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A history of the global understanding of the Earth

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ABSTRACT

The author contributes to the development of a history of the global understanding of the Earth. He summarizes the main steps in the knowledge of the Earth's interior from antiquity to the present time and draws some lessons from this history.
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A history of the global understanding of the Earth is seldom encountered in the literature. Works can be found about the history of geology (Ellenberger, 1988, 1994; Gohau, 1990; Greene, 1982) and monographs on geophysical aspects such as geodesy (Levallois, 1988; Todhunter, 1873), magnetism (Courtillot and Le Mouël, 2007) or seismology (Ben-Menahem, 1995). Fragmented information is also scattered in historical works about astronomy or natural sciences, or sometimes offered as an appendix to classical sciences (Taton, 1957). But few general works exist dealing with the global vision of the Earth. Indeed, since antiquity up to the age of space techniques, the Earth has been observed, explored, modelled and even sometimes invented and constitutes a subject of research in its own right. Our work aims at contributing to the development of a global history of geosciences and thus helps to fill the gap that subsists, for instance, as compared to astronomy whose specialists have already developed such a history in their own domain. In this article, we summarize the main steps in the knowledge of the Earth's interior from antiquity to the present time and we draw some lessons from this history.

1. How is it possible to know the inside of the Earth?

Since Anaximander, in the 6th century B.C., understood that the Earth constituted an isolated object in space, philosophers and scientists have tried to apprehend it as a whole, to understand its constitution and structure. How was it possible to know the inside of the Earth? How was it possible for human beings to discover what cannot be accessed? From Aristotle's concepts to present-day physics, evolution has journeyed from spherical stratification of the four elements: earth, water, air and fire to a rigorous investigation of our planet's interior. How was it possible to unveil the inside of the globe? Indeed, today as yesterday, it is impossible to go there, to study on site the Earth's interior. Direct exploration being definitely ruled out, the interpretation of observations gathered on the surface is the only source of knowledge pertaining to what lays inside the globe. Knowledge about the planet's depths is thus a result of a continuous dialectic between observation and interpretation.

Certain observations are likely to supply information about the Earth's depths are evident. Mountains, earthquakes, volcanoes, springs, etc. have always existed. The questions that these phenomena raised have been recurrent over the centuries: what is the internal

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constituent of the Earth? Are the internals dense or light, warm or cold, fluid or solid, still or moving? What is the structure of these internals: are they full or empty, striated with channels or stratified? But other observations require preliminary conceptual developments or the implementation of appropriate measuring tools. These include geodetic and astronomical, physical (measurements of gravity, temperature, magnetism, seismicity, physical parameters of rocks) or geological observations. Interpreted within a physical or mechanical scientific framework, they have allowed the progressive refinement of our knowledge of the Earth.

2. Presentation of the seven main periods

The study of the Earth's interior from Antiquity to the present time can be divided into seven main periods. The first period is vast since it extends from Aristotle to the year 1450. It may be regarded as an introduction. The general vision of the world is dependent on Aristotelian mechanics. The latter spells out the subdivision between the superlunar world (the field of stars and eternity) and the sublunar sphere (the field of generation and corruption) and is based on the theory of positions and movements of the four elements: earth, water, air, and fire. During these eighteen centuries, reflections on the Earth are related to two works by Aristotle: *On the Heavens* and *Meteorology*, and their comments. The main issues concern the relative position of the four elements and the interpretation of natural phenomena such as volcanoes, earthquakes, caves, mountain erosion and the presence of shells over land areas.

The second period extends from 1450 to 1650 and could be called a "new world". The Copernican and Galilean revolutions ruin the Aristotelian structure and allow new designs to emerge. The period begins with the exploration expeditions expanding the area of known lands. Geological reflections become clearer with Leonardo da Vinci, Bernard Palissy, and Agricola. The significant change is the emergence of an interest in the interior of the Earth and its history. Already present in the works of Kepler and Galileo, this interest is evident in Descartes and Kircher, offering the first two depictions of the globe's interior.

The third period, from 1650 to 1750, reveals an evolution in the investigation of the depths of the Earth in association with the development of Newtonian mechanics. Multiple theories of the Earth are published. They seek to give a historical and mechanical explanation of the internal structure of the earth and attribute to water a key role. Geological observations remain dispersed even if Steno outlines the principles of stratigraphy and tectonics. Geodetic and gravimetric measurements develop and bring a famous controversy on the equilibrium shape of the Earth. Buffon closes the period by proposing the original fusion of the globe.

The fourth period, from 1750 to 1830, is marked by an increase in geological and physical observations. The study of rocks, tectonics and paleontological stratigraphy gains momentum. At this time we pass from Werner's neptunism to Hutton's plutonism and from Cuvier's catastrophism to Lyell's actualism. Geodetic and gravimetric measurements allow the precise determination of the figure of the Earth and produce speculation about the internal density distribution, especially by Laplace. Thermal measurements play a vital role and allow Cordier in 1827 to say that the Earth is currently still molten, covered by a thin solid crust. This idea appears to be the synthesis of different sources of knowledge of the Earth.

The fifth period, from 1830 to 1900, is dominated by the confrontation between the vision of geologists and that of physicists. Volcanism, mountain formation and isostatic equilibrium of the crust require an internal fusion under a thin crust. Mechanical works on Earth with a fluid core (Hopkins, then Poincaré), the elastic deformations of the earth (Lord Kelvin, Newcomb), on the plastic deformation of the Earth (G. Darwin, Schiaparelli) and the figure of world equilibrium (Roche, Radau, Poincaré) favor instead a solid globe. The century ends with the affirmation of internal solidity.

The sixth period begins in 1900 and ends in the late 1950s. Progress is rapid and significant in all areas and comes from the multiplication of physical measurements: seismological, geodetic, magnetic, elastic deformations of the ground, motion of the pole of rotation, of the physical parameters of rocks. Research on terrestrial dynamics develops with works on isostatic movements, on continental drift and on convective motions. During this time, studies specialize and lead to different models of the earth: elastic, seismic, thermal, gravimetric, magnetic, tectonic and mineralogical, but without the emergence of a comprehensive synthesis.

The last period begins in the late 1950s that is to say with the International Geophysical Year (1957–1958) and the launch of the first artificial satellites. These events can be considered as marking the beginning of the current era with the emergence of a unifying theory: the theory of plate tectonics and mantle convection. It provides simple and compelling responses to the questions posed by the observations and surface measurements and allows different members of the geoscience community to agree on a common vision.

3. The lessons of this history

Looking retrospectively at various visions of the planet over time, we can see that certain views, certain problems seem to appear and disappear only to reappear again. Old ideas are regularly re-emerging. Yet, obviously, knowledge of the planet is perfected. There is both an evolution and a constantly renewed and ongoing evaluation of more or less old ideas. We can illustrate this with a specific theme, although many others are possible, regarding spherical symmetry and lateral heterogeneities.

The Earth, recognized as spherical since the ancients, has a very high degree of symmetry in volume, while the distribution of land and mountains on its surface is very irregular. This fact, both simple and disturbing, undoubtedly had a great influence on the visions of the planet. The first two representations of the inside of the Earth were given by Descartes and Kircher, respectively in 1644 and in 1665. They offered two typical concepts of the depths. Descartes' model (Fig. 1), excepted crustal breaks

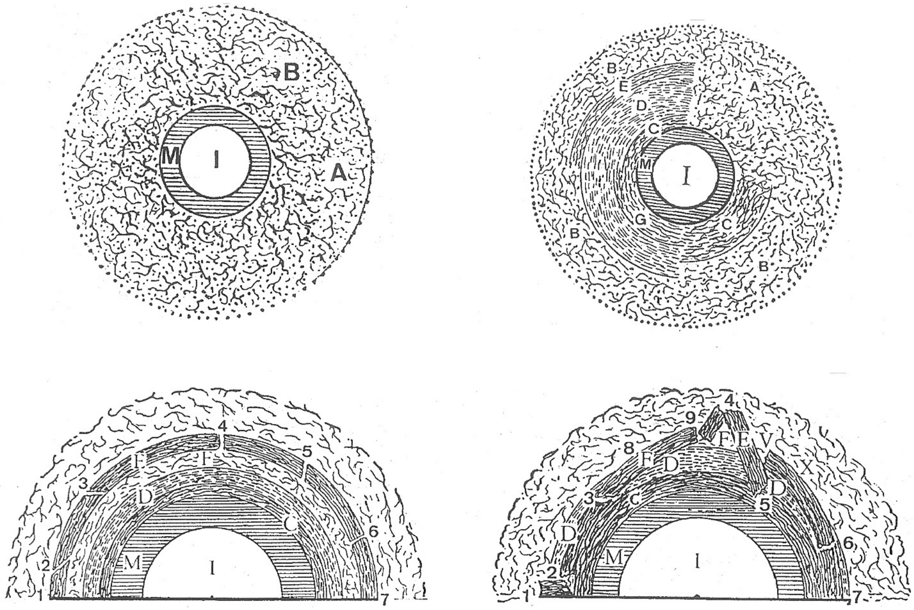

Fig. 1. Descartes' model of Earth (1644).

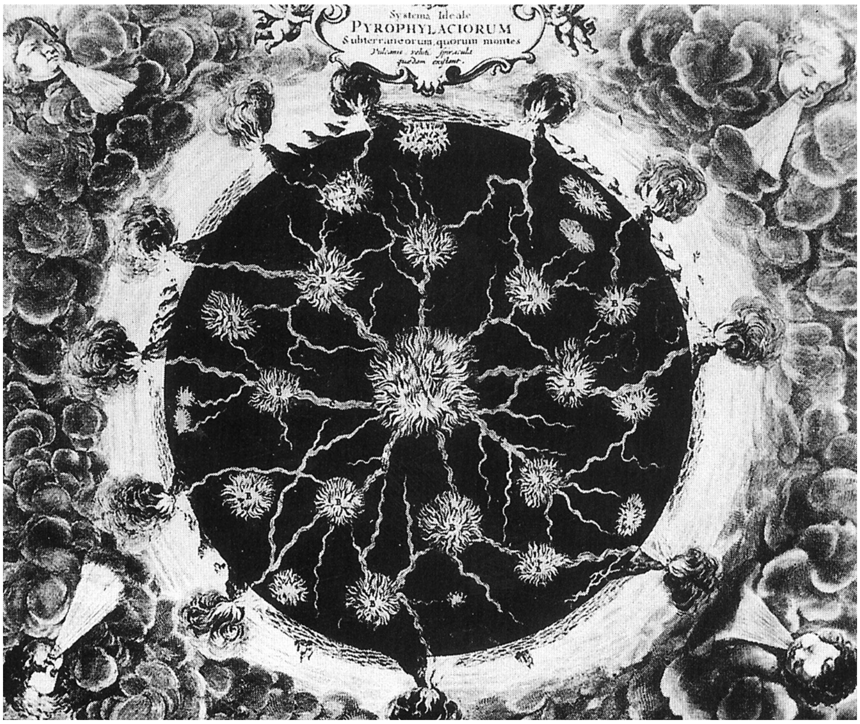

Fig. 2. Kircher's model of Earth (1665).

responsible for the random position of the continents, is a layered model, perfectly spherical, where the surface is independent of internal activity. Kircher's model (Fig. 2), with its canals and radial veins allowing the flow of volcanic material, on the other hand, shows a strong preponderance for lateral heterogeneities. It admits links between surface phenomena and deep phenomena. Whatever the arguments that led to such models, these two conceptions of a spherically symmetric Earth and an Earth with lateral heterogeneities reveal two deep insights into the structure of our planet.

Up until now Kircher's views have been overshadowed in relation to Descartes'. At the end of the seventeenth and the eighteenth centuries, under the influence of Newtonian mechanics, the spherical model is found in most theories of the Earth by Burnet, Whiston, Woodward, and Bouguet. Clairaut's hydrostatic theory accentuates the idea of density stratification. Moro's model alone, influenced by the dynamism of volcanoes, can be connected to Kircher's. Buffon, meanwhile, eliminates the problem by assuming that the globe is homogeneous.

The nineteenth century was exclusively interested in a stratified Earth. The globe, considered as a fluid and hot ball, becomes an elastic and hot ball. During the twentieth century, the development of convective theories by Holmes, Pekeris and Vening Meinesz enables the concept of small deviations from a stratified equilibrium but these models still show a very high symmetry and cannot account for superficial structures. Not before the late twentieth century did both conceptions of Descartes and Kircher converge. The layered model is completed in the beautiful models of the Earth realised by the seismologists and Kircher's intuition reappears in models of mantle convection where the descents of layers of cold materials and ascents of plumes of hot materials imply strong lateral heterogeneities. Stratified models are always more or less related to static or equilibrium processes like the hydrostatic model, while lateral heterogeneities are at the origin of dynamic processes and play a major role in surface phenomena. The current view of the Earth thus highlights the complementarity of the partial views of Descartes and Kircher.

This example demonstrates, and this would remain true for many other themes, that the current view of the Earth brings together different ideas expressed over time, reconciling partial views that seemed sometimes opposed. We have put forward these views in a book, written in cooperation with Hilaire Legros. This book explores the various concepts of the inside of the Earth from antiquity to the present time (Deparis and Legros, 2000).

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