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GEOSCIENCES. A HISTORICAL ESSAY

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RESUMEN

Los minerales han sido objeto de atención por parte de los investigadores desde los tiempos antiguos. Las colecciones de minerales de las Escuelas de Minas y de los museos poseen un gran valor didáctico. Muchos de los metales fueron descubiertos durante los estudios de nuevos minerales. Nuevas técnicas analíticas, como el microscopio polarizado, contribuyeron a asentar a la mineralogía como ciencia, mientras que la difracción de rayos X y la utilización del microscopio electrónico sirvieron para su avance. Sobre esta base se fundó la cristalografía. Los fósiles jugaron también un papel importante en la construcción de la paleontología como ciencia, y el reconocimiento de los meteoritos como objetos procedentes del espacio exterior ayudó a entender el origen de la Tierra y tuvo un importante impacto sobre la metalografía y la ciencia de los materiales.

PALABRAS CLAVE: Minería, geología, minerales, fósiles, meteoritos, difracción de rayos X, microscopio electrónico, metalografía, cristalografía.

ABSTRACT

Minerals have attracted attention of researchers since ancient times. Mineral collections at the former Schools of Mines and in museums have tremendous educational value. Many metals have been discovered when analyzing new minerals and not accounting for their full composition. New analytical tools such as the polarizing microscope contributed to creating the science of mineralogy, while X-ray diffraction and electron microscopy extended the studies. On their basis the science of crystallography was founded. Fossils played an important role in building up the science of palaeontology while the recognition of meteorites as objects from outer space helped understanding the origin of the Earth and had an impact on metallography and material science.

KEY WORDS: Mining, geology, minerals, fossils, meteorites, X-ray diffraction, electron microscopy, metallography, crystallography.

INTRODUCTION

Mining and geology have often been associated. The contribution made to the knowledge of the Earth through mining was particularly significant in the period from the sixteenth to the eighteenth century. In antiquity, the experience gained in mining of metals and precious stones helped the development of theoretical petrology and mineralogy. Quarrying in ancient Egypt was certainly highly advanced as attested by the 4000-year old pyramids of Giza. The earlier miners had no knowledge of the morphology of the strata, but they soon started to notice some characteristics where precious stones were found. These observations are the foundations of the later sciences of geology and mineralogy.

The recognition that geology could provide benefits for industrialization and national prosperity encouraged many governments to promote and finance geological surveys for compiling inventories of local geological and mineral resources. The establishment of these new institutions obviously improved the quality and the diffusion of geological cartography, particularly from the 1830s.

The beauty of minerals attracted scientists to study them (Fig. 1). Collection of minerals became a fascinating hobby not only for scientists but also for monarchs (Fig. 2). Wealthy people also found it a fashionable attraction. Joseph Franz Maximilian Lobkowitz (1772-1816) Duke of Roudnice (Fig. 3), who is remembered as the greatest of Beethoven's patrons to whom Beethoven dedicated many works, had a huge mineralogical collection. Alexandra Pavlovna (1783-1801) (Fig. 4), daughter of Tsar Paul I of Russia and sister of Emperors Alexander I and Nicholas I, who became Archduchess of Austria upon her marriage to Archduke Joseph of Austria, Governor of Hungary had also a fascinating collection that was arranged by the famous mineralogist of that time Ignaz von Born (1742-1791) (Fig. 5). Museums for natural history were founded in most European capitals.

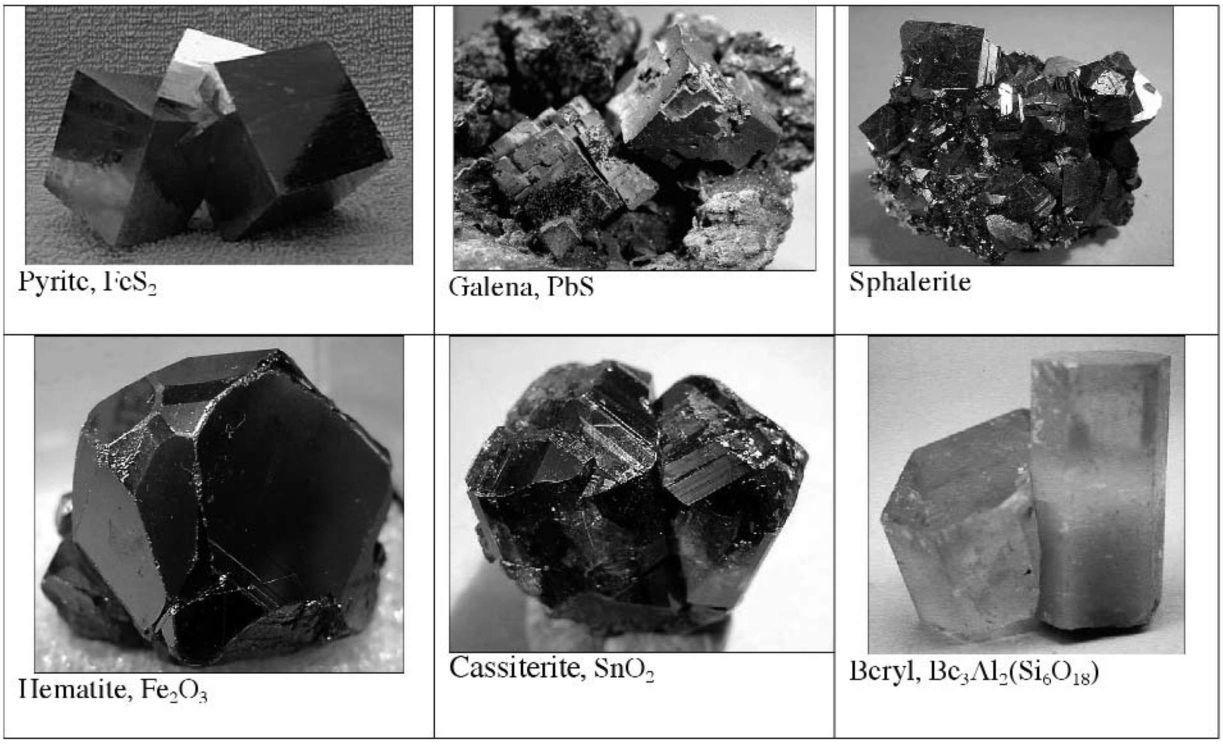


Figure 1. The beauty of minerals attracts the attention of scientists and laymen.

Figure 2. Emperor Franz I (1708–1765) of Austria studies minerals and fossils with his scientists at the Museum of Natural History in Vienna.

Volcanoes and earthquakes caused much panic and great damage, were once thought to be a punishment from God because people were not following his commandments. Stones and lumps of metal falling from the sky, now known as meteorites, were once worshipped and considered to be messages from God. Geologists changed all that and explained the origins of these phenomena.

MINERALS AND MINERALOGY

From earliest times man has found important uses for minerals, and these uses have expanded tremendously with the expansion of science and industry. At first minerals were used as they were found: clay for bricks and pottery; flint, and quartz, for weapons or implements; oxides of iron and manganese as paints; turquoise, garnet, amethyst, jade, and other coloured stones for ornaments. One of the earliest writings on minerals was the book *On Stones* by the Greek philosopher Theophrastus (372–287 BC). Pliny, in the first century AD, recorded a

Figure 3. Joseph Franz Maximilian Lobkowitz (1772-1816).

Figure 4. Grand Duchess Alexandra Pavlovna (1783 –1801).

Figure 5. Ignaz von Born (1742-1791).

great deal of natural history as it was understood by the Romans, and described a number of minerals that were mined as gemstones, as pigments, or as metallic ores (Fig. 6).


C. PLINII SECUNDI
NATURALIS
HISTORIÆ,
TOMUS PRIMUS.
Cum Commentariis & adnotationibus HERMOLAI BARBARI, PINTIANI, RHENANI, GELENII, DALECHAMPII, SCALIGERI, SALMASII, IS. VOSSII, & Variorum.
Accedunt praeterea variae Lectiones ex MSS. compluribus ad oram Paginarum accurate indicatae.
Item JOH. FR. GRONOVII Notarum Liber Singularis ad Illustrem Virum Johannem Capelanum.

LUGD. BATAV. ROTERODAMI. } Apud HACKIOS, A°. 1669.

Figure 6. A 1669 edition of Pliny's book *Natural History.*

Georgius Agricola (1494-1555) (Fig. 7) in Saxony, published in 1546 *De Natura Fossilium* in which he recorded the state of geology, and mineralogy, at that time. The Dane Niels Stensen (1638 –1686) (Fig. 8), better known by the Latinized version of his name, Nicolaus Steno, published his geologic studies in *De solido intra solidum naturaliter contento dissertationis prodromus*, or Preliminary discourse to a dissertation on a solid body naturally contained within a solid in 1669. He also found that the angles between corresponding faces on crystals are the same for all specimens of the same mineral, a fundamental law that formed the basis of subsequent inquiries into crystal structure, which was to lead to the development of the whole science of crystallography.

Throughout the eighteenth century new minerals were recognized and described, and various attempts were made to classify them. Most of the active workers in this endeavour were in Sweden and Germany. While Carl Linnæus made the classification of plants, another Swedish chemist Axel Fredrik Cronstedt (1722–1765) (Fig. 9) published in 1758 a classification of minerals based on their chemical composition. He had collected more than 5000 specimens of minerals when he was only in his early thirties. His book was translated in English under the title *An Essay Towards a new System of Mineralogy* in 1770.

Figure 7. Georgius Agricola (1494-1555).

Figure 8. Nicolaus Steno (1638 –1686).

Figure 9. Axel Fredrik Cronstedt (1722-1765), studied at Uppsala. In 1744-1745 he visited the most important Swedish mines and in 1746-1748 studied assaying and chemistry at the Royal Mint in Stockholm where he later became Chief Assayer. He discovered nickel in 1751.

A great teacher of the time was Abraham Werner (1750–1817) (Fig. 10), Professor at the Mining Academy in Freiberg, who attracted students from all parts of Europe. At that time, mineralogy and chemistry were closely linked, since the chemists of the day worked largely with minerals as their raw materials. This resulted in the discovery of many new elements — cobalt, manganese, tungsten, molybdenum, uranium, and others. The significance of crystallography in the study of minerals was brought out largely by the work of the French scientist Haüy (1743–1822) (Fig. 11) who taught at the École des Mines in Paris.

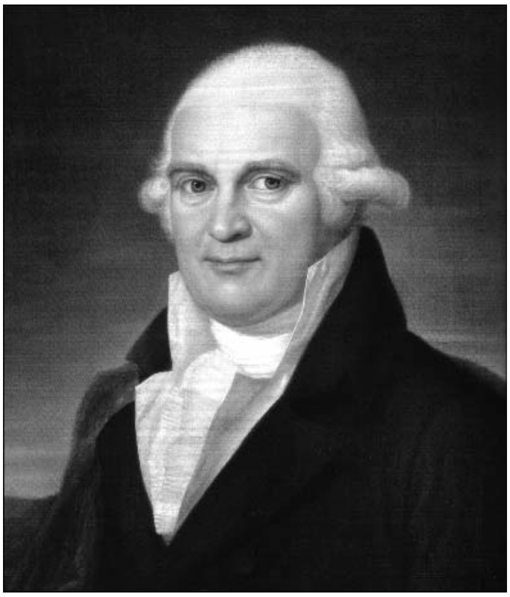


Figure 10. Abraham Werner (1750–1817).

Figure 11. French scientist Haüy (1743–1822).

The early years of the nineteenth century saw rapid advances in mineralogy, following the introduction of the atomic theory by John Dalton and the realization that minerals were chemical compounds with a definite composition. The invention of the reflecting goniometre also provided the means for much more precise measurements on crystals and an acceptable classification of crystal forms and crystal systems. The Swedish chemist Jöns Jakob Berzelius (1779–1848) (Fig. 12) and his pupils, especially Eilhard Mitscherlich (1794–1863) (Fig. 13) studied the chemistry of minerals and worked out further the principles of their chemical classification.

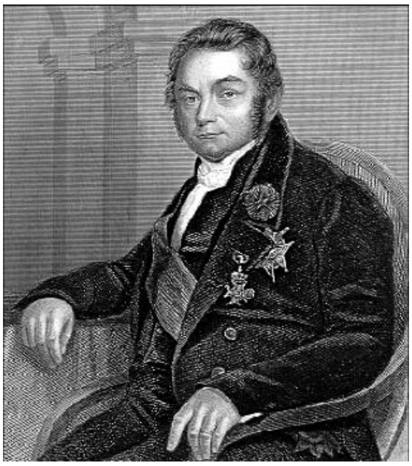


Figure 12. Swedish chemist Jöns Jakob Berzelius (1779–1848).

Figure13. Eilhard Mitscherlich (1794–1863).

Throughout the nineteenth century many new minerals were discovered and described, often as a result of the opening up of new mining districts in previously unexplored territories. The development of the polarizing microscope, and its application to the determination of the optical properties of minerals from about 1870 on, placed a new and powerful tool in the hands of the mineralogist. It also made possible the study of the fine-grained rocks of the earth's crust, which established the fact that rocks like granite are aggregates of minerals. The more powerful tools of X-ray diffraction and electron microscopy have extended the study.

Max von Laue (1879-1960) (Fig. 14) in Germany in 1912 discovered that crystals diffract X-rays and that the diffraction patterns can be interpreted to give the actual positions of the atoms in the crystal. This allowed the mineralogist to investigate the internal structure of minerals in addition to the external form, optical properties, and chemical composition. Since 1912 the structures of hundreds of minerals have been determined.

Figure 14. Max von Laue (1879-1960).

As science progressed, other properties unknown at the time of the original description of minerals became important, and it was therefore necessary to re-study many minerals. This would often be impossible if it were not for the mineralogical collections housed in the numerous museums throughout the world. These museum collections thus have an importance far above that of displaying the mineral specimens to the public. Many of those collections originated by professors in the former Schools of Mines.

FOSSILS

The word "fossil" comes from a Latin word meaning "to dig" and was originally applied to anything dug up out of the Earth. Today it refers to the remains and traces of animals and plants which are found naturally embedded in rocks, i.e., the stony objects that seemed to possess structures like those of living organisms (Fig. 15).

Most scholars felt that fossils had to be once-living things that had somehow turned to stone. This subject attracted the particular attention of a French biologist, Georges Léopold Cuvier (1769–1832) (Fig. 16) who studied the anatomy of different creatures, comparing them carefully, and systematically noting all similarities and differences. He pushed biological knowledge into the far past and established the science of palaeontology, the study of ancient forms of life. He considered them to represent the record of an evolution of species. The deeper and older a fossil was, the more it differed from existing life forms, and some could be placed in consecutive order in a manner that seemed to demonstrate gradual change.

Cuvier, however, was a pious man who could not accept the possibility of evolutionary changes. He adopted instead an alternative view that although the Earth was indeed ancient, it underwent periodic catastrophes during which all life was wiped out. After each such catastrophe, new forms of life would appear, forms that were quite different from those that had previously existed. Modern forms of life (including man) were created after the most recent catastrophe. In this view, evolutionary processes were not needed to explain the fossils, and the biblical story, supposed to apply only to events after the last catastrophe, could be preserved.

METEORITES

Meteorites are other objects that contributed to the understanding of the history of the Earth. The fall of stones from the heavens is such an unexpected event, especially as it is usually accompanied by thunderous

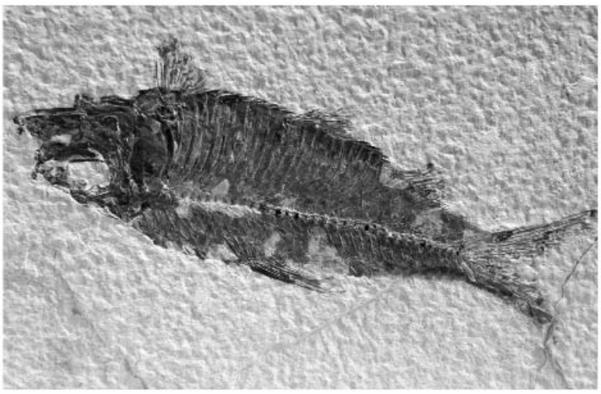
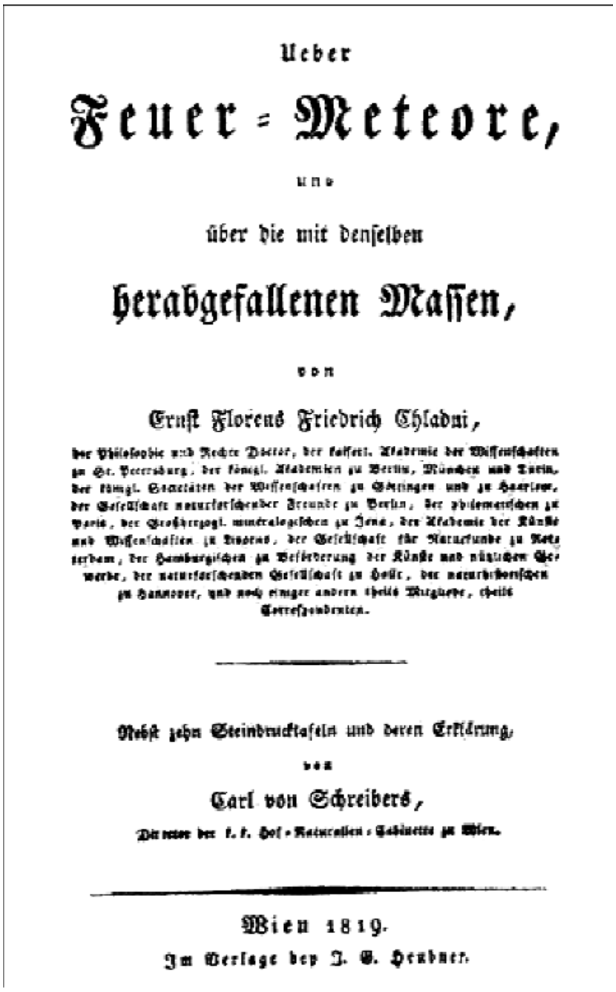


Figure 15. Fossils, the stony objects that seemed to possess structures like that of living organisms, attracted the attention of scientists and became the basis of the science of palaeontology.

Figure 16. Georges Léopold Cuvier (1769–1832), French biologist, established the science of palaeontology.

noises and by smoke trails, that it must have terrified primitive peoples. It was not until 1790 that members of the French Academy of Sciences had to reverse their denial of the possibility of such events. When the distinguished scientist of the day Jean Baptiste Biot (1774–1862) was asked by the Academy to investigate the claim of falling stones, he came to the indisputable and amazing fact that masses of iron and stone do rather frequently come in from interplanetary space and fall on the surface of the Earth. Ernst Chladni (1756–1827) (Fig. 17) at Göttingen then wrote his first book on meteorites in 1794, followed by another in 1819 (Fig. 18) thus establishing the science of meteorites. In this second monograph, Chladni presented the first imprints made by Aloys von Widmanstätten (1754–1849) in Vienna of polished and etched sections of iron meteorites showing a characteristic pattern that became referred to by metallurgists as the Widmanstätten structure. A modern polished and etched meteorite sample is shown in Figure 19.

Figure 17. Ernst Chladni (1756–1827).



Ueber

Feuer-Meteore,

und

über die mit denselben

herabgefallenen Massen,

von

Ernst Florens Friedrich Chladni,

der Philosophie und Rechte Doctor, der kaiserl. Akademie der Wissenschaften zu St. Petersburg, der königl. Akademien zu Berlin, München und Turin, der königl. Societäten der Wissenschaften zu Göttingen und zu Haarlem, der Gesellschaft naturforschender Freunde zu Berlin, der philomatischen zu Paris, der Großherzogl. mineralogischen zu Jena, der Akademie der Künste und Wissenschaften zu Livorno, der Gesellschaft für Naturkunde zu Rotterdam, der Hamburgischen zu Beförderung der Künste und nützlichen Gewerbe, der naturforschenden Gesellschaft zu Halle, der naturhistorischen zu Hannover, und noch einiger andern theils Mitgliede, theils Correspondenten.

Nebst zehn Steindrucktafeln und deren Erklärung,

von

Carl von Schreibers,

Director der k. k. Hof-Naturalien-Cabinette zu Wien.

Wien 1819.

Im Verlage bey J. G. Heubner.

Figure 18. Ernst Chladni's second book on meteorites (1819).

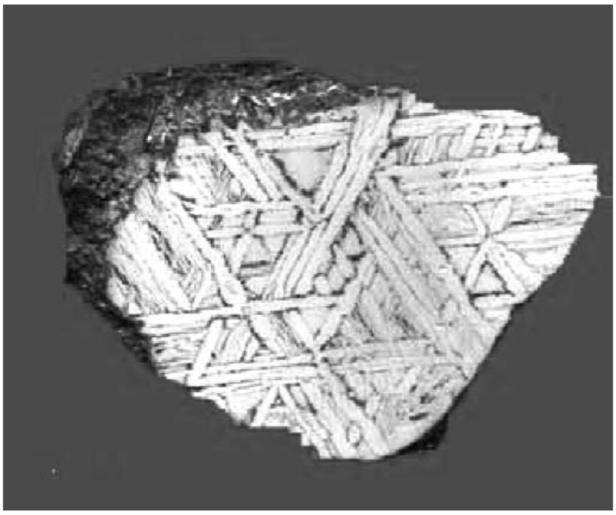


Figure 19. Polished and etched section of a meteorite showing the characteristic Widmanstätten structure.

The study of meteorites not only contributed to the advancement of geological sciences but also to metallurgy and material science. In metallurgy, the appearance of a characteristic pattern on polishing and etching of a meteorite surface inspired introducing metallographic technique in the study of metals. In material science, the corrosion resistance of meteorites and the discovery that they contain nickel, suggested alloying iron with nickel or other metals to render it corrosion-resistant. The largest meteorite that is still in its place of fall and can be inspected is at Hoba in Namibia (Fig. 20). It fell in 1920 and weighs 80 tonnes.

Figure 20. Hoba meteorite in Namibia weighing 80 tonnes.

GEOLOGY

In 1785, James Hutton (1726–1797) (Fig. 21), a Scottish physician who had taken up geology as a hobby, published a book called *Theory of the Earth*. In it, he reviewed the manner in which the action of water, wind, and weather slowly changed the surface of the Earth. He then pointed out that to account for such gigantic changes as the building of mountains, the creation of river canyons and so on, vast ages of time were required. The Earth, therefore, must be many millions of years old. This new concept of the age of the Earth was at first greeted with a hostile reception, but it had helped make sense of the fossils that were now beginning to preoccupy biologists.

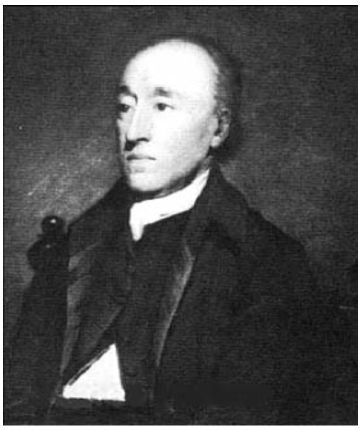


Figure 21. James Hutton (1726–1797), Scottish physician, wrote *Theory of the Earth*.

If the Earth were as old as Hutton suggested, fossils might be extremely ancient remains that had very slowly replaced their ordinary substance by the stony material in the soil about them. A new look at fossils came with William Smith (1769–1839), an English surveyor turned geologist. He surveyed routes for canals, then being built everywhere, and had the opportunity to observe excavations. He noted the manner in which rocks of different types and forms were arranged in parallel layers or "strata." He noted in addition that each stratum had its own characteristic form of fossil remains, not found in other strata. No matter how a stratum was bent and crumpled, even when it sank out of view and cropped up again miles away, it retained its characteristic fossils. Eventually, Smith was able to identify different strata by their fossil content alone.

If Hutton's views were correct, then it was reasonable to suppose that the strata were laid in the order in which they were very slowly formed, and that the deeper a particular stratum was laid, the older it was. If the fossils were, indeed, the remains of once-living creatures, then the order in which they lived might be determined by the order of the strata in which they were to be found.

In 1830, the Scottish geologist Charles Lyell (1797–1875) (Fig. 22) began the publication of a three-volume book, *Principles of Geology*, in which he popularized Hutton's views that Earth underwent only gradual and non-catastrophic changes. Some forms of life survived each period where a catastrophe was suggested. Indeed, some forms now alive have existed virtually unchanged for many millions of years. Catastrophism held out for a while among Cuvier's followers, particularly in France, but after Lyell's book appeared, it was clearly a dying belief. By the mid-nineteenth century, it finally collapsed.

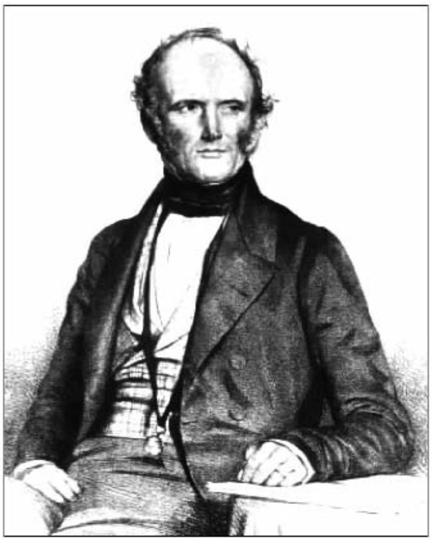


Figure 22. Charles Lyell (1797–1875), Scottish geologist, wrote *Principles of Geology* in three volumes.

THE FIRST CHAIRS

The first chair of geology was established in France in the new *Musée d'Histoire naturelle de Paris*, which replaced the Jardin du Roi in 1793 (Fig. 23). In European

Figure 23. Jardin du Roi in Paris.

universities the teaching of mineralogy (usually associated with chemistry) had instead been introduced since the mid-eighteenth century in countries with a strong mineralogical tradition, such as at Uppsala University in Sweden. Already in the Mining Academies that had been established in the late eighteenth century, some courses were very nearly courses of geology, such as the course of Gebirgslehre (rock theory) given by Werner in the Mining Academy of Freiberg from 1778 to 1817.

In those institutions the predominant subject was mineralogy, which also included the study of rocks and the Earth's surface. It was complementary to the teaching of mining techniques. Geology became an established discipline in the mining academies before it did in the universities. The Mining Academy in Mexico City established a chair of geology in 1794, while the École des Mines of Paris did so in 1835

GEOLOGICAL SURVEYS, ACADEMIES, AND PUBLICATIONS

The earliest Geological Survey, also known as Geological Committee in some countries, e.g., in Russia, was planned in France in 1822 within the Corps Royal des Mines and the fieldwork for mapping the whole country started in 1825. A short time later several national geological surveys began to be established in Europe and in North America. In the United States, most of the state surveys were founded between the 1830s and the 1850s, and the national geological survey in 1879. The Geological Survey of England and Wales was established in 1835 under Henry Thomas de la Beche (1796–1855) (Fig. 24) and was followed by a similar institution in Canada in 1842 and in other countries (Table 1).

The proceedings of scientific academies and societies established in Europe, especially during the eighteenth century, such as *Philosophical Transactions of the Royal Society of London*, *Transactions of the Royal Society of Edinburgh*, or *Memoirs of the French Academy of Sciences*, included several studies on geological subjects and contributed to the diffusion of these new researches. The first Geological Society was established in London in 1807. The Société géologique de France was founded in 1830, while the Deutsche Geologische Gesellschaft in Germany and a similar institution in Hungary were established in 1848. Numerous European and non-European societies were founded after the mid-nineteenth century.

Figure 24. Henry Thomas de la Beche (1796–1855).

1835	England, Wales
1842	Canada
1849	Austria–Hungary, Spain
1851	India
1858	Sweden, Norway
1859	Switzerland
1868	France
1869	Portugal
1873	Prussia, Italy
1875	Brazil
1878	Belgium
1879	USA*
1882	Russia
1894	Egypt
1907	Brazil

Table 1. The first Geological Surveys. (*State Geological Surveys were founded earlier.)

A standard reference work in mineralogy has long been *Dana's System of Mineralogy*. The first edition of this book was written by James Dwight Dana (1813-1895) (Fig. 25) and published in 1837, and it aimed at a complete account of all minerals described up to that time. It was revised and brought up to date by successive editions and by supplements issued at intervals between each edition. The seventh edition appeared in four volumes.

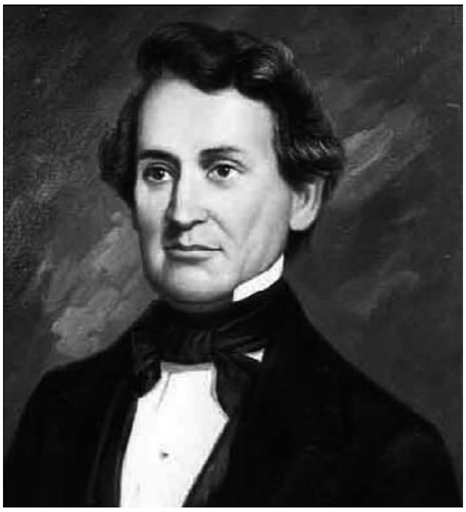


Figure 25. James Dwight Dana (1813-1895).

Two comprehensive treatises on mineralogy, both in German, have been published: *Handbuch der Mineralchemie*, by C. Doelter and co-workers, published 1911–1931, and *Handbuch der Mineralogie*, begun by C. Hintze and carried on after his death by other workers; the first volume appeared in 1897, the last in 1933, and supplementary parts covering new minerals and new data on previously described minerals are published from time to time.

Significant developments took place between 1885 and 1915 when the tectonic theory by Eduard Suess (1831–1914) (Fig. 26) published in his *Das Antlitz der Erde* (The Face of the Earth, 1883), Lord Kelvin's calculation of the age of the Earth (1899), and the "continental drift" of Alfred Wegener (1880–1930) in 1912.

Figure 26. Eduard Suess (1831–1914).

METALLOGRAPHY

Henry Clifton Sorby (1826-1908) (Fig. 27) used the microscope for examining rocks in thin sections by transmitted light. He was led from this study to that of iron and steel. Metals are, however, opaque even in thin sections and Sorby solved the problem by the provision of reflectors positioned so as to throw the light directly down on the object and from this reflected through a microscopic lens in such a manner that a polished surface appeared bright, and a rough surface comparatively dark. An important part of Sorby's contribution was his polishing technique secured by the use of rubbing with a sequence of emery papers commencing with a coarse paper and finishing with the smoothest.

Figure 27. Henry Clifton Sorby (1826-1908).

Etching was usually accomplished by dilute nitric acid which served to differentiate the various constituents by differences in the light reflecting power of the metal surface. By his technique Sorby showed that metals were crystalline, and recognized that as carbon was added in increasing amounts to iron, a sequence of constituents appeared.

Sorby was born at Woodbourne, Attercliffe into a wealthy middle class English family. After leaving Sheffield Collegiate School at the age of 15 he studied at home with a private tutor. In 1847 when he was 21 his father died and Sorby found himself with a comfortable income and no need to earn a living. He immediately established a laboratory and workshop at his home.

In 1849 he pioneered a new branch of geology "Microscopic Petrography" the microscopic examination of very thin sections of rock. He ground thin slices of rock by hand to one thousandth of an inch thickness and then examined them under a microscope in normal and polarised light. In 1857, aged only 31 he was elected a Fellow of the Royal Society in recognition of this work. From his microscopic study of rocks he became interested in meteorites and the microscopic examination of iron and steel. In 1863 he again pioneered a new field of study, that of "Microscopic Metallurgy". His microscopic work in metallurgy led Sorby to studying the pigment of leaves, fungi, insects, plants, algae, and semi precious stones, and other objects.

In 1878 Sorby bought a yacht equipped as a laboratory and staffed by five people. For the next 20 years he cruised up and down the east coast of England every summer studying geology, botany, meteorology, archaeology and marine biology. He developed his own special techniques for mounting specimens of marine animals and plants directly on to lantern slides so that they could be projected on to a screen without distortion. Many of these slides still exist in Sheffield City Museum. Sorby never married and lived his whole life in Sheffield. He was active with Mark Firth in the development of higher education in Sheffield, became the President of Firth College in 1882 after Mark Firth's death and worked hard for the establishment of a University in the City. This was eventually founded in 1905 and in his will Sorby left a considerable sum to the University. He authored: *On the Microscopic Structure of Crystals*, and *On the Microscopic Structure of Iron and Steel.*

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