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Chapter 8

# At the Service of Industry

## The Industrial Revolution

Buffon's interest in mineralogy was at least partly practical, because he was the owner of foundries at the hamlet, close to Montbard, from which his name originated. In the eighteenth century, the study of the earth's layers was thus no longer the sole domain of theologians talking at length about the Deluge and the Creation of the world. Indeed, it became of interest to industrialists who wanted to improve mining in their country.

This interest was not entirely new. At the beginning of the sixteenth century, Agricola (1494–1555) was interested in both mineralogy and metallurgy, and his 1546 work, *De re metallica* (Of metallurgy), described the state of the art in geology, mineralogy, and metallurgy of his time. However, in the eighteenth century, mining became much more important because of increasing needs related to the industrial revolution.

England was the leading coal producer, with huge production increases. In 1700 the annual yield was 2.5 million tons of coal in the entire country. In 1770 it was 6 million; in 1800, 10 million; and in 1830, 30 million tons per year. Coal production thus increased 12-fold in 130 years.

France and Germany lagged far behind. It was only after the Treaty of Utrecht (1713) that the French mining industry developed. In 1744 it was decided that mines could be granted to persons other than the owners of the land, a decision that greatly enhanced the rise of the industry. In 1747 the École des ponts et chaussées (School of Civil Engineering) was founded and began to train some of its students each year as mining engineers.

## Mines

H.-L. Bertin, in charge of the French technical ministry for the supervision of both agriculture and mining, proposed in 1765 the creation of a school of mines. It opened in 1783 but lasted only five years. It was reopened in 1795, during the French Revolution.

At the time of Bertin's suggestion of a French School of Mines (in 1765), Germany founded its Bergakademie in Freiberg, Saxony, in response to the same general demand for teaching the art and science of mining. The location was not a random choice; for a long time the miners and workers of Saxony had enjoyed the reputation of competence in the field of metallurgy. Ore deposits had been extracted there for a thousand years. Agricola, the "father of mineralogy," was from Saxony.

To exploit ores it was, of course, necessary to know how rocks visible in **outcrops** extended down below the surface. Miners had some empirical knowledge handed down during centuries of practice. However, when industrial needs increased dramatically, it became urgent to rationalize research methods. Beginning in the middle of the eighteenth century, geologists made great strides in their knowledge of the order of rock layers. Exploration of mountains (chapter 6) had already led to the distinction of primary and secondary rock formations. Most of the naturalists who advanced this knowledge were working in the field and wanted to improve the use of mineral resources. They did not hesitate to take advantage of the miners' empirical knowledge.

For instance, Lehmann, whose recognition of three classes of mountains we have already mentioned (chapter 6), first studied medicine. When practicing medicine at Dresden, in Saxony, he soon became interested in mining and metallurgy and studied the arrangement of layers in that area, in particular, in the Erzgebirge. He also visited the Harz, another mining region to the north, where mining had begun in the year 745. In 1754 Lehmann was appointed mining councillor or Bergrat, and he served as director of a copper mine.



Arduino, who had recognized two orders of mountains at the same time as Lehmann, was also actively involved in mining. He even worked in a mine in his youth before becoming an expert on mining (as well as on problems in agriculture and industry).

## Subdividing Secondary Mountains

A simple distinction between two (or three) classes of mountains was not good enough for miners. It was within each of these classes that the order of superposition of layers had to be established. It was most important to locate the oldest class since it was known to be richest in metals; however, the horizontal secondary layers were easier to classify and were well understood before all others.

Lehmann was the first to realize the importance of the order of strata and to make use of the accumulated knowledge of quarrymen and miners. However, these people distinguished strata with such fine points, often too precise for geologists, that certain subdivisions were of purely local interest. Lehmann knew how to adapt this empirical knowledge to the demands of the emerging new science. He divided the stratified rocks (*Flötz-Gebürge*) that surround the Harz and which always lean against primitive mountains (*Gang-Gebürge*) into red beds consisting of coarse sand and pebbles, followed by beds of coal, shales, limestones, and finally by "salted springs."[1] In modern terms, this sequence represents the **Permian,** a period ending the Paleozoic, the sequence consisting of red conglomerates, sandstones, shales, and coal beds, followed by black shales, limestones, and finally **evaporites.**

Georg Christian Füchsel (1722–1773), physician to a prince of Thuringia (a former state in central Germany), improved upon Lehmann's classification. In 1761 he published in Latin a history of the land and the sea based on the investigation of his province (*Historia terrae et maris*).[2] Above the layers of salt and gypsum, he recognized variegated sandstones and fossiliferous limestones (called *Muschelkalk*, or shelly limestone), which form two of the rock formations in the first period of the second era (Mesozoic), today known as **Triassic.**

Füchsel's superiority over Lehmann lies in his understanding that layers were formed successively over long periods of time, and not during the unique event of the Deluge. He said, "In the formation of deposits, nature must have followed present-day laws: every deposit forms one stratum, and a series of strata of the same composition represents a formation or an epoch in the history of the globe."[3]

Füchsel's division of epochs in the earth's past, based on the investigation of "formations" of strata, opened the door to the naturalist whose name became most closely linked with the classification of strata (perhaps at the expense of his predecessors): Abraham Gottlob Werner (1749–1817). Like Lehmann and Füchsel, Werner was a typical product of the young academy at Freiberg, where he studied from 1769 to 1771 before becoming a professor in 1775. His ancestors had occupied important positions in the industry of mining and metallurgy of that area since the beginning of the sixteenth century.

## Werner

Werner began his scientific career with a work on mineralogy, *Von den äusserlichen Kennzeichen der Fossilien* (On the external characters of minerals), which was received with enthusiasm all over Europe and was translated into many languages.[4] Mineralogy was then developing as quickly as historical geology and was supported by chemistry, another fast-emerging science. However, Werner's goal was purely practical: he based his classification on the external characters of minerals such as color, cohesion, external shape, luster, fracture, transparency, hardness, specific weight, smell, and so on. He put little emphasis on crystal shape and chemical composition of minerals, although his contemporaries in France, first Romé de l'Isle and then René Just Haüy, were showing that the external shapes of crystals resulted from a small number of crystalline systems (as they were later called, although Haüy named them the "integrant molecules").[5]

## Geognosy

Throughout his life, Werner continued to elaborate on his work of classification. A new science was born, which Werner called geognosy after a term used earlier by Füchsel.

Jean-François d'Aubuisson de Voisins, Werner's student, said that "in geognosy, rock formations and superposition are considerations of first order. Consequently, mineral masses have to be arranged and classified, as much as possible, according to their order of superposition or their relative age."[6] This shows that the Wernerian method addressed two concerns at once: one taxonomic and pedagogic, the other scientific. By classifying and naming rock formations according to their order of superposition, miners could learn about the structure of the subsurface. At the same time, the system made the scientific point that this order accurately represented the relative age of layers.



The second point is, of course, a simple application of the principle of superposition stated by Steno 120 years earlier—a well-established fact in science. However, when the rule was applied in practice, it had to take account of some exceptions because it originally assumed that layers had not been disturbed after deposition. If a series has been overturned during folding (**recumbent fold**), the lower layers are the youngest. Similarly, if a rock mass has been thrust over another one (**overthrust**) during compression (chapter 15), the superposition of layers no longer follows the rule, at least not at the site of the "abnormal contact."

Moreover, the principle of superposition does not apply to igneous rocks when magma intrusions cut through older rocks. Based on the principle of cross-cutting relationships, any sedimentary rock that is cut by an igneous intrusive body is older than that intrusion.

Werner refused to accept either tectonics or **magmatism;** he believed that layers preserved the position they had when they were deposited. The present superposition was therefore one of deposition. Furthermore, according to him granite was not an intrusive rock but a primitive deposit, so plutonism did not exist.

According to Werner's view in *Kurze Klassifikation*, the order of deposition of the principal rocks made it possible to distinguish four classes of rocks (or mountains): primitive (*Uranfängliche*), in layers (*Flötze*), volcanic, and alluvial. Around 1796 he inserted a new group between the first two classes: the transitional mountains (*Übergangsgebirge*), which included tilted and fossiliferous late Paleozoic layers resting on primitive igneous and metamorphic rocks. Each of these classes was naturally divided into various categories.[7]

Stratified mountains, for instance, were subdivided into twelve formations, beginning with the period today known as **Devonian.** At the top were the salt-bearing layers of the Zechstein (an evaporite-bearing formation), and thereafter those of variegated sandstone and fossiliferous limestone of the Triassic, and so on. The series ended with basalt layers and other volcanic rocks Werner believed to be sedimentary, followed by chalk of the Cretaceous, which he placed, strangely enough, on top of the series, above the gypsum of the Paris region, which is actually younger.

## Long-range Correlations

It was not sufficient to reject igneous phenomena and tectonic movements to establish a "geognostical column" of "formations," or rock layers. A problem, today called **long-range correlation,** arose instantly. When drilling in the ground at some point on the earth, we find superposed layers, which we assume to be increasingly older according to the principle of superposition. Of course, eighteenth-century observers did not have any drilling equipment at their disposal. However, if layers are tilted in a regular fashion, it is possible in the field to trace successive strata in their order of increasing age without drilling. That is, the naturalist would seek a superposition in the field that was similar to a stack of cards that had been tilted and slid apart as the cards were spread on a table. Ever since the middle of the eighteenth century, geologists had known that the edges of mountains offer this arrangement and thus show the oldest rock formations.

However, if the same exploration were made in another country, or on a different continent, who could guarantee that the same layers would be found? We touched on this problem in chapter 6 and noted that it was partially solved in favor of a universal order of superposition of layers. As a contemporary of Saussure and Ramond, Werner, too, wanted to find the same arrangement in various areas. More precisely, once the study of several mountains had shown a similar arrangement of large masses of rocks, Werner accepted the hypothesis that this similarity also existed at the level of layers. In other words, he believed that a particular type of rock was characteristic of a particular time. It was merely necessary to observe one area carefully in order to know the universal order of all layers of the earth. Werner, of course, chose to study systematically his native country.

## The Need for Classification

Werner was by nature always tempted to classify, to put things in order. Georges Cuvier compared him to Linnaeus. It is true that the two naturalists had the same concern for nested classifications. Like



the Swedish botanist, Werner distinguished classes (of mountains), which he divided further into distinct kinds and varieties. In his definition of divisions, Werner, like Linnaeus, was searching for "characteristics which were constant" rather than those that varied in a disorderly fashion.

However, in both cases, the enterprise was superhuman because the authors wanted a simultaneously practical and natural classification. Werner, for whom natural order was the order of deposition, ended up placing *all* formations of the world in the *same* column. Two difficulties appeared immediately. One was a question of principle, the other of facts.

Werner believed that *general* and *partial* formations existed and that the former were "produced by a general cause" and the latter by "particular and local causes." True, partial formations could be dated in relation to general formations. However, when local formations occurred far apart (i.e., when they were not in contact with one another), they could not be dated by comparing one to the other because the principle of superposition could not be applied. Their relative age could not be determined even if two distant partial formations occurred between two general formations. However, since the Wernerian system was based on superposition and since the system could not visualize a lateral transition between formations, partial formations of the same age were simply superposed in one way or another. This was the first difficulty.

The second difficulty was worse. Having at one's disposal only a limited number of local series, formations are, of course, more or less in the same order. Since he believed that numerous universal formations covered the entire earth like layers of an onion, Werner's ambition was to offer a single column that included rock formations from the entire world. Alexander von Humboldt (1769–1859), one of Werner's most famous students, traveled all over South America trying to establish such an order of layers.

The system now showed its weaknesses because a given formation could have only one place in the column. As Aubuisson observed, it seemed as if "what had already been put in order, was plunged into confusion again." Granite, which was believed to be older than gneiss, reappeared above gneiss—even above **micaschists,** if not on top of the even younger **phyllites.**[8]

Today, the reason for this confusion is obvious. The distinction of the two classes of mountains in Germany corresponds to reality: the superposition of a younger sedimentary cover over the older

Hercynian basement. But divisions inside these two units are less obvious, especially in the Hercynian basement, where intrusive granites cut across gneiss and micaschists so that the same "formations" appear at different levels of the "column." Things are less complicated in the sedimentary cover because there is neither intrusion nor metamorphism. But there, superposed layers are dated by their fossil fauna and flora and not by the nature of rocks, that is, their lithofacies.

This is where the Wernerian system failed. Today, it is common knowledge that epochs cannot be distinguished by a single and unique deposit. Indeed, everybody can observe that layers of different kinds are being deposited at the surface of the earth. Here it is sand, there it is argillaceous mud, elsewhere calcareous ooze, and so forth. Why not accept what is, so to speak, written on the wall?

## Anti-Uniformitarianism

The school of Freiberg as well as all neptunists refused to accept this evidence. They were not at a loss for arguments when they asked: Why should we believe that in the past nature was identical to the present? Convinced that granite was formed as a deposit, they argued that nothing is happening today that produces granite. They reasoned that the primitive earth had been surrounded by a universal ocean, which held in solution all the materials that were thereafter precipitated successively.

They believed that what can be observed today does not offer any clues about these ancient formations. J.-A. Deluc said, "The residue of the *primordial liquid* which is the sea no longer forms *layers of minerals*." Ancient layers were formed, he said, by "primordial causes which exist no more." Their formation can be explained only when "going back farther than present-day causes."[9]

We find here a serious objection to uniformitarianism. It is, however, a paradox that Deluc, who first used the phrase present-day causes, or more precisely, "causes now operating," actually wished to refute uniformitarianism. In other words, he first used a term characterizing the method governing modern geology in order to refute that method. I shall return to this point. For the time being, I merely want to stress that the study of the archives was, once more, at a standstill.

The neptunists posited that the order of precipitation of materials in the universal ocean "born from chaos" was not random. They stated that the first deposits consisted of large transparent crystals. With increasing movement of the waters, crystals became smaller and less distinct, drowned in an opaque loose material. Furthermore, the waters of the ocean lowered progressively (by evaporation, according to Werner) and the highest primitive sediments, deposited on top of elevations of the primitive crust, began to emerge. They provided "mechanical" deposits, which mingled with the primordial "chemical" precipitations, contaminating them with completely opaque materials: crystalline granites were replaced by sandstones and conglomerates.



Neptunism was, of course, not as homogenous a doctrine as given in this all too brief summary. Indeed, on the one hand, Werner was not anti-uniformitarian, and on the other, Deluc, following Füchsel, introduced in his system collapses that interrupted the regular course of events.

Nevertheless, despite important differences among themselves, neptunists adopted many common themes embodied in the main doctrine. For instance, many accepted the position that the history of the earth is regressive. Ever since Celsius and Linnaeus it was believed that the earth was losing its water. The Wernerian system introduced the idea that the ocean also became impoverished in dissolved materials. In fact, for two reasons the earth had as yet no real history.

## A World without a Future

On the one hand, the neptunists believed that, if there were a law of evolution, it would be sufficient to study one region in order to know the arrangement of layers throughout the world. Thus the problem posed by the two classes of mountains returned in a new form—and required no long-term investigation. To naturalists it seemed that the search for archives had reached its limit. Science seemed on the verge of its own completion; the mere statement of a general law seemed to be a dispensation that excused travelers from further explorations.

On the other hand, the neptunists' arguments implied not only that science was coming to a standstill, but also that the history of the earth ended equally abruptly with the present world. The planet thus had a past but no future. It was a common belief that the forces that had formed the earth were being depleted. One finds here again the idea cherished by Buffon, which actually goes back to Lucretius;

namely, that nature loses its power of reproduction and that its productions are becoming more and more puny. Working under such assumptions, Deluc or Werner could imagine a formation but not a history of the earth. Such a history had to overcome these two obstacles and state the following propositions:

Each region has its own unique history, and the history of the world consists of the juxtaposition of local events. Our research in the archives is never finished. Geology means fieldwork. No general law of evolution will ever save us from traveling around the world, hammer in hand.

The present moment is only one point on the uninterrupted thread that unravels the history of the earth, starting with the planet's first revolutions. The forces that fashioned it are still in action, and they shall modify the earth, or rather they are changing it imperceptibly in front of our eyes. However, to take into account such slow yet always active causes, we must accept enormous durations of time.

In order to solve the second problem, that of the vast time spans, which no one, not even Buffon, had proposed, geologists needed a mechanism capable of ensuring earth processes at a uniform rate. Hutton was to propose this mechanism. The first problem could be solved only when geologists had learned how to use this mechanism for each region—or rather had learned to recognize locally the effects of internal processes of the earth. Only then would it make sense to return to the study of the geological archives.

## Desmarest on Volcanism

Nonetheless, quite some time before arriving at the stage of understanding the major internal processes of the earth, some naturalists had tried to undertake the regional approach. In other words, they had used the archives provided by their microcosm to sketch a pretty valid history.

In 1779, shortly after the publication of Buffon's "Époques de la nature," Nicolas Desmarest (1725–1815) wrote an article called "On the Definition of Some Epochs of Nature by the Products of Volcanoes and on the Use of These Epochs in the Study of Volcanoes."[10] The modest title shows the limitations of the work: only "some" epochs were considered. Indeed, the author did not go back to the origin of the earth but only to relatively recent volcanic events. Moreover, his work concerned only volcanism. However, there are times when the most scientific approach to a problem is to rein in ambition, to narrow the field of investigation to a more limited but more detailed study.



Compared to Buffon's, Desmarest's method of investigation was new. Instead of presenting the history from beginning to end, he reversed it, starting at the present and going backward by induction based on documents. Hence, this memoir was far from plagiarizing Buffon's book; it was, in fact, just the opposite. Desmarest first read his essay in 1775 at the Academy of Sciences in Paris, before Buffon's "Époques de la nature" was published.

The interest in volcanism gave Desmarest another priority because he was the first to understand that basalt is ancient lava. Since 1752, Guettard, friend and student of Réaumur, had observed that the mountains in Auvergne were nothing but extinct volcanoes. However, he separated basalt, found abundantly in that region, from volcanic lava.[11] In 1763 Desmarest confirmed Guettard's observations. However, he went further and declared that basalt was also volcanic.[12] His discovery started the debate between vulcanists, who followed him, and neptunists, who continued to believe that basalt was a sedimentary rock.

The most famous neptunist, Werner, remained adamant until his death, despite the increasing number of proofs to the contrary. His disciple Aubuisson de Voisins remained respectful of the prejudices of the great man and waited until Werner's death for the publication of his observations on Auvergne, which finally destroyed neptunistic ideas.[13] One must admire both his loyalty as a student and his freedom of thought, which allowed him to arrive at the truth in spite of the prejudices of his master. Indeed, one measure of Werner's significance is the number of his students who came to dissent from his conclusions but continued to acknowledge the quality of his method of investigation.

## Soulavie

Desmarest did not, in fact, present a complete regional study. Such a study can be found, however, in the seven volumes of the *Natural History of Southern France* by J. L. Giraud Soulavie (1752–1813), published between 1780 and 1784.[14] For the area between Auvergne and Montpellier, he sketched a more complete history than Desmarest had done; he not only recognized the volcanic nature of the

## Coal Mining

The word *coal* first meant charcoal. The use of fossil fuels in Europe, in particular coal, occurred relatively late. Apparently, blacksmiths used coal in coal basins as early as the ninth century. The first coal mine existed at Zwickau, in Saxony. In the area of Liège, Belgium, coal was extracted in the eleventh century. According to some, the French word for coal (*houille*) derived from a blacksmith of that area called Houllos or Hullioz.

In the twelfth century, coal came to the rescue of the forests, which had been overused, and the importance of coal increased at the beginning of the thirteenth century. Thereafter, coal mines were discovered at Saint-Étienne and Newcastle. According to a document of 1315, a citizen of Pontoise loaded wheat to sell at Newcastle and brought home coal.

In the fourteenth century, people began to complain about pollution produced by the burning of coal, and Henry IV of England forbade its use in London. In the middle of the sixteenth century, the king of France, Henry II, condemned blacksmiths who used coal. Nevertheless, coal mining became more and more important. The first mine in the northern basin of France was opened at Anzin in 1734. French coal production reached 250,000 tons in 1789. In 1815, it was 1.8 million tons. In the beginning of the nineteenth century, new needs had to be met. In 1801, Philippe Lebon invented gas lighting. In 1807, Fulton constructed the first steamboat. And the first locomotive ran between Paris and Versailles thirty years later.

Plateau of Coirons, but also included a relatively detailed and precise stratigraphic study. In his stratigraphy he used two novel methods, which later became common practice: the use of a map on which he recorded the various outcrops, and the use of fossils to separate the various levels of "the limestone realm."

In chapter 10, we shall see that Soulavie anticipated works done at the end of the century and the first years of the next. He was nevertheless preceded in that area by P.-A. Boissier de la Croix de Sauvages (1710–1795), who as early as 1749 divided the mountains near Alès, covering a surface of about twenty square kilometers, into ten "chains," which he tried to classify according to their rocks and fossil fauna.[15]

However, before returning to the problem of the beginning of biostratigraphy, let us make a small detour by way of James Hutton's tectonics and plutonism.