THE 1755 LISBON EARTHQUAKE: REVISITED

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The 1755 Lisbon Earthquake: Revisited

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250th Anniversary of the 1755 Lisbon Earthquake

Editorial Note

The 1755 earthquake and tsunami were influential not only in Portugal but in all European and North African countries, where its devastating effects were felt. The entire world was deeply impressed and the discussion of its causes generated a large amount of scientific and metaphysical speculation. It inspired philosophers, poets and writers. The socio-economic consequences of the event were great and affected the future organization and development of Portugal. The eventuality of a similar occurrence urges society and the scientific community to reflect on its lessons.

250 years after the 1755 earthquake, the opportunity to put together scientists, engineers, historians, philosophers, urban planers, architects, economists and policy makers, provides an integrated view on our global perception of natural disasters and how must Society deal with them.

In order to invocate this event an international conference - "250th Anniversary of the Lisbon Earthquake International Conference" – was organized in Lisbon from 1 to 4 November 2005, devoted to the following topics:

1) Socio-economic impact on communities exposed to earthquakes and tsunamis;
2) Urban Planning facing natural Hazards; information and warning;
3) Propagation and local effects on the seismic destruction;
4) How to build earthquake resistant buildings under the environmental constrains;
5) New approaches to the seismogenesis of the 1755 earthquake;
6) Global response to large earthquakes.

A large number of contributions was received covering the above mentioned topics, organized in a Volume of Proceedings, a number of which with high scientific quality and social interest deserving a more wide diffusion through a well known publisher, impacting an extensive audience.

In this publication we are very pleased to offer the opportunity to interested readers and users to dispose of a collection of high quality papers dealing with

the different aspects of geosciences, engineering and humanities related to this kind of catastrophic event.

Authors were invited to submit selected improved versions of the original Proceeding papers, namely the invited lecturers, and the convenors of the Conference topics.

This Book should be considered as a quality reference in Institutional Specialized Libraries and Bookstores. It is a tribute from the academic society to acknowledge the contribution of Prof. Bruce Bolt to mitigate earthquake impacts. Prof. Bruce Bolt was an enthusiastic supporter of the Organising Committee to present the state-of-the-art and the importance of the scientific and technical background already achieved in this field of human kind. We are very proud to include his name as an expression of gratitude for his contribution to the advancement of science and public awareness.

The editors would like to express to all the contributors to the "250th Anniversary of the Lisbon Earthquake International Conference" which, in one way or another, have supported the idea of this evocation and made the Conference and the corresponding Proceedings a success. The high scientific level presentations in the Conference were the seeds of this Book.

We would like to highlight all supporters, institutions and entities involved in the "International Conference" as well as the devoted work performed by Dr. Alexandra Carvalho for the arrangements and contacts established with the authors of this Book.

Lisbon, January 2008

L.A. Mendes-Victor
Carlos Sousa Oliveira
João Azevedo
António Ribeiro

Part I
Introduction

Introduction

L.A. Mendes-Victor and Carlos S. Oliveira

The success of the "250th ANNIVERSARY of the LISBON EARTHQUAKE" motivates the challenge to produce a collection of papers, which make a "revisitation" of the 1755 Lisbon earthquake.

In order to achieve the objectives of wider outreach of all scientific and technical communities interested in this matter, the Editors were able to provide a selection of papers reflecting the most expressive contributions to assure those objectives, adopting similar distribution of the Conference topics, requesting from the convenors the designation and approval of the ideas.

We realize the importance of the work developed by Prof. Bruce Bolt to the efforts to join the communities of Seismology and Earth Engineering and to embrace the policy of seismic mitigation, being a strong personality launching this idea. We want to give our recognition to Prof. Bruce Bolt, an enthusiastic supporter of the International Conference whose surprise did not allow him to be present. His colleagues at the University of Berkeley wrote a short attribution to Prof. Bruce Bolt.

The historical framework constitutes a very expressive topic reported by a scientific Group of Personalities providing review of the most important aspects of the historical interpretations of the sources, coeval reports, impact and consequences of the event.

The social-economical impact of large event such as the 1755 Lisbon earthquake was analysed from different points of view but expressing modern concepts and assessment evaluations, involving the mitigation of seismic risks.

Urban planning facing natural hazards were another topic selected for presentation by several experts with illustrations in different European environments.

Propagation and local efforts was brought into discussion being new models to explain instrumental and macroscopic observations.

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The modern earthquake engineering concepts were treated in another topic with relevance to analytical and experimental modelling and comporting with the reality of damage observatory in past events.

A topic of still great controversy is the seismogenesis of the 1755 earthquake. New approach to the problem is presented representing the most updated development achieved in the last decade.

A final topic, global Response to large earthquake was a challenge for different experts to present their own views in different geodynamic environments, including several regions and countries with high potential seismic and tsunami risk.

We have to emphasize the excellent of all presentations providing some important guidelines as far as earthquake mitigation, prevention and management of risk are concerned.

Part II
Historical Framework

The Lisbon Earthquake of 1755 in Spanish Contemporary Authors

Agustín Udías and Alfonso López Arroyo

1 Introduction

The Lisbon earthquake of 1 November 1755 was felt over the whole Iberian Peninsula causing heavy damage by the shaking and subsequent tsunami, specially, in the nearby Spanish cities of Huelva, Cadiz and Seville (Martínez Solares 2001; Martínez Solares and López Arroyo 2004). This extraordinary event produced an abundant literature published in Spain, especially in Seville. Many were short popular accounts about how the earthquake was felt in some determined localities or religious considerations about the event, most of them anonymous. These were generally short works of a few pages of a popular character with exaggerated narratives of damages or curious occurrences during the earthquake. Some were of religious character asking or giving thanks for the deliverance from the effects of the earthquake; a few of them were written in verse. Other publications were extended treatises on the physical, philosophical and religious aspects of the event, written by ecclesiastics, philosophers and scientists. A list of the publications we have identified and examined is given in Appendix 1 (publications with author) and in Appendix 2 (anonymous works).

Most authors writing about the earthquake that we will examine in some detail handled two questions. The first was whether this was a natural event or a supernatural one, that is, one directly attributed to God. The second was about the natural causes of this earthquake and, in general, about the origin of earthquakes. In this second question traditional and modern ideas were presented and debated. Regarding the characteristics of this particular earthquake it was discussed, especially, how it was possible that the earthquake, which caused the main destruction in Lisbon, was felt at the same time in regions separated by long distances through the Iberian Peninsula and as far as central Europe and how it generated such large waves in the ocean.

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2 Natural or Supernatural Event

The occurrence of the Lisbon earthquake generated in Europe an intense debate about what has been called "eighteenth century earthquake-theology" (Kendrick 1955). In the center of this debate was the opinion, generally asserted by many of the clergy, that the earthquake was a deliberate punishment by God of sinful people. A constant theme in sermons, tracts and moralizing poetry, throughout Europe was that God in His anger had destroyed Lisbon because of the sins of its inhabitants. In Portugal the debate took a special strong character with the figure of the Jesuit Gabriel Malagrida on one side and Sebastian José de Carvalho e Mello, Marquis of Pombal on the other. Malagrida with an extreme position insisted in his sermons that the earthquake had been caused by the wrath of God for the sins of the people of Lisbon. Pombal, who took a pragmatic attitude to organize the care of the victims and the reconstruction of the city, regretted the sermons of the clergy that in his opinion motivated certain passivity in the people. Pombal ordered to put Malagrida in prison and four years later his cruel execution by the Portuguese Inquisition.

In France the earthquake came to question the generally sensed optimism, which held that the world was a good place in which everything that happened was viewed to be "for the best" (Kendrick 1955). François Marie Voltaire, in his poem, *Poème sur la désastre de Lisbonne* and his novel *Candide,* wrote the most furious and hard attacks on this optimistic view. On the other side authors like Jean Jacques Rousseau defended the optimist position, and rejected Voltaire gloomy picture of man's unhappy fate on earth. In Germany Immanuel Kant, adhering to the optimistic theodicy of Gottfried Wilhem Leibniz, who held that this is "the best of the worlds", published three short papers on the Lisbon earthquake in 1756. He was in fact more interested in the scientific aspects of the phenomenon, but touched also on the subject of earthquakes in relation to God's government of the world. The optimist position was heavily wounded by Voltaire's sharp attacks in *Candide*, which finally carried the day in the enlightened Europe.

In Spain the debate was centered about the supernatural or natural character of the earthquake. It is generally accepted that before the Enlightenment common knowledge assigned the cause of earthquakes to God's punishment of sins, but this is an oversimplification. This was true in popular or religious accounts, but not in philosophical treatises, where Aristotelian ideas were held about the natural causes of earthquakes. Commentaries by Spanish authors of the 16th to 18th century on Aristotle's *Meteorologica*, where the problem about the origin of earthquakes is treated, do not mention God's intervention in these phenomena. On the other hand in the popular and religious writings the situation was different. For example, an earthquake, which caused heavy damage in the city of Malaga in 1680, was interpreted as God's punishment for sins with no dissenting voices. In the earthquake of 1755 opinions were on both sides arguing in favor and against considering the earthquake as God's punishment.

The references of the published works and manuscripts of the authors who are mentioned in the following paragraphs are given in Appendix 1.

The debate began a few days after the occurrence of the earthquake, with many popular publications many of them anonymous and sermons in the churches, in which the supernatural character was presented (Fig. 1). Some asked for the help of heavenly patrons in this situation or thanked for their protection, among them of the Virgin Mary, St. Francis of Borgia, St. Philip of Neri, St. Justa and St. Rufina. Many of the titles of the anonymous publications given in Appendix 2 correspond to this kind of texts and most of them were published in Seville. At popular level and by many of the clergy it was taken for granted that the earthquake was God's punishment for the sins, and public religious services were organized in the subsequent days for this reason (Aguilar Piñal 1973). The two sermons of Francisco Olazaval y Olayzola, Canon of the cathedral of Seville, preached on 27 of April of 1755 and 28 February 1756, were an example of this type of literature. Olazaval insisted in the many sins of the city of Seville, as the cause of this punishment, which the mercy of God had not permitted to be even greater. Agustín Sanchez, a Trinitarian theologian and preacher, insisted in a note included in Nifo's work, "God uses the creatures to infuse fear in sinners and to move them to repentance". The most firm defender of the supernatural character was Miguel de San José, Bishop of Guadix and Baza (Granada), who published a short letter in which he refuted the opinions of those who defended that this was a natural event, specially José de Cevallos, and went as far as to affirm that: "only to deny or doubt that earthquakes and other disasters are usually the effect of the wrath of God, can be considered as an error in the faith".

José de Cevallos (1726–1776), a theologian from Seville and later Rector of the University of Seville presented the contrary opinion, defending the purely natural character of the earthquake. He expressed his position in his introductory note (*Censura*) included in Feijoo's work published in 1756. He used arguments from the Scriptures and the Church fathers against considering earthquakes as signs of God's wrath and concluded firmly "the earthquake has been entirely natural, caused by natural and proportioned second causes". He recommended preachers not to be carried by devotion in their sermons and be guided by wisdom and discretion. Juan Luis Roche, a physician born in Catalonia and established in Seville, defended the same opinion, adding that there is no relation between the sins committed and the occurrence of earthquakes (Fig. 2). Rhetorically he asked: "Are Lisbon and Seville worse than other cities?" For him this type of considerations was only "pious opinions of theologians".

The natural character of the earthquake was also defended and discussed in several lectures held at the *Real Academia de Buenas Letras*, a learned society of Seville where enlightened ideas were discussed. Roche held the first lecture about the earthquake ten days after its occurrence (*Sobre el terremoto del 1 de Noviembre,* 12 November 1755). Jerónimo Audixe de la Fuente (*Formación y efectos de los terremotos,* 27 March 1756) and Francisco de Céspedes Espinosa

EL DESENGANO

A LA PRESUMPTUOSA IGNORANCIA,

Que intenta perſuadir efecto de los Elementos los eſtragos del Terremoto, diſtrayendo la compuncion de los Timoratos.

CANTO TRAGICO.

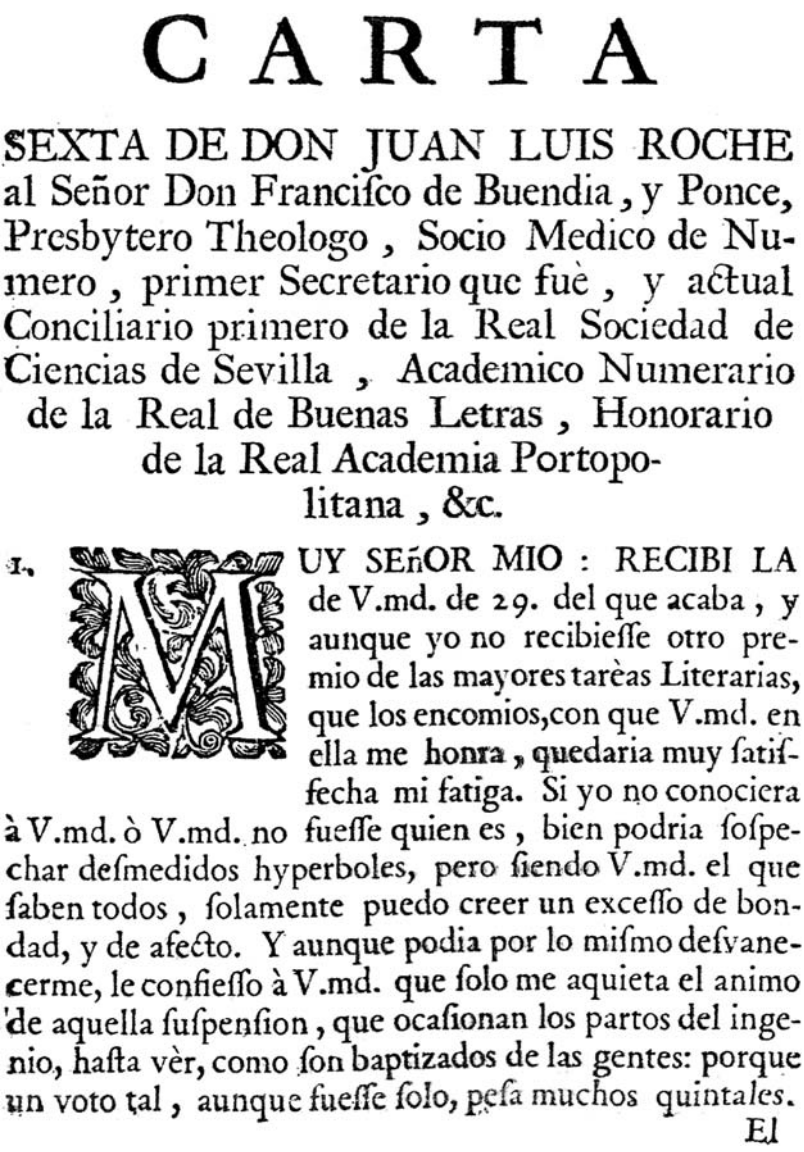
POR

D. FRANCISCO IGNACIO DE LA CRUZ.

CON PERMISSO EN MADRID.

En la Imprenta de los Herederos de Don Aguſtin de Gordejuela, Calle del Carmen.

Fig. 1 Poem by Francisco de la Cruz presenting the earthquake as God's punishment for sins



CARTA

SEXTA DE DON JUAN LUIS ROCHE al Señor Don Franciſco de Buendia, y Ponce, Presbytero Theologo, Socio Medico de Numero, primer Secretario que fuè, y actual Conciliario primero de la Real Sociedad de Ciencias de Sevilla, Academico Numerario de la Real de Buenas Letras, Honorario de la Real Academia Portopolitana, &c.

MUY SEñOR MIO: RECIBI LA de V.md. de 29. del que acaba, y aunque yo no recibieſſe otro premio de las mayores tarèas Literarias, que los encomios, con que V.md. en ella me honra, quedaria muy ſatisfecha mi fatiga. Si yo no conociera à V.md. ò V.md. no fueſſe quien es, bien podria ſoſpechar deſmedidos hyperboles, pero ſiendo V.md. el que ſaben todos, ſolamente puedo creer un exceſſo de bondad, y de afecto. Y aunque podia por lo miſmo deſvanecerme, le confieſſo à V.md. que ſolo me aquieta el animo de aquella ſuſpenſion, que ocaſionan los partos del ingenio, haſta vèr, como ſon baptizados de las gentes: porque un voto tal, aunque fueſſe ſolo, peſa muchos quintales.

El

Fig. 2 Letter by Juan Luis Roche defending the natural origin of the earthquake

(*Relación histórica del terremoto de 1755,* 17 September 1756) made presentations on the following year. These lectures discussed the occurrence of the earthquake from a purely secular perspective outside any religious consideration. Although members of the clergy took part in these sessions, the Academia stood away from formal theological discussions (Sánchez Blanco 1999).

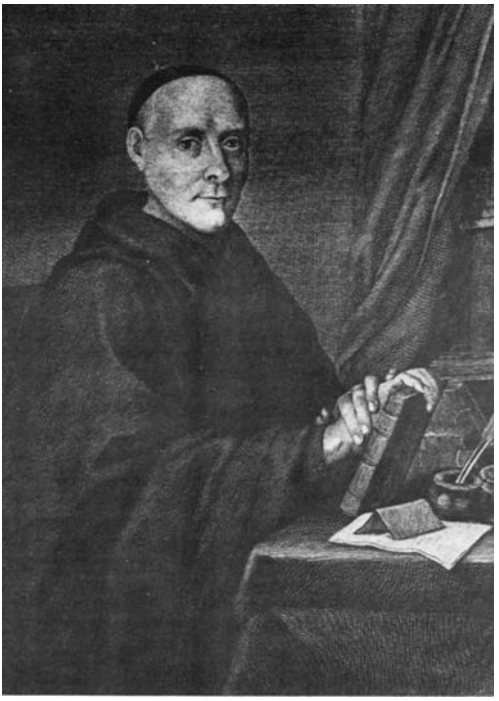


Fig. 3 Benito Jerónimo Feijoo y Montenegro (1676–1764)

Both Cevallos and Roche supported their opinions with the authority of Benito Feijoo y Montenegro (1676–1764), a Benedictine professor of theology at the University of Oviedo, author of *Teatro crítico universal* and *Cartas eruditas,* two very influential works in the introduction of modern scientific ideas in Spain (Fig. 3). Feijoo defended the natural character of the earthquake, but already an old man, did not enter the controversy. He wrote that man should fear more sudden deaths than earthquakes, since they are more common. Another defender of the natural character was Antonio Jacobo del Barco y Gasca (1716–1783), an ecclesiastic and historian of Huelva, whose main work was dedicated to the history and agriculture of the region. Barco in his writing said that he intended to study "as a philosopher" the causes, duration, extension and effects of the earthquake. Defending the natural character he added that natural does not mean "casual", and that this type of occurrence must be used as an occasion for men to turn to God. Isidoro Ortiz Gallardo de Villarroel, Professor of Mathematics of the University of Salamanca, explained the natural causes and did not want to enter into the theological question of whether it was a warning from the divine Providence.

Some authors held the mixed position that the earthquake was a natural event, but God has used it to punish or warn sinners. Miguel Cabrera, of the Order of Minims, a theologian of Seville, defended that the earthquake was "natural in its causes, in its being and in its consequences", but, however, a

special Providence could have ordered it to happen at a particular place and time. Francisco de Buendía y Ponce (1721–1800), an ecclesiastic from Seville, poet and physician of the Archbishop of Seville, author of works on history and medicine, held the same opinion. He stated that earthquakes, although of natural causes, could be sometimes a "punishment by the Divine Hand". Francisco Martinez Moles, professor at the University of Alcalá de Henares who argued that earthquakes could be signs of divine wrath took a similar position. He wrote that "if this natural phenomenon was caused naturally, can be investigated". However, he continued, there are motives to say that Providence have ordered the earthquake as punishment for sins.

Francisco Mariano Nifo y Cagigal (1719–1803), founder of the first newspaper in Madrid, held a similar view. After explaining the natural causes of earthquakes, he added the consideration of what can be considered their moral causes and effects, as God can use these phenomena as warnings to sinners for their repentance. Juan de Zúñiga in a letter to Feijoo explained the natural causes of earthquakes and how God uses natural causes to show its displeasure of man sins. Pedro Trebnal, a member of the learned societies of Seville, after giving the details of this debate in his manuscript, gave a twist to the problem and, rejecting the supernatural character, defended that although it was a natural event it was not entirely so, but it had a preternatural character, that is, some evil spirit may have produced the earthquake.

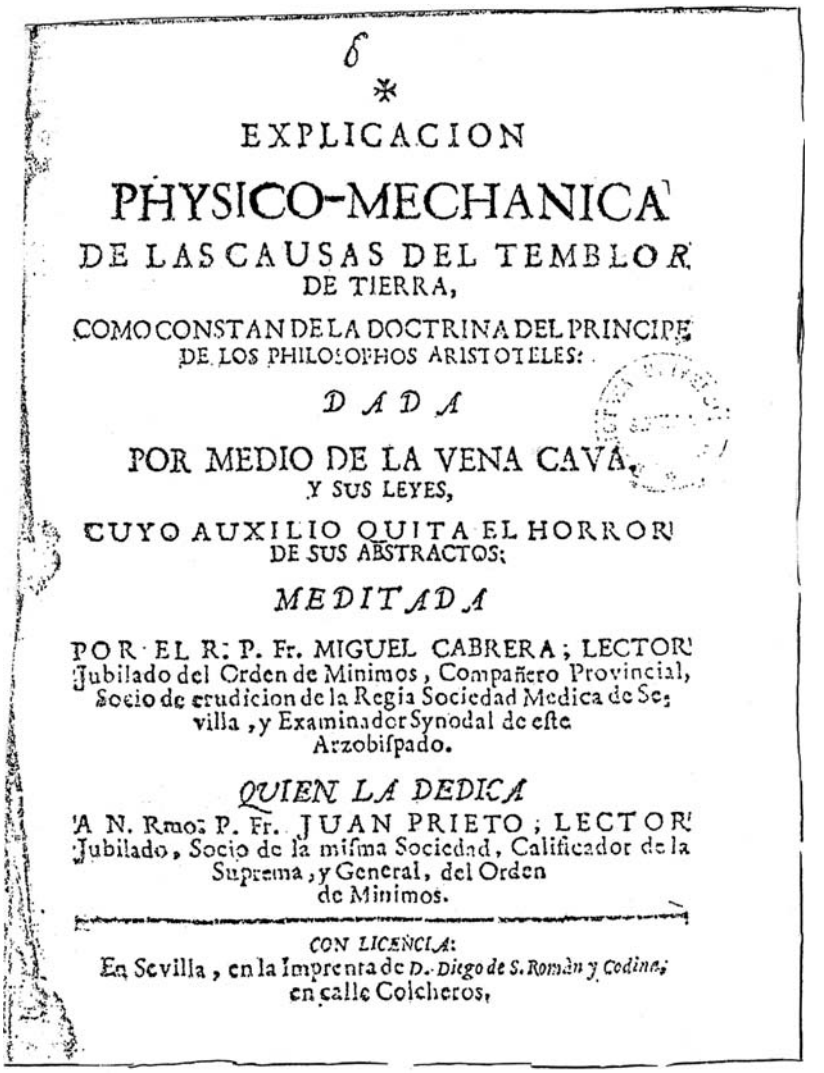
In conclusion, in Spain there were defenders of both opinions about the natural or supernatural character of the earthquake. Authors holding the modern ideas of the enlightenment (*ilustrados*) defended that the earthquake was a natural event and one should not see in it a punishment from God, while traditional clergymen considered the earthquake as a punishment or warning of God to sinners. Even as late as 1784 a Dominican friar, Alvarado, showing his rejection of modern ideas, wrote that: "we prefer to be mistaken with St. Basil and St. Augustine than to be correct with Descartes and Newton" (Aguilar Piñal 1973). An intermediate position was also presented in which the earthquake was thought to be a natural phenomenon, but God's providence used it to warn sinners to repentance. There was not, however, any reference to the debate in Europe about the optimistic or pessimistic views of the world. Spanish authors never mentioned Voltaire, Leibniz, Kant or any other of the participant in this debate.

3 The Natural Causes of Earthquakes

The authors who held that the earthquake was a natural phenomenon took this occasion to explain the general causes of earthquakes. In their explanation we can see to what extent they knew about the modern scientific ideas being developed at that time in Europe. In the end of the 17th century and beginning of the 18th century new theories about the origin of earthquakes were proposed

which substituted the traditional views based on the doctrine proposed by Aristotle. According to him the causes of earthquakes are the dried exhalations (spirits or winds) contained in cavities inside the earth which trying to escape shake the earth. The criticism to Aristotelian ideas on other subjects by the proponent of modern science extended also to the production of earthquakes. Martin Lister in England in 1648 and Nicolas Lemery in France about 1700 proposed that large explosions of inflammable material formed by a combination of sulfur, carbon, iron pyrites and other products accumulated in the earth interior produced earthquakes (Taylor 1975). These authors compared earthquakes with the explosions in mines. This theory became soon very popular and can be found in Newton's *Optics* (1718) and Buffon's *Histoire naturelle* (1749–1788).

In the writings of Spanish authors we find a variety of theories proposed, from the traditional Aristotelian doctrine to the ideas introduced by modern authors. Cabrera presented the most traditional point of view and defended the Aristotelian doctrine against the attacks of modern authors, especially Descartes, whom he called "the chief of this new sect," and their followers (called in Spain *eruditos* or *novatores*) and extended his criticisms of modern authors to Newton's gravitational theory (Fig. 4). He introduced organicistic ideas in which the earth is compared with a living organism and departed from the strict Aristotelian explanation. In these ideas he showed the influence of the *Mundus Subterraneus* (1664) by Atanasius Kircher, Jesuit professor of mathematics at the Collegio Romano, whose ideas were at that time very popular in Spain (Glick 1971; Capel 1980; Sierra 1986). Kircher had proposed the existence in the interior of the earth of three systems of conducts through which fire, water and air circulate, named by him *pyrophylacia*, *hydrophylacia* and *aerophylacia*. He proposed that the first are related to the volcanoes and connected them with a fire in the center of the earth. For Kircher the cause of earthquakes is the underground fire of the *pyrophylacia*, which heats the air in the cavities of the earth expelling it with shaking forces. Cabrera proposed a somewhat different system of conducts consisting in a large cavity in the interior of the earth, following its axis with many ramifications, in which water and winds circulate. He called this cavity *vena cava,* in analogy with the main vein in the human body. In fact Cabrera thought that this cavity and its ramifications function in the earth as the veins in animals and men. He supposed that all phenomena in the earth (winds, fountains, earthquakes, etc.) could be explained in terms of this system, in analogy with the function of veins in living organisms. Thus he stated that earthquakes could be considered as "sicknesses of the earth". In the Lisbon earthquake, the shaking propagated through the ramifications of the "*vena cava*" explained how it was felt as far away as Germany. He stated also that the influence of the Sun, Moon and stars affects the occurrence of earthquakes in the same way as it affects living organisms. He refuted nominally the opinions of Nifo and López de Amezua and their criticism of Aristotle, and Feijoo's electrical theory.



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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; LECTOR Jubilado del Orden de Minimos, Compañero Provincial, Socio de erudicion de la Regia Sociedad Medica de Sevilla, y Examinador Synodal de este Arzobiſpado.

QUIEN LA DEDICA

A N. Rmo. P. Fr. JUAN PRIETO; LECTOR Jubilado, Socio de la miſma Sociedad, Calificador de la Suprema, y General, del Orden de Minimos.

CON LICENCIA:

En Sevilla, en la Imprenta de D. Diego de S. Roman y Codina, en calle Colcheros.

Fig. 4 Miguel Cabrera's explanation of the origin of earthquakes

Nifo followed with certain criticisms the traditional Aristotelian doctrine, and explained that the cause of earthquakes is dry exhalations produced by winds, that penetrate through cavities inside the earth. For this reason, earthquakes are more frequent in spring and fall, when winds are stronger. In a like manner, Trebnal followed in part the Aristotelian doctrine. He showed his knowledge of the modern theories, making references to the French Antoine Pluche and the ideas presented by Roche and Feijoo, but found insufficient

their explanations. He proposed that the main cause of earthquakes is the mechanism of the elastic force of condensed air trapped in cavities inside the earth, without the need of the action of fire. Trebnal proposed that the force of the sea introduces the air in these cavities and when the air is sufficiently condensed it releases its elastic energy shaking the ground. He quoted modern authors like Robert Boyle and Nicolas Lemery in this context.

Some authors adhered to the more modern theory of the explosive nature of earthquakes. Barco who wrote in Huelva, where the earthquake was very strongly felt, compared the origin of the earthquake with the explosion in a mine. For him the accumulation of inflammable materials like sulfur, nitrate and bitumen inside the earth caused these explosions by the contact with rarified air and fire. Barco examined the problem about where the shaking began, and located "focus" of the earthquake under the ocean nearer to the African coast than to that of Portugal. He assigned the origin of the tsunami to the motion of the ocean bottom and explained the occurrence of aftershocks as produced by the inflammable materials, which had not been exploded in the first shocks. Roche, following modern theories and quoting Lemery, also assigned the cause of earthquakes to the explosion of the mixture of inflammable materials accumulated at certain places inside the earth. Ortiz Gallardo combined the explosive nature with Kircher's theory of the existence inside the earth of conducts of fire, water and air. The fire in these conducts, which gets in contact with the accumulated inflammable material, is the true cause of its explosion. He stated that in the 1755 earthquake, the frequent rains and snow in the winter of the previous year, the moderate summer and, again, many rains in the fall, produced an accumulation of a mixture of water with inflammable materials, which favored its explosion.

Feijoo presented the most modern ideas about the origin of earthquakes in his five letters (Glendining 1966; Ordaz 1983). After refuting in the third letter the common ideas held at the time for the cause of earthquakes, especially the collapse of underground cavities and the explosion of inflammable material inside the earth, he presented in his fourth letter his new theory in which electric charges produced earthquakes. He stated that, in the same way that lightning and thunder are produced in the atmosphere by the electricity of the clouds, earthquakes are caused by the electricity accumulated inside the earth by the action of vitreous materials. William Stuckley in England in 1750 and Giovanni Battista Beccaria in Italy in 1753 had proposed already these ideas about the electrical nature of earthquakes (Taylor 1975). Feijoo didn't mention these authors and claimed for himself the originality of this theory. For him the electrical theory explained well, in the case of the Lisbon earthquake, that it was felt at the same time in so distant places up to central Europe, since electricity propagates at very high velocity. However, he didn't rule out completely the explosive nature, as electricity could have also caused the explosion of concentrations of inflammable materials accumulated in some places inside the earth.