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Chapter 14

Unraveling the Earth's Age

Division of Time

In 1829 Alexandre Brongniart published *Tableau des terrains qui composent l'écorce du globe* (Table of rock units which form the earth's crust), in which he proposed dividing geological time into two periods: a Saturnian period during which continents were more or less covered by the sea; and a Jovian period corresponding to the time when continents began to acquire their present shape.[1] The first included all the marine transgressions and **regressions** since the beginning of time up to the last one, and the second period referred only to that most recent regression.

Brongniart's classification, inherited from J.-A. Deluc and Cuvier, was very egocentric (or anthropomorphic) because it treated modern times in a very subjective fashion. However, every history favors the present over the past, if only because of the unequal amount of data available for the two.

A historian of the earth, no less than the chronicler of human history, cannot escape curtailing the past, simply because so little is known about older rocks. For instance, modern terminology uses *era* to designate spans of time that are increasingly long the more remote they are from the present. For instance, the Cenozoic era is 65 million years long, the Paleozoic era, 345 million years, and the Precambrian era at least 4,000 million years. Furthermore, common speech (in comic strips, for example) often lumps all geological eras into one "prehistoric" or even antediluvial period. An objective division of the history of the earth can only be achieved in a distant future, if ever, when our knowledge of the strata of all ages will be known with the same degree of accuracy.

During the 1830s and 1840s, the exploration of older epochs provided an excellent incentive to get to know rocks that had never been studied before. Geologists were busy describing rocks older than the coal-bearing strata.

British Geologists

It is not surprising that the oldest rocks of the Paleozoic were first studied in Great Britain. Indeed, the old massifs in France that represent the basement (chapter 6) date from the Hercynian orogeny (second half of the Paleozoic), whereas the greatest part of the British Isles is older, dating back to the **Caledonian orogeny,** at the beginning of the Paleozoic. Hence, induration of rocks in Great Britain preceded the same process in France. As a result, the Devonian (whose age is between these two orogenies) forms in England a horizontal deposit represented particularly by the Old Red Sandstone, a very thick sequence (several thousands of meters) of lacustrine (formed at the bottom or along the shore of a lake) or fluvial rocks. Its equivalent in France was highly folded during the Hercynian orogeny.

At the beginning of the nineteenth century, several British geologists played an important part in the unraveling of the Devonian. The ensuing controversy has been studied in detail by Martin J. S. Rudwick.[2]

Adam Sedgwick (1785–1873) was a professor of geology at the University of Cambridge starting in 1818. His friend and co-worker, Roderick Impey Murchison (1792–1871), remained an amateur and country gentleman for some time. Encouraged by his wife, he finally decided to become a scientist. He chose geology because it allowed him to continue outdoor exercise and hunting. He attended lectures in geology given by William Buckland (1784–1856) at Oxford.

Buckland was first appointed reader at Oxford because there was no chair of geology at that famous university, which apparently did not favor such scientific studies. In 1818 he petitioned, with success, for the additional title of Reader in Geology. Every geologist of the generation of Murchison and Lyell was a student of Buckland, whose merits as a teacher were highly praised. His inaugural lecture rehabilitated the close relation between geology and Genesis.[3] Rudwick wrote that this was "partly an attempt to reassure Oxford colleagues that the pursuit of geological science would not subvert Christian faith and piety, and that it was therefore a proper subject to be taught at the university that was the intellectual center of established religion in England."[4]

Cambrian and Silurian

Toward 1830, little was known about rocks older than the coal-bearing strata. Abundant **detrital rock** units found underneath the coal were simply named the Old Red Sandstone, but strata lower yet remained a confusing mass of so-called transition rocks. Henry Thomas De la Beche (1796–1855), the first director of the Geological Survey of Great Britain and author of teaching manuals (chapter 13), divided older rocks into **grauwacke** and lower fossiliferous group. Murchison, in turn, began the study of these rocks in western England and Wales. He described a series of four formations characterized by their faunas, which he interpreted as underlying the Old Red Sandstone. In 1835 he named these formations **Silurian** in honor of a Celtic tribe who had fought valiantly against the Romans. In 1839 he published a synthesis entitled "The Silurian System."[5]

Sedgwick arrived at a different conclusion. He was more influenced by tectonic events than by faunas and described rocks with few fossils, which appeared to him older than those mentioned by Murchison. He proposed the name **Cambrian** (Cambria is the Latin name for Wales) for rocks that included Murchison's Lower Silurian.[6]

Élie de Beaumont provided a synthesis by restricting the term Cambrian to rock units older than the Silurian, as defined by Murchison. To avoid all ambiguity, he replaced the name Cambrian with Cumbrian, which remained in use for some time before it was changed back again to Sedgwick's term.

Simultaneous studies showed that the fauna of rocks in Devonshire was in part very similar to that of the Silurian and in part to that of the Carboniferous, whereas a third portion appeared to be unique. After further studies by Murchison and Sedgwick, it was concluded that these formations were equivalent to the Old Red Sandstone in Scotland, southern England, and Ireland. Because this marine fauna was richer than that of the continental Old Red Sandstone, it was given the name Devonian, a system between the Silurian and the Carboniferous.[7]

Shortly after, the Permian, the last period of the Paleozoic era (with deposits of the New Red Sandstone), was named by Murchison in 1841 when corresponding rocks were found in the Russian government or territorial area of Perm. With the exception of the **Ordovician,** all the systems of the Paleozoic era were thus named and described. Therefore, "transition rocks" of the Wernerian school no longer represented a mysterious ancient world that was subject to conditions unrelated to those of the modern world.

It is true that rocks even older than the Cambrian (or the Silurian for authors who refuted Sedgwick's division) existed. They were called **Precambrian.** However, the term did not catch on in the 1840s. Murchison and French geologist Édouard de Verneuil (1805–1873) preferred the term **Azoic,** referring to an environment devoid of life. Indeed, the great problem now was determining when life on earth began.

Primitive Fauna

The solution to that problem would allow the writing of the history of the earth in a direct time order. Werner, who had been sure—although today known to be wrong—that the earth's first state was a primitive ocean, had told its history in a direct time order too. He started at the bottom of strata and went up through successively younger ones. However, his followers cautiously retreated from this ambitious goal. It became a habit to start with the present and proceed in reverse time order—"from the known to the unknown," as Ami Boué used to say. Indeed, in 1830 naturalists preferred the inductive method because inductive reasoning and uniformitarianism (with its central concept: the present is the key to the past) were in fact two facets of the same approach.

Murchison returned to the direct time order in 1839 when he believed he had a new starting point. According to B. Balan, the time was ripe to accept "a positive time direction which is first of all the direction of gradual development of life, starting from a base level considered as initial."[8]

Shortly afterward, Joachim Barrande (1799–1883) continued his search for what he called the "primordial" fauna. Educated in Paris at the Polytechnic School and the School of Civil Engineering, he became tutor to the grandson of Charles X and left France with the royal family in 1830. After some travels, he remained in Prague and became interested in local fossils such as **trilobites.**

In his huge work *Système silurien du centre de la Bohème* (The Silurian system in the central part of Bohemia), he stated that the rare fossils found in rocks older than the "primordial fauna" are sporadic forerunners of that fauna; that there is not much hope of finding fossils numerous enough to earn the name of fauna in rocks that we call azoic; and that the present fauna is the richest.[9] According to Barrande, starting from the present level and tracing these fossils backwards through the geological record, we will see some of the most highly organized types disappear, bed by bed, so that by the time we reach the level of the primordial fauna we find only one well-developed family, that of trilobites, and some lonely species as sporadic forerunners of mollusks and radiata.

Before Barrande, it was believed that the absence of organic remains in the oldest rocks could not necessarily prove that life did not exist as yet simply because metamorphism had made these rocks (called metamorphic schists after the dismissal of the adjective "primitive") unreadable. Of course, the numerous supporters of "normal metamorphism," who claimed that these rocks had been metamorphosed during their deposition, could add that life was incompatible with the conditions of such a transformation. However, none of these arguments could match that by Barrande who, upon discovery of the primordial fauna, established an origin of life. His thesis became all the more plausible when geologists started to explore weakly metamorphic Precambrian rocks and discovered that they were indeed azoic.

However, as always when things become very probable, when facts prove the most solid theories, exceptions appear, accumulate, and finally invalidate the system. In 1858, remains of what appeared to be organisms were found in Precambrian rocks on the banks of the Ottawa River in Canada. John William Dawson (1820–1899) at McGill University in Montreal carefully examined these remains and concluded that "these remarkable structures are truly organic." He classified them among foraminifers (microscopic unicellular animals with calcareous tests—hard protective shell or cover of certain invertebrates), named them *Eozoön canadense* (1865), and proposed replacing the name Azoic with Eozoic to designate Precambrian times.[10] The prefix *eo-* stems from the Greek *ēōs*, dawn or morning, hence, the dawn of life.

But Dawson was wrong. Formed by tiny superposed layers of calcite and serpentine, connected by pillars, these purely mineral structures were indeed found later in limestone blocks on Monte Somma, ejected by eruptions of Vesuvius after having been torn off from Jurassic layers of the substratum of the volcano.[11] Nevertheless, the search was on, and in the following years an authentic Precambrian fauna was discovered.

In 1894 Charles Barrois collected microorganisms in old rocks at Lamballe, Britanny.[12] Thereafter, such organisms were found in graphitic layers between metamorphic schists in Finland. Today, numerous types of Precambrian fossils are known. Besides the two most abundant types, bacteria and algae, the latter forming reefs called **stromatolites,** relatively complex organisms have been found: jellyfish, worms, and others.

Absolute Time of the Catastrophists

With increasing knowledge about earlier times and further exploration of the past, questions about the absolute geological age of these rocks, as well as that of the earth, became more and more acute. For a long time, only indirect and unreliable methods existed to answer these questions.

Stratigraphers who studied successively superposed rocks had determined their relative age so that they could be placed in a column, as geognosists had done earlier. However, they were still unable to give their duration or their age in millions of years. Naturalists had long tried to make up for that deficiency by various means. For instance, Buffon estimated the duration of the earth's cooling by comparison with that of cannonballs. He also calculated the rate of deposition of shales based on the opinion that a yearly deposit of such a sediment could be no more than five feet. Others calculated the rate of erosion. Gautier, for instance, measured "how much mud was transported by rivers from land to sea each year, and he deduced the time necessary to erode continents."[13] Palassou stated that one million years were needed to destroy the Pyrenees.[14] Other naturalists—from Maillet to Linnaeus—supported the theory of the diminution of the sea, making calculations that were just as speculative.

In the nineteenth century, time was at stake in debates about the action of supposedly slow present-day causes. Recall Lyell, for example, who was led to such theories after his guess at a geological time scale. It would be, however, too simple to conclude that every catastrophist was in favor of short chronologies, even if they did not still subscribe to the seventeenth-century belief in a global history of a scant six or eight thousand years.

Cuvier, for instance, did not hesitate to talk about "thousands of centuries" when referring to the past of the earth in his *Discours* (1812). However, in subsequent editions he omitted any reference to time. In 1838 Marcel de Serres talked about millions of years.[15]

The British were even more daring. Buckland, who wanted to demonstrate "the wisdom and the benevolence of God shown in his works of Creation," talked about "millions and millions of years."[16] His friend William Conybeare set a record by estimating the age of the earth at "quadrillions of years."[17]

We should not be astonished at the audacity of some catastrophists. The durations of deposition measured geological time—and almost everyone agreed on that point—but the durations of orogenies and of biological "revolutions" did not. Catastrophists placed orogenies between phases of deposition, whereas uniformitarians placed them during these phases. Hence, catastrophists did not have to assume shorter durations than their adversaries.

Nevertheless, all chronologies of directionalists had one major flaw. Paradoxically, they were not too short, but too long. We all know that anything exaggerated is not reliable. To come up with numbers as enormous as they were unjustified meant that naturalists were not truly concerned with measuring geological time.

Time According to Uniformitarians

Lyell, on the contrary, tried to estimate time without indulging in too-risky speculations. He compared faunal changes in the Quaternary with changes during earlier periods. He noticed that 5 percent of the fauna had changed during the glacial period. Assuming a constant rate of renewal (a uniformitarian hypothesis), he calculated that twenty times more time was necessary for a biological "revolution"

Sedgwick, Buckland, and Murchison

In his autobiography, Charles Darwin referred to Sedgwick, Buckland, and Murchison in the following terms:

> Professor Sedgwick intended to visit N. Wales in the beginning of August [1831] to pursue his famous geological investigation amongst the older rocks, and Henslow asked him to allow me to accompany him. Accordingly he came and slept at my Father's house.
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> A short conversation with him during this evening produced a strong impression on my mind. Whilst examining an old gravel-pit near Shrewsbury a labourer told me that he had found in it a large worn tropical Volute shell. . . . I told Sedgwick of the fact, and he at once said (no doubt truly) that it must have been thrown away by someone into the pit; but then added, if really embedded there it would be the greatest misfortune to geology, as it would overthrow all that we know about the superficial deposits of the midland counties. These gravel-beds belonged in fact to the glacial period, and in after years I found in them broken arctic shells. . . .
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> All the leading geologists were more or less known by me, at the time when geology was advancing with triumphant steps. I liked most of them, with the exception of Buckland, who though very good-humoured and good-natured seemed to me a vulgar and almost coarse man. He was incited more by a craving for notoriety, which sometimes made him act like a buffoon, than

to occur. Lyell counted four revolutions since the end of the Cretaceous and eight others for earlier times. Since his contemporary James Croll (1821–1890) had estimated—based on astronomical calculations—that the glacial period had lasted one million years, Lyell concluded: "If each, therefore, of the twelve periods represents twenty million years on principles above explained, we should have a total of two hundred and forty millions for the entire series of years which have elapsed since the beginning of the Cambrian period."[18] (Radioactive dating of rocks in the twentieth century doubled this number so that the Cambrian began in reality 570 million years ago.)

At the end of the nineteenth century, sudden doubts arose about the old age of the globe. The distinguished physicist Lord Kelvin (William Thomson, 1824–1907), known for his work in thermodynamics (Kelvin scale), calculated, on the basis of present heat flow at

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> by a love of science. He was not, however, selfish in his desire for notoriety; for Lyell, when a very young man, consulted him about communicating a poor paper to the Geol. Soc. which had been sent him by a stranger, and Buckland answered—"You had better do so, for it will be headed, 'Communicated by Charles Lyell,' and thus your name will be brought before the public."
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> The services rendered to geology by Murchison by his classification of the older formations cannot be overestimated; but he was very far from possessing a philosophical mind. He was very kind-hearted and would exert himself to the utmost to oblige anyone. The degree to which he valued rank was ludicrous, and he displayed this feeling and his vanity with the simplicity of a child. He related with the utmost glee to a large circle, including many mere acquaintances, in the rooms of the Geolog. Soc. how the Czar Nicholas, when in London, had patted him on the shoulder and had said, alluding to his geological work—"Mon ami, Russia is grateful to you," and then Murchison added rubbing his hands together, "The best of it was that Prince Albert heard it all."*

*Charles Darwin, *The Autobiography of Charles Darwin: 1809–1882*, with original omissions restored, edited with appendix and notes by his granddaughter Nora Barlow (New York: Harcourt, Brace and Co., 1958), 69, 102–103.

the surface, that the earth could not be more than 100 million years old and was likely much less.[19] This time limit reduced the duration of biological evolution. This is why Thomas Huxley (1825–1895), a friend of Darwin's, disputed Kelvin's calculations.

Nevertheless, Kelvin's results did impress geologists who had become accustomed to counting on longer durations. The controversy ended when John Joly (1857–1933) published *Radioactivity in Geology* in 1909 and showed that the earth's heat resulted not only from its initial heat, but also from heat produced by radioactivity.[20] The accidental discovery of natural radioactivity by Henri Bécquerel in 1896, followed by the important studies done by Pierre and Marie Curie on the origin of radioactivity, reversed the results obtained by Kelvin.

It was found that helium, which was known to exist in the sun, occurred on earth as a product of radioactive decay of uranium. Lord Ernest Rutherford (1871–1937) studied the relationship between helium and uranium in minerals. Starting in 1917, it became possible to know absolute geological time.

Of the many radioactive isotopes that exist in nature, rubidium 87, strontium 87, and uranium 235 and 238 are used to date rocks that are millions of years old, whereas potassium 40 and argon 40 date rocks as young as fifty thousand years. Carbon 14 is used to date events of even more recent geological history.

Radioactive isotopes are not only useful for measuring geologic time: "Recent advances in nuclear physics have allowed new research in geochemistry; its technical and practical importance results from the distribution of isotopes which can explain dispersion and concentration of chemical elements."[21]