quo Philosophiae studiosi munus palam suscipere cupivisti, mihi studium illud tam assidue colenti non potuit non esse acceptissimum.

Sed si ad eam quaestionem me convertam, quam tu de terrae motuum causis nunc mihi proponis, vix in toto Physices dominio aliam difficiliorem inveniam, vix aliam quae antiquorum et recentiorum philosophorum ingenia tantopere torserit, vix quae pluribus hypothesibus originem dederit. Quae omnia enarrare, perpendere, falsa refutare, vera confirmare, non oratiunculae, qualis hic desideratur, sed plurium, longarumque orationum esset opus. Neque tu ea omnia quaeris, fili carissime, sed tremendis Calabriae et Siciliae calamitatibus merito commotus, rogas, an non inter omnia inventa quibus recentior physica gloriatur, aliquid sit, quod in tenebrosam profundamque terribilium istorum phaenomenorum causam aliquam lucem infundere possit.

Iam igitur non antiquata et iamdudum explosa systemata desideras, nec veterum centralem ignem, nec Cartesii incrustatum solem, nec Buffonii abrasos de sole Cometas audire efflagitas; tu enim, quantumvis in philosophicis hospes, ea omnia non minus quam Graecorum inferos Plutonemque et Neptunum terras mariaque quassantes inter fabulas vel commenta fabulis proxima mandas. Vero similiora finxerant qui, vastas sub telluris cortice speluncas, sulphure, lithanthrace aliisve bituminibus plenas supposuerant, eorumque corporum inflammationi aerisque inde dilatati oscillationibus telluris superimpositae tremitus tribuerant.

Ea tamen principia multis terrae motuum phaenomenis explicandis insufficientia deprehendit ingeniosus physicus Anglus nomine Stukeley. Nec mirum. Si enim considerentur distantiae ad quas nonnulli terrae motus sentiti [For the classical Latin *sensi*] fuerunt, et exigua temporis intervalla quibus illae distantiae a terrae motibus percussae fuerunt, nullatenus intelligi poterit, vel inflammationis progressus, vel terrae solidae oscillationes immo et ipsius aeris in speluncis inclusi undulationes tam rapide et tam longinque potuisse propagari. Sic, v.g., terrae motus quo inclyta urbs Ulyssipona deleta est, eodem die eademque ferme hora et in Mauritania et Hafniae Daniae capiti perceptus fuit. Memoratur enim navis Hafniensis ad Indos proficiscentis ducem, qui operarios suos festinationis ob tempestatem necessariae causa, illo die, qui dies festus erat, navem reparare et adornare cogebat, ictu subito, qui e maris fundo oriri videbatur, simul cum omnibus nautis perculsum non mortuum quidem, sed tamen saucium cecidisse: quae in illo momento, quo Ulyssiponensis clades adhucdum ignorabatur paene propter violatum festum miraculo inflicta visa est. Quomodo autem motus tam exiguo temporis intervallo ad 860 leuiarum distantiam propagatus per inflammationem et aeris undulationem intelligi posse videretur?

Tantae praeterea speluncae tantas distantias sub telluris cortice sine intermissione pervadentes, hominibus terram tam profunde et tam crebro metallorum conquirendorum causa terebrantibus nusquam innotuere; nec illarum speluncarum formationis ulla verosimilis ratio reddi potest; et licet simul cum ipsa tellure creatae supponerentur, quomodo ab aquarum et subterranearum et marinarum irruptione praecaveri potuissent; praesertim cum ipsae illae explosiones quae in eis ipsis peragi supponuntur, hiatus immensos, innumerasque fissuras necessario aperuissent, sicque omnigenis aquis eas repleturis facilem aditum brevi concepissent. Si autem unicum pro singulo terrae motu focum in telluris visceribus alte reconditum fingeres, fortioribus adhuc, ne dicam plane insolubilibus obiectionibus te exponeres.

Sagacissime enim supra laudatus Anglus observat, quod si terrae motus in circulo triginta milliarium diametri perceptus fuerit, eiusque causa in unico foco subterraneo collocanda sit, focus ille ad viginti milliarium sub telluris superficie profunditatem debet supponi, ut sic enormis massa coni inversi triginta milliaria lati et viginti milliaria alti ab explosione concuti debuerit. Quid autem si terrae motum Asiae minoris initio Aerae nostrae devastatorem, quid si terribilem illum Ulissiponae eversorem consideras, tunc formae similis conus, sed centies immo et millies, maior concussus debet supponi.

Neque hoc tantum; licet enim terrae motuum foci ad sexcentarum leuearum profunditatem depressio iam e longinquo absurdum redolere videatur, pleraque phaenomena terrae motus praecedentia et concomitantia longe maiorem cum telluris superficie vicinitatem manifesto demonstrant.

Sic v.g. Terrae motuum cum atmosphaerae statu relationes quomodo intelligi possent si eorum causa tantam ad profunditatem depressa lateret. Constat autem in regionibus quae calamitatibus illis obnoxiae sunt, verbi gratia in America meridionali illas ab incolis saepe saepius praevideri ex signis mere atmosphaericis, nempe ex aeris tranquillitate cum insolito calore iuncta, ex eiusdem aëris opacitate, ex solis et lunae colore, ex quodam infausto et longinquo murmure quod in aëre ipso videtur audiri. Quin etiam saepe saepius earumdem regionum incolae in Europam nostram forti fortuna terrae motuum tempore advecti, iisdem illis signis eos praecognoverunt; narratur enim Americanos Ulissiponae degentes eodem die quo terrae motu praeclara urbs illa subversa est, omnia illa signa sole oriente concurrere videntes, dixisse quod si ista signa in America visa fuissent de terrae motu eodem die grassaturo nullatenus dubitatum fuisset: idemque Londini in terrae motu anni 1749 accidisse perhibent.

Praeterea singularis illa commotio quam naves in alto mari a terrae motu perculsae experiuntur nullatenus cum profunda causa potest conciliari. Omnes asserunt eundem percipi sensum ac si navis subito in durissimum scopulum impulsa fuisset, vel si ingenti durissimae materiae ictu navis carina perculsa fuisset. Si autem ex intimis terrae visceribus oriretur ictus, immensa terrarum, immo et aquarum interposita massa eum omnino obtunderet et in lenem lentamque undulationem necessario converteret. Nonnullorum tandem terrae motuum causas ad telluris superficiem restringendas esse demonstrant illi terrae motus in Anglia observati, qui dum homines domusque telluris superficiei insistentes non mediocriter commovebant, ne minimam quidem commotionem in profundis fodinis eidem superficiei suppositis excitabant (Philos. Trans. v. 71, p. 193 et 331).

Quibus aliisque brevitatis causa non recensendis argumentis merito percitus ingeniosus Anglus, terrae motuum causam in atmosphaera ipsa maxima pro parte quaerendam esse censuit. Electricum nempe fluidum novum illum potentissimumque Naturae ministrum plerumque terrae motuum causam esse fere demonstravit. Notum est nempe fluidi illius densitatem variis modis vel in aëre vel in ipsa tellure posse immutari. Nec minus notum est illud ubi in certis locis condensatum et in aliis rarefactum fuit ad restituendum aequilibrium fortissimo nisu tendere.

Si igitur calore et siccitate diuturnis in superioribus atmosphaerae stratis condensatum, simulque in aliis regionibus contrariis causis rarefactum fuerit, vel etiam si internis terrae mutationibus vel fermentationibus, v.g. in quibusdam terrae tractibus accumulatum, ex aliis vero subtractum fuerit, tandem ruptis carceribus ex densiori loco in rariorem ingenti impetu irruet, omnesque interpositas terras fortissime concutiet.

Qua adhibita explicatione, iam nec communicationis velocitas, nec externorum phaenomenorum consensus, nec subita navium commotio in aliis hypothesibus insolubiles ullam tibi molestiam creant. Alia vero insuper addam quae Angli philosophi hypothesim adhuc verosimiliorem reddent.

Terrae motus ceteris paribus in regionibus calidis meridionalibusque longe frequentiores observantur. Cum autem calor solis nullibi ultra exiguam 80 pedum profunditatem penetret, fossilibus bituminibus solis calore incensis frequentiam illam certe non tribues, sed potius electrico fluido, quod in frigidis regionibus non magnopere potest condensari seu quod evaporatio quae fluidum electricum ex telluris superficie ad excelsiora atmosphaerae strata defert in calidis longe maior, propptereaque eius in eis regionibus facilior promptiorque accumulatio: seu quod aër in septentrionalibus frigidisque et humiditate maiori ex frequentioribus pluviis electrico fluido pervius diuturnam magnamque eius accumulationem non nisi raris in circumstantiis possunt fovere.

Nec minus isti hypothesi favet maior in regionibus maritimis, et iuxta ipsa maris litora, ut et in fluminum ripis terrae motuum frequentia. Electricum enim fluidum aquas facillime permeat, vel in earum superficie gliscit, semperque in aequilibrii restitutionem vias sibi faciliores affectat.

Quin etiam et tonitrua et procellae et globi ardentes aliaque meteora ab electrico igne oriunda iis annis quibus terrae motus grassati sunt frequentiora semper visa fuerunt. Immo etiam quod evidentiam fere perfectam gignit ipsissimo momento quo terrae motus anni 49^i^ Londini sensus est Doctor Halsius testis certe omni fide dignus fortissimum murmur ingenti explosione et lucidissimo fulgure terminatum audivit.

Ipsa tandem experimentalis physica parvis quidem sed dilucidis pulcherrimisque tremendorum illorum naturae phaenomenorum adumbrationibus totam illam theoriam confirmare visa est.

Si enim asser ligneus madidus aquae supernatet; illique asseri columnae non nimis solidae domunculas nostras terrae superficiei superpositas imitantes imponantur; et fortissima Leydensis apparatus scintilla ad asseris superficiem lambendam determinetur, totus asser commovebitur, pleraeque corruent columnae, et manus in aquam explosionis momento immersae impetum subsultumque illi quem naves in alto mari a terrae motu recipiunt similem experientur.

Sed nunc postquam ad tribuendam fluido electrico terrae motuum causam tot argumenta congessi, id unum timeo, fili carissime, ne omnes telluris commotiones ab illa unica causa oriri arbitreris. Haec enim humano ingenio, iuvenili imprimis nimis est innata propensio ut ea quae in plerisque casibus vera esse deprehenderunt ad omnes quoscumque sine ulla exceptione extendant. Illud enim sophisma non effugit supra laudatus Anglus, qui nullam aliam, praeter electricum fluidum terrae motibus causam adsignavit. Dantur tamen terrae motus, qui a subterraneis ignibus originem suam procul dubio repetunt. Ii, v.g. qui novas e mari nascentes insulas concomitantur, illique qui ad ignivomorum montium radices, in Italia, Sicilia, Islandia, Peruvio, heu nimium frequenter observantur, cum subterraneorum ignivoma explosione manifestam ostendunt concordantiam.

Vix enim ulla montium ignivomorum notabilis datur eruptio, quin simul terribiles terrae motus vicinas regiones fortissime conquassent. Et ego ipse, cum Aetnae vertici insisterem, ubi longinquarum in imo gurgite explosionum surdum rumorem audiebam, totum simul montem sub pedibus meis tremere sentiebam.

In plerisque autem maioribus Vulcaniorum eruptionibus utriusque ad telluris subversionem causae formidabilis observatur concursus. Ubi scilicet ex imo telluris gremio immensa exsurgit, fumo, flammis omnigenisque vaporibus mixta columna, caelorum ignes terrestribus obviam venire videntur fulmina et fulgura numero paene incredibilia totum columnae verticem, immo et latera perpetuis ictibus perfundunt.

Nam simul ac ingens ista vaporibus referta columna superiora atmosphaerae strata attingit, frigus ibi perpetuo regnans vapores illos condensat, fluidum electricum quod formandis illis vaporibus adhibitum fuerat liberum evadit, maxima quantitate in excelsis illis regionibus accumulatur, et inde a terra quae vaporum formatione eodem fluido spoliata fuit fortissime attractum sub fulminum fulgurumque forma pristinam sedem repetit, aequilibriumque tellurem commovendo restituit.

Utramque autem causam ad Italiae inferioris calamitates concurrisse, vix dubitare fas est. Iam enim subterraneorum ignium in illis regionibus praesentiam Aetnae et Aeoliarum insularum vicinitas ostendunt. Horrendi praeterea subsultus, qui ex ima tellure proficisci videbantur, aquae ex terrae visceribus in altum proiectae, devastatio in locis humilioribus constanter maior, immo et telluris strata eo magis deturbata quo profundius sub externa superficie demersa iacebant; ne loquar de terribili maris nonnullis in locis ebullitione, de piscibus profundissimarum voraginum ordinariis hospitibus ad superficiem expulsis; ea inquam omnia aliaque brevitatis ergo omittenda convulsionum illarum focum subterraneum fuisse demonstrant. Sed ab alia parte nubium immobilitas et procellosi imbres qui plerosque illos motus praecedebant, fluidum electricum in atmosphaera accumulatum et mediantibus imbribus telluri restitutum, non modo per se ipsum terram commovisse, sed etiam aërem inflammabilem in subterraneis speluncis conclusum flammasque huc et illuc ex terrae fissuris erumpentes producentem incendisse videtur.

Sicque redditur ratio, quare saepius praecesserint horizontales ab electrico fluido excitatae oscillationes, quas dein sequebantur verticales vel vorticosi subsultus a profundis explosionibus oriundi.

Sic enim duas illas diversas terrae motuum causas per duos effectus dignoscendas censerem, ut illi qui promptissime ad maximas distantias horizontalibus oscillationibus propagantur, quique externa quidem aedificia conquassant immo et subvertunt, telluris vero superficiem ceteroquin vix immutant, ab electrico fluido, qui vero verticali motu, magnisque, sed passim extensis subversionibus se manifestant ab ignibus subterraneis derivari merito possint.

Vix igitur sperare fas est, quod audacius nonnulli auctores promiserunt, frequenti Conductorum uti dicunt in telluris superficie erectione perpetuoque mediantibus illis fluidi electrici servato aequilibrio omnes praecaveri posse telluris quassationes. Quis enim hac arte subterraneos ignes extingui posse autumabit? Cum tamen interruptum illud aequilibrium, terrae motuum, immo et internorum incendiorum causa esse videatur, cumque illae virgae ad arcenda ea fulmina, et procellas et hurricanos et turbines immo et ipsam grandinem conferre fere unanimo physicorum consensu videantur, earum usum et in urbibus et in agris vix satis commendari posse arbitror.

Sed ea omnia quae nunc dubitans et veluti balbutiens de velatis adhuc Naturae phaenomenis effero, mox vel omnino confirmari vel verioribus certioribusque refelli videbuntur: Tot enim, tantorumque ingeniorum vires ad Naturam omnibus modis interrogandam explorandamque collimant, tam mira, tam insperata, paucorum annorum intervallo prodita sunt inventa, ut nil fere sit, in physicis saltem, quod humana non sperare possit industria. Ergo, age, fili carissime, solidissima Philosophiae fundamenta profundis Logices et Matheseos studiis iace, ut dein suavissimo Naturae studio si ad illud te ferat animus, totum te tradens, tu quoque ad eius cognitionem promovendam aliqua saltem ratione conferas.

Dixi.

TRANSLATION INTO ENGLISH OF THE ORATION ON EARTHQUAKES AND ELECTRICITY

A Question

What pleasure it gives me, as I take my first steps in science, to behold in you, my most dear father, the one who guides both my private and my public studies. Yet my footing on the threshold of learning is still insecure. You have been used to answering my questions at home, and for this reason I have been most eager here also to play the part of a student of science and in this public place to put to you my enquiries.

Indeed, my question was already prepared. I have shown no small energy in building and brandishing balloons, and have gained no small reputation for this. My plan therefore, already formed, was to ask you about the theory, direction and uses of those wonderful contraptions[1]. But I heard a boyish speaker addressing this very question, and not merely looking at those devices from his youthful angle, but being bold enough to fly up into the sphere reserved for students of nature and science, and learnedly resolving all my doubts[2].

But this argument has been aired in all the conferences and in all the learned journals, and all possible reflections on it I have heard already to be so commonplace and so well weighed that it has passed beyond the power of even the most cultivated palate to digest, and this theme would be quite surprising to this learned assembly.

Where may I turn therefore so that we may hear from you, my most dear father, something less hackneyed, yet nevertheless with some relevance to the happenings of the year which has just passed? I know! I will reverse direction, and since heavenly journeys now seem somewhat commonplace, and since he [the boyish speaker] first got in ahead with his invasion of the skies, I for my part will descend to the lower world, and ask you to enter the very bowels of the earth with me at your side, so as to show me everything which the recent efforts of physicists have revealed concerning the causes of earthquakes. If you draw from them general principles which may serve to render intelligible the dreadful misfortunes recently occurring in South Italy[3] (Fig.4), I am sure that you will be performing a service most pleasing to this Distinguished Assembly.

Discourse

No less pleasing to me than to you, my most dear son, is the double and even threefold relationship which joins me to you; that of father, as well as that of instructor both in private and in public. And that enthusiasm which has led you openly to embrace the task of student of science could not help being most pleasing to me, who am so devoted to precisely that study.

But, if I turn to that question you now put to me concerning the causes of earthquakes, scarcely in the entire realm of physics will I find one more difficult, or one which has so tormented the minds of students of nature both in the ancient and modern worlds, or one which has given rise to more hypotheses. To detail all these, to weigh them thoroughly, to refute the false, to confirm the true, would not be a task for a brief lecture such as is appropriate here, but for many long discourses. And, my dear son, you do not merely confine your enquiry to all these topics but, rightly disturbed by the fearful disasters in Calabria and Sicily, you ask whether among all the discoveries in which modern physics takes pride there is something able to shed some light on the dark and deep cause of those terrible phenomena.

This means that you are not hankering for those old-fashioned and long ago exploded systems. The demand you put is not to hear of the central fire of the ancients[4],

Divers effets du tremblement de terre, de 1783 près de Sitizzano et de Cosoleto, en Calabre.

FIG. 4.
Effects of the 1783 earthquake of Calabria near Sitizzano and Cosoleto. Collapsed and highly tilted blocks of Pliocene rocks supporting olive tree growths have dammed surface waters into a lake partially filled by torrential sediments. (Plate III of Fleuriau de Bellevue,1806).

nor the encrusted sun of Descartes, nor of Buffon's comets abraded from the sun. For, novice in matters scientific though you may be, you assign all these to legend or to stories close to legend, just as much as you do the lower world of the Greeks, and Pluto and Neptune as shakers of earth and sea. More probable indeed were the suppositions of those who had postulated that there were huge caves beneath the earth's surface, filled with sulfur, coal and other bituminous solids, and had assigned the tremblings of the earth above to the combustion of those materials and to the concussion of the air thereby expanded[5].

Yet it was the talented English doctor by the name of Stukeley[6] who detected that those principles were insufficient to explain many phenomena associated with earthquakes. And no surprise. For if the distances are considered over which certain earthquakes have been felt, and the short intervals of time at which those distant points were struck by earthquakes, it will be quite unintelligible that either the progress of some conflagration or the shakings of solid earth or even wave motions of air enclosed in caves could have been spread so quickly and so far. Thus, for example, the earthquake by which the famous city of Lisbon was destroyed was felt on the same day and more or less at the same hour both in Mauritania and in Copenhagen, the capital of Denmark. It is recorded that the captain of a Danish ship leaving for the Indies was urging on his crew to repair and equip the ship, since haste was essential because of the weather. But on that particular day, which happened to be a holy day, he was struck by a sudden blow seeming to come from the depths of the sea, and fell down, along with all the sailors, not dead, but injured: something that at that moment seemed, when the disaster at Lisbon was still unknown, to have been inflicted almost by a miracle because of the desecration of the holy day. But how could a motion at such a short interval of time that spread to a distance of 860 leagues seem intelligible in terms of combustion and air waves?

Moreover, such great caves, spreading such distances beneath the surface of the earth without interruption, have never been found by those who bore so deeply and so often into the earth in their search for metals. Nor can any probable reason be given for the formation of these caves, and even if they were regarded as created along with the earth, how could they have been protected against the incursion of waters both subterranean and marine, especially since those very explosions which are supposed to take place in them would inevitably have opened huge crevices and countless fissures, and thus have easily given entry in a short time to waters of every kind likely to have filled them to the brim[7]. Yet, the assumption that each earthquake has a single focus, deeply buried in the bowels of the earth, means that you would expose yourself to even stronger — not to say quite insoluble — objections.

For the learned Englishman mentioned above has another very shrewd observation. If an earthquake were felt in a circular area of thirty miles' diameter, and if its cause were to be set in a single center under the earth, that center must be regarded as at a depth of twenty miles beneath the earth's surface. This means that an enormous mass in the shape of an inverted cone thirty miles wide and twenty miles deep must have been shaken by the explosion. But what if you think of the earthquake that laid waste Asia Minor at the beginning of our century, or the one that devastated Lisbon? Then a cone of similar shape, but a hundred and even a thousand times bigger, must be supposed to have been shaken.

And more than this. Although even from a distance to go down as deep as 600 leagues to find the center of earthquakes seems to smack of the ridiculous, many phenomena preceding and accompanying earthquakes clearly indicate a much greater proximity to the surface of the earth.

Thus, for example, how could the links between earthquakes and the condition of the atmosphere be understood if their causes were concealed by being submerged to so great a depth? But it is agreed that in regions liable to those disasters, for example in South America, they are often foreseen by the inhabitants from merely atmospheric signs, such as from the stillness of the air allied to unusual heat, from the density of that same air, from the color of the sun and moon, or from a sort of threatening and distant rumbling which appears to be heard in the air itself. Indeed, on numerous occasions, the inhabitants of those same regions, if chance takes them to our own Europe during a period of earthquakes, have forecast them by those very same signs. It is said that native Americans living at Lisbon, on the same day on which that famous city suffered its disastrous earthquake, saw all those signs together at sunrise, and remarked that, if they had been seen in America, there would have been no doubt about the onset of an earthquake on that same day. The same story is told about the earthquake occurring at London in 1749.

Moreover, that extraordinary jolt which ships struck by an earthquake out at sea experience can in no way be reconciled with any deeply situated cause. All declare that the same sensation is felt as if the ship had suddenly been driven on to a very solid reef, or as if the ship's keel had been struck a severe blow by some extremely hard material. But if the blow originated in the inmost bowels of the earth, a huge volume of earth, and even of waters, acting as a barrier would completely blunt its force, and would necessarily turn it into a gentle and slow undulation. Finally, that certain causes of earthquakes must be restricted to the surface of the earth is shown by the earthquakes observed in England. They had quite a serious effect on men and houses resting on the surface of the earth, but did not arouse even the least disturbance in the deep mines beneath that same surface (Philos. Trans. v. 71, p. 193 and 331)[8].

The shrewd English observer, rightly influenced by these and other arguments which time prevents me from reviewing, has come to the conclusion that the cause of earthquakes for the most part is to be sought in the atmosphere itself. He has more or less shown[9] that it is the electric fluid, that unexpected and most powerful instrument of nature, which is, for the most part, the cause of earthquakes. It is known that the density of that fluid may be changed in various ways, either in the air or in the earth itself. It is equally well known that, when in certain spots it has condensed, and in others become rarefied, it rushes with the strongest force towards restoration of the equilibrium.

Suppose therefore that the fluid has been made dense by prolonged heat and dryness in the upper strata of the atmosphere, and at the same time in other regions for opposite reasons has become rarefied; or even that by changes or fermentations within the earth, for example, in certain tracts of land, it has accumulated, while being depleted in others. At long last, breaking free of all barriers, it will rush with mighty force from the place where it is dense into the one where it is more rarefied, and will shake all the intervening earth with great force[10].

In the light of this explanation, neither the speed of transmission, nor the association of external phenomena, nor the sudden disturbance of ships which are inexplicable in other hypotheses, make the slightest problem for you. I will now add further points which will make the hypothesis of the English scholar even more probable.

Earthquakes in other similar regions which are warm and southerly are observed much more frequently. Since however the sun's heat nowhere penetrates beyond the shallow depth of 80 feet, you will certainly not attribute that frequency to fossil bitumens kindled by the sun's heat, but rather to an electric fluid. In cold regions, this fluid is not particularly able to condense. One reason may be that the evaporation which carries the electric fluid from the surface of the earth to the upper layers of the atmosphere is much greater in warm regions, and on this account its accumulation in those regions is easier and quicker. Or the explanation may be that in northern and cold regions, where the humidity is greater and where the more frequent rains provide a pathway for the electric fluid, the air can only in exceptional circumstances foster its lengthy and large-scale accumulation.

No less support is given to this hypothesis by the greater frequency of earthquakes in maritime regions both along the actual shores of the sea and on river banks. The electric fluid very easily penetrates water, or intensifies on its surface, and always chooses the easiest paths for itself in order to restore equilibrium.

Moreover, peals of thunder and storms and balls of fire and other celestial phenomena arising from electric fire have always been more frequently observed in those years characterized by the occurrence of earthquakes. Indeed — something that affords almost unchallengeable proof — at the very moment at which the earthquake of the year 49 was felt at London, Doctor Halsius[11], certainly a most trustworthy witness, heard a very strong rumbling ending with a huge explosion and a brilliant flash of lightning.

Finally, experimental physics of itself, by small yet manifest and very impressive rehearsals of those tremendous natural phenomena, has seemed to confirm that whole theory.

Suppose a wooden stick floats soaking on the surface of water, and on top of that stick are set certain not too solid columns, in the way in which our own houses rest on the surface of the earth: suppose then that a strong spark from a Leyden jar is set to play on the stick's surface: the entire stick will be set in motion, and most of the columns will collapse, and hands plunged in the water at the moment of the explosion will experience a shock and jolt just like the one received by ships out at sea from an earthquake.

But now that I have assembled so many arguments with the aim of assigning to the electric fluid the cause of earthquakes, my only fear, dear son, is that you may think that all earthquakes arise from this single cause. There is a tendency native to the human mind, and especially to the young, to extrapolate what they have found to be true in very many cases to all cases without exception. The English observer mentioned above has not escaped this illusion in assigning to earthquakes no other cause except the electric fluid[12].

But there are earthquakes which undoubtedy take their origin from subterranean fires. Those, for example, which accompany the rise of new islands from the sea[13], and those which are observed only too frequently at the foot of volcanoes in Italy, Sicily, Iceland and Peru, show a clear affinity with the fiery explosion of underground matter.

For hardly any notable volcanic eruption occurs unless simultaneously fearful earthquakes powerfully shake the neighboring areas. And I myself, when standing on the top of Etna, where I could hear at the bottom of the crater the dull rumble of explosions, felt at that very moment the whole mountain shaking beneath my feet[14].

In most larger volcanic eruptions, the combination of both causes is noted as a potent factor leading to destruction on earth. For when from the inmost bowels of the earth a huge column arises made up of a mixture of smoke, flames and every kind of gas, celestial fires seem to meet those of earth, and lightning flashes too numerous to count strike and cover the entire top of the column, indeed even its sides, with their incessant bolts[15].

As soon as that huge column filled with gases reaches the upper layers of the atmosphere, the cold forever prevailing there condenses those vapors. The electric fluid needed to form the vapors is released in those lofty regions. There, it accumulates in vast quantities, and from there is powerfully attracted by the earth which, in order to form those vapors, lost that same fluid. In the shape of lightning and thunderbolts, it seeks again its old haunts, and by causing an earthquake it restores equilibrium.

It is hardly possible to doubt that both causes united to bring about the earthquakes in South Italy[16]. The presence of subterranean fires in those regions is shown by the proximity of Etna and the Aeolian islands. Moreover, there were terrifying shakings which seemed to arise from the earth's very depths. Waters were hurled from the bowels of the earth into the sky. There was a steady increase in devastation in lower areas, and indeed a disturbance in the earth's strata, which was all the greater the deeper they lay beneath the topmost surface. This is not to mention the fearful boiling of the sea at certain spots, nor the fishes usually living in the deepest pools which were then cast up to the surface. All these facts — and others which time forbids me to detail — prove that the focus of those convulsions was underground. But, on the other side, given the motionless clouds and stormy rains which preceded most of those movements, the electric fluid building up in the atmosphere and with the aid of the rains restored to the earth, not only in itself seems to have caused an earthquake, but also to have ignited that combustible air enclosed in subterranean caves and producing flames which burst out in all directions from the crevasses in the earth.

And so a reason is found why more often there have been first horizontal shakings caused by the electric fluid, which were then followed by vertical or spiral shock waves resulting from deep explosions.

Thus I would consider those two different causes of earthquakes as requiring analysis in the light of their effects[17]. Those which are most readily transmitted to the greatest distances by horizontal waves, and which shake and even throw down buildings, but in other respects scarcely affect the surface of the earth, may rightly be derived from the electric fluid. But those which have a vertical motion, and manifest themselves in great but widely dispersed destructive effects, may be thought to come from subterranean fires.

It is scarcely possible to hope, as some authorities too boldly have promised[18], that the widespread erection of what are called conductors on the surface of the earth, and the use of their constant intervention to preserve the equilibrium of the electric fluid, will provide a precaution against all earthquakes. For who will maintain that by this method the subterranean fires can be extinguished? But since the disturbance of the equilibrium seems to be the cause both of earthquakes and indeed of internal fires, and since those lightning rods, by the almost unanimous agreement of scientists, seem to be useful in warding off lightning bolts and storms and hurricanes and whirlwinds and even actual hail, I hardly think it possible to over-recommend their use both in cities and in the countryside.

What I say now about Nature's as yet hidden secrets is hesitant or even incoherent, but soon it will be seen either to be completely confirmed or refuted by truer and more certain arguments. The talents of so many minds, and such great minds at that, are collaborating to put every kind of searching question to Nature, and such wonderful and unexpected discoveries have been revealed in so short a space of years, that in physics at least almost nothing seems beyond the hope of human effort. So come then, my dear son, lay the most solid foundations of science by profound studies of logic and mathematics, so that afterwards, if your inclination so leads, you may utterly surrender yourself to the very rewarding study of Nature, and so that you in your turn in some way at least may make a contribution towards its understanding and advancement.

The End.

ENDNOTES OF ENGLISH TRANSLATION

[1] Nicolas-Théodore refers here to his father's trip to Lyon where he participated, on January 19, 1784, in the aerostatic experiment by Joseph Montgolfier of his balloon inflated with hot air. Upon his return, Saussure made his own experiments to prove what had not been previously recognized, namely that the ascending power was due solely to the lightness of heated air compared to that of air at lower temperature. An extensive discussion of the Montgolfier machine and a comparison of the relative powers and uses of fire and gas balloons is given in his letter to Faujas de Saint-Fond, dated February 22, 1784 (*in* FAUJAS DE SAINT-FOND, 1783-1784, vol. II, pp. 112-127).

Saussure was interested in using balloons for his Alpine research not so much for establishing altitude records but to investigate the constitution of the upper atmosphere. Saussure's experiments were not always successful in spite of all the scientific care he put in them. FRESHFIELD (1920, p. 341) recalled the comments of some visitors during a failed experiment at Conches: "The illustrious Professor was in a terrible temper; he scolded his sons and several savants who, with folded arms, were looking on in silence, or asking questions which did not make him any happier. The rest of us laughed at the whole scene." (See also SIGRIST, 1993, pp. 84-86).

[2] The real identity of the "boyish speaker" who discussed the subject of balloons in a youthful as well as serious scientific manner, and who seems to have been familiar to the audience, remains a puzzle. A possibility (according to René Sigrist, personal communication, June 1995) could be Nicolas Paul (1763-1806), a scientific instrument maker and inventor. He was the son of Jacques Paul, well known as maker of the numerous instruments invented by Jean-André Deluc and particularly by Saussure. Nicolas Paul was the technician associated with Henri-Albert Gosse who undertook, independently from Saussure and at the same time (1784), systematic but not very successful experiments on the possibility of steering balloons. A subscription to build such a dirigible was opened, and Gosse even contemplated writing a treatise on aerostats (See B.P.U. Geneva, Papers of H.-A. Gosse, dossier aérostats, Ms fr. 2652). It is therefore quite possible that Nicolas Paul, at the time 21 years old, could have explained to Nicolas-Théodore, who was four years younger, the major aspects of the project in which he was actively involved.

[3] A reference to the catastrophic earthquake which hit Calabria and Sicily on February 5, 1783. It was described by HAMILTON (1783), DOLOMIEU (1784), and particularly with respect to its spectacular geological effects by FLEURIAU DE BELLEVUE (1806). For a general review of the question and a reproduction of Fleuriau de Bellevue's plates, see CAROZZI (1990, p. 281-283).

[4] This pre-Christian myth is very old and cannot be specifically traced to any classical author.

[5] This opinion of CARDANO (1550) was generally accepted in the latter half of the seventeenth century until KIRCHER (1665).

[6] In the entire oration, Stukeley is designated either as talented doctor, learned Englishman, shrewd observer, or English scholar but never as naturalist or physicist. See also endnote 9.

[7] Obviously, Saussure had serious doubts on the very existence of the large caves he had postulated in the formation of the Alps and other mountains, either for the explosion of elastic fluids or for engulfing the waters of the "*grande débâcle*." A few months after writing this oration, he discovered the fundamental concept of horizontal thrusting or "*refoulements*" in mountain building thus making the concept of caves totally obsolete except for active volcanoes and surrounding areas.

[8] The first reference in the Philosophical Transactions mentions indeed that during a violent earthquake in Wales, miners operating in lead and coal mines neither perceived any shock nor noticed the fall of loose or weak roof rocks particularly in coal mines (PENNANT, 1781). The second reference dealing also with earthquakes describes mostly surface effects (LLOYD, 1781). Thomas Pennant (1726-1798) was a well-known naturalist and traveler who published extensively on zoology; little is known about John Lloyd (1750-?).

[9] This statement of Stukeley having " more or less" shown electricity as being the major cause of earthquakes indicates that Saussure considered Stukeley's arguments somewhat simplistic.

[10] Saussure, 34 years after Stukeley's hypothesis, proposed an expanded concept of electricity, according to Franklin's well-known views, as the major cause of earthquakes. He stated that the electric fluid can be accumulated or depleted (condensed or rarefied) both in the upper atmosphere and in the upper part of the earth. This introduces 3 cases of discharge from positive (+) to negative (-) areas between the atmosphere and the ground and within the ground which are capable of generating earthquakes: 1. Ground to cloud (Stukeley's hypothesis); 2. Cloud to ground during volcanic eruptions; 3. Ground to ground as well as across oceans.

[11] Latin name for Stephen Hales (1677-1761), doctor in theology, he was vicar at Teddington near Twickenham in Middlesex, then was given the "living" of Portlock (Somerset) and Faringdon (Hampshire). Fellow of the Royal Society since 1717 and foreign correspondent of the Academy of Science of Paris since 1751. The reference is to his paper on earthquakes (HALES, 1750) which is in the same supplement of the Philosophical Transactions of the Royal Society as those of his friend Stukeley.

[12] This statement is not entirely true. Stukeley wrote that the majority of earthquakes were due to atmospheric electricity and a minority related to subterranean vapors and inflammable substances as well as volcanic action.

[13] Reference to the numerous instances of new volcanic islands by MORO (1740).

[14] Mentioned in "*Notes sur l'Italie*" (SAUSSURE, 1773a), a manuscript account of his travels to Italy and Sicily between October 1, 1772 and August 22, 1773. The ascension of Etna took place on

June 5, 1773. On Etna, Saussure was feeling the shallow focus earthquakes generated within volcanoes by movements of magma underground, often signaling an imminent eruption.

[15] Strong volcanic eruptions of Vesuvian, Vulcanian, Strombolian, and Plinian type are accompanied by violent storms and spectacular lightning resulting from the discharge of electricity due to friction among ash particles involved in high atmospheric turbulence.

[16] In these sections, Saussure outlined his ideas that the coincidence of large volcanic eruptions with earthquakes destroying towns and generating large morphological and geological changes in adjacent areas, like in southern Italy, displayed the convergence of the effects of atmospheric electricity and subterranean fires. He considered the following scenario: gases, smokes, and flames of the plume of an eruption transfered electricity to the upper atmosphere where it accumulated. Through rain, it discharged as lightning which striking the ground generated an earthquake while restablishing electrical equilibrium. Almost simultaneously, lightning ignited the combustible air inside subterranean caves producing deep-seated explosions responsible, as often observed, for another earthquake immediately following the first. A similar idea was proposed by BECCARIA (1753, Book II, Chap. VII, p. 230, § 678).

Lightning is suggested here during volcanic eruptions as the agent responsible for lighting subterranean fires rather than the widely accepted idea of spontaneous combustion of fermenting pyrite, coal beds, or other bituminous substances supposed to exist inside the earth.

[17] In summary, Saussure introduced here two types of earthquakes expressed by their distinct effects. A first type of pure electric nature, characterized by horizontal waves transmitted over great distances, destroying cities but scarcely affecting the surface of the earth. A second type, originating from subterranean explosions (secondarily triggered by electricity during volcanic eruptions), characterized by great vertical waves, destroying cities and generating strong morphological and geological changes in landscapes over more localized areas.

These types of waves have naturally nothing in common with those distinguished in modern seismology.

[18] It was not possible to identify the authors (most probably Italian) who apparently believed in atmospheric electricity as the cause of earthquakes in active volcanic areas and therefore proposed a generalized erection of lightning rods to prevent or attenuate the effects of the shocks. Although G. Beccaria might be a candidate, our search of his major works failed to provide an answer. Saussure rightly pointed out that this proposal would still not extinguish previoulsy lit subterranean fires. Possibly these authors might have expressed their ideas in learned periodicals or even newspapers making their identification even more difficult.

Nevertheless, Saussure used this opportunity for a renewed plea in favor of lightning rods in general as outlined in his pamphlet of 1771.

FINAL POSITION OF SAUSSURE ON EARTHQUAKES AND ELECTRICITY

It seems reasonable to assume that a physicist of the caliber of Saussure, while reading the primary sources for his oration became aware of the discrepancy mentioned above between Franklin's original paper and the interpretation derived from it by Stukeley. Indeed, Saussure had in his own library the third and fourth editions (1760-1765, 1769) of Franklin's works on electricity as well as a complete set of the Philosophical Transactions of the Royal Society of London including the years of Stukeley's papers (CAROZZI & BOUVIER, 1994, respectively Nos. 919, 920, and 1150).

As mentioned before (endnote 6), Saussure never called Stukeley a naturalist or a physicist and, because of his calvinistic audience, he did not mention Stukeley's religious implications of earthquakes even if God was assumed to have used natural processes. In the same context, even the famous but free-thinking Franklin was not mentioned.

Nevertheless, Saussure credited Stukeley ("more or less" as he wrote) of having shown that atmospheric electricity was the major cause of earthquakes regardless of whether Stukeley misunderstood the process or not. Besides an oration was no place for technical disputes. Even 34 years later, Saussure felt that electricity, considered in a broader sense along Franklin's views, remained a valid explanation for non-volcanic related earthquakes of widespread to regional extent, and indirectly for volcanic related earthquakes of smaller size yet highly destructive, an aspect that Stukeley had not considered. The main reason for accepting electricity as the main cause of earthquakes until 1784 was certainly the astounding velocity of propagation of seismic waves. However, the idea presented by MICHELL (1761) of steam and vapors from subterranean fires, similar to volcanoes, and originating from the spontaneous combustion of coal and pyritic shales, propagating along bedding planes, was no longer acceptable when Saussure wrote his oration. In fact Saussure substituted lightning as the cause of subterranean fires and related explosions generating volcanic-related earthquakes.

In October 1784, 6 months after the presentation of the oration, Saussure reached the fundamental concept of horizontal thrusting (*refoulements*) in the formation of the Alps and other mountains. To our knowledge, there are no manuscripts or publications indicating that Saussure between 1784 and 1799, the date of his death, developed this concept any further. Horizontal thrusting in mountain-building forecasted the 19th century theories of the contraction of the earth. Such an idea was too much ahead of its time for a theoretical or field demonstration (CAROZZI, 1989). Saussure did not speculate or evaluate that if electricity caused earthquakes which in turn caused horizontal thrusting, then electricity would become responsible for mountain building. A demonstration of the absence of such reasoning is found in the section of the *Agenda* entitled "*Studies to make on earthquakes*" of the *Voyages...* (SAUSSURE, 1796, § 2323) where he wrote:

No.9. Verify the simultaneity, or at least the amazing velocity of the effects of earthquakes over long distances.

No.10. Search for examples in which, at the time of an earthquake, a small area of land or of mountain was uplifted high above its previous level, and subsequently remained in such a state of uplift.

In raising such questions, Saussure disclosed not only his primary motive why he accepted electricity as an explanation of earthquakes but he also questioned their potential orogenic significance. It is interesting to point out that still today the fundamental question of the (cumulative?) role of earthquakes in mountain building remains entirely open.

ACKNOWLEDGMENTS

The authors are grateful to Professor I. Bernard Cohen of Harvard University for his valuable and perceptive analysis of the problem presented by the discrepancies between the writings of Franklin and Stuckeley. René Sigrist of the University of

Geneva is thanked for his suggestions about the identity of the "boyish speaker." Gratitude is also expressed to Philippe Monnier, curator of manuscripts at the Public and University Library of Geneva for his devoted help during our studies of the Saussure's archives. Marguerite Carozzi contributed extensively to the editing of this paper.

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