HISTORY OF GEOLOGICAL SCIENCE

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Contents

Summary

This chapter aims to provide a broad picture of the development of geological science, as detailed as possible. Geology as a modern science started roughly around two centuries ago. But as knowledge of the Earth it has existed since the beginnings of humankind. We begin by mentioning the ideas of ancient peoples – Greeks and Romans. We continue up to the Renaissance (15th century), explaining that practically all schools of thought shared a fairly integrated and unified vision of all the Cosmos. In a Geocentric world, Earth suffered the influence of all other planets and stars and so did everything in it, whether it was human, animal, vegetal or mineral. The planet was not composed only of its own element, but also by fire, water and air, as Aristotle had already postulated.

The context of the so-called ‘Scientific Revolution’ implicated profound changes and discoveries that led to a conceptual revision of the knowledge about the Earth: Astronomy redefined by Copernicus denied the central place of the earth in the planetary system. At the same time, the construction and use of the telescope showed that the world was almost infinitely large, and that Earth and the Solar System did not occupy a special place in the Universe.

As the changes brought about by the ‘Scientific Revolution’ were consolidated, the knowledge and study of the Earth greatly increased. The meaning of fossils was greatly altered, changing from its broader meaning – synonymous with any matter excavated from the soil – to reference to petrified organic remains. We also address the relevant debate about the origin of rocks that involved ‘plutonists’, ‘neptunists’ and ‘volcanists’, as well as the crucial methodological issue between ‘uniformitarianism’ and ‘catastrophism’. Around the beginnings of 19th century, the expansion of modern colonial empires and the advance of the first Industrial Revolution had an impact on the demand for raw materials. The institutions responsible for collecting data of natural

resources were called Geological Surveys, which became a “trademark” of Geology, thus contributing to the professionalization of geologists, and to the impressive development of geological science in the 20th century.

1. Beginnings

When does Geology begin to be a subject? As a modern science, it started around two centuries ago. However, as knowledge of the Earth (Geo + Logos), it has existed since the beginnings of humankind, for the use of natural resources and the observation and control of Nature are as old as the human race. Throughout time, knowledge and research of the planet walked side by side and overlapped, through cosmic views and mineral extraction. This set of ideas was organized and evolved around three basic and interlinked axes: time, the composition of matter and structures. In this way, speculative sciences like Cosmology, Cosmogony and Natural Philosophy; sciences of the elements and of matter such as Alchemy and Chemistry; science of structures such as Mineralogy, Gemology and Crystallography; environmental sciences such as Physical Geography, Topography, Geomorphology and Oceanography; and the sciences of living or dead creatures like Paleontology and Biology were all connected in the study of the planet.

In the same way as a considerable part of western culture, especially European, Earth Sciences are derived from the traditional thought developed by societies from North Africa and the Middle East (Egypt, Sumer, Assyria, Babylon for example) or from the Mediterranean (essentially Greece and Rome) whose societies were agrarian or pastoral and largely dependent on soil resources. On the one hand, this constant contact with the forces of nature led human beings to recognize, through endless laboring, the need to adapt to the rhythm of the seasons, the unquestionable force of volcanoes and earthquakes, of floods and droughts, of hurricanes and tsunamis, of deserts, swamplands and mountains. On the other hand, beyond the limits of Europe and part of Asia lay an unknown world. All these aspects together favored the surge of explanations that today are classified within the category of myths – boiling tropics, lost continents and all kinds of monsters – some of which were only repudiated in the 15th century, as a result of the great voyages that reached India, having rounded southern Africa or crossed the Atlantic.

We shall begin by mentioning the ideas relating to something quite tangible for ancient peoples: the shapes of the surface. The Greeks, a people with strong ties to the sea, already in the 5th century BC observed “shell-shaped deposits of stone” at a site very far from the coast at that time. The author who made this surprising and interesting observation concluded that that place had previously been the sea. The famous historian and geographer Herodotus (c.484-420B.C.) took up these observations and stated that Egypt had been a gulf in the past. Other important observations of Greek authors refer to the action of water that they recognized as sculpting the surface and flattening protrusions.

It is worthwhile briefly highlighting the ideas of Aristotle (384 – 322 B.C.), not for their uniqueness, rather for the importance and influence of this philosopher up until medieval times, in the case of Cosmology and Astronomy, and the 14th century in the

case of Geology. He studied in Athens with Plato and was the teacher of Alexander the Great. He founded the *Lyceum* as a teaching and research center. For Aristotle, the Earth was composed of four elements: that is earth, water, fire and air and was located at the centre of the universe. For him, earthquakes and volcanoes were compared to earthly thunder and lightning and climatic phenomena, such as storms, were produced by the meeting of the humidity of the rain with subterranean winds, of differing intensities. He thought that the most "earthly" objects were due to exhalations of the Earth: the fossils and minerals resulting from the dry exhalations, metals from moist exhalations. Aristotle attributed the animal or vegetable form of fossils, nowadays proof of their organic origin, to a plastic feature of the Earth that had the power to imitate live Nature. This philosopher was also concerned about the origin of springs and rivers and seemed to accept that rainwater were not the only supplier of the sources, since he proposed that the Earth, given its 'coldness' was capable of producing water.

Another author from early history who is relevant to Geology is Pliny the elder (23 – 79 AD), a Roman naval official who left behind him a vast work on Natural History, in which he talks about fossils and minerals and their diverse uses. As a good observer of Nature he died from breathing in toxic gases during the eruption of Vesuvius, which destroyed the cities of Pompeii and Herculaneum, since he was an eyewitness (and was very close) to the volcano.

2. Middle Ages and the Renaissance

Generally speaking, up to the Renaissance (15^{th} century) practically all schools of thought shared a fairly integrated and unified vision of all the Cosmos. Christianity and the powerful Catholic Church inherited most of classical knowledge (Greco-Roman), adapting and reinterpreting it according to their conceptions and needs. In this picture, Earth could only be fully understood in terms of its place and function among the bodies comprising the Universe, at whose center it lay. In a Geocentric world, Earth suffered the influence of all other planets and stars and so did everything in it, whether it was human, animal, vegetal or mineral. The metallic minerals originated and increased by the influence of the planets: iron through the action of Mars, lead by Saturn, and gold depended on the Sun. Gems (transparent or precious minerals) reflected cosmic light. In accordance with this view, the Earth was seen not only as a planet but, rather, as an element that permeated all matter in the corruptible regions of the Cosmos. In turn, the planet was not composed only of its own element, but also by fire, water and air, as Aristotle had already postulated.

The coherence of the vision that perceived the Earth as an intrinsic part of the universe manifested itself also in relation to humans: the fate of the planet was inseparable from that of the Cosmos and, in the same way, that of Man was inseparable from that of the planet. Thus, the universe was more than geocentric: it was anthropocentric. The Earth had been created to be the habitat of Man, a superior creature whose intelligence allowed him to work the land, extract mineral wealth, map out the territories and make use of them. In their functioning and workability, the human being and the planet were of the same nature, intimately connected with one being the reflection of the other. For example, in the classic tradition of Greek medicine the humors of human beings, the symptoms of their illnesses, their temperament and disposition were understood as the

equivalent, in the microcosmic human body, of the combination of the dryness and humidity, heat and cold of the macrocosmic elements (earth, water, fire and air) that composed the body of the Earth. The Hippocratic tradition of medicine explained many illnesses as caused by climatic and environmental imbalances: effluvia expelled by the Earth, excessive humidity caused by rivers, flooded areas or poisoned air in the neighborhood of mines. Natural catastrophes, such as comets, storms and earthquakes were forebodings of human catastrophes. Due to this correspondence, minerals and fossils possessed medicinal value, in the broad sense, and were used as medicines. Thus, for example, the amethyst protected against intoxication: rock crystals were recommended for nurses and other healers, increasing their capacities; onyx stimulated hatred, malignant visions and blood-letting; in contrast, beryl preserved and increased love and conjugal peace; hematite would be recommended to treat illnesses related to the blood and so on. This knowledge, as well as the heraldic and symbolic functions of minerals, rocks and fossils, the etymology and even anecdotes related to them were preserved and transmitted through the great books called *Lapidaria*, which endured and were transformed throughout the centuries. This was due above all to the additions introduced by Christian wise men (the so called doctors of the Church) such as Saint Augustine (354-430 AD) and Isidore of Seville (560-636 AD); Arabs, such as Avicenna (908-1037 AD) and Averroës (1126-1198 AD); or scholars such as Saint Albertus Magnus (1193- 1280 AD).

In the same theoretical vein, it was believed that the external portions of the planet were composed of four great mineral classes: the “earths”, the “metals”, the “salts” and the “bituminous substances”. They were the result of combinations of water, fire, earth and air, in different proportions. In turn, each element was characterized by a pair of its basic qualities, namely: heat, dryness, humidity and coldness. Thus, the earth was cold and dry, the water cold and humid, the air hot and humid and fire hot and dry. All could be distinguished among each other by their reactions to heat and water, and were arranged in extensive masses such as rocks, veins and layers. These minerals had been fluid, which later were solidified by the removal of fire or of water. The whole of this wisdom made up the body of knowledge that constituted Mineralogy. The “consolidation”, as the transition from fluidity to solidification was called, was so relevant that it signified a great, if not the greatest, problem faced by those studying rocks and minerals up until the end of the 18th century. In turn, Mineralogy was not a mere sub-discipline, but it comprised most of the subjects that are currently considered Geology, that is Crystallography, Mineralogy, Petrology and Paleontology and also overlapped considerably with what is nowadays the dominium of Chemistry. Mineral classes played a key role in the theories on the structure or History of the Earth. On the one hand mineralogists had to explain why the earth’s crust was differentiated among these classes and on the other they used mineral classes to explain the great features of the crust: its rocks and, finally, its Physical Geography and thus reconstruct the history of the Earth.

By contrast, the Earth was explained as an organic and live replica of the human body and of other beings. Its round shape suggested an egg, with earth’s crust as the shell and a series of fluids beneath it (inside it), which was alternately considered hollow, fluid or solid. Mountain chains were frequently compared to bones, rivers to veins and arteries, mounds and hills were called the warts on the Earth’s face, an Earth that grew old and

decayed like human beings. In contrast to the divine world, synonym of perfection, permanence and immutability, the planet was the theater of change, decadence and imperfection. Plato (428 – 427 BC, 348 – 347 BC) saw the Earth as "unreal", a mere reflection of the world of ideas and of the Ideal Truth. In popular medieval Catholicism, the center of the Earth was the place of Hell. Even though the planet was nothing in comparison to God, or the gods, who created it, it still showed signs of divine intervention and purpose. Practically all the cultures, not only in the European continent, but also in Hawaii, in Meso-America or Australia, volcanoes, earthquakes, storms, droughts and floods were considered to be divinities or actions undertaken by divinities. Certain mountains, rivers, springs, islands or caverns became sacred places. The Earth was enchanted and peopled by good and bad spirits. In a Christian Protestant version, it was the Book of God's works, in which the wise men could read and find all the signs and markings of divine purpose. Thus, glorifying God through a perfect nature was also linked to the idea of gratitude towards Him, owing to His benevolence in creating a perfect natural world for the survival of His most sublime creation: Man. The vision of nature at this time possessed a utilitarian character since it had been created to serve Man's purpose.

Within this more general picture of ideas, observations and more practical work were developed and led to reflections. For example, the exploitation of mines together with the notion that the planet was a living organism raised the following question: were metals and minerals generated and did they grow? If the answer was affirmative, how did this come about? For many centuries, the vitalist explanation was believed, that is, small grains of minerals or metals would be like seeds that, under propitious conditions, would germinate, giving rise to new minerals. Propitious conditions involved the closing of the mines in religious rituals for long periods after their exploration, but prior to exhaustion, in such a way that enough grains should be left over, so that the action of the corresponding planets, as mentioned above, would replenish the minerals. In the same way as the womb of women and females in generals, mineral grains would become pregnant as was illustrated, for instance, in the book *De Lapide Haematite et Aetite*, by Bausch, that showed "an Aquilina pregnant by another Aquilina, which is also pregnant".

The interest in what happened to the planet as a whole led to reflections on the interactions between the crust and the remaining terrestrial spheres, such as the interior, the hydrosphere and the atmosphere. Volcanic activity, with its lavas, ashes and smoke, suggested, for example, that the Earth's interior was full of imprisoned fire trying to get out. At the same time, the fact that rivers originated in springs coming out of rocks generated the idea of the existence of great reservoirs connected to the oceans, in a system that flowed continuously. For the Jesuit Athanasius Kircher (1601/1602 – 1680 AD) in his work *Mundus Subterraneus*, the interior of the planet would be crossed by veins that transported fire and water, just like the human body. The contact of the interior fire with the surface would give rise to volcanoes, that of water to springs, and the contact between the water system and the fire transport system would create hot springs.

Since the beginning of time seeing the Earth as a theater of change also led to an interest in superficial transformations: the changes in the courses of rivers, estuaries and deltas,

like the Nile; the landslides in the river banks; the creation and destruction of land by deposits of sediment and silt, or by erosion. The Pythagorean and Stoic philosophies expressed by naturalists such as Strabo and Pliny, or by poets like Ovid, supported the idea that the continents and oceans, mountains and valleys were in constant revolution based on pieces of shells and bones found embedded in rocks and petrified. However, the debate as to whether fossils were really organic remains would only be settled at the end of the 18th century, as we shall see further on. Until the Renaissance (15th and 16th centuries), ancient and medieval science accumulated knowledge about the planet both in regard to the permanent and changeable aspects of terrestrial nature.

After the Renaissance, with the rediscovery of classical Greek and Roman works and authors, previously expurgated by the Church, the study of the Earth as well as the sky and living beings gained new momentum and was profoundly transformed. This was undoubtedly the result of an "intellectual and scientific revolution" that included: the invention of the printing press and thus a greater distribution of writings; an increase in the number of schools, either monastic or lay, with a direct impact on the educational level; the weakening of the authority of the Catholic Church, due to denunciations and scandals that resulted in schisms in Christianity such as Protestantism; great advances in navigation, in particular in Portugal, leading to overseas voyages and the discovery of new worlds, that not only did not fit into the ancient descriptions but that also demanded, because of their novelty, new descriptions and definitions (match 'the names' to the 'things') with a huge impact on the contemporary world view and, consequently, knowledge and techniques.

Materials as well vegetables and animals coming from the New World were used in Medicine and Pharmacy besides the importance of metals in the emerging mercantile system. In addition, as a consequence of being able to witness with their own eyes, the voyages contributed to destroy well established myths, such as that ocean water boiled around the tropics due to the high temperature and the presence of constant fire. As the Italian historian Paolo Rossi (1979 p.53) asserted:

"*The greatest obstacle faced by the defenders of biblical orthodoxy is the Discovery of America* [...] *Indeed, the American continent is not contiguous to any part of Asia, of Europe, of Africa and is inhabited by men and by all species of animals. In aspect, in language and habits, these men are different from the Asians, from the Europeans and from the Africans. The animals are different from those that live in the other three continents. These difficulties lent new vigor to the sacrilegious theses that advocated that the eternity of the world and the idea of life originating from matter* [...] *It was deduced that either the Biblical Flood was not universal or that after it, a new creation of animals was confirmed in America*".

However, the most accepted explanation as to the formation and composition of the earth's surface remained imbricated in the Christian narrative, in this case the Biblical Flood. In accordance with this account, water had covered the earth's surface and, after its evaporation, the uncovered crust showed its irregularities. This explanation, based on the Scriptures, was empirically proved by marine fossils found in the mountains. Only with the development of new theories about fossils in the 17th and 18th centuries was a break with this Christian tradition possible.

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Biographical Sketch

Silvia Figueirôa graduated in geology from the University of São Paulo (1981), and got her Master Degree (1987) and Ph.D. (1992) in Social History from the University of São Paulo, both in the specialty of the History of Sciences. She received the Habilitation in 2001 at the University of Campinas (UNICAMP), where she became full professor in 2006. Her postdoctoral studies were at the Centre Alexandre Koyré d'Histoire des Sciences et des Techniques (France, 2002). Since 1987 she teaches at the Institute of Geosciences, UNICAMP, where she currently holds the position of Director (2009-2013). She has experience in history, with emphasis on the History of Science, as well as on the thematic of scientific archives, acting on the following topics: history of sciences and geosciences, with emphasis on Brazil; relationships between history of science and education; scientific documentation / technology. She is active in undergraduate and postgraduate levels supervising undergraduate, master, and Ph.D. students.