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Historical Earthquake Theories from ARISTOTLE to KANT

By ERHARD OESER*)

With 7 Figures and 1 Table

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Historische Erdbeben-theorien von ARISTOTELES bis KANT

Zusammenfassung

In der Antike lieferte ARISTOTELES als erster eine umfassende rationale Theorie der Erdbeben. Im Gegensatz zu mythischen und astrologischen Theorien (Konjunktion von Planeten, Kometen) faßte er Erdbeben als analoge Erscheinungen zu atmosphärischen Ereignissen (Blitz, Donner) auf und lieferte eine Klassifikation der Erdbeben. Die Erdbebenforschung des Altertums, des Mittelalters und der Frühneuzeit zeigt nur geringe Weiterentwicklungen und beruft sich vorwiegend auf Aristoteles. Erst in der frühen Neuzeit entstehen im Zusammenhang mit der Copernikanischen Astronomie und im Rahmen von Theorien der Erdentwicklung neue und zum Teil höchst phantastische Vorstellungen von den Ursachen der Erdbeben und ihrer Bedeutung für die Gestaltung der Gebirge. In der Zeit der Aufklärung war das Erdbeben von Lissabon (1755), dem die Beben von Callao und Lima 1746 vorausgingen und das große Erdbeben von Kalabrien 1783 folgte, Anlaß zu einer Diskussion um die Ursache der Erdbeben, an der sich auch KANT beteiligte. Aus dieser Diskussion resultierte eine Vielfalt von alternativen Theorien über Erdbeben, in der sich vor allem die zeitgenössischen physikalisch-chemischen Theorien und Experimente widerspiegeln.

Abstract

ARISTOTLE was the first to deliver a rational theory of earthquakes. In contradistinction to mythical and astrological theories (conjunction of planets, comets) he considered earthquakes in analogy to atmospheric events (thunder, lightning) and drew up a classification system of earthquakes. The occidental research of earthquakes underwent only minor developments during classical times and the middle ages. Only in modern times new and in part very weird ideas on the causes of earthquakes and their impact on the development of mountains emerged in connection with Copernican astronomy and in the framework of theories of the development of the earth. In the age of enlightenment discussion about the causes of earthquakes was triggered by the Lisboa earthquake (1755), the earthquake of Callao and Lima (1746) and Calabria (1783). This discussion, in which among others the German philosopher KANT participated, resulted in a variety of alternative theories of earthquakes, reflecting mainly contemporary theories and experiments in physics and chemistry.

*) Author's address: Dr. ERHARD OESER, Institut für Wissenschaftstheorie und Wissenschaftsforschung der Universität Wien, Sensengasse 8, A-1090 Wien.

1. Introduction

Historical accounts of earthquakes usually give evidence, directly or indirectly, of contemporary theories on earthquakes. It is a fascinating task to follow the development of human conceptions of the causes and mechanisms of earthquakes which obviously runs parallel to the development of physics and chemistry. There are important reasons to refer to historical earthquake theories in a monograph about historical earthquakes. This monograph mainly consists of a documentation of important events of the past. Contemporaries describe not only damage to buildings caused by the earthquake but also what they observed during the event. Many of them do it very carefully, however, with a background information of earthquake theories of the respective time. This background information gives them not only a special interpretation but even a particular perspective – may be very different from ours – of what they felt, saw and realized during the event. Therefore – also for practical reasons – it seems helpful to learn more about the contemporary earthquake theories¹⁾.

First a general metatheoretical and historical remark:

Theoretical explanations of earthquakes are made against an obvious pragmatic background. In all fields of natural sciences theoretical explanations serve prognosis. Both are logically structured as deductions. An astronomical theory of the solar system for instance explains both past and future events such as planet positions, eclipses of sun and moon. The same applies to earthquake theories.

Yet there are differences:

- 1) Earthquakes are not repetitional phenomena as most astronomical events but singular historic events.
- 2) Earthquakes are caused by a multitude of complex interrelated causes, whereas in astronomy the supposition of gravity suffices.

These epistemological difficulties are the reason for the historical fact that there have been competing theories at the same time since the beginning of scientific earthquake research in Ancient Greece until the 19th century. The contrast between “Neptunists” and “Volcanists” or “Plutonists”, most stressed in the 19th century can already be found with Pre-Socratic researches, although later the pneumatic theory prevailed because of the authority of ARISTOTLE. This contrast between Neptunists and Volcanists returns in early Modern Times, in addition there were still some animistic theories stemming from ancient times. The comparison between the earth and living beings was not just a heuristic analogy, but was taken as reality, even by the great astronomer KEPLER. Increased knowledge on chemical reactions could refute animistic speculations. But the structure of the interior of the earth was still unknown. Thus divergent theories of the development of the earth could be conceived on a speculative basis.

¹⁾ Theories of earthquakes from ARISTOTLE to KANT are represented in this paper. The theories of the nineteenth century, that constitute the foundation of today's opinions, will be treated in a following part.

In spite of all historically provable variations of theories on earthquakes, a coherent basic structure can be seen, always dealing with

- 1) the proof of the real cause of earthquakes, such as water, fire, air or ether,
- 2) the processual mechanisms of earthquakes, such as the lifting or bursting of the earth's surface due to the pressure of heated air or the crumbling of the earth's crust eroded by water etc. and finally
- 3) a classification of earthquakes according to different phases of earthquakes and according to their impact.

The following chapters are trying not only just to list and describe historical theories of earthquakes in temporal succession, the aim is rather the reconstruction of the research context in which these theories have developed not independent of each other. It will be shown how theories have developed in competition on different levels and how finally these theories prevailed over physico-chemical theories.

The method to be used is the following: first the historical material (if possible original works) is analysed and documented. Then the history of its development and its structural features are reconstructed. The underlying principle is that of self-interpretation, which works in the reversed temporal succession, since the author of almost every comprehensive theory of earthquakes accompanies his presentation with explicitly citing precursors and opponents at the beginning or at least afterwards or in addition. ARISTOTLE, for example, continues Ionic philosophy of nature and most authors in the Middle Ages and in modern times are in the Aristotelian tradition. But KANT breaks with this tradition, he rather relies on researchers such as RAY and BUFFON who had tried to solve this problem within comprehensive theories of the evolution of the earth.

But a continuous reason in two thousand years to create theories have been historic earthquakes themselves. Thus it is not strange that the scientific research of earthquakes has its origin in Greece, since there were many severe earthquakes, not only in mainland Greece, but also on the isles and in Asia Minor. The most famous devastating earthquake of Greek Antiquity in 373 B.C., when the town Helice was drowned in the sea and the town Bura vanished in a big gap in the earth, happened during the life of ARISTOTLE. The destruction of Pompeji and Herculaneum, when PLINY died, was the reason for SENECA to deal with theories of earthquakes.

MEGENBERG, the author of the first natural history in German, was impressed by the earthquake in Villach (Austria) in 1348, LEONARDO DA VINCI by the seaquake in 1489 and Italian authors of the 18th century saw the severe earthquakes in 1703 and the mysterious genesis of Santorin in 1707.

A sudden rise in the efforts invested in such an earthquake theory takes place in the 18th century, where several severe earthquakes occurred, especially the Lisboa earthquake (1755), the earthquakes in South America (Callao and Lima 1746) and Calabria (1783).

2. Theoretical Explanations of Earthquakes in Classical Antiquity

As is wellknown the works of authors of classical antiquity who theorized about the natural causes of earthquakes already in the fifth century B.C. are lost²⁾. What we know about them is based on accounts by ARISTOTLE^{3,4)} or by SENECA⁵⁾.

Whereas ARISTOTLE himself created a scientific earthquake theory of his own, SENECA was not an expert, but rather a skilled and rhetorically trained author who 300 years later copied – in part superficially – from Greek works in order to write the chapter on earthquakes in his *Questiones naturalium*. Thus we have to expect misunderstandings, inaccuracies and gaps in his presentation.

In addition he even suppresses the name of the author of a theory. Nevertheless this synoptic account by SENECA is – also according to HUMBOLDT – the most important source of our knowledge of the whole seismological theory of ancient times. But ARISTOTLE, the only known author of an earthquake theory we can read in its original form, did not try to present with rare account on his predecessors a complete doxography of Greek seismologists.

But the basic development of classical earthquake theories and their main types can be clearly seen in spite of fragmentary and unreliable sources.

THALES OF MILET (around 600 B.C.) who considered the earth to be swimming on water like a ship, regarded earthquakes as shaking of earth on the water and water erupting through the earth (see Fig. 1)⁶⁾. To verify this he pointed out that after each earthquake new fountains sprung up. SENECA is opposed to this theory because of the following reasons: If the earth were supported by water and sometimes shaken by it, there would always be earthquakes and we would not be amazed that the earth is shaken but that it remains at rest. The second reason is that the amount of new water is negligible:

“Thales Milesius totam subiecto iudicat umore portari et innare, sive illud oceanum vocas, sive magnum mare, sive alterius naturae simplicem adhuc et umidum elementum. Hac, inquit, unda sustinetur orbis velut aliquod grande navigium et grave his aquis quas premit ... Hanc opinionem falsam esse non est diu colligendum. Nam, si terra aqua sustineretur et ea aliquando concuteretur, semper moveretur, nec agitari illam miraremur sed manere; deinde tota concuteretur, non ex parte; numquam enim navis dimidia iactatur. Nunc vero terrarum non universarum sed ex parte motus est. Quomodo ergo fieri potest ut, quod totum vehitur, totum non agitetur, si eo quo vehitur agitatum est? ‘At quare aquae erumpunt?’ Primum omnium saepe tremuit terra et nihil umoris novi fluxit. Deinde, si ex hac causa unda

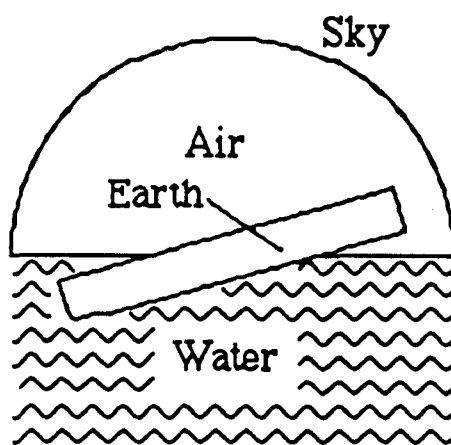


Figure 1. Earthquake mechanism according to THALES OF MILET. The earth is regarded as a disk swimming on water. The earthquake corresponds to the tiltings of this disk, due to temporary motions of the water.

prorumperet, a lateribus terrae circumfunderetur, sicut in fluminibus ac mari videmus incidere ut incrementum aquarum, quotiens navigia desidunt, in lateribus maxime appareat. Ad ultimum non tam exigua fieret quam tu dicis eruptio nec velut per rimam sentina subreperet, sed fieret ingens inundatio ut ex infinito liquore et ferente universa.”⁷⁾

ANAXIMENES (2nd half of the 6th century B.C.) held a theory of collapse fitting in rather well with the limestone areas and their multitude of caves. ARISTOTLE points out in reply to this opinion that it should be possible to observe the earth sinking in many places⁸⁾:

Ἀναξίμενης δέ φησι βρεχομένην τὴν γῆν καὶ ξηραίνουμένην ῥήγνυσθαι, καὶ ὑπὸ τούτων τῶν ἀπορρηγνυμένων κολωνῶν ἐμπιπτόντων σειέσθαι· διὸ καὶ γίνεσθαι τοὺς σεισμοὺς ἔν τε τοῖς αὐχμοῖς καὶ πάλιν ἐν ταῖς ὑπερομβρίαις· ἐν τε γὰρ τοῖς αὐχμοῖς, ὥσπερ εἴρηται, ξηραίνουμένην ῥήγνυσθαι, καὶ ὑπὸ τῶν ὑδάτων ὑπερυγραινομένην διαπίπτειν. Ἔδει δὲ τούτου συμβαίνοντος ὑπονοοτούσαν πολλαχού φαίνεσθαι τὴν γῆν.

DEMOCRIT (460–371 B.C.) believed that heavy rainfalls mixing with water enclosed inside the earth caused the earth to tremble⁹⁾.

Δημόκριτος δέ φησι πλήρη τὴν γῆν ὕδατος οὖσαν καὶ πολὺ δεχομένην ἕτερον ὄμβριον ὕδωρ, ὑπὸ τούτου κινεῖσθαι· πλείονός τε γὰρ γινομένου διὰ τὸ μὴ δύνασθαι δέχεσθαι τὰς κοιλίας ἀποβιαζόμενον ποιεῖν τὸν σεισμόν, καὶ ξηραίνουμένην καὶ ἔλκουσαν εἰς τοὺς κενούς τόπους ἐκ τῶν πληρεστέρων τὸ μεταβάλλον ἐμπῖπτον κινεῖν.

ANAXAGORAS (500–428 B.C.) saw the cause in ether entering the earth. A special aspect of this explanation lies in the fact that ether, as the lightest of all elements, streams upwards, the presupposition being that the earth is spherical¹⁰⁾ and its lower, uninhabited part rests on ether. If the upper stratum of the earth, that is usually completely porous, is plugged up as a con-

²⁾ Siehe CAPELLE, W.: Erdbebenforschung. – In: Paulys Real-Encyclopädie der Classischen Altertumswissenschaft, Suppl. IV, Stuttgart 1924.

³⁾ ARISTOTELES: Meteorologicorum Liber II. – In: ARISTOTELES GRAECE ex rec. Imm Bekkeri, 343b–370a, 30, Berol 1831.

⁴⁾ ARISTOTELES: Liber de Mundo. – In: ARISTOTELES GRAECE ex rec. Imm Bekkeri, 396a, 25–40, Berol. 1831.

⁵⁾ SENECA: Quaestiones naturalium Liber VI. – In: Opera omnia ab Andrea Schotto, Tom. I, p. 752–776, Genevae 1665.

⁶⁾ THALES still considered the sky a hemisphere. The first one to complement the hemisphere which was also assumed by the Babylonians to be a sphere was ANAXIMANDER (born in 610 B.C.) who thought that the stars are revolving in fiery wheels around the cylindrical earth freely floating in the universe.

⁷⁾ SENECA: Quaestiones naturalium Liber VI. – In: Opera omnia ab Andrea Schotto, Tom. I, p. 757f., Genevae 1665.

⁸⁾ 365b, 6–13.

⁹⁾ 365b, 1–6.

¹⁰⁾ According to DIOGENES LAERTIUS Diels S 9A1 and HIPPOLYTOS Diels 59A42 ANAXAGORAS assumed that the earth is flat.

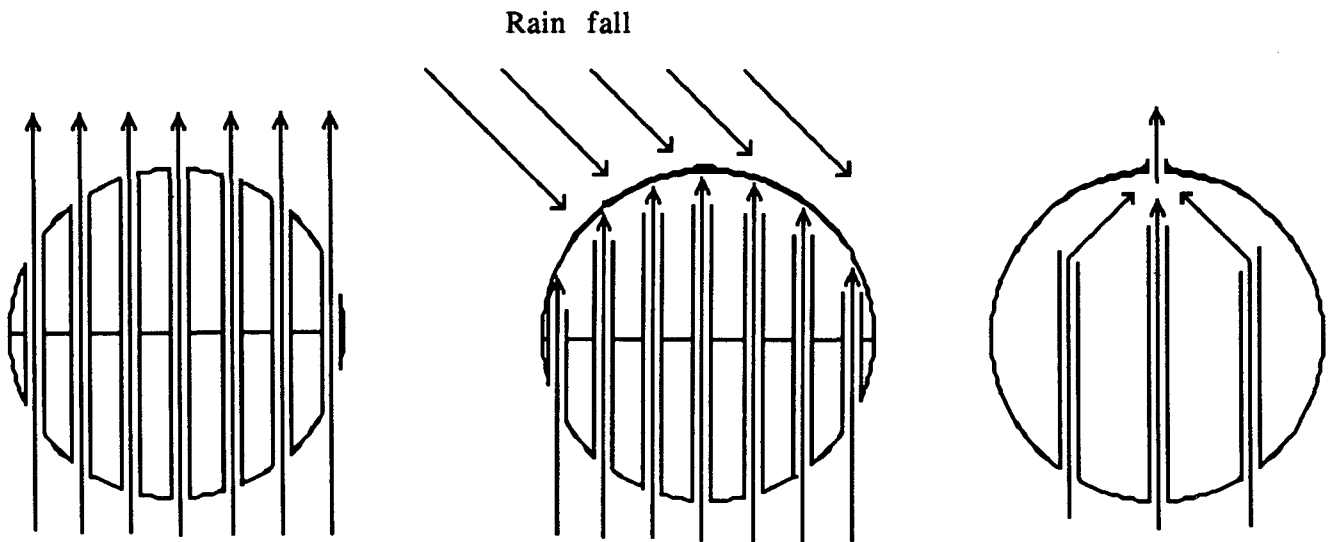


Figure 2.

ARISTOTLE's understanding of ANAXAGORAS' theories.

- Ether forces its path through pores and penetrates the earth.
- The pores are plugged up by rain water. Ether is prevented from penetrating the earth.
- Ether forcibly generates an exit and escapes. This process is associated with an earthquake.

sequence to the downpours, the ether will obtain an exit forcibly – by means of an earthquake¹¹⁾.

Ἄναξαγόρας μὲν οὖν φησὶ τὸν αἰθέρα πεφυκότα φέρεσθαι ἄνω, ἐμπύπτοντα δ' εἰς τὰ κάτω τῆς γῆς καὶ τὰ κοῖλα κινεῖν αὐτήν· τὰ μὲν γὰρ ἄνω συναληθίζθαι διὰ τοὺς ὄμβρους, ἐπεὶ φύσει γε πᾶσαν ὁμοίως εἶναι σομφήν, ὡς ὄντος τοῦ μὲν ἄνω τοῦ δὲ κάτω τῆς ὅλης σφαίρας, καὶ ἄνω μὲν τούτου ὄντος τοῦ μορίου ἐφ' οὗ τυγχάνομεν οἰκούντες, κάτω δὲ θατέρου.

Presumably ARISTOTLE understood ANAXAGORAS' theories as visualized in Figs. 2a, 2b and 2c.

ARISTOTLE (384-322 B.C.) who criticized this theory as primitive suggests another one in which he tries to combine two areas: on the one hand atmospheric events such as wind, thunder and lightning, on the other subterranean events. Both are considered earthy secretions: damp earth is being heated up by internal heat and by the sun, creating winds which contrary to solid bodies can thrust through the earth¹²⁾:

Ἄλλ' ἐπειδὴ φανερόν ἐστι ἀναγκαῖον καὶ ἀπὸ ὕγρου καὶ ἀπὸ ξηροῦ γίνεσθαι ἀναθυμιάσιν, ὥσπερ εἴπομεν ἐν τοῖς πρότερον, ἀνάγκη τούτων ὑπαρχόντων γίνεσθαι τοὺς σεισμούς· ὑπάρχει γὰρ ἡ γῆ καθ' αὐτήν μὲν ξηρά, διὰ δὲ τοὺς ὄμβρους ἔχουσα ἐν αὐτῇ νοτίδα πολλήν, ὥσθ' ὑπὸ τε τοῦ ἡλίου καὶ τοῦ ἐν αὐτῇ πυρὸς θερμαινομένης πολὺ μὲν ἔξω πολὺ δ' ἐντὸς γίνεσθαι τὸ πνεῦμα· καὶ τούτο ὅτε μὲν συνεχῆς ἔξω ρεῖ πᾶν, ὅτε δ' εἴσω πᾶν, ἐνίοτε δὲ καὶ μερίζεται. εἰ δὲ τούτ' ἀδύνατον ἄλλως ἔχειν, τὸ μετὰ τούτου σκεπτέον ἂν εἴη ὁποῖον κινητικώτατον ἂν εἴη τῶν σωμάτων· ἀνάγκη γὰρ τὸ ἐπὶ πλείστον τε πεφυκὸς εἶναι καὶ σφοδρότατον μάλιστα τοιοῦτον εἶναι. σφοδρότατον μὲν οὖν ἐξ ἀνάγκης τὸ τάχιστα φερόμενον· τύπτει γὰρ μάλιστα διὰ τὸ τάχος· ἐπὶ πλείστον δὲ πέφυκε διεῖναι τὸ διὰ παντὸς ἰέναι μάλιστα δυνάμενον, τοιοῦτον δὲ τὸ λεπτότατον, ὥστ' εἴπερ ἡ τοῦ πνεύματος φύσις τοιαύτη, μάλιστα τῶν σωμάτων τὸ πνεῦμα κινητικόν· καὶ γὰρ τὸ πυρὸς ὅταν μετὰ πνεύματος ἢ γίνεται φλόξ καὶ φέρεται ταχέως. οὐκ ἂν οὖν ὕδωρ οὐδὲ γῆ αἴτιον εἴη, ἀλλὰ πνεῦμα τῆς κινήσεως, ὅταν ἔσω τύχη ῥυέν τὸ ἔξω ἀναθυμῶμενον.

11) 265a, 19-25.

12) 365b, 21-366 a 5.

ARISTOTLE compares this to the winds inside the human body which cause tremors and cramps. They are hard to control in sick people he believes, because they are pneumatic movements¹³⁾:

δεῖ γὰρ νοεῖν ὅτι ὥσπερ ἐν τῷ σώματι ἡμῶν καὶ τρώμων καὶ σφυγμῶν αἰτίον ἐστὶν ἡ τοῦ πνεύματος ἐναπολαμβανομένη δύναμις, οὕτω καὶ ἐν τῇ γῇ τὸ πνεῦμα παραπλήσια ποιεῖν, καὶ τὸν μὲν τῶν σεισμῶν οἶον τρώμον εἶναι τὸν δ' οἶον σφυγμόν, καὶ καθάπερ συμβαίνει πολλάκις μετὰ τὴν οὕρησιν διὰ τοῦ σώματος (γίνεται γὰρ ὥσπερ τρώμος τις ἀντιμεθισταμένου τοῦ πνεύματος ἔξωθεν ἔσω ἀθρόου), τοιαῦτα γίνεσθαι καὶ περὶ τὴν γῆν. ὅσῃ δ' ἔχει τὸ πνεῦμα δύναμιν, οὐ μόνον ἐκ τῶν ἐν τῷ ἀέρι δεῖ θεωρεῖν γιγνομένων (ἐνταῦθα μὲν γὰρ διὰ τὸ μέγεθος ὑπολάβοι τις ἂν τοιαῦτα δύνασθαι ποιεῖν) ἀλλὰ καὶ ἐν τοῖς σώμασι τοῖς τῶν ζώων· οἳ τε γὰρ τέτανοι καὶ οἱ σπασμοὶ πνεύματος μὲν εἰσι κινήσεις, τοσαύτην δ' ἔχουσιν ἰσχὴν ὥστε πολλοὺς ἄμα πειρωμένους ἀποβιάζεσθαι μὴ δύνασθαι κρατεῖν τῆς κινήσεως τῶν ἀρρωστούντων. τὸ αὐτὸ δεῖ νοεῖν γινόμενον καὶ ἐν τῇ γῇ ὡς εἰκάσαι πρὸς μικρὸν μείζον.

According to different kinds and different effects of erupting air, ARISTOTLE classifies different types of earthquakes¹⁴⁾:

- "Inclinary earthquakes" effecting diagonally;
- "Shakers" effecting vertically up and down;
- "Ruptures" where compressed air escapes to the surface;
- "Howlers" effecting inside the earth without outside disruption.

τῶν δὲ σεισμῶν οἱ μὲν εἰς πλάγια σειόντες κατ' ὀξείας γωνίας ἐπικλίνονται καλοῦνται, οἱ δὲ ἄνω ῥιπτοῦντες καὶ κάτω κατ' ὀρθὰς γωνίας βράσται, οἱ δὲ συνιζήσεις ποιοῦντες εἰς τὰ κοῖλα χασματῆται· οἱ δὲ χάσματα ἀνοίγοντες καὶ γῆν ἀναρρηγνυῖτες ῥήκται καλοῦνται. τούτων δὲ οἱ μὲν καὶ πνεῦμα προσαναβάλλουσιν, οἱ δὲ πέτρας, οἱ δὲ πηλόν, οἱ δὲ πηγὰς φαίνουσι τὰς πρότερον οὐκ οὔσας. τινὲς δὲ ἀνατρέποντες κατὰ μίαν πρόωσιν, οὗς καλοῦσιν ὥστας. οἱ δὲ ἀναπάλοντες καὶ ταῖς εἰς ἑκάτερον ἐγκλίσει καὶ ἀναπάλλεσι διορθοῦντες αἰεὶ τὸ σειόμενον

13) 366b, 14-30.

14) 396a, 1-14.

παλματῖαι λέγονται, τρώμω πάθος ὁμοιον ἀπεργαζόμενοι. γίνονται δὲ καὶ μυκητῖαι σεισμοί, σείοντες τὴν γῆν μετὰ βρόμου. πολλάκις δὲ χωρὶς σεισμοῦ γίνεται μύκημα γῆς, ὅταν τὸ πνεῦμα σείειν μὲν μὴ ἦ αὐτάρκες, ἐντειλούμενον δ' ἐν αὐτῇ κόπτηται μετὰ ῥοθίου βίας.

The importance of ARISTOTLE's explanatory achievement is shown by the fact that he has systematized the chemism of the rising vapours – and that his clear system has been valid until the beginning of modern times. The fundamental idea is that moist vapours do not rise as high as dry vapours. The moist vapours

form the metals under the earth, clouds, rain, snow, and hail in the atmosphere and finally the phenomenon of the halo in space. The dry and smoky vapours cause earthquakes under the earth, wind, thunder, lightning, comets in the atmosphere, siderical comets, the northern lights and the galaxy in space.

According to H. WILSDORF¹⁵⁾ ARISTOTLE's theory about the genetic chemism of the rising vapours can be expressed in the following table (see Table 1).

This presentation clearly shows ARISTOTLE's linkage between subterranean and atmospheric events. Its

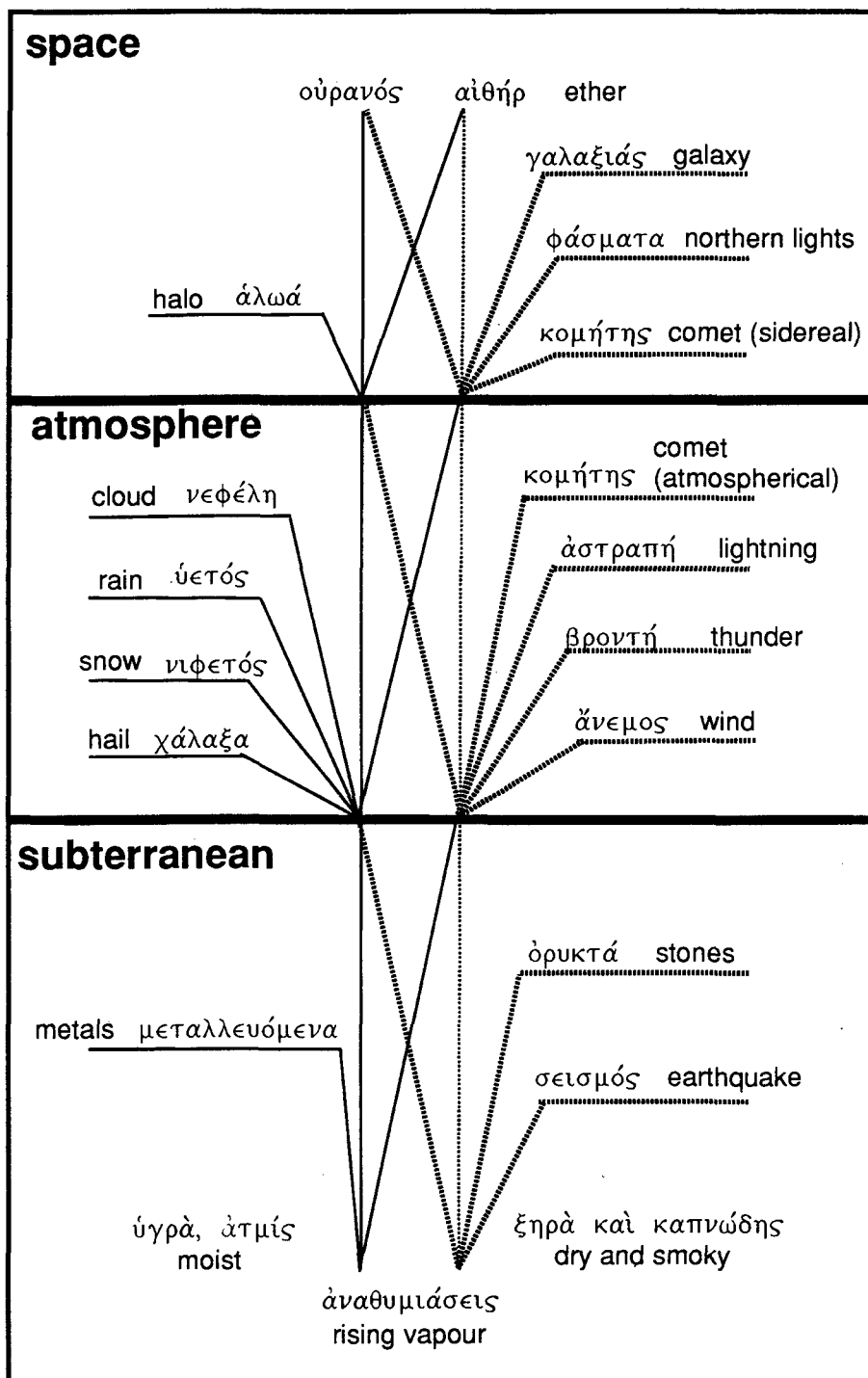


Table 1. ARISTOTLE's theory about the genetic chemism of rising vapours.

¹⁵⁾ WILSDORF, H.: Zu den wissenschaftstheoretischen Darlegungen über Metalle und Metallogenese bei Aristoteles. – In: J. IRMSCHER & R. MÜLLER (Hrsg.): Aristoteles als Wissenschaftstheoretiker, p. 135, Berlin (Akademie-Verlag) 1983.

consequence is important in the history of science. Starting with ARISTOTLE every book or treatise on meteorology until the middle ages (ALBERTUS MAGNUS) had also provided an explanation of the reasons of earthquakes.

In addition to classifying types of earthquakes, attempts were made to combine earthquakes and volcanic eruptions. Both PLATO and ARISTOTLE and other authors of the time were convinced that there existed "fire streams"¹⁶⁾ and "fire hearths"¹⁷⁾ inside the earth, although they differed as to their causes. They agreed, however, that either the fire inside the earth was not spreading evenly or that the thickness of the earth's crust varied in different locations.

The fragments of the Sophist ANTIPHON (5th century B.C.) from Athens are Pre-Socratic evidence, although difficult to reconstruct, of a volcanic earthquake theory, since ANTIPHON attributes the cause of earthquakes to a subterranean fire creating curvatures and rifts at the surface of the earth. According to CAPELLE¹⁸⁾ ANTIPHON is the author of the following volcanic hypothesis mentioned by SENECA (VI, 9) without indicating the name of the author: the cause of earthquakes is a smoldering subterranean fire expanding to neighbouring parts of the earth and scorching them. Thus these parts crumble destroying the surface and thus leading to earthquakes.

*"Sed quia pluribus obrutus locis ardeat, et proxima quæque consumat. Quæ si quando exesa ceciderint, tunc sequi motum earum partium, quæ subiectis adminiculis destitutæ labant, donec corrueant, nullo occurrente, quod onus exciperet. Tunc chasmata, tunc hiatus vasti aperiuntur: aut tum diu nutavere, super ea se quæ supersunt stantque, componunt."*¹⁹⁾

Another author also not mentioned by SENECA by name was presumably not a contemporary of ARISTOTLE, since he already links his theory with the pneumatic hypothesis of ARISTOTLE. He assumes that fires inside the earth make subterranean water boil and produce vapour, which in turn moves the pneuma through the earth trying to find an exit and thus leading to vibrations and eruptions.

*"Quidam ignibus quidem assignant hunc tremorem, sed aliter. Nam cum pluribus locis ferueant, necesse est ingentem vaporem sine exitu voluant, qui vi sua spiritum intendit: et si acrius insilit, opposita diffundit: si vero remissior fuit, nihil amplius quam movet. Videmus aquam spumare, igne subiecto. Quod in hac aqua facit inclusa et angusta, multo magis illum facere credimus, cum violentus ac vastus ingentes aquas excitat. Tunc ille vaporazione inundantium aquarum, quicquid pulsaverit, agitat."*²⁰⁾

Regarding ARISTOTLE's successors, SENECA emphasizes above all the importance of STRATON OF LAMPSAKOS (280 B.C.). STRATON regarded the fight between cold and warm air as the cause for earthquakes:

*"Frigidum et calidum semper in contraria abeunt et una esse non possunt: eo frigidum confluit, unde vis calida discessit: et inuicem ibi calidum est, unde frigus expulsum est."*²¹⁾

¹⁶⁾ PLATO: Phaidon, 111d.

¹⁷⁾ ARISTOTELES: 395 b 20.

¹⁸⁾ CAPELLE: Erdbebenforschung. – In: Paulys Real-Encyclopädie der Classischen Altertumswissenschaft, Supl. IV, p. 366, p. 369, Stuttgart 1924

¹⁹⁾ SENECA: Quaestiones naturalium Liber VI, cap. 9. – In: Opera, Tom. I, p. 760.

²⁰⁾ SENECA: Quaestiones naturalium Liber VI, cap. 11. – In: Opera, Tom. I, p. 761.

²¹⁾ SENECA: Quaestiones naturalium Liber VI. – In: Opera omnia ab Andrea Schotto, Tom. I, p. 762, Genevae 1665.

SENECA also accounts a theory still being supported at the beginning of modern times by LEONARDO DA VINCI, GIORDANO BRUNO and even by KEPLER: In this theory the earth is seen in analogy to a living being. Like a living being has arteries and veins, the earth also has canals with air and water. In normal conditions these canals let the substances freely flowing through. But in diseases or with old age they are obstructed and narrowed. There are similar conditions in the earth when the pneuma wants to flow through the earth, meeting with obstructions and leading to severe earthquakes.

*"Sunt qui existiment, spiritu quidem, et nulla alia ratione tremere terram, sed ex alia causa, quam Aristoteli placuit. Quid sit quod ab his dicatur, audi. Corpus nostrum et sanguine irrigatur, et spiritu, qui per sua itinera discurrit. Habemus autem quædam angustiora animæ receptacula, per quæ nihil amplius quæm meat: quædam potentiora, in quibus colligitur et unde dividitur in partes. Sic hoc totum terrarum omnium corpus, et acquis, quæ vicem sanguinis tenent, et ventis, quos nil aliud quis quam animam vocaverit, pervium est. Hæc duo alicubi concurrunt, alicubi consistunt."*²²⁾

POSEIDONIOS (approx. 135–50 B.C.) was the last author of Greek earthquake theories, but none of his writings is still existing. His theory has been made famous by SENECA who in turn relies on a disciple of POSEIDONIOS, named ASKLEPIODOT. He seems to be one of the first to recognise the enormous depth of the hypocenters and the extent of one and the same earthquake distributed over various countries.²³⁾

Compared with the Greek, the Romans do not deliver any new aspects of the theory of earthquakes. According to ALEXANDER VON HUMBOLDT, SENECA's chapter about earthquakes in the Quaestiones naturalium is considered as the most comprehensive description of all that has recently been observed and told about the causes of earthquakes. As the beginning of this chapter explains, the immediate occasion of SENECA's detailed occupation with earthquake theories of the Greek can be found in the earthquake of Pompei and Herculaneum in 63:

"Pompeios, celebrem Campaniæ urbem in quam ab altera parte Surrentinum Sabianumque litus, ab altera Herculaneense conveniunt, mareque ex aperto conductum amoeno sinu cingit, deseisse terraemotu, vetaxis quaecunque adiacebant regionibus, Lucisi virorum optime, audivimus, et quidem diebus hibernis, quos vacare à tali periculo maiores nostri solebant promittere."

The deep impression that such an event had given the inhabitants of the destroyed towns is described by SENECA with the following words: "What can seem secure to us at all, if the globe itself is shaken? If the only thing that is immovable and firm in the world, that carries everything, moves backwards and forwards, if the earth has lost her characteristic, the stand still – where should we find a holding in our fear, a refuge?"

*"Quid enim cuiquam satis rutum videri potest, si mundusipse, concutitur, et partes eius solidissimæ labant? Si quod unum immobile est in illo fixumque, ut cuncta insentitia sustineat, fluctuat? Si, quod primum habet terra, perdidit, stare: ubi tandem resident metus nostri? Quod corpora receptaculum inveniente?"*²⁴⁾

But later he himself followed ARISTOTLE's explanations and adopted also his classification of earthquakes.

Even in the famous historia naturalis by PLINIUS the few remarks about the causes of earthquakes are sur-

²²⁾ SENECA: Quaestiones naturalium Liber VI, cap. 14. – In: Opera, Tom. I, p. 763.

²³⁾ CAPELLE: Erdbebenforschung. – p. 372.

²⁴⁾ SENECA: Opera, Tom I, p. 752.

prisingly poor. PLINIUS himself was killed in Pompei in the dreadful eruption of the Vesuvius in the year 79. He considers earthquakes as nothing but underground thunderstorms, that take place under the earth, while they are not in existence above the earth, in the air. In his opinion both the rolling deafening noise, that accompanies the landslides, and the kind of the elastic forces, that shake by tension, speak for this theory:

*"Ventos in causa esse non dubium reor. Neque enim unquam intremiscunt terrae, nisi sopito mari caeloque adeo tranquillo, ut volatus avium non pendeant, subtracto omni spiritu qui vehit; nec unquam nisi post ventos conditos, scilicet in veas et cavernas ejus occulto afflatu. Neque aliud est in terra tremor, quam in nube tonitruum; nec hiatus aliud quam cum fulmen erumpit, incluso spiritu lucante et ad libertatem exire nitente."*²⁵

3. The Authority of ARISTOTLE in Middle Ages

During the middle ages and the early modern times no new concepts about earthquake mechanisms and causes had been developed.

The authority of ARISTOTLE was so strong that all ideas on the causes and mechanisms of earthquakes had been just comments on the opinions of ARISTOTLE, which were repeated almost literally. The only difference to ARISTOTLE was that all Christian authors of the Middle Ages wrote that God is the first supernatural cause of earthquakes, while the natural causes presented by ARISTOTLE were considered secondary. While ARISTOTLE based his theoretical position on empirical facts, Aristotelians in the Middle Ages did not carry out empirical research, but confined themselves to commenting the works of ARISTOTLE. As is well known, this way of doing natural research from the books of ARISTOTLE only led to extremes, such as the Aristotelian Cesare CREMONINI from Padua (16th century) who refused to look through the telescope. As the Copernican system became widely accepted and Aristotelian philosophy of nature was replaced by GALILEI with experimental physics, new developments in the theories on the causes of earthquakes became possible. Until this period the authority of ARISTOTLE and the classical authors of antiquity had dominated.

ALBERTUS MAGNUS (1193–1280), the most famous natural scientist of this period, primarily dealt with the works of ARISTOTLE and their Arabic und Jewish commentaries. His theory of earthquakes is nothing else than a free repetition of ARISTOTLE's insights, mixed with ideas of ANAXAGORAS.

He also thought that earthquakes are caused by dry vapour originating through the heat of the sun in the "intestines" of the earth:

"Terraemotus causa materialis est, vapor siccus, et grossus valde et terrestris efficiens causa est calor solis penetrans in viscera terrae: locus est terra oppilata in superficie."

The old idea by ANAXAGORAS about the blocked pores of the earth is also revived by ALBERTUS MAGNUS. But he distinguishes 3 different causes: such blockages of the pores of the earth originate either because the soil becomes wet due to the tides near the sea, or because of frequent rainfalls, or because the earth is rocky or consists of rocks.

"Terraemotus locus oppilatus est tribus de causis, aut quia est non arenosus, mari tamen vicinus, ita ut fluxus et refluxus sint ad terminos ipsius, et sic humido maris oppilatur locus: aut quia pluviis multis oppilantur pori: aut quia terra est saxosa continua saxo."

In this way the mountains of the earth emerged. But this novel idea by ALBERTUS MAGNUS by far exceeds the opinions of ARISTOTLE.

*"Terraemotus vapor, si est frigidus minor in loco non aquose et terre multum oppilati pori, elevabit terram, ita ut videbitur mons; vel collis, et si cum impetu non projicit in alium locum, tunc residet egresso vapore in toto, vel in parte: si multus et sint aquae in illo loco, absorbebit aquas donec resideat, quod elevatum est, si aqua est in profundo, projicit terram, et facit eam apparere."*²⁶)

But concerning the classification of various types of earthquakes and their mechanisms ALBERTUS MAGNUS is sticking to ARISTOTLE's theory:

*"Est item aliquando effectus terræmotus in modo diverso movendi terram quam concutit: aliquando enim movet motu agitato modo ad dextram, modo ad sinistram; aliquando autem subvertendo terram, ita quod inferius facit esse superius, et e converso: aliquando autem scissivo, faciendo tantum aperturam unam in ipsa: aliquando autem movet motu perforativo, faciendo plurima foramina non magna in terra: aliquando autem movet motu tremulo, sive motu titubationis, quando exitum naturalem egreditur, et statim redit ad eundem: aliquando autem movet motu ruinoso, quando superior pars terræ cadit in profundum: aliquando autem movet motu impulsivo, quando superior pars terræ longe repellitur a situ suo et loco: aliquando autem motu vectionis, ut quando superior pars ab inferiori vehitur: aliquando autem movet motu depressionis et elevationis, ut quando superficies terræ modo deprimitur, et mod exaltatur. Et hos omnes motus habet terræmotus: præter motum quem habet in aqua, et præter motum quem habet in igne et sulphure, de quibus supra dictum est: et horum omnium volo redere causas."*²⁷)

Finally ALBERTUS MAGNUS mentions an idea which has been repeatedly expressed in the history of earthquake theories, since he states that earthquakes are often followed by the plague: the poisonous vapour always being kept in the dark is killing animals, in particular birds.

*"Scias etiam, quod frequenter pestilentia præcipue omnem sequitur terræmotum: vapor enim inclusus et privatus sic luce et aere libero grosso est habens quasi veneni naturam, et ideo animalia interficit, præcipue quæ terræ quasi semper proximum os tenent, sicut oves."*²⁸)

As theologian and philosopher, THOMAS AQUINO (1225–1274), the most important disciple of ALBERTUS MAGNUS, puts the Christian doctrine before scientific knowledge. He believes that earthquakes are always caused by God and only secondarily by natural causes such as vapours or winds.

*"Terraemotus causatur principaliter a Deo; secundo autem à vento impellente alium ventum in terram."*²⁹)

Other elements were taken over by THOMAS AQUINO from ARISTOTLE's earthquake theory. He also considers inflamed or dry exhalations as the natural causes of earthquakes or subterranean thunders:

"Terraemotus, tonitruum et coruscatio possunt duobus considerari modis: primo formaliter ut terraemotus, est motus: tonitruum sonus factus ab exhalatione: coruscatio ab exhalatione incensa, et

²⁶) ALBERTUS MAGNUS: Liber de passionibus aeris, sive de vaporum impressionibus; taken from: Florilegii magni seu Polyantheae floribus novissimus sparsae, libri XX. Jam olim a Domenico Nano Mirabellio, Bartholomaeo Amantio, Francisco Tortio, ex Auctoribus cum sacris, tum profanis vetustioribus et recentioribus, collectum. Studio dehinc et opera Jephii Langii Argentorati 1645 Art. Terraemotus 2916 f.

²⁷) ALBERTUS MAGNUS in 3. meteor. tract. 2.c.18.

²⁸) ALBERTUS MAGNUS in 3. meteor. tract. 2.c.12.

²⁹) B. Thom. super Psal. 12 col. 6.

²⁵) PLINIUS: Historia naturalis II, 79.

sic sunt diversae species: secundo ex iisdem generantur, et sic sunt idem specie, quia sunt exhalatione sicca."³⁰⁾

ALBERTUS MAGNUS also influenced the author of the first natural history written in German, Konrad von MEGENBERG (1309–1374)³¹⁾. He describes the earthquake, which had destroyed the town of Villach/Austria in 1348. He contemplates about ARISTOTLE's idea that winds – which he calls "düunst" – included in caverns and holes inside the earth cause the shattering when they try to escape:

"... der erbidem künnt da von, daz in der erden hölrn und allermaist in holem gepirge vil erdischer düunst gesament werdend, und daz der düunst also vil wirt, daz si niht dar inne beleiben mügent; so stozen si umb und umb an die wend und fliegend auz ainem kehr in den anderen und wahsent immer mer zuo, unz daz si ain ganz gepirg derfüllent ... so nu die düunst lang gevehent in der hölrn, so wirt ir stozen ze letst so stark, daz si auz prechent mit gewalt und werfent ainen perg auf den anderen. mügent aber si niht auz geprechen, zehant so schütelt si doch daz erreich vast ..."

His text reflects the contemporary sense of miracles and associations to metaphors taken from the bible as follows:

"... wizz auch, daz der erpidem vil wunderleicher werck würrt. daz ain ist, daz dike von dem dunst, der auf get von dem erpidem, leüt und andreu tier ze stainen werdent und allermeist ze salzstainen und allermaist auf dem gepirg und da pei, da man salzerz grebt."

But it is interesting to observe, that even in the 16th century scholars felt guilty when referring to natural observations as earthquakes. These circumstances make understandable why, for example, the scholar Wolfgang LINDNER³²⁾ starts the description of his earthquake theory with an excuse. As an eye-witness of the destructing earthquake of 1590 in Lower Austria he writes:

"... Hic studio praetereo, quae alibi damna ex tantis terrae motibus consecuta sint. Etsi manifesta Dei punitio fuit et praesagium futuri belli turcici, tamen fieri potuit, ut ex causis naturabilibus suam originem sumpserit."

After this introduction to his theory he explains that water played the decisive role in the generation of this earthquake. Ten weeks before the event there was a great heat, so that cracks and fissures opened in the surface of the dry soil, where wind and air could penetrate. Several days later a strong rain followed, so that the rivers extremely swelled and then inundated lowlands. Therefore the "winds" in the "stomach of the earth" were included and set free by explosive rumbling. This theory follows the old ideas by ANAXAGORAS without mentioning them.

Italian humanism, represented by G.F. PICO DELLA MIRANDOLA (who died in 1533), nephew of the famous GIOVANNI PICO DELLA MIRANDOLA (1463–1494), also subordinated philosophy and natural science to religious interests. His considerations on the causes of earthquakes in his work "Examen vanitatis doctrinae gentium et veritatis Christianae disciplinae" only contain a short remark on NICOLAUS CUSA and an enumeration of authors of ancient times:

"Terraemotus causam Nicolaus Cusa esse dixit, quod terra tremat intus, quo motu et tremore corrumpunt. Anaximenes siccitatem, et

"Terraemotus causam Nicolaus Cusa esse dixit, quod terra tremat intus, quo motu et tremore corrumpunt. Anaximenes siccitatem, et raritatem terrae causam esse putavit, Anaxagoras aërem, alii ignem, Stoici humorem, qui in aërem succedit, et excidit, Peripatetici pugnam caloris et frigoris. Nam quum calidum ad superiora contendat, ejus adversa exhalatio obsistat, excitat commotionem. Metrodorus non putat moveri naturaliter, sed aliquos locos ab aliis impelli. Democritus et Parmenides non moveri terram quum aequaliter ab omnibus partibus distet, sed solum quassari. Anaximenes ob latitudinem cubare, alij malunt eam super aquam moveri, non secus ac quae ea latitudine pollent."³³⁾

4. The Influence of the Copernican Astronomy – Theoretical Explanations of Earthquakes in Early Modern Times

In the beginning of modern times LEONARDO DA VINCI (1452–1516) developed totally new ideas about the position of the earth in the universe and its internal structure. Even before COPERNICUS he explicitly stated that the sun is stable and the earth is a star³⁴⁾. But since he also stated that the centre of the universe does not lie in the earth, he not yet adheres to the heliocentric model of the world, but rather to an idiosyncratic idea of the internal structure of the earth.

He assumed that the earth is not only covered for the most part of its surface with water, but that it is full with water also in its inner part, like a vessel, since he thought that the ratio water-earth must be 10 : 1. The visible seas at the surface of the earth do not suffice for that, thus there must be much more water in the interior of the earth. LEONARDO tries to show these facts with a cross section through the earth.³⁵⁾

Whereas the solid earth tends to distribute equal weights around the centre of the world in opposite directions, fluid water tries to distribute water in equal distances from it according to the laws of hydrodynamics LEONARDO knew at that time. According to LEONARDO the centre of gravity can only be identical with the centre of the world in two cases: if the earth is totally spherical, and either be totally covered with water, or if its opposite parts outside water would have the same weight. But since water is mixed with earth in a ramified network, it can only be at the surface, equally far away from the centre, with the continents and mountains rising above it.

Earthquakes develop, because rising mountains crumble with the air included in caves breaking up the earth when violently escaping. Similarly LEONARDO explains the seaquake in 1489 near Rhodos in the sea of Satalia as the crumbling of the bottom of the sea. During the seaquake an opening at the bottom of the sea emerged, in which such an amount of water disappeared that the bottom of the sea was bare for more than three hours.³⁶⁾

LEONARDO who can be considered a forerunner of the neptunists with these explanations of earthquakes explains volcanic eruptions in a very similar way. In anal-

³⁰⁾ D.Thom. in 2. meteor. lib.6.

³¹⁾ MEGENBERG, K. von: Das Buch der Natur 1349. – p. 107 ff., Stuttgart (hrsg. von F. Pfeiffer) 1861.

³²⁾ Taken from: SCHIFFMANN, K. (Hrsg.), Die Annalen (1590–1622) des Wolfgang Lindner, in Archiv für die Geschichte der Diözese Linz, Beilage zum Linzer Diözesenblatt, hg. vom bischöflichen Ordinariat, Jg VI/VII (Linz 1908) 9/10.

³³⁾ Joan. Picus MIRANDOLA, in exam. vani. doct. gent. lib, 1 cap 12.

³⁴⁾ LEONARDO DA VINCI: Quaderni d'Anatomia, Windsor V, 25 r; Ms Institut de France F 25 v. – In: Tagebücher und Aufzeichnungen nach den italienischen Handschriften übers. und hrsg. von Th. Lücke, p. 200, p. 188.

³⁵⁾ LEONARDO DA VINCI: Cod. Leicester, 36. Lücke p. 256.

³⁶⁾ LEONARDO DA VINCI: Cod. Leicester, 36. Lücke p. 243.

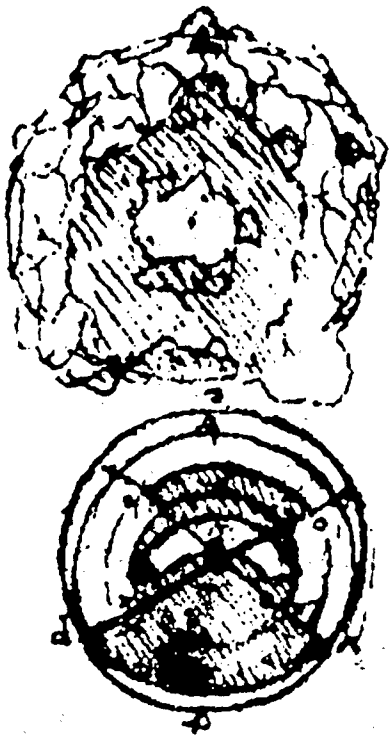


Figure 3.
Cross Section through the earth by LEONARDO DA VINCI.
Cod. Leicester, fol. 36 recto.

- a) Cross section through the earth with the true distribution of land masses (land and mountains) and water (oceans, lakes and rivers at the surface, water ball in the interior).
b) Cross section through the earth with an ideal distribution of land masses and water with a totally flat surface.

ogy to a living organism, with the earth being the flesh, the stones being the bones, and the water being the veins and arteries, the fire locked in the earth is to be – according to LEONARDO – considered as the warmth of the unconscious ‘spirit of the earth’ escaping at different locations of the earth from hot springs, sulfuric and volcanic eruptions.³⁷⁾

GIORDANO BRUNO (1548–1600), who already knew the Copernican system, applied this metaphor of the earth as a living organism to all celestial bodies. In contrast to ARISTOTLE and his graduated scale ranging from the most dense and heaviest matter, earth and water, to finer and lighter matter such as vapour, air, fire and ether, BRUNO’s celestial bodies do not consist of a celestial matter of its own, but of earth, water, air and fire, just as the Earth itself. If in this composition fire predominates, they are suns radiating their own light, if water predominates, they are earths, moons or similar celestial bodies receiving light from the sun.

“Perche dico vno essere il continente et comprensor di tutti corpi, et machine grandi, che ueggiamo come disseminate et sparse in questo amplissimo campo: oue ciascuno di cotai corpi, astri, mondi, eterni lumi, é composto di ciò che si chiama terra acqua aria fuoco.”³⁸⁾

Thus it can be assumed according to GIORDANO that there are countless celestial bodies that are moons, earths with this earth apparently revolving about them, just as they seem to revolve about this earth.

³⁷⁾ LEONARDO DA VINCI: Cod. Leicester, 46.

³⁸⁾ BRUNO, G.: Le opera italieane, Vol. I, p. 353.

“Onde possiamo stimare che de stelle, innumerabili sono altre tante lune, altre tanti globi terrestri, altre tanti mondi simili á questo, circa gli quali par che questa terra si uolte, come quelli appaiono ruolgersi et aggirarsi circa questa terra.”³⁹⁾

GIORDANO BRUNO considers these bodies not only as accumulations of dead matter, but also as living beings having special spirits of life and warmth, just as animals do. Being organisms and machines at the same time, these bodies have a complex structure. Rocks, lakes, rivers, wells, seas, sand deserts, metals, caves, mountains, plains etc. correspond to bones, intestines, veins, arteries, flesh and nerves forming organs and limbs. Thus GIORDANO considers meteorological events such as fog, rain, lightning, thunderstorms and also earthquakes as diseases of this living body corresponding to catarrhs, rashes, dizziness, fever and inflammations in small organisms.

“In questi dunque astri ó mondi (come le uoglam dire) non altrimenti si intendeno ordinate queste parti dissimilari secondo uarie et diuerse complessioni, di pietre, stagni, fiumi, fonti, mari, arene, metalli, cauerne, monti, piani, et altre simili specie di corpi composti, de siti, et figure: che ne gl’ animali son le parti accette etherogenee secondo diuerse et uarie complessioni di ossa, di intestini, di uene, di arterie, di carne, di nerui; di pulmone, di membri di una, et di un’ altra figura, presentando gli suoi monti, le sue ualli, gli suoi recessi, le sue acqui, gli suoi spiriti, gli suoi fuochi, con accidenti proportionali á tutte metheoriche impressioni quai sono gli catarrhi, le erisipile, gli calculi, le uertigini, le febri, et altre innumerabili dispositioni, et habiti, che rispondeno alle nebbie, piogge, neui, caumi, accensioni, alle saette[.] tuoni, terremoti et uenti, á feruide, et algose tempeste.”⁴⁰⁾

The theory of animated celestial bodies is also taken over by the great astronomer JOHANNES KEPLER (1571–1630) for explaining the causes of earthquakes. But in the revival of this theory he rather cites the Italian Aristotelian JULIUS CAESAR SCALIGER who wrote a commentary entitled “Exercitationes exotericæ” concerning the 15 books “De subtilitate” by HIERONYMUS CARDANUS. The young KEPLER was so impressed by this book containing the theory of spiritual forces determining the universe that he called the moving cause of planets a soul (anima)⁴¹⁾ in its first astronomical book “Mysterium cosmographicum” (1596). Although in the second edition (1621) he substituted the term ‘anima’ by ‘vis’ (force), he continued to use the metaphor of the earth as an animated organism when explaining earthquakes in his “Harmonica mundi” of 1619. He even links the metaphor explicitly to outdated ideas, already rejected by ARISTOTLE, of linking meteorological events and earthquakes to the constellation of planets and the appearance of comets. KEPLER even ran ARISTOTLE and AGRICOLA down who attributed these events to rationally explainable terrestrial causes such as dry and fiery vapours. The excellent refutation of astrology by the elder PICO DELLA MIRANDOLA was rather rejected by KEPLER instead of rejecting the astrological theory of aspects. It is not the constellation of planets as such, i.e. their distance and position to each other which is the aspect of a qualitative property, but the spiritual relationships of such qualities. Such a spiritual relationship is not a matter of a body, but rather of a soul. This spiritual force in the constellation of planets

³⁹⁾ BRUNO, G.: Le opera italieane, Vol. I, p.352.

⁴⁰⁾ BRUNO, G.: Le opera italieane, Vol. I, p. 353.

⁴¹⁾ see OESER E.: Kepler. Die Entstehung der neuzeitlichen Wissenschaft. – Göttingen – Zürich – Frankfurt 1971.

also needs a soul at the terrestrial level which is admonished and roused by this aspect.

*"Quae si quis diligenter perpendit, nullâ is difficultate secum concludere poterit, ut Numerum, sic has quoque commotiones momentaneas, ab Aspectu, Rationis Ente, profectas, non corporis esse sed Animalium facultatum: Animam itaque esse oportere, quae ab Aspectu admonita et velut excitata, cieat meteora et tempestates."*⁴²⁾

KEPLER did not worry about the fact that thunderstorms do not always temporally correspond to the aspects. He rather finds an explanation which expands the analogy between the earth and an animated living being. The earth does thus not resemble a dog-like obedient animal but rather an ox or an elephant which do not get outraged so quickly, but as soon as they are, wreaking havoc:

*"Hic valde me confirmavit id opsum, quod alium aliquem absterere potuit; scilicet, quòd non semper ad amussim respondent commotiones Tempestatum Aspectibus; sed terra subinde segnis videtur et contumax: alio tempore (scilicet post graves et diuturnas configurationes) exacerbata, indulget evaporationibus, etiam sine aspectuum continuatione. Non est quippe Terra, animal tale, quale Canis, ad omnem nutum promptum; sed tale, quale Bos aut Elephas, tardum ad iram, tantòque violentius, cùm excanduit."*⁴³⁾

This analogy leads KEPLER to a precise correspondence of the inner structure of the earth and that of the body of an animal: Similar to the hair on the skin of the body, the earth has plants and trees. Lice correspond to caterpillars, crickets and other insects and sea monsters. Just as the body secretes lacrimal fluid, nasal mucus, cerumen and sometimes a glutinous fluid from pustules in the face, the earth is secreting amber and bitumen. Like urine is coming from the bladder, rivers are flowing from the mountains. Like the body is secreting excrements with a sulfurous stench and loud inflammable winds, the earth is secreting sulfur and subterranean fire with thunder and lightning. Just as blood and consequently sweat are developed in the vessels of the animal, metals, crystals and vapour are produced in the vessels of the earth.

*"Quae analogie cùm succederet, effecit, ut eandem ulteriùs prosequer, comparans etiam corpora Animantium cum corpore Terrae: videbam pleraque omnia, quae ex corpore animantis provenienta, testantur animam in illo inesse, provenire etiam ex Telluris corpore. Vt enim corpus in cutis superficie pilos, sic terra plantas arboresque profert; inque ijs ibi pediculi, hic erucae, cicadae, variaque insecta et monstra marina nascuntur: et ut corpus lachrymas, blennam, auriumque recrementa, est ubi et gummi ex faciei pustulis, sic Tellus electrum, bitumen: utque vesica urinam: sic montes flumina fundunt; et ut corpus excrementum sulphurei odoris, crepitusque, qui etiam inflammari possunt, sic Terra Sulphur, ignes subterraneos, tonitrua, fulgura: utque in venis animantis generatur sanguis, et cum eo sudor, extra corpus ejectus; sic in venis terrae, Metalla et fossilia, vaporque pluvius."*⁴⁴⁾

In comparison to GIORDANO BRUNO's and LEONARDO DA VINCI's idea that the earth is full of water, KEPLER thinks in a much more direct analogy that the soul of the earth can be found not only at the surface, but also inside the earth, in caves and in channels of the mountains.

"... erit igitur anima ista, non in superficie tantummodò telluris, sed intus etiam in cavernis subterraneis, in meatibus montium; denique Terrae globus tale corpus erit, quale est alicujus animalis:

⁴²⁾ KEPLER, J.: *Harmonice Mundi*, lib. IV, cap. VII. – Gesammelte Werke, hrsg. v. M. Caspar, vol. 6, p. 268.

⁴³⁾ KEPLER, J.: *Harmonice Mundi*, lib. IV, cap. VII. – Gesammelte Werke, hrsg. v. M. Caspar, vol. 6, p. 268.

⁴⁴⁾ KEPLER, J.: *Harmonice Mundi*, lib. IV, cap. VII. – Gesammelte Werke, hrsg. v. M. Caspar, vol. 6, p. 268 f.

*quodque animali est sua Anima, hoc erit Telluri haec, quam quaerimus, Natura sublunaris, quae ad praesentiam aspectuum movet tempestates."*⁴⁵⁾

The following fact, affirmed in many countries, serves for KEPLER as the empirical proof for the existence of a soul inside the earth: if somebody throws a small stone from the top of a high mountain into very deep crevices usually causing noise or into a mountain lake (which – in his opinion – cannot be explained either), a thunderstorm arises immediately. Animals are also scared, when inserting something into their sensitive ears and noses and tickling them; they shake their heads or rush away.

*"Quid quòd et sensus quidam vel tactus vel auditus Telluris globo inesse videtur, argumento hoc, quòd constanti plurimarum provinciarum traditione confirmatur, si quis in altissimorum montium cacumina enisus, lapillum in hiatus quos habent illi profundissimos conjiciat, unde solet excitari sonitus; aut si in lacum montanum (qui procul dubio et ipsi fundo carent); è vestigio tempestates excitari. Sic enim et animalia, si quis in teneros aurium nariumve meatus titillans, aliquid inserat; horrore correpta, caput quassant, aut in cursu se praecipitant."*⁴⁶⁾

Based on this theory of animated earth KEPLER rejects the mechanistic and physical explanation of earthquakes being caused by comets, because he was convinced that a comet is neither a fiery burning body, nor can it come so close to the earth, according to TYCHO BRAHE's observation that comets are not atmospheric phenomena but rather celestial bodies far above the moon.

*"Denn das die Cometen meistens weit über dem Mond und tieff im Himmel drinnen seyn ist von dem hochberühmten TYCHONE BRAHE statlich erwiesen."*⁴⁷⁾

Thus he also rejects the idea that the heat of a comet dries the earth, generates winds, pollutes the air with smoke and even causes a subterranean wind leading to earthquakes.

*"Denn das ich die Wahrheit sage / so wil mir diese weise / fast gleich / so wenig eingehen / als die jenige / davon theils Aristoteles / theils nach ihm die Calenderschreiber andeutung thun / welche lächerlicher weise fürgeben / ein Comet bringe darumb grossen Wind / weil er ein brinnendes Feuer sey / und die Flamme nicht alle Feistigkeit verzehren möge / sondern den Rauch auff allen seyten von sich schlahe / und also einen Wind verursache: Und aus solchen Winden das Meer bewegt / auff das Land getrieben / und hierdurch Gewässer verursacht werden. Item / das ein Comet der Erden ihre Krafft und Feuchtigkeit entziehe; Ich möchte wissen / mit was für einem Kopff oder ventosen das zugienge. Item / das von dem Rauch dieses Brands die Luft vergiffet werde; als wenn man ein Liecht au- bleschet / und den Butzen stincken lesset. Item / daß der Comet einen Wind unter der Erden / an verschlossenen Orten erwecke / welcher die Erde beben und zittern mache."*⁴⁸⁾

KEPLER thinks that comets can nevertheless cause earthquakes and other catastrophes in a different way: in his opinion the soul of the earth reacts in this way, if something strange is happening in the sky. The soul inside the earth is for instance scared when a comet ap-

⁴⁵⁾ KEPLER, J.: *Harmonice Mundi*, lib. IV, cap. VII. – Gesammelte Werke, hrsg. v. M. Caspar, vol. 6, p. 268.

⁴⁶⁾ KEPLER, J.: *Harmonice Mundi*, lib. IV, cap. VII. – Gesammelte Werke, hrsg. v. M. Caspar, vol. 6, p. 269 f.

⁴⁷⁾ KEPLER, J.: *Außführlicher Bericht Von dem newlich im Monat Septembri und Octobri diß 1607 Jahrs erschienen Haarstern/oder Cometen/und seinen Bedeutungen.* – In: *Gesammelte Werke*, Hrsg. M. Caspar & F. Hammer, vol. IV, p. 59.

⁴⁸⁾ KEPLER, J.: *Außführlicher Bericht Von dem newlich im Monat Septembri und Octobri diß 1607 Jahrs erschienen Haarstern/oder Cometen/und seinen Bedeutungen.* – In: *Gesammelte Werke*, Hrsg. M. Caspar & F. Hammer, vol. IV, p. 61f.

pears and then its moist vapours lead to rain and floods and consequently to plagues, catarrhs or even pestilence, wherever the moist has dried up, the force caused by the comet is attacking dry vapours producing sulfur and power catching fire and causing earthquakes.

"Von diesem allem ich (weil gewiß / daß der Comet nicht brenne / auch nicht so nahe an der Erden stehe) weniger denn nichts halte / so lang es an einer lebhaftten Krafft mangelt / die an deß abwesenden Cometen statt / solche oder dergleichen Dinge in dem Erboden wircke. Derhalben so etwas daran / das nach Ordnung der Natur / die besagte Zustände / als Wind / Gewässer / Trückne / Erdbeben / Pestilenz / durch einen Cometen verursacht / und also vorbedeutet werde / so muß es folgender gestalt zugehen. Wann etwas seltsames / entweder von starcken constellationibus, oder von neuen Haarsternen / im Himmel entstehet / so empfindet solches / und entsetzet sich gleichsam darob die ganze Natur und alle lebhaftte Kräfte aller natürlichen dinge. Diese sympathia mit dem Himmel / gehet sonderlich diejenige lebhaftte Krafft an / so in der Erden steckt / und deroselben innerliche Wercke regieret / davon sie gleichsam entsetzet / an einem Ort / nach dessen qualitet / viel feuchte Dämpffe aufftreibet / und herfür schwitzet; darauß langwirriger Regen und Gewässer / und damit (weil wir auß der Luft leben) allgemeine Landseuchen / Hauptwehe / Schwindel / Catharr (wie Anno 1582.) auch gar die Pestilenz (wie Anno 1596.) entstehet. Oder da die Erdkugel etwa an einem Ort an Feuchtigkeit erschöpffet; dann so greiffet diese / durch den Cometen erhitzte lebhaftte Krafft deß Erdbodens an / was sie findet / nemlich dürre Dämpffe / welche die Erde unfruchtbar machen: und machts / schwefelt / pulverisirt / und treibet es auff ihre verborgene Art / so lang / das endlich das Pulver unter der Erden angehen / und mit macht einen Außgang suchet / also ein Erdbeben verursacht wird."⁴⁹⁾

In later stages of the development of earthquake theories, however, not this fanciful but in its intention realistic analogy of the earth as a living being, but rather the ideas based on experience in mining of Georg BAUER (1494–1555) – better known under the Latin name "AGRICOLA" – prevailed. He disputed the old theory that the subterranean fire was inflamed by the rays of the sun. On the other hand he supposed the existence of a "fire spirit" (spiritus ignitus) which inflames itself when searching a passage out of the subterranean caves:

"Nam cum Solis radij, qui maximam vim caloris habent, non inflamment locos bituminosos, vel sulfurosos aeri expositos; qui possunt incendere inclusos penitus in venis atque visceribus terrae? In quos etiamsi penetrare possent, vim tamen suam, fractam subterraneis frigoribus conferrent. Jam vero usque eò ipsos non pervenire meallorum fossore norunt. Igitur multo minus alliarum stellarum vires ignem intra terram gignere nequent. Sed eum accendit spiritus ignitus is verò ignescit, cum ipsum frigus vel expremat tam quam nube fulgura elidunt: vel in locorum angustias impellit: per quas se torquens, exitumqu quaeres ipso conflictu et attritu exardeseit ac inflammatur."⁵⁰⁾

A similar view has been adopted by DESCARTES (1596–1650). He, however, assumes that there was no direct connection between the "central fire" and the local fire-hearths observable in the crust of the earth. According to DESCARTES the fire-fluid and sunlike core of the earth is surrounded by a spherical shell of metals. This solid shell is enclosed by another one consisting of water and another one consisting of air. Beyond this last shell there is the freely floating earth crust which, however, is broken in several pieces. Thereby mountains and seas have been formed. As for

earthquakes as well as eruptions of volcanoes they are caused by an accidental spark which is inflamed by sulphuric vapour in crevices and caves of the earth's crust. Thus the walls of the caves are shaken:

"Sed cum celerius agitantur, quam ut ita in oleum verti possint, si forte in rimas et cavitates terrae magna copia affluant, pingues ibi et crassos fumos componunt, non absimiles iis qui ex candela recens exstincta egrediuntur; ac deinde, si quae forte ignis scintilla in istis cavitatibus excitetur, illi fumi protinus accenduntur, atque subito rarefacti, omnes carceris sui parietes magna vi concutiunt, praesertim cum multi spiritus ipsis sunt admisti: et ita oriuntur terrae motus."

Earthquakes often last for hours or days because there are generally several caves detonating successively:

"Denique, durat aliquando terrae-motus per aliquot horas, aut dies; quia non una tantum continua cavitas esse solet, in qua pingues et inflammabiles fumi colliguntur, sed plures diversae, terra multo sulphure aut bitumine satura disjunctae; cumque exhalatio in unis accensa, terram semel concussit, aliqua mora intercedit, priusquam flamma per meatus sulphure oppletos, ad alias possit pervenire."⁵¹⁾

Fig. 4 shows the earth model suggested by DESCARTES. It visualizes how the earth's crust breaks into pieces forming mountains and in parts subducting into the air shell below. Many elements of the modern concept of Plate Tectonics as the plate boundaries, which play an important role in the generation of earthquakes, seem to be anticipated (see numbers 4, 5 and 6 in the figure). The tilting of block E in the figure indicates a conception not too far from ours about the earthquake-prone subduction zones in the lithosphere, wellknown in modern textbooks of seismology.

In the subsequent period the Jesuit Athanasius KIRCHER⁵²⁾ (1601 – 1680) took up the supposition of a central fire in his famous "Mundus subterraneus" (1655). The concept of a "central fire" as the direct cause of eruptions of volcanoes and earthquakes was not sufficient to explain the movements on the surface of the earth. Apart from the central fire Athanasius KIRCHER believed that there were more fire-hearths (Pyrophyllacia) which are caused by the burning of sulphur, bitumen and pit-coal. They are supposed to be connected with the "central fire" through subterranean caves and passages (see Fig. 5).

In his small book published in Florence in 1669 the Danish physician Nikolaus STENO (1638–1687) attributed an important role to subterranean fire. In contrast to the somewhat weird ideas of KIRCHER STENO rather relied on empirical evidence. In the 16th century miners already knew the regular sequence of layers of rock. But STENO was the first to draw theoretical consequences from this experience. With a detailed investigation into the geological structure in Tuscany he proved not only the temporal subsequence of the genesis of individual layers, but also changes in the structure of these layers through lifting or crumbling in the form of terrible earthquakes. For him this was the main cause of the genesis of mountains, and thus he rejected the idea of LEONARDO, BRUNO, KEPLER and also KIRCHER holding that mountains are growing like plants or that they resemble the skeleton of an animal.

⁴⁹⁾ KEPLER, J.: Außführlicher Bericht Von dem newlich im Monat Septembri und Octobri diß 1607 Jahrs erschienen Haarstern/oder Cometen/und seinen Bedeutungen. – In: Gesammelte Werke, Hrsg. M. Caspar & F. Hammer, vol. IV, p. 62.

⁵⁰⁾ AGRICOLA: De ortu et causis subterreaneorum, Lib. II, cap XX, Basel 1558.

⁵¹⁾ DESCARTES, R.: Principia Philosophiae. – p. 168, Ultima Editio Amsterdam 1664.

⁵²⁾ KIRCHER, A.: Mundus subterraneus. – 3. ed., 2 vol., Amsterdam 1678.

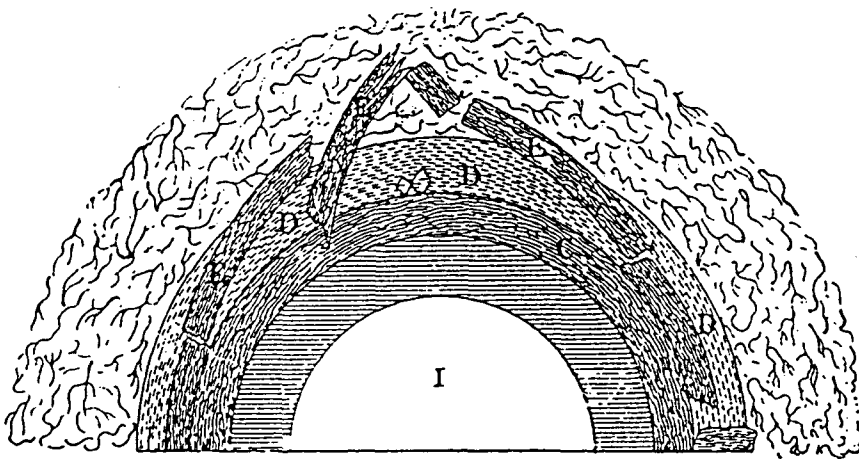
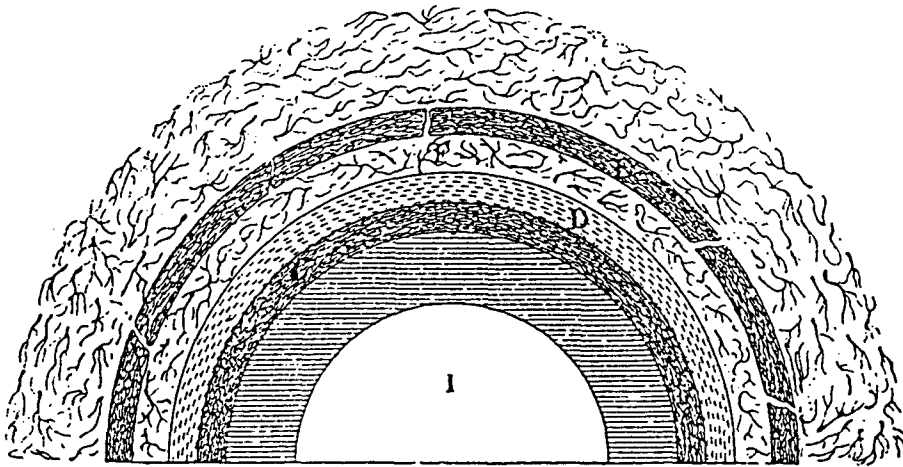


Figure 4.
The earth model by RENÉ DESCARTES (*Principia Philosophiae*, 1644)

Robert HOOKE⁵³), a contemporary of NEWTON, tried even before STENO to deduce the change of the earth's surface from earthquakes. He thought that due to earthquakes considerable parts of the earth have risen without destroying layers and the mountains on them. HOOKE also assumed that major earthquakes have moved the centre of gravity of the earth and thus the direction of the earth's axis.

In total contrast to this idea the French scientist ABBE PLUCHE⁵⁴) thought that God changed the position of the earth's axis thus breaking the earth's crust and raising subterranean water.

K. SCHULTE⁵⁵) has discovered another interesting explanation of earthquakes which was published in "Philosophical Transactions Num 157" (1683). The author, Martin Lyster⁵⁶), was an English physician. According to Lyster sulphur is the cause of earthquakes as well as thunderstorms. He was of the opinion that there is sulphur in the air because of the sulphuric smell occurring during a strike of lightning. Chemical

experiments of his time showed that vapours of sulphur escape when a brimstone or a pyrite is set on fire:

"That these subterraneous cavities are at certain times and in certain seasons full of inflammable Vapours; the Damps in our Mines sufficiently witness; which fired, do every thing as in an Earth-quake, save in a lesser degree. Now, that the Pyrites alone (which is our present Task) of all the known Minerals, yeilds this inflammable vapour, I think it highly probable, for these Reasons. Because no Mineral or Ore whatsoever is Sulphureous, but as it is wholly, or in part a Pyrites: And altho this does contradict the general opinion of the Chymists; yet they must excuse me, if I diffent form them in this particular; for wherever any of them, shall find me Brimstone Naturally, contain'd in an Ore, there, I am very forward to beleive, I shall find them Iron also by the load-stone, so that betwixt us, we shall have discovered the Pyrites disguised in that Ore or Mineral. I have carefully made the experiment in very many of the Fossils of England, and do find them all to contain Iron, wherever Brimstone, as I have elsewhere declared ... "

Based on the ideas of AGRICOLA and R. DESCARTES G.W. LEIBNIZ (1646–1716) explained his doctrine of the evolution of the earth in his book "Protogaia". In his opinion the earth has originally been a sunlike burning body which later on got a solid crust. The fiery core, however, continues to burn in the center. He thinks that the earthquakes and eruptions of volcanoes are caused by local fire-hearths breaking out in caves which were formed by the cooling down of the earth's crust:

"Neque adeo mirari oportet calorem terras coquentem in lapidem, aut metalla in minerales massas fundentem, aut materiam in figurata corpora sublimantem, aut remittente solutione atque aestu deponentem in crystallos; cum non solum eruditorum plerique credant, ignem esse inclusum huic globo, cujus vix crusta nobis

⁵³) Posthoumous Works. – London 1705.

⁵⁴) Spectacle de la nature à la Haye 1738, Tom II p. 2.

⁵⁵) SCHULTE, K.: Über eine Erdbeben-theorie Martin Listers aus dem Jahre 1684, 18th International Congress of the History of Science, Hamburg – Munich 1988.

⁵⁶) Lyster, M.: Of the Nature of Earth-quakes. More particularly of the Origin of the matter of them, from the Pyrites alone, – In: Phil. Trans. Num. 157, March 20, 1683.

explorata est; sed terrae etiam motus validissimi pyrios intus cuniculos innuant, et Vulcani ingentes late patentia pyrophyllacia ostendant."⁵⁷⁾

On occasion of the earthquake in 1703 devastating major parts of Italy and Rome in particular the Italian anatomist Giorgio BAGLIVI (1668–1707), the founder of so-called iatromechanics, wrote a long treatise⁵⁸⁾. BAGLIVI's ideas are based on ARISTOTLE and SENECA. But as an anatomist and physician he was rather influenced by physiological ideas than by ARISTOTLE. He mentions subterranean veins with fire inside and arteries causing earthquakes like the pulse of the earth. But besides that BAGLIVI is also adopting ARISTOTLE's classic distinction of types of earthquakes:

"Ac proindè in telluris centro communicationes esse incredibiles inter ignes subterraneos, aquas, ac alia submarina asserendum est, ... quod revera ignes subterranei per venas subterraneas ad instar aquarum longius serpant ... Diversae autem sunt terraemotuum species rationes diversi modi, quo quatitur terra, sive ratione diversi effectus inde nascentis: Quinque numerantur ab Aristotele, Plinio, et aliis. Quando enim ignis subterraneus accensus interioris antri, sive specus terrae fornicem sursum ejaculat, ut fit in bellicis cuniculis, (vulgò les Mines,) adeòut, adinstar Arteriae pulsantis erigatur, et subsidat, tunc terraemotus, indè factus vocatur ab Aristotele Pulsus. Cum verò dicte Caverne latera accensum ignem veluti captivum detinentia alternatim, et subsultim vibrantur, Tremor, tunc dicitur, qui non ita perniciosus est aedificiis, quia inclinata cito restituntur: Nec ita vehemens est talis terraemotus, quia accensus ignis, neque ita potens est, neque ita copiosus. Denique quando terra tremens hinc inde aequaliter non libratur, ut mens hinc inde aequaliter non libratur, ut loco suo celeriter restituatur, Inclinatio tunc dicitur, aedificiis maximè molesta, et perniciosa: nam parietes, et tecta extra per pendiculum, suspens collabuntur. Inclinatio itaque caeteris terraemotibus est longè periculosior cum terra tremat, sive potiùs nutet navigii more: Nisi enim motus ex altera parte inclinata restituat, ruina statim sequitur."⁵⁹⁾

Like ATHANASIUS KIRCHER he attributes the existence of subterranean fires to inflamed minerals such as sulphur and bitumen.

"Ad unum penè omnes Philosophi credunt dari ignem subterraneum, sive ut dicunt centalem in terre gremio ardentem, cui generationem mineralium, effluxus omnes subterraneos, sulphuris, bituminis, aluminis, carbonum fossilium procreationem, ipsos deinceps terraemotus, thermarumque originem referunt acceptam. Dari revera talem ignem ipsi Montes ignivomi satis apertè ostendunt."⁶⁰⁾

In contrast to the authors of ancient times and the Middle ages BAGLIVI can claim – based on the discoveries of seafarers in modern times – that all over the world there are mountains which are spewing fire and earthquakes. In particular he could refer to the geographical theory of VARENIUS and the descriptions of Jesuite missionaries⁶¹⁾ of both Indias (East Asia and America).

"In Italia Vesuvius, et Aetna perpetuo ardent; et hujusmodi Regionis prae aliis Italiae, obnoxiae sunt frequentibus terraemotibus. In

⁵⁷⁾ LEIBNIZ, G.G.: Protogaea sive de prima facie telluris et antiquissimae historiae vestigiis in ipsis naturae monumentis dissertatio, in act. erud. Lips an. 1693. – In: LEIBNITII Opera Omnia, p. 216, Genf 1768 (ed L. Dutens).

⁵⁸⁾ BAGLIVI, G.: De Terraemotu Romano et Opera Omnia. – Venetiis 1721.

⁵⁹⁾ BAGLIVI, G.: Opera, p. 342–p. 347.

⁶⁰⁾ BAGLIVI, G.: Opera, p. 344.

⁶¹⁾ BAGLIVI is citing: Ioan, Petri Maffei, Historiarum Indicarum Libri XVI. Selectorum, item, ex India Epistolarum, eodem interprete, Libri IV, Coloniae Agrippinae MDXCIII. In this book a mountain in Japan that is spewing fire is described, the name of which was still unknown: montes cu alij passim, tum duo praecipua nobilitate visuntur, quoru alter, incertae appellationis, assiduè flammas evomit. p. 241.

Hecla Islandiae monte continui sunt ignes, qui cum exitu libero careant, sonos edunt tristes, et lamentationibus similes: Multos alios refert Varenus in sua Geographia generali. Ut montem in Java Insula, qui anno 1586. cum antea non arsisset primùm disruptus est, excitato terraemotu, et flagrantis sulphuris eruptione: adeo ut decem milia hominum in agris perierint. Mons in Sumatra Insula Etnae similis fumum, et flammam vomit Omitto alios Montes ignivomos è Maphaeo, et rerum Indicarum scriptoribus adnotatos, ut in Moluccis Insulis, in Philippinis, Japonia, in Peruvia quoque, et variis Americae jugis, in quibus, potissimum vero in Urbe Lima, frequentes sunt terraemotus, ob montium ignivomorum copiam: et ingentes Auri, Argenticque fodinas."⁶²⁾

Several years after the earthquake in Italy, in 1707, the island of Santorini raised out of the sea, leading to further theoretical speculations going back until the genesis of the earth. Anton Lazaro MORO⁶³⁾ for instance used the hypothesis of a central fire being surrounded by a thick crust, which in turn had been covered by water in the beginning. The central fire broke through the crust in some parts leading to the development of continents, islands and mountains. This hypothesis was also used for explaining the occurrence of muscels on mountain tops.

5. Earthquake Theories within Theories of the Evolution of the Earth

At the end of the 17th century a new approach to the explanation of earthquakes within theories of the genesis and evolution of the earth was adopted, based on preliminary works of DESCARTES and LEIBNIZ.

Although all these theories were based on the biblical account of the genesis of the earth they finally led to a general theory of the earth, first established by BUFFON. Consequently earthquake theories have no longer been considered apart from theories of the evolution of the earth.

The first was Thomas BURNET⁶⁴⁾, who still based his work "Telluris theoria sacra" totally on the biblical account of the creation of the earth. He thought that in the beginning the earth was fluid chaos. Later the heavier parts sank down and formed the core of the earth which still may have been fiery in its inner part. The solid core of the earth was surrounded by deep water (abyssos) on which the totally flat crust emerged (see Fig. 6). After 1600 years the crust had dried up so much that it tore into pieces crumbling into the water. This led to the Big Flood and to an uneven surface of the earth in the form of mountains and valleys.

Whereas BURNET still thought that the core of the earth was solid and fiery, WOODWARD'S⁶⁵⁾ theory was that the earth consisted of a very big sphere of water surrounded by a hard crust. The crust broke apart and dissolved in the water of the Flood. The dissolved parts of the crust sedimented and formed a new solid crust which later broke again, thus leading to deepening and heightenings of the earth (see Fig. 7).

⁶²⁾ BAGLIVI, G.: Opera, p. 345 f.

⁶³⁾ De' crostacei e degli altri marini corpi, che si trovano su monti, libri due in Venez. 1740.

⁶⁴⁾ Telluris theoria sacra, orbis nostri originem et mutationes, quas aut iam subiit aut subiturus est, complectens. – London 1681.

⁶⁵⁾ Historia natur. telluris (London 1695) and Essay towards a natural history of the earth and terrestrial bodies (London 1733).

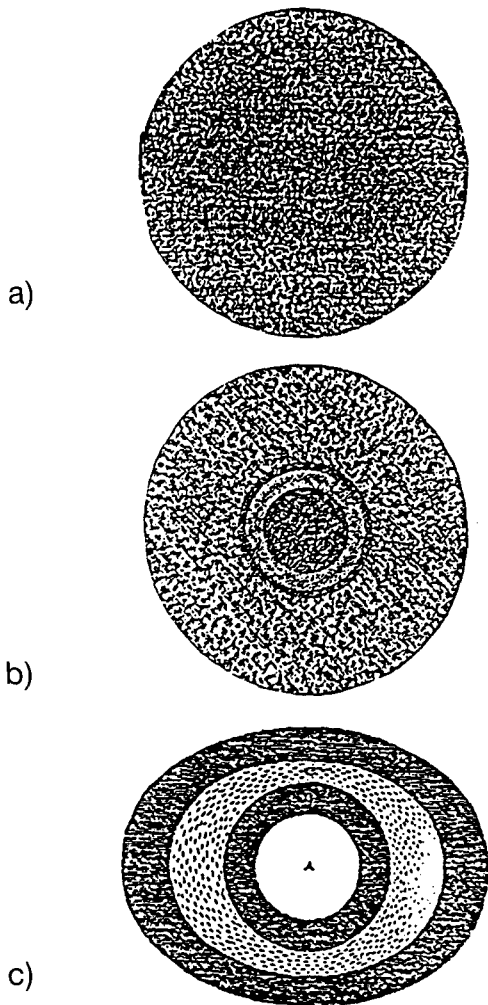


Figure 6.
Stages of development of the earth according to BURNET (1681).
a) Chaos in the Earth.
b) Genesis of the solid kernel of the earth.
c) Formation of different layers.

John RAY⁶⁶⁾ also thought that the heavy solid parts fell apart in the primordial chaos. They sank until they formed a hard core surrounded by water. According to John RAY earthquakes played a decisive role in the genesis of the earth: even during the creation of the earth from chaos subterranean vapours and winds caused earthquakes raising mountains and dry land out of the water. Subterranean fires broke through the earth's crevices, caused by such liftings, and volcanoes emerged. RAY explains the Flood as a natural consequence of a small shift of the centre of gravity of the earth leading to major changes at the surface.

The most famous of the British authors dealing with the theory of the genesis of the earth was William WHISTON, who in 1701 followed NEWTON as professor of mathematics in Cambridge. His book 'New Theory of the Earth' first published in London in 1696, caused a big sensation because of its phantastic and unusual hypotheses. During his lifetime six editions were published. Both NEWTON and John LOCKE praised this book and even BUFFON, who strongly criticized the theories

⁶⁶⁾ Physico-theological discourses concerning the primitive chaos, the general deluge and the dissolution of the world. - London 1692.

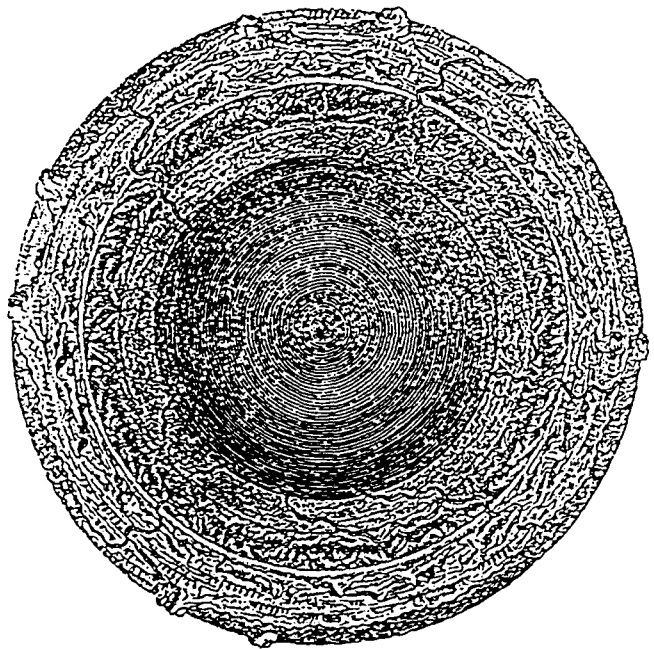


Figure 7.
Cross section of the earth according to the theory of John WOODWARD (1733).

of BURNET and WOODWARD, described WHISTON's theory in detail and with great respect.

WHISTON wanted not only to show that the biblical account of the creation of the earth corresponded to his new theory of the earth, but also to qualify the prophecy of the future dawn of the earth by burning as a scientific prognosis. According to his theory the earth first was a big comet with a very excentric trajectory. God transformed this excentric trajectory of this comet into a circle with a rotation about its axis. Then three shell-like layers developed out of this chaotic comet: a heavy hot core, above water and finally the crust which formed the basis for the genesis of life.

According to the Bible a huge comet with its tail filled with water caused the Big Flood in 1349 B.C. Following his predecessor NEWTON, WHISTON also thought that the gravitational force of the comet also affected the subterranean layer of water, thus breaking the crust of the earth and forming today's land masses, mountains and seas.

WHISTON believed that a comet will also lead to the end of the earth. But this comet was supposed to be a very fiery one. When this comet will approach the earth, many terrible earthquakes will occur and the earth will burn due to the approaching heat of the comet and finally the earth will be glazed and transparent.

In 1707 the Swiss physician D. Joh. SCHEUCHZER sent another treatise on the origin of mountains or the genesis of the earth to the Academy of Sciences in Paris. According to STENO the development of layers took place in different periods: one period in which the earth had neither plants nor animals and a second period in which the earth already had living beings. Whereas STENO explained the fact that remnants of plants had been found in very deep layers of rock, with earthquakes and other catastrophes, SCHEUCHZER, BURNET and WOODWARD preferred the general Flood as the reason for this curious fact.

But SCHEUCHZER's explanation yields the problem that the formation of mountains must be explained which cannot origin from fluid earth. Thus SCHEUCHZER had to assume that God was the creator of the mountains. His almighty hand pushed the water back into subterranean reservoirs and broke the horizontal layers.

"Des parties d'Animaux terrestres, ou aquatiques, des branches d'arbres, des feuilles, etc. trouvées dans des lits de pierre, même assez profonds, confirment ce système de la fluidité de la Terre. Quel autre moyen que tout cela eût été enfermé où il l'étoit? Mais il est vrai aussi qu'il faut supposer une seconde formation des lits ou couches, beaucoup moins ancienne que la première, du temps de laquelle la Terre n'avoit encore ni Plantes ni Animaux. Stenon établit plusieurs secondes formations causées en differens temps par des inondations extraordinaires, par des tremblemens de terre, par les matieres que vomissent les Volcans. Burnet, Woodward et M. Scheuchzer aiment mieux attribuer au Déluge universel une seconde formation générale, qui n'exclut pourtant pas les particulieres de Stenon.

Mais les Montagnes semblent renverser le Système de la fluidité, elles n'auroient jamais dû naître, puisque tout ce qui est liquide se met de niveau. Cependant ce Système est si vrai-semblable en lui-même, et il se soutient si bien dans la plus grande partie du globe terrestre, qu'il merite qu'on fasse quelque effort pour le conserver. C'est pour cela que M. Scheuchzer adopte la pensée de ceux qui on crû qu'après le Déluge universel Dieu voulant faire rentrer les Eaux dans des Réservoirs fôuterrains, avoit brisé et déplacé de sa main toute-puissante un grand nombre de lits auparavant horizontaux, et les avoit élevés sur la surface du globe."⁶⁷⁾

J.G. KRÜGER used the experience of mining and experimental chemistry for explaining the causes of earthquakes in the 'Geschichte der Erde'. KRÜGER had to prepare an expertise for the Preussian king concerning continuing coal fires in the mines. In his book published in 1745⁶⁸⁾ he proposed three stages in the development of the earth. First the earth was surrounded by water, then it caught fire, the water began to boil and finally earthquakes led to the formation of mountains, hills and valleys. Concerning the explanation of the causes of earthquakes he also mentioned the self-inflammation of sulphur and other inflammable matter. Earthquakes arise either due to the expansion of heated air or due to the mixing of heated matter with water:

"... Denn setzet, daß sich in einer unterirdischen Gruft verschiedene Materien miteinander vermengen, und anfangen sich zu entzünden, so wird die Luft in dieser Höle gewaltig erhitzt werden; durch die Hitze wird ihre Elastizität vermehrt, und so stark gemacht, daß sie mit der grÜßten Gewalt einen Ausgang sucht. ... wenn unter der Erde eine sehr große Hitze entsteht ... und es vermischt sich das Wasser mit dergleichen erhitzer Materie, so verwandelt sich auf einmal eine sehr grosse Menge desselben in Dünste, welche eine so große Gewalt haben, daß es eben so viel ist, als wenn man eine Mine gesprengt hätte .. "⁶⁹⁾

All these theories of the origin of the earth by LEIBNIZ, BURNET, WOODWARD, WHISTON and SCHEUCHZER had been integrated into the 'Théorie de la Terre' by Georg Louis Lecrec BUFFON (1707–1788). This book was published as the first volume of his "Histoire naturelle" in

⁶⁷⁾ Histoire de l'Academie Royale des Sciences. – Année 1708, p. 37 f., Amsterdam 1709.

⁶⁸⁾ KRÜGER, J.G.: Der Weltweisheit und Arzneygelahrtheit Doctors und Profeßors auf der Königl. Preußischen Friedrich Universität, Geschichte der Erde in den allerältesten Zeiten. – Halle 1746.

⁶⁹⁾ Taken from: Borman, P.: Der Beitrag Immanuel KANT's zur Entwicklung wissenschaftlicher Vorstellungen über die Natur der Erdbeben. – In: Geschichte der Seismologie, Seismik und Erdgezeitenforschung, Tagungsband Eisenach, 5.–7. Dez. 1979. Veröffentlichungen des Zentralinstituts für Physik der Erde, Nr. 64, 1981, S. 17–24.

1749, had several revised editions and can be considered – until this point of time – the best way of explaining earthquakes in the framework of a general theory of the earth.

BUFFON criticizes all these theories assuming a direct intervention of God in terrestrial events. Thus he considers the theories of BURNET, WOODWARD and SCHEUCHZER to be not more than well written, sometimes ridiculous, novels for entertaining the reader but lacking a serious basis. He only respects LEIBNIZ and STENO and also qualifies WHISTON as a scientific predecessor, in spite of his theory of the earth being a comet, since he himself explains the genesis of the earth by the phantastic idea of the crash of a comet with the sun in the last version of his theory of the earth⁷⁰⁾. He thought that the earth was one of the blazing pieces the comet had torn out of the sun. In his first theory of the earth in 1749 he assumed a central fire and subterranean fire-hearths and directly linking volcanoes and earthquakes. There is nothing that can be compared to the huge force and violence of these subterranean fires. Even the big earthquakes with crumbling mountains are only secondary causes lacking a decisive role in the evolution of the earth.

"Ces grands affaissements, quoique produits par des causes accidentelles et secondaires, ne laissent pas de tenir une des premières places entre les principaux faits de l'histoire de la terre, et ils n'ont pas peu contribué à changer la face du globe. La plupart sont causés par des feux intérieurs, dont l'explosion fait les tremblements de terre et les volcans: rien n'est comparable à la force de ces matières enflammées et resserrées dans le sein de la terre, on a vu des villes entières engluties, des provinces bouleversées des montagnes renversées par leur effort."⁷¹⁾

6. A Failed Attempt – Electricity as the Cause of Earthquakes

Both earthquakes in London, 8 February and 8 March 1749 and another earthquake on 30 September 1750, which was noticed in vast parts of England, gave rise to a new, hitherto unknown attempt of explanation. In the latter earthquake no fire, vapour or smoke could be detected, thus all theories failed which tried to attribute the causes of earthquakes to subterranean winds, fires or chemical explosions.

William STUKELEY was the first to assume in an treatise in Philosophical Transactions that electricity is the cause of these earthquakes. He justified his opinion with the missing proof of the assumption that the interior of the earth consists of caves and tunnels. He rather assumed that the interior of the earth is more or less solid with only little space for such gigantic explosions or vapours. In addition extensive earthquakes at the surface of the earth would have to originate deeply inside the earth and with such an enormous force which could never be produced neither by vapours nor by fire explosions. Thus he concluded that earthquakes can be nothing else than electrical shocks, exactly of the same nature as those made popular by FRANKLIN's electrical experiments:

⁷⁰⁾ Epoche de la nature 1778.

⁷¹⁾ Histoire de theorie de la terre. – In: Oeuvres complètes de Buffon I, p. 107, Paris 1847.

"Admitting this, there is nothing wanting, to produce the wonderful Effect of an Earthquake, but the Touch of any non-electric Body; on that must necessarily be had ab extra, from the Region of the Air, or Atmosphere. We had lately a very pretty Discourse read here, from Mr. FRANKLYN of Philadelphia⁷²⁾ concerning Thundergusts, Lights, and like Meteors. He well solves them by the Touch of Clouds, rais'd from the Sea (which are Non-electrics), and of Clouds rais'd from Exhalations of the Land (which are electrify'd): 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, if a nonelectric Cloud discharges its Contents, 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; Contact, be the horrible uncouth Noise thereof."⁷³⁾

The idea that earthquakes were caused by electricity was common also in Italy and France. In a treatise⁷⁴⁾ published in Perugia in 1751 Andrea BINA, for instance, tried to explain the origin of earthquakes in analogy to the experiment with the Leyden jar, already known at that time. He replaced the jar with subterranean water containers coated by sulphur and pitch and linked among each other by subterranean tunnels instead of iron wires. The strong stroke that can be felt when a Leyden jar is discharged corresponds to the earthquake which is nothing else than a discharge of the subterranean water containers.

The most important argument for explaining earthquakes as an effect of electricity was the hitherto unexplainable propagation speed of earthquakes which, according Giovanni Battista BECCARIA (1716–1781)⁷⁵⁾, professor of physics in Torino, proved the identity of electrical shocks and earthquakes. BECCARIA gave empirical evidence that during the eruption of the Vesuvius light flames spouting out like lightning from the interior the earth could be observed. Exactly these lightnings could be observed in many earthquakes, accompanied by a rumbling din, similar to thunder.

Another proof of the opinion that earthquakes do not origin from slow earth elevations both rather from a sudden electrical shock, BECCARIA mentions that during an earthquake a sudden stroke can be felt on ships which are far off the coast, as if the ship would crash into a cliff. In order to prove these theories on the electrical causes of earthquakes both BECCARIA and CAVALLO⁷⁶⁾ carried out the following experiment: even if two wires cast in glass are charged electrically, the glass is strongly shaken or even broken.

In France a combination of traditional theories of the origin of earthquakes by fire and vapour with electricity was held. In these theories electricity was seen as the origin of the inflammation of fire hearths. On this hypothesis Bertholon ST. LAZARE⁷⁷⁾ based his proposal to protect whole regions of France against the effects of earthquakes by using lightning conductors. He pro-

posed to drive long iron rods with various kinds of tips and wires on both ends into the soil. In this way a steady equilibrium between the atmosphere and the interior of the earth should be sustained.

Although these attempts of explaining earthquakes with the effect of electricity were widespread for a short period of time, they later were given up quickly. KANT, whose ideas on the causes and mechanisms of earthquakes will be discussed in detail later, was the first to reject the opinion of father BINA, as free excesses of greed for new discoveries which are different from well founded and careful reasoning which are based on experience and which can claim reasonable credibility.

7. KANT and the Great Lisboa Earthquake of 1755

A decisive incentive for theoretization was derived from a series of major earthquakes in the 18th century, the Lisboa earthquake in 1755, the earthquakes of Calao and Lima in 1746 and Calabria in 1783. The number of casualties (40.000–50.000 in Lisboa, about the same in Calabria) triggered the discussion about the causes of earthquakes in the hope of making predictions safer and finding meaningful safeguards. The events fell into an epoche, where many elementary laws of classical mechanics were already known. 50 years earlier NEWTON had published his theory of gravity applied to the planets. This theory allowed the estimation of the gravity forces of planets in relationship to the earth. The law of inertia as well as special chemical reactions such as the generation of FeS were commonly known to contemporary scientists. Thus they were able to use this background knowledge as a basis to understand the mechanisms of earthquakes.

The German philosopher Immanuel KANT^{78,79,80)} wrote three essays on these issues. The first entitled "Von den Ursachen der Erderschütterungen bei der Gelegenheit des Unglücks, welches die westlichen Länder von Europa gegen das Ende des vorigen Jahres betroffen hat" was written under the impression of the Lisboa earthquake in 1756. One year before KANT had published his "Allgemeine Naturgeschichte und Theorie des Himmels", which already showed that he knew BUFFON's theory of the earth. But he knew much more about NEWTON's astronomical theories and physics than BUFFON. Thus these three essays and the earthquake theory contained in them should be considered in a wider context of the origin of the earth and the solar system. Whereas he praises John RAY and BUFFON

⁷²⁾ Read Nov. 16, 1749, published with other Tracts on Electricity by Mr. Peter COLLINSON F.R.S., London 1750.

⁷³⁾ STUKELEY, W.: On the causes of Earthquakes. – Phil. transact. Vol XLVI., n. 491., p. 641–646.

⁷⁴⁾ BINA, A.: Ragionamento sopra le cagione de terremoti. – Perugia 1751.

⁷⁵⁾ Lettere dell'elettricismo. – Bologna 1758.

⁷⁶⁾ Vollständige Abhandlung der Lehre der Elektrizität. – vol I, p. 67, 224, Leipzig 1797.

⁷⁷⁾ ROZIER journal de physique, Aout 1779.

⁷⁸⁾ KANT, I.: Von den Ursachen der Erderschütterungen bei der Gelegenheit des Unglücks, welches die westlichen Länder von Europa gegen das Ende des vorigen Jahres getroffen hat, 1776. – In: KANT's Werke I, Akademie-Textausgabe, 417–428, Berlin 1968.

⁷⁹⁾ KANT, I.: Geschichte und Naturbeschreibung der merkwürdigsten Vorfälle des Erdbebens, welches an dem Ende des 1775sten Jahres einen großen Teil der Erde erschüttert hat, 1776. – In: KANT's Werke I, Akademie-Textausgabe, 429–462, Berlin 1968.

⁸⁰⁾ KANT, I.: Fortgesetzte Betrachtung der seit einiger Zeit wahrgenommenen Erderschütterungen, 1756; – In: KANT's Werke I, Akademie Textausgabe, 463–472, Berlin 1968.

for their numerous accounts and proof of earthquakes that took place, he rejects WHISTON's comet theory (still popular at that time) as crazy dreams. He explicitly wanted to deal only with probable causes of earthquakes as the only true ones.

The 20th century's reader has to observe that many important concepts of wave propagation were not yet commonly known at that time. Contemporary scientists imagined that seismic energy propagates similar to that of mass transport as – for instance – air particles, when they are transported by wind. The most important peculiarity of wave propagation in solid media, the transport of energy and impulse by elastic deformation only but without mass transport, had not been realized yet. Therefore, contemporary writers found it difficult to explain special effects at greater distances from the epicenter, such as seiches. When searching for a suitable transport mechanism of seismic energy KANT developed the following idea: the caves inside the earth, supposed since antiquity, run parallel to mountain ranges and big rivers. They carry the effects of wind, fire or a blast over longer distances⁸¹). This "natural relatedness" results from events in the evolution of the earth. In Italy, e.g. this direction is North–South (this can be detected by watching church lamps swing) and in Lisboa it is West–East (which is the direction of Europe's highest mountain ranges):

"Das erste, was sich unserer Aufmerksamkeit darbietet, ist, daß der Boden, über dem wir uns befinden, hohl ist und seine Wölbungen fast in einem Zusammenhang durch weitgestreckte Gegenden sogar unterm Boden des Meeres fortlaufen ... Ich müßte bis in die Geschichte der Erde im Chaos zurück gehen, wenn ich etwas Begreifliches von der Ursache sagen sollte, die bei der Bildung der Erde den Ursprung dieser Höhlen veranlaßt hat ... Die Ursache mag aber sein, welche sie wolle, so ist es doch gewiß, daß die Richtung dieser Höhlen den Gebirgen und durch einen natürlichen Zusammenhang auch den großen Flüssen parallel ist; denn diese nehmen das unterste Theil eines langen Thals ein, das von beiden Seiten durch parallel laufende Gebirge beschränkt wird. Eben dieselbe Richtung ist es auch, wornach die Erderschütterungen sich vornehmlich ausbreiten. In den Erdbeben, welche sich durch den größten Theil von Italien erstreckt haben, hat man an den Leuchtern in den Kirchen eine Bewegung von Norden fast gerade nach Süden wahrgenommen; und dieses neuliche Erdbeben hatte die Richtung von Westen nach Osten, welches auch die Hauptrichtung der Gebirge ist, die den höchsten Theil von Europa durchlaufen."⁸²

From this KANT deduced that houses and streets should never be built parallel to mountains and rivers in endangered areas:

"Wenn in so schrecklichen Zufällen den Menschen erlaubt ist einige Vorsicht zu gebrauchen, wenn es nicht als eine verwegene und vergebliche Bemühung angesehen wird allgemeinen Drangsalen einige Anstalten entgegen zu setzen, die die Vernunft darbietet, sollte nicht der unglückliche Überrest von Lissabon Bedenken tragen sich an demselben Flusse seiner Länge nach wiederum anzubauen, welcher die Richtung bezeichnet, nach welcher die Erderschütterung in diesem Lande natürlicher Weise geschehen muß."⁸³

He points out that Lisboa suffered more because it was built alongside the river Tejo:

⁸¹) KANT uses the idea of caves below mountain ranges in order to understand the propagation of seismic energy. The same idea was an important step in the course of the development of the theory of isostasy. BOSCOVIC (1755) suggested this concept as an interpretation of BOUGUER's observation in Peru, which indicated that the gravity force of high mountains turns out smaller than expected. BOUGUER published his results in 1749. KANT does not refer to this important contribution of BOUGUER, mentioning his earthquake theories only.

⁸²) KANT's Werke I, p. 420.

⁸³) KANT's Werke I, p. 420 f.

"Das Unglück von Lissabon scheint also durch seine Lage vergrößert zu sein, die es der Länge nach an dem Ufer des Tagus gehabt hat; und nach diesen Gründen müßte eine jede Stadt in einem Lande, wo die Erdbeben mehrmals empfunden werden, und wo man die Richtung derselben aus der Erfahrung abnehmen kann, nicht nach einer Richtung, die mit dieser gleichlaufend ist, angelegt werden."⁸⁴

KANT who had chosen an especially uneventful and quiet life style happily remarked that his homeland Prussia was safe from earthquakes as it was flat and the earth's crust even. Mountainous countries such as Peru and Chile are much more endangered:

"Der Hauptstrich der Erdbeben geht in der Richtung der höchsten Gebirge fort, und es werden also diejenige Länder hauptsächlich erschüttert, die diesen nahe liegen, vornehmlich wenn sie zwischen zwei Reihen Berge eingeschlossen sind, als in welchem Falle die Erschütterungen von beiden Seiten sich vereinbaren. In einem platten Lande, welches nicht in einem Zusammenhange mit Gebirgen steht, sind sie seltener und schwach. Darum sind Peru und Chili diejenige Länder, die fast unter allen in der Welt den häufigsten Erschütterungen unterworfen sind."⁸⁵

Trying to explain the active causes of earthquakes KANT does not stop at wind and fire as does ARISTOTLE, but gives a chemical explanation. In accordance with contemporary experimental chemistry⁸⁶) he presumes that a certain mixture – 2 parts vitriol oil, 8 parts water, 2 parts iron – produces steam and flames:

"Zwei Quentchen Vitriolöl, mit 8 Quentchen gemeines Wasser vermischt, wenn man sie auf 2 Quentchen Eisenfeil gießt, bringen ein heftiges Aufbrausen und Dämpfe hervor, die sich von selber entzünden. Wer kann zweifeln, daß die vitriolische Säure und Eisentheile in genugsamer Menge in dem Inneren der Erde enthalten sind? Wenn das Wasser nun hierzukommt und ihre gegenseitige Wirkung veranlaßt, so werden sie Dämpfe ausstoßen, die sich auszubreiten trachten, den Boden erschüttern und bei den Öffnungen feuerspeinder Berge in Flammen ausbrechen."⁸⁷

Another explanation pertains to tidal and compressional waves caused by earthquakes. KANT relies on an experiment mentioned in the German translation of the Memoires de l'Academie Royale in Paris of 1705: CARRÉ described the firing of a bullet of a shot gun into a wooden box, filled with water. The sudden stroke compressed the water which burst the box:

"Damit ich nun gewisser würde, ob die Gefäße von der starken Bewegung und Bestrebung des Wassers, oder von der dadurch gehenden Kugel zersprengt würde; so habe ich mir einen viereckigen Kasten machen lassen. Er ist 1 Fuß hoch und 6 Zoll dicke. Die vier langen Breiter sind, jedes 1 Zoll dicke; die beyden Breiter an den Enden, jedes 2 Zoll, damit man die andern Breiter mit Nägeln recht stark daran befestigen könne. Diesen habe ich durch ein kleines Loch mit Wasser angefüllt, und nachher meinen Schuß gethan, die Breiter sind davon durchlöchert, und nicht zersplittert worden. Allein das Wasser ist dergestalt gepresst worden, daß es die Breiter aus einander getrieben, und den Kasten zersprengt hat."⁸⁸

⁸⁴) KANT's Werke I, p. 421.

⁸⁵) KANT's Werke I, p. 421.

⁸⁶) BOORHAEVE already reports on the self-ignition of sulphur and mixed with water. In an edition of his 'Elementare Chemiae' of 1766, p. 875 he wrote: "Nehmet 8 Unzen von eben solchen mit Schwefel gehörig vermischten Eisenfeil, knetet selbiges mit Wasser, so daß es ein dicker Teig werde, selbigen drücket in einen irdenen Gefäß wohl auf einander, und setzes es bey seite, so wird es in kurzen von selbst anfangen warm zu werden, sich zu erhitzen, sehr heiß zu werden, Rauch von sich zu geben, und zuletzt zum öfftern gar anzubrennen."

⁸⁷) KANT's Werke I, p. 426.

⁸⁸) CARRÉ: Physische Versuche von der Refraction der geschlossenen Flintenkugeln im Wasser, und von dem Widerstande dieses flüßigen Körpers. – Der Königl. Akademie der Wissenschaften in Paris. Physische Abhandlungen, Zweyter Theil. Aus dem Französischen übers. von W.B.A. von Steinwehr, p. 550, Breslau 1748.

Pour m'assurer davantage si c'étoit le grand mouvement et l'effort de l'eau qui faisoient briser ces vaisseaux, et non-pas la balle en passant au travers; j'ai fait faire une caisse quarrée d'un pied de haut, et des fix pouces d'épaisseur, dont les quatre ais qui faisoient la longueur, avoient chacun un puce d'épaisseur, et les deux du bout en avoient chacun deux, afin d'y bien attacher les autres avec force cloux; j'en ai remplie d'eau par un petit trou, ensuite j'ai tiré mon coup qui a percés les ais fort exactement sans les briser, mais l'eau s'est tourmentée de telle maniere qu'elle a fait écarter ces ais les uns des autres et a brisé la caisse."⁸⁹⁾

Based on these mechanical hydrodynamic experiments KANT asserts that even water can react like a solid body when suddenly compressed. Thus it can transmit shocks nearly without softening them. Water-pressure remains the same even at a distance (200–300 miles) and is especially high in narrow channels such as the one between England and France.

"Dieser plötzlichen Rüttelung widerstand das aufliegende Wasser so, daß es nicht, wie bei langsamen Bewegungen geschieht, nachgab und in Wellen aufschwoll, sondern es empfing seinen ganzen Druck und trieb das umliegende Wasser ebenso heftig zur Seite fort, welches bei so schnellen Eindrücke als ein fester Körper anzusehen ist, davon das entfernte Ende mit eben derselben Geschwindigkeit fortgedrückt, als das angestoßene fortgetrieben wird. Also ist in jedem Balken der flüssigen Materie (wenn ich mich dieses Ausdrucks bedienen darf) ob er gleich 200 oder 300 Meilen lang ist, keine verminderte Bewegung, wenn er als in einem Canal eingeschlossen gedacht würde, der an dem entfernten Ende eine ebenso weite Eröffnung als beim Anfange hat."⁹⁰⁾

Speaking about inland lakes KANT makes an interesting observation: Although they are without any visible connection to the sea, they react nevertheless to tidal waves caused by earthquakes which hints at them having a "subterranean link" to the sea:

"Bei dieser Pressung der Wasser ist das Allersonderbarste, daß sie sogar in Landseen, die gar keinen sichtbaren Zusammenhang mit dem Meere haben, bei Templin und in Norwegen, gespürt worden. Dieses scheint beinahe der stärkste unter allen Beweisen zu sein, die man jemals vorgebracht hat, die unterirdische Gemeinschaft der mitelländischen Gewässer mit dem Meere zu beweisen."⁹¹⁾

After having explained his fundamental concepts, KANT wrote another and longer treatise (see footnote 79), describing and explaining the Lisbon earthquake. In this essay he also arrives at a correct explanation of the movements of those inland lakes which are not connected with the sea. Many years later (1892–96) Francois Alphonse FOREL minutely described the movements, which he called "Seiches", quoting as an example the Lake of Geneva. According to KANT these movements do not occur as a result of varying atmospheric pressure (especially after storms) but they are to be attributed to the slightly varying tilt of the earth's surface which may occur during big earthquakes at great distances. These earthquakes may not be noticed. However, as a consequence of this tilting, rather strong movements of water in these lakes can occur:

"Dagegen werden die Seen diese unempfindliche Bewegung sehr merklich haben machen müssen. Denn wenn ein See z.E nur 2 deutsche Meilen lang ist, so wird sein Wasser durch dieses geringe Wanken seines Bodens schon in eine recht starke Schaukelung versetzt werden ... Man wird sich also nicht mehr wundern, wenn alle inländische Seen in der Schweiz, in Schweden, in Norwegen und in Deutschland, ohne eine Erschütterung des Bodens zu fühlen, so unruhig und aufwallend erblickt worden."⁹²⁾

⁸⁹⁾ CARRÉ: Sur la Refraction des balles de Mousquet dans l'eau, et sur la résistance de ce fluide. – Histoire de l'Academie Royale des Sciences. Année MDCCV, p. 278, Amsterdam 1707.

⁹⁰⁾ KANT's Werke I, p. 425.

⁹¹⁾ KANT's Werke I, p. 425 f.

⁹²⁾ KANT's Werke I, p. 440 f.

Although these reports taken from newspapers back a scientific foundation according to today's opinion⁹³⁾, this nevertheless led to a correct explanation of the waves of the water of inland lakes caused by earthquake waves. P. BORMANN (see footnote 69) has mentioned additional astonishing anticipations of current explanations. KANT had already noted a link between the Lisboa earthquake and the under-water mountains near the Azores.

"Durch die Vergleichung der Zeit ersehen wir, daß der Entzündungsplatz bei dem Erdbeben vom 1 ten Nov. in dem Boden der See gewesen. Der Tajo, der schon vor der Erschütterung aufschwoll, der Schwefel, den Seefahrende mit dem Senkblei aus dem erschütterten Boden brachten, und die Heftigkeit der Stöße, die sie fühlten, bestätigen es. Die Geschichte vormaliger Erdbeben giebt es auch deutlich zu erkennen, daß in dem Meeresgrunde jederzeit die fürchterlichsten Erschütterungen vorgefallen sind und nächst diesem in den Örtern, welche an dem Seeufer oder nicht weit davon entfernt liegen. Zum Beweise des ersteren führe ich die tobende Wuth an, womit die unterirdische Entzündung oft neue Inseln aus dem Boden des Meeres erhoben hat und z.E. im Jahre 1720 nahe bei der Insel St. Michael, einer von den azorischen, aus einer Tiefe von 60 Klaffer durch den Auswurf der Materie aus dem Grunde der See eine Insel auswarf, die 1 Meile lang und etliche Klaffer über dem Meere erhoben war."⁹⁴⁾

KANT also dealt with a problem which could be solved only recently by the geologico-geophysical proof of 'see floor spreading': he discusses the fact that those towns are hit by earthquakes more often which are near the sea:

"Der Bemerkung der häufigen Erschütterungen des Seegrundes hängt mit der Frage natürlicherweise zusammen: woher unter allen Örtern des festen Landes keine heftigern oder öfteren Erdbeben unterworfen sind, als diejenige, die nicht weit vom Meeresufer liegen."⁹⁵⁾

When Lisboa was again shaken by an earthquake in 1756, KANT wrote his third treatise entitled "Fortgesetzte Betrachtung der seit einiger Zeit wahrgenommenen Erderschütterungen". In his extensive second treatise (see footnote 79) KANT applied his fundamental concepts to the Lisboa earthquakes of Nov 18, Dec 9 and 26, 1755 and tried to find a law governing the spreading and the intervals.

The explanation for both problems is as follows:

- 1) Earthquakes spread as a result of hot, compressed air in subterranean caves under big mountain ranges:

"Die Erdbeben haben uns offenbart, daß die Oberfläche der Erde voller Wölbungen und Höhlen sei, und daß unter unsern Füßen verborgene Minen mit mannigfaltigen Irrgängen allenthalben fortlaufen ... Diese Höhlen enthalten alle ein lodernes Feuer, oder wenigstens denjenigen brennbaren Zeug, der nur einer geringen Reizung bedarf, um mit Heftigkeit um sich zu wüthen und den Boden über sich zu erschüttern oder gar zu spalten."⁹⁶⁾

- 2) Intervals are determined by a chemical respiratory process: fiery compressed air is pushed out through the "throats" of volcanoes. Inside the earth fire is quenched for lack of oxygen. It is kindled again when air returns into the empty caves from outside. This creates a gigantic periodic respiration process inside the huge subterranean caves comparable to a gigantic lung on which we human beings stand:

⁹³⁾ SCHMIDT in P. BORMANN. KANT is citing in this connection the "Königsbergischen Anzeigen". – KANT's Werke I, p. 439.

⁹⁴⁾ KANT's Werke I, p. 448.

⁹⁵⁾ KANT's Werke I, p. 449.

⁹⁶⁾ KANT's Werke I, p. 432 f.

“Wenn das unterirdische Feuer in Entzündung geräth, so stößt es alle Luft aus den Höhlen umher von sich. Wo diese Luft nun, die mit den feurigen Theilen angefüllt ist, eine Öffnung findet, z.E. in dem Rachen eines feuerspeienden Berges, da fährt sie alsdann hinaus, und der Berg wirft Feuer aus. Allein so bald die Luft aus dem Umfange des Herdes der Entzündung verjagt ist, so läßt die Entzündung nach, denn ohne Zugang der Luft verlöscht alles Feuer, alsdann tritt die verjagte Luft, da die Ursache, die sie vertrieben hatte, aufhört, wieder in ihren Platz zurück und weckt das erloschene Feuer auf, auf solche Weise wechseln die Ausbrüche eines feuerspeienden Berges in gewissen Zwischenzeiten richtig nach einander ab. Eben die Verwandtniß hat es mit den unterirdischen Entzündungen, auch selbst da, wo die ausgedehnte Luft keinen Ausgang durch die Klüfte der Berge gewinnen kann. Denn wenn die Entzündung an einem Orte in den Höhlen der Erde ihren Anfang nimmt, so stößt sie die Luft mit Heftigkeit in einem großen Umfange in alle die Gänge der unterirdischen Wölbungen fort, die damit Zusammenhang haben. In diesem Augenblicke erstickt das Feuer selbst durch den Mangel der Luft. Und so bald eben diese ausdehnende Gewalt der Luft nachläßt, so kehrt diejenige, die in allen Höhlen ausgebreitet war, mit großer Gewalt zurück und facht das erloschene Feuer zu einem neuen Erdbeben an.”⁹⁷⁾

It should be stressed that KANT rejects the assumption that the constellations of the moving planets could cause earthquakes. He refers to NEWTON's theory and gives a numerical estimate which proves the gravity forces as too small. He refutes all mystical, astrological or religious interpretations of earthquakes as God's punishment: Wir haben die Ursache unter unseren Füßen “We stand with our feet on the cause”.⁹⁸⁾

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⁹⁷⁾ KANT's Werke I, p. 447.

⁹⁸⁾ KANT's Werke I, p. 469.

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