Two Hundred Years Ago the *Dissertatio de terrae motu Mórensi* and the First Isoseismal Map Appeared

by P. Varga, G. Timár, and M. Kiszely

INTRODUCTION

Two hundred years ago, in 1814, according to the order of the Royal Governor Council, two eminent professors of the Royal University of Pest, Pál Kitaibel and Ádám Tomcsányi, published a 120-page book written in Latin on the M 5.4 earthquake that occurred in the vicinity of Mór, Hungary on 14 January 1810. This book (short title: *Dissertatio de terrae motu Mórensi*) also includes a 66 cm × 47.5 cm map, the first isoseismal map in the history of seismology (Kitaibel and Tomcsányi, 1814).

This seismic event was not large in terms of magnitude. About 500 such earthquakes occur worldwide annually, and there have been significantly greater earthquakes in Hungary. Even so, this earthquake caused a relatively large amount of damage, and it was felt in remote locations as far away as Sopron, Vienna, and Prague. The earthquake was associated with the Mór graben (Weber and Süle, 2014), which has an axis connecting the cities of Székesfehérvár and Komárom and separates the mountain ranges of Bakony and Vértes. This geological structure shows moderate seismicity, and its most recent significant event took place in Oroszlány (29 January 2011, M 4.5) (Fig. 1) (Kiszely and Győri, 2015).

Since the middle of the eighteenth century, the most important European earthquakes were followed by governmental damage assessments that stimulated scientific research for understanding the nature of earthquakes. Perhaps the first such centrally organized survey of an earthquake took place in connection with the 1755 Lisbon earthquake (M 8.5–9.0, Gutscher *et al.*, 2006), which affected an area of $\sim 800,000$ km^2 with a death toll of some 100,000 people (Chester, 2001).

Similar damage assessment was initiated by Queen Maria Theresa in 1763 in Hungary after the earthquake that struck Komárom (M 6.4). Following the 1783 Calabria earthquake, for the first time in its history, the government of the Kingdom of Naples requested academic institutions to investigate the effects and cause of an earthquake sequence. In the case of this seismic series, scientists experienced in the natural sciences—and more specifically in the earth sciences—also participated in the examination of the effects of earthquakes. This fact is of great importance, even though we know that these professionals worked partly independently and without coordination (Davison, 1927).

The committee organized by the Royal University of Pest for the study of the 1810 Mór earthquake worked according to a uniform plan approved by the University Council. A committee led by three professors familiar with different fields of earth sciences, together with local county officials, worked very quickly and efficiently. The detailed examination of the area hit by the earthquake began shortly after the earthquake on 3 February and was completed before the end of the month. The report of the committee, which included an early version of the first isoseismal map in the history of the earthquake research, was discussed by the Council of the University and on 10 April 1810 was sent to the Royal Governor Council. This report served as a basis of the book "Dissertatio de terrae motu Mórensi," published four years later in 1814.

EARTHQUAKE THEORIES FROM THE SEVENTEETH CENTURY TO THE FIRST DECADES OF THE NINETEENTH CENTURY

The limited knowledge about the Earth's interior was the reason that human imagination was employed to propose theories on the nature of earthquakes. Starting in the middle of the seventeenth century, many excellent scientists wrote treatises on seismological subjects. Martin Lyster (1639–1712), who was solving problems of geological and animal taxonomy and developing mirror-manufacturing technology for Newtonian telescopes, like several other authors of that age, explained the origin of earthquakes as chemical processes that involved the decomposition of pyrites (Lyster, 1684). An essay by the extremely versatile Robert Hooke (1635–1703) that was published two years after his death connected earthquakes with orogenic forces (Hooke, 1705). John Flamsteed (1693), the first Astronomer Royal, remembered the tragic earthquake in Catania and used it to discuss the problem of the spatial and temporal distribution of seismic activity in 1693. Tobias Mayer (1723–1762), a professor at Göttingen University who was famous throughout the world due to his work in astronomy and cartography, in his study on earthquakes explained this phenomenon as the effect of gravitational mass redistribution (Gray Forbes, 1967).

Seismological theories before 1800 can be divided into three groups: ideas based on (1) mechanical movements, (2) the central fire hypotheses, and (3) models based on the effect of electrical phenomena. Regarding these theories, the following comments are needed:

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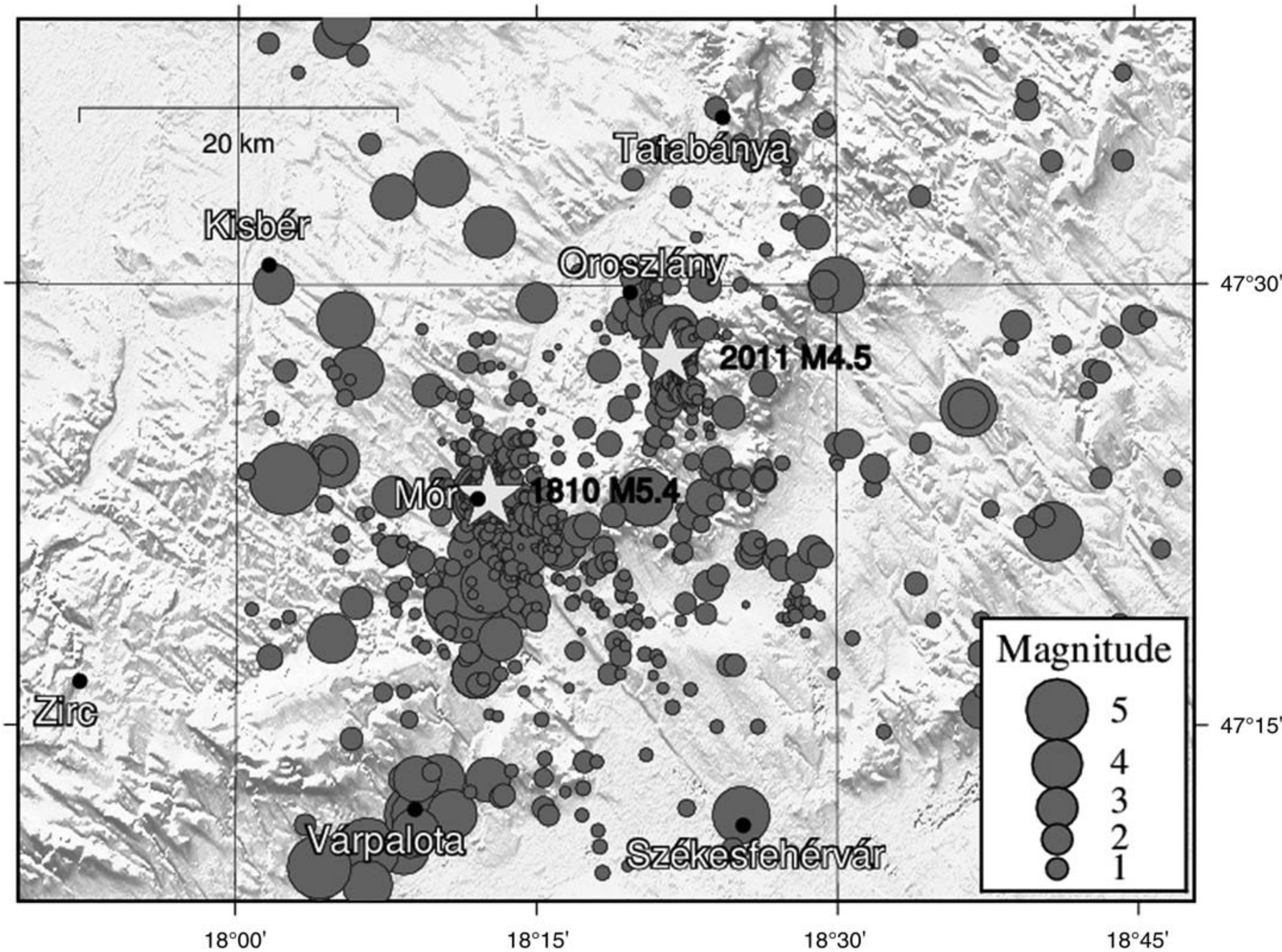


▲ **Figure 1.** Seismicity of Mór graben. The events of Mór (1810 M 5.4) and Oroszlány (2011 M 4.5) are marked with white stars.

1. The mechanical theory by René Descartes (1596–1650) explained terrestrial processes, including earthquakes, by mechanical stresses due to the cooling of the Earth (Descartes, 1644).
2. The most common theories of earthquake science of the baroque era were connected with fire or fires inside the Earth's core and mantle. The most influential works of this type belong to German Jesuit Athanasius Kircher (1602–1680). In the Kircher (1678) model, in addition to the central fire, further fire sources are included that are responsible for the activity of both volcanoes and earthquakes. The fires—the source of which are sulphur, bitumen, and coal—are interconnected by channels. Buffon (1707–1788) explained earthquakes as the underground explosion of burning materials (Buffon, 1749). Although he accepted the idea of a central fire, in his dual thermal-mechanical theory Gottfried Wilhelm Leibniz (1646–1716), relied on the mechanical idea of Descartes (Leibniz, 1749). Leibniz was also the first to recognize that some rocks originated from inside the Earth, whereas other rock types are formed at the Earth's surface.
3. From the second half of the eighteenth century, the emergence of earthquake theories based on electrical phenomena were connected with contemporary electrical experiments. William Stukeley (1687–1765), the pioneer of prehistoric archaeology, assumed that earthquakes are generated as a result of electrical discharges between the solid Earth and the atmosphere (Stukeley, 1750). To illustrate how widespread the electrical discharge earthquake theory was in the second half of the 1700s, we recall what happened after the earthquake in 1763 in Komárom (M 6.5). The residents of the city asked the authorities to build metal pyramids to reduce the effect of aftershocks, because the pyramids were thought to dissipate the electricity of the Earth.

The whole of mankind was shocked by the great earthquake in Portugal in 1755 that almost completely destroyed the world's fourth-largest city, Lisbon. After this disaster and for the first time in history, governmental action took place that provided help for the victims of a major disaster, took stock of exact losses due to the earthquake, and took steps to reduce the impact of future earthquakes. José I, King of Portugal, gave almost absolute power to the Minister Sebastião José de Carvalho e Melo

(1699–1782) (in 1770, Marquis of Pombal). Melo's contribution in seismology is his questionnaire that was sent out to all parishes in the country. The questionnaire asked about animal behavior before the earthquake, about water level variations in wells, and about the number and kind of building destruction.

Emmanuel Kant, the philosopher, showing high interest throughout his career in the natural sciences, wrote three significant studies in 1756 (Kant, 1756a,b,c) about the impact of the Lisbon tragedy. Kant's two main findings were that the effect of earthquakes spread along underground channels (parallel to mountain ranges and rivers) to great distances and that the seismic events are triggered by chemical processes. Also due to the impact of the earthquake of 1755, the extremely versatile John Michell published the first modern seismological study (Michell, 1760). Michell attached particular importance to the volume of the Earth's interior, where forces are generated and from which the effect of these forces, in the form of vibrational motion, propagate. Michell described three methods to determine the location of the earthquake source. Using these methods, he arrived at the correct conclusion that the hypocentrum of the Lisbon earthquake was under the Atlantic Ocean, more than a hundred kilometers from the city of Porto. He proposed a method to determine the depth of the earthquake source based on inclinations of building cracks resulting from earthquakes.

The Calabrian earthquake sequence in 1783 also contributed to the development of seismology. This was the first earthquake for which scientists were involved in the evaluation and analysis of the damage caused by the seismic event. As part of this work, the first map of the damage distribution was completed by Schiantarelli and Stile (1784). The consequences of the Calabrian earthquakes were investigated by two foreign scientists. The British ambassador to the Neapolitan kingdom, William Hamilton (1783), recognized the amount of damage was strongly dependent on the local geological conditions. The French geologist de Déodat Gratet de Dolomieu gave the first estimate of the earthquake's source size of an earthquake source, and he provided measurements of the surface displacements produced by the earthquakes (1809).

THE ORGANIZATION AND IMPLEMENTATION OF RESEARCH ACTIVITIES AFTER THE EARTHQUAKE OF MÓR

On 17 January 1810 at a few minutes after 6 p.m. local time (the local time of the place in question is determined on the basis of its geographical latitude), a strong earthquake rocked Mór and its surroundings. The incoming shock stopped the clock of the Vienna observatory at 5 hr 53 min local time (there is no information about the time of the clock failure in the Buda Observatory, which was nearer to the epicenter). Using the locations of Vienna and Mór, the earthquake apparently occurred at 6 hr 10 min local time (Réthly, 1910). According to observers in the epicentral area, the earthquake occurred between 6 hr 45 min and 7 hr 30 min. The differences in time of occurrence reported using observatory and local clocks shows that time data from the epicentral area contains about a half-hour uncertainty. It can be also stated that the local authorities took action quickly. Fifty minutes after the event, József Novák, the county physician, was already on his way to visit the area hit by the earthquake. He gathered much useful data, which he sent on 6 March to the Council of the Royal University of Pest. In his report, Novák asked for the help of professors from his alma mater to investigate the cause and the consequences of the earthquake. Earlier, on 23 January, the Royal Governor Council requested a report from the county and sent out a questionnaire for data collection (Table 1). On the same day, the Royal Governor Council (Réthly, 1910) requested from the University a posting of professors to "Mór and the bordering settlements… and … to discover with physical and chemical experiments" what happened. Accordingly, the Rector gave instructions on behalf of the University Council to professors Pál Kitaibel (chemistry and botany), Ádám Tomcsányi (physics and mechanics), and Lajos Fabrici (agriculture and land

Table 1
The Questionnaire of the Royal Governor Council to All Settlements Affected by the Earthquake

1. Before the earthquake was there stronger cloudiness or any other weather event?
2. Was there fear in animals or humans prior the unrest? Did someone hear a subterranean growl?
3. Was there observable change on the barometer or thermometer?
4. At what time did the first impulse arrive?
5. How long was its duration?
6. Was it possible to determine the direction of the shock? Was the direction detectable from the surface undulation or from crack formation?
7. Was the quake was of undulating nature?
8. Were there phenomena due to the earthquake like flames, water eruptions, clicks, or pops?
9. Were there detectable changes during the earthquake in temperature and air pressure?
10. Did cracks arise in the ground and the rocks?
11. At which place was the earthquake the strongest? Where was its focal location?
12. What phenomena become permanent (oscillation, underground noise)?
13. Was there change observed in the coal mine at Zselye?
14. Did any changes arose in the quarrying layers?

survey) to "examine scientifically the cause and impact of the detected earthquakes and accompanying phenomena."

The three university professors were well qualified for this work. Kitaibel was working intensively in geography, hydrology, and mineralogy; Tomcsányi was active in many fields of solid state physics and electricity; and Fabrici was familiar with geodetic measurements and cartography. In addition, all three professors—due to the University curricula—were familiar with the contemporary geological literature. The University defined a detailed work plan for the three professors and provided physical, chemical, and mineralogical research tools. Before the departure to the area affected by the earthquake, Tomcsányi (Varga, 2008) investigated some rock samples of dolomite, which is the most significant component of the surface geological formations of the area, with "electromometer (?) and capacitor." He found that this rock has no significant electrical influence on its environment.

The professors began their field work on 4 February, together with József Novák and other county officials. Under difficult winter conditions, they traveled continuously and stayed in the area affected by the earthquake until 17 February. In addition to public interviewing and damage assessment, the research team carried out hydrological and geological observations (such as investigating water discharge and the chemical composition of water in the springs and describing the composition of the rocks that formed the local geological formations) and measured the earthquake-induced fissures (at the village Sikátor, they found several crevices, the longest and largest of which was 200 fathoms in length and one fathom wide [one fathom is ~1.9 m]). The research by these investigators led them to examine building damage, the possible causes of the damage, and the spatial distribution of the damage. The professors also recorded the dates of aftershocks. The number of aftershocks was the highest during the first night after the earthquake, their number gradually decreased with time, but even in 1812 some were observed.

The professor's report was significantly augmented by the work of József Novák, who collected data based on the questionnaire of the Royal Governor Council. The three professors submitted their report, with an attached map of the damage distribution, on 19 March 1810 to the University Council, who in turn submitted it to the Royal Governor Council on 10 April. The king was informed about the report on 1 May. Because of the significant domestic and international interest in this earthquake, on 10 May 1810 the king ordered the printing of the document. This had also been urged by the professors of the University of Vienna.

By his letter on 9 February 1812, the Royal Governor Council ordered the director of the University Printing House to publish the book by Kitaibel and Tomcsányi together with a map of the area affected by the earthquake. The printing of the book, *Dissertatio de terrae motu Mórensi*, was completed in 1814. The greater part of the text of the book is identical to the text of the report of 1810. The differences are formal: the name of Lajos Fabrici is missing because he died on 2 August 1810, and the book contains a large number of contemporary scientific references.

DISSERTATIO DE TERRAE MOTU MÓRENSI, 1814

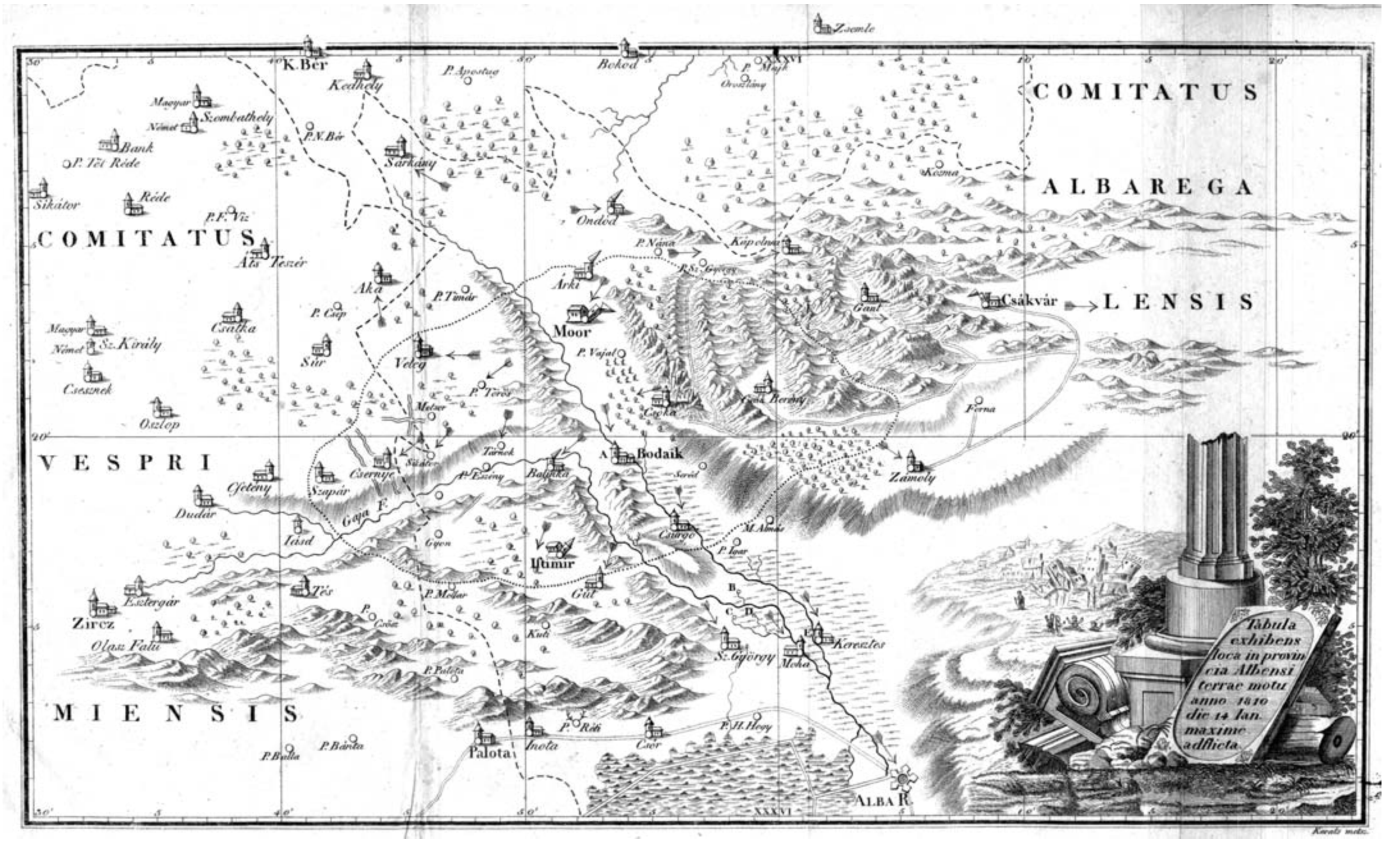
The printed book is surprising to modern readers for two reasons. First, although the authors of the book are teachers of chemistry and botany (Kitaibel) and physics (Tomcsányi), Fabrici, who was an author of report but died before book was published, was responsible for teaching agriculture and land survey. Their report to the University was prepared only a month after the earthquake (it was signed on 19 March 1810 by the three professors) and shows a thorough geological, seismological, and hydrological knowledge by the authors. In addition, the large number of references used in the text of the book suggests that the authors also were familiar with the activity of their contemporaries. They quote more than 50 authors (some of them are still known: Newton, Buffon, Gay-Lussac, Biot, Dolomieu, Volta, Stukeley, Tobias Mayer, Dalton, *Lavoisier*, Desormes, *Clement, Vivenzio*, Hell, and Sajnovics).

The text of the book, as was confirmed by reviewers from the Royal Court, is objective and accurate. To illustrate this, the definition of the term "earthquake" can be quoted from the first chapter of the book ("The earthquake in general and its various implications"): "The earthquake is a violent shock of the Earth's surface, affecting a large area. Although this phenomenon lasts usually only few seconds, during which terrible effect can be caused by it."

The prognostic phenomena of earthquakes, collected from different sources, are also described in this chapter. The opinion of Kitaibel and Tomcsányi on this issue is, "Sorrowful thing is that it is not easy to observe secure and definite signs from which the oncoming peril can be predicted." Also in this part of the book, the authors explain why the upper parts of the buildings are damaged by the earthquakes. The authors conclude that, because an earthquake spreads over long distances, its source should be deep in the Earth.

The second chapter of the book has the title, "In particular, on the Mór earthquake which since the 14 January 1810 already for the third year raging in Fejér County." Here Kitaibel and Tomcsányi dealt in detail with the morphology and description of the rocks of the area. Rocks forming mountains on both sides of the Mór graben are dolomite, named for Déodat Gratet de Dolomieu, who first described these rocks in *Journal de Physique* in 1792. "This rock was already known earlier in Hungary, however, under a different name" can be read in this part of the book. This statement is followed by a description of the chemical composition of the dolomite. Turning to hydrological issues and on the basis of laboratory investigations, it was reported that the physical properties and chemical composition of all source waters are similar.

This part of the report is followed by the most interesting scientific conclusion of the book. "Those settlements where the devastating impact of the earthquake was the most significant… were separated on the map with a dotted line. The more we move away from any direction from the encircled area the fewer traces are left from the damage." This means that Kitaibel and Tomcsányi plotted an isoseismal on their map and in this way produced the first isoseismal map (Varga, 2008; Fig. 2). Before



▲ **Figure 2.** The first isoseismal map published in Kitaibel and Tomcsányi (1814) *Disertatio de terrae motu Mórensi*.

this map, isolines were barely used in cartography (Timár, 2015). Among the rare early examples are the global representation of the Earth's magnetic field by Halley (1705) (Cook, 1998) and the first isobath map of Marsigli (1725) (Gercsák, 2009).

The main sources of water on the Kitaibel and Tomcsányi map are marked with A, B, C, and D. Major earthquake-generated ground displacements and cracks are also indicated. The accuracy of the isoseismal line is supported by the fact—as stated by Réthly (1960)—that places with cracks on the Earth's surface, *soil liquefaction, and earthquake-generated springs* were found only within the isoseismal.

On the basis of the analysis of building damage, it was established that the low farmhouses built of adobe suffered less damage, but in most cases their walls suffered cracks. Brick or limestone houses were more damaged, especially to the arch of the structure. The most severe damage occurred in higher buildings, towers, and chimneys.

The third part of *Dissertatio de terrae motu Mórensi* deals with the causes of earthquakes, particular with regard to the Mór earthquake. The book describes theories on this issue that were popular until the beginning of the nineteenth century. At that time some authors proclaimed that earthquakes are generated as a result of underground fires—not from a central fire as assumed by Athanasius Kircher, but from fire sources that are closer to the Earth's surface. According to Buffon, Gay-Lussac and *Lavoisier* stress generation in the Earth's interior is caused by water and water vapor generated during the warming effect of the underground fire. William Stukeley's theory based on electrical effects was rejected by Kitaibel and Tomcsányi. Their criticism is connected with the observation that the propagation of seismic impact takes a measurable amount of time, whereas, in the case of the electric effect, the time of propagation cannot be detected because the speed is too fast. The authors arrive at the conclusion that the "elastic fluids" penetrating from the surface to depth and accumulating there generate vibrating movements, which spread as wave motion and decrease gradually as a function of the distance from the source. In other words, the authors had an idea close to that of Buffon, Gay-Lussac, and *Lavoisier*. The authors recognized that their idea cannot be considered as fully established due to their incomplete knowledge.

The last part of the book deals with ideas concerning protection against earthquakes, as proposed from ancient times until the early nineteenth century. "Unfortunately, we are compelled to admit that we did not know about such a possibility" is a conclusion of the authors.

CONCLUSIONS

The *Dissertatio de terrae motu Mórensi* earned its reputation primarily because of the attached map, the world's first isoseismal map. The research following the 14 January 1810 earthquake and the book based on the research were important in many other ways. For the first time in the history of seismology, an academic institution (the Royal University of Pest) sent out a group of experts who had the necessary qualifications in the Earth sciences to investigate an earthquake and who based their conclusions on land surveying and on geological, hydrological, chemical, and physical experiments. Another new development was how the authors classified and evaluated the observed building damage. Modern readers are impressed with how thoroughly the authors analyzed their data and reviewed the published literature. Kitaibel and Tomcsányi were aware of how far they were from understanding of the nature of earthquakes, and therefore they closed their work with a quotation from Seneca: "There will be a time when our successors will be surprised that we had been unable to perceive a matter so easily understandable."

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