#501

The Founding of Geology in America: 1771 to 1818

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ABSTRACT

Geological research in North America developed from a few isolated inquiries in the eighteenth century to a mature descriptive science by 1818. In 1771, the study of earth science in America was limited to a few observations on diverse subjects. Systematic investigation and classification of rocks, minerals, and fossils was unknown. Several European and American scientists recognized the need for a standardized nomenclature and unambiguous identification methods in the earth sciences. Thus by 1818, through the efforts of Werner and Maclure in field geology, Cuvier and Brongniart in paleontology, and Cleaveland in mineralogy, systematic classification of geological materials had been introduced to America. These contributions established the science of geology in the United States and enabled the next generation of earth scientists to describe fully the natural history and resources of North America. *Key words: history of geology, North America.*

INTRODUCTION

"Energy crisis," "environmental protection," "dwindling natural resources" — these everyday phrases of our decade reflect the increasing reliance of society upon the contributions of earth scientists. Yet, in spite of the dependence of our technological age on geology, the history of North American earth-science development remains a virtually unexplored field of study. While Europeans have long recognized the contributions of Abraham Werner, James Hutton, William Smith, and others, the men who mapped and described this nation's vast natural resources remain practically unknown. This essay will review the earth-science literature produced in North America from 1771 to 1818 in an effort to evaluate the developing concepts and significant contributions of North American scientists during that half-century.

The scientific community of the late eighteenth century did not recognize geology as a branch of the natural sciences. While chemists, natural philosophers, and astronomers all investigated certain aspects of the earth sciences, there were few Europeans and virtually no North American researchers who addressed themselves primarily to what is now known as geology. Consequently, a summary of geology in Revolutionary America analyzes what was, to eighteenth-century scientists, a diverse body of scientific endeavors. This essay will examine individually several important topics studied by early earth-science investigators. Six subjects which are considered include (1) the origin of the Earth, (2) field geology, (3) earthquakes and volcanoes, (4) vertebrate paleontology, (5) invertebrate paleontology, and (6) mineralogy. Although these topics reflect a somewhat modernized division of earth-science knowledge, they conveniently incorporate the several hundred American publications on geology presented between 1771 and 1818.

While the half-century from 1771 to 1818 may seem a somewhat arbitrary time period, these years do represent important dates in the publication of American earth-science studies. The first official volume of the American Philosophical Society's *Transactions* (our nation's first scientific journal) appeared in 1771. The year 1818 marks the formation of the American Geological Society and the publication of a half-dozen landmark articles and books. However, the maturation of the earth sciences in America from the first explorers and settlers to the present proceeded with few revolutionary "turning points"; there were numerous highlights in this advance, but few, if any, quantum jumps.

ORIGIN OF THE EARTH

The inquiring spirit of the Enlightenment naturally led to speculation on the origin and present state of the Earth. While the seven days of Genesis may have satisfied certain theologians, some eighteenth-century scientists searched for a history of the Earth that was more in harmony with known physical laws. The formation of the Earth and its celestial analogs was a puzzle which primarily involved astronomers, but others also studied the problem. Before discussing American efforts to reconstruct the Earth's history, it is necessary to review three theories which emerged in seventeenth- and eighteenth-century Europe and influenced subsequent American speculations. Schneer (1969, p. 7) credits René Descartes with "the first attempt at a secular account of the origins of the earth since classical times." In *Principes del la Philosophie* of 1644, Descartes suggested that the planets formed from a series of vortices (that is, whorls of matter) which collapsed due to gravitational attraction. The Earth was said to be a small, cooled star differing from the Sun in size only. The Cartesian theory laid the base for several subsequent speculations.

Later in the same century, the German philosopher and mathematician Gottfried Wilhelm von Leibnitz described the Earth as a fiery body, cooling from the outside to leave a hard crust. Vapors condensed onto this crust to form the oceans, and these waters received the first sediments. Almost a century later, Georges Leclerc, Marquis de Buffon, presented *Epoques de la Nature* (1779), which was "the most fully developed of those theories that began with the Earth as a cooling star" (Schneer, 1969, p. 7). Buffon followed the Leibnitz concept of a molten star-like Earth, cooling from the outside to form a crust onto which oceans could precipitate. However, Buffon supported his ideas with a careful mathematical description of the formative process. These three similar descriptions of our planet's beginnings became the foundation for subsequent efforts in both Europe and the United States.

The sole pre-1818 American contribution to this question was made by our nation's foremost eighteenth-century scientist, Benjamin Franklin. Franklin's "Conjectures concerning the Formation of the Earth," excerpted from a private communication, appeared as the first article in the 1793 *Transactions* of the American Philosophical Society. Despite its brevity (only four and one-half pages), it contained several remarkable insights. First, Franklin speculated that at least part of the Earth's interior was hot dense liquid, as evidenced by volcanic activity. The vast amount of heat thus stored in our planet was produced, according to Franklin, during the Earth's formation through the release of potential energy. This energy release occurred "as soon as the Almighty fiat ordained gravity," for at that time many small particles were drawn to a "common centre" (p. 2). The vortex created by these rapidly collapsing particles is now manifest in the Earth's rotation. Franklin suggested that a metal-rich core caused the Earth's strong magnetic field, and that the partially molten state of this metal

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might explain the well-known wandering of the magnetic north pole. While none of these speculations was completely original to Franklin, he was remarkably successful at synthesizing the best ideas from several previous efforts.

FIELD GEOLOGY: THE ORIGIN AND CLASSIFICATION OF ROCKS

Two great European controversies set the stage for early American contributions to field geology. Geologic processes, we now realize, are extremely slow and require thousands or millions of years to alter the landscape of our planet. However, to many Enlightenment thinkers, such great time spans were inconceivable, especially within the framework of the Bible. To rationalize the great complexity of the Earth's crust, they argued for the primacy of catastrophic events in the shaping of our planet's surface; mountains were built and valleys carved by earthquakes, volcanoes, and floods. It was James Hutton "who first clearly grasped the full significance and immensity of geological time" (Holmes, 1965, p. 43). The Scottish naturalist believed that thousands of years of gradual and uniform erosion or uplift were responsible for many of the Earth's topographical and geological features. Hutton's *Theory of the Earth* (1795) rapidly converted many investigators to this uniformitarian view of geology, and virtually all American field geology research was begun with this theory in mind.

Even as the intellectual battle between catastrophists and uniformitarianists raged, a new debate was beginning in European earth-science circles. Although most scientists agreed that rocks were continually being created and destroyed, there was little agreement on the mechanism of rock formation. Parker Cleaveland summarized this controversy: "It is, perhaps, universally admitted that the fluid agent employed in the formation of minerals, must have been either *water* or *caloric* (i.e. heat). Hence two geologic systems have arisen, according as the principle agency . . . is attributed to water or caloric. . . . Supporters of these theories are called *Neptunians* or *Vulcanists*" (Cleaveland, 1822, p. 43). The neptunian water-deposition view was almost universally accepted in America between 1785 and 1818.

Abraham Gottlieb Werner first proposed this neptunian theory of rock formation in *Kurze Klassifikation* in 1785 (Ospovat, 1967). Werner divided all of the world's rocks into four classes based on the period in the Earth's history when the rocks were formed. "Primitive rocks" of the original crust were easily recognized by their coarse crystalline or irregular texture. Today these would constitute many of our metamorphic and intrusive igneous rocks. "Transition rocks," the next to be formed, were deposited on the floor of a vast ocean covering the whole earth and could be recognized by the fragments of primitive rocks which they contained. Volcanic basalts and sedimentary limestones were among these "neptunian" formations. After a period of ocean subsidence, a second ocean or flood created the "secondary or floetz rocks." Such rocks differed from the transition formations in that they were less deformed and more evenly layered. Famous sedimentary rock formations such as England's Old Red Sandstone and Dover Chalk were included in this class. Finally, "alluvial rocks" were defined as unconsolidated sediments such as sand, gravel, and peat. It was this rock classification scheme which "guided geological observations . . . from 1786 to about 1825" (Schneer, 1969, p. 242).

Werner drew strong support from American scientists. William Maclure, America's first true field geologist, praised the German for having "reduced the nomenclature to some regular form," and added that "the system of Werner is still the best and most comprehensive that has yet been found" (Maclure, 1818c, p. 2). Maclure (1818b, p. 387) claimed "geology owes more to him than any other man." Amos Eaton, a student of Werner's "proclaimed the task of American geology to be one of filling in the details of Werner's system" (Schneer, 1969, p. 14). American support for the neptunian theory was not limited to verbal praise. T. P. Smith (1799, p. 445) described crystallized (volcanic) basalts near Philadelphia and presented "proof of their neptunian origin." A similar article by Benjamin Henry Latrobe (1804) described evidence for the ocean deposition of freestone quarry rock (actually a basalt). These and other North American earth-science investigators were in complete support of Werner's theory of rock formation.

Geological maps, first introduced in late eighteenth-century Europe, provided a less direct means of supporting Wernerian doctrine. A geological map consists of a standard geographical map with superimposed colors or other markings representing the distribution of various rock types at the Earth's surface. The ultimate configuration of colors on such a map depends upon the system of rock classification used, and all American geological maps produced before 1825 were based on the Wernerian scheme. The first such American map appeared in 1809 and accompanied the first version of William Maclure's "Observations on the Geology of the United States," which represented the largest geological mapping project yet attempted anywhere in the world. This effort was remarkable for both its scope and accuracy. Maclure traveled thousands of miles on foot to complete this survey which covered an area of well over 500,000 sq mi. Even more surprising is the correlation between the geologist's colored zones and those on modern maps. Maclure's delineation of the alluvial deposits of the Carolina coast and deep South and the secondary rocks of the Midwest perfectly match the now-accepted limits of, respectively, Tertiary-age and Paleozoic-age sediments.

No new American maps appeared for fourteen years, but four separate Wernerian maps were published in 1818. Eaton (1818) issued a detailed map and cross section of a strip from northern New Jersey and New York City to Albany as the first of several regional studies of New York State. The Dana brothers, James and Samuel (Samuel was the father of the famed nineteenth-century mineralogist James Dwight Dana), presented their "Outlines of the Mineralogy and Geology of Boston and Vicinity" in the fourth American Academy *Memoirs* (Dana and Dana, 1818). Edward Hitchcock (1818) took advantage of his years as principal of the Deerfield Academy in central Massachusetts to study the geology of the Connecticut River Valley and nearby regions in New Hampshire, Vermont, and Massachusetts. The resulting hand-colored map is amusing in that the distinctive red sandstones of this region were believed by Hitchcock to be the same New Red Sandstone that was known in England and France. This interpretation was then added to the 1818 second version of Maclure's "Observations," which represented the fourth North American field mapping effort of 1818.

In 1818, William Maclure (1818a) published his "Essay on the Formation of Rocks." This landmark article represented the first major break with neptunian doctrine in the United States and established Maclure as our nation's first geological philosopher. In the first section of his three-part article, the author noted fallacies in both neptunian and plutonist theories. However, using a combination of these modes of rock formation, he accounted for virtually all known lithologies. On this basis, Maclure established a new classification scheme based on two large "classes" of earth materials: the neptunian (or Wernerian) rocks and the volcanic rocks. The neptunian rocks, as the name implies, were water-deposited sediments, while volcanic rocks included all those formed by the action of heat. Maclure correctly recognized the igneous nature of basalts and granites, and the neptunian origin of the similar-looking graywacke sandstones and metasediments. A detailed subdivision of orders, families, genera, and species was provided, but the significant achievement remains Maclure's recognition that both water and heat are contributing mechanisms in rock formation. Maclure's "Essay" provided a guide for subsequent American field studies, and his division of rocks represents a prototype of modern lithological classification. In this sense, William Maclure introduced systematic field geology to the United States.

NATURAL PHENOMENA: EARTHQUAKES AND VOLCANOES

Among the most spectacular natural phenomena are earthquakes and volcanoes, and it is not surprising that such events have drawn varied speculations on the origins and predictability of the forces within the Earth. While there are no active volcanoes in eastern North America, a series of earthquakes rocked eighteenth-century New England, causing much comment and some alarm. New England earthquakes were recorded as early as 1638 in the diaries of some Puritan settlers, though widespread public notice of these natural phenomena did not arise until after the somewhat stronger shocks of 1727 (Williams, 1785). Hindle (1956, p. 94) states that 27 earthquake-inspired publications, "nearly all of them sermons," appeared following the Boston shock of that year. Indeed, virtually all such natural phenomena were generally accepted as "acts of God," and the physical laws governing such occurrences were seldom explored. The great triple-earthquake and subsequent tidal waves that destroyed Lisbon in 1755 stimulated world-wide denunciations of the moral degeneracy which precipitated Portugal's disaster. On the other hand, the philosophers Immanuel Kant and Jean Jacques Rousseau declared that earthquakes were purely natural phenomena and that men "cannot expect to prevent an earthquake at a particular place merely by building a large number of churches there" (Holmes, 1965, p. 899).

John Winthrop (1755) of Harvard College was the first American to attempt a detailed physical explanation of these natural phenomena and their origins. Inspired by the Lisbon earthquake of 1755 and a smaller shock which rattled Boston in the same month, Winthrop delivered "A Lecture on Earthquakes" and soon thereafter published his thoughts in pamphlet form. Winthrop began by carefully relating his own observations, as well as those of other reliable persons. He noted a systematic decrease in the quake's severity with increasing distance from Boston, while the time of first disturbance in various North American towns was discovered to increase with distance from the Massachusetts capital. Winthrop logically concluded that the energy of an earthquake propagates in the form of an expanding "wave of the earth" (p. 11), analogous to the wave caused by an object thrown into a still pool. Furthermore, the speed of this wave was shown to be faster than the speed of sound, since earthquakes were invariably felt before they were heard. He argued that this "undulatory motion of the earth" resulted from the rapid expansion of hot gases in "long, crooked . . . passages which run . . . through a great extent of the earth, and form communication between very distant regions" (p. 18). Finally, Winthrop speculated that volcanoes are the "safety-valves" of this subterranean network, and noted the common association of volcanoes and earthquakes as supportive evidence. While his speculations on earthquake origins may now seem rather fanciful, John Winthrop's contribution marked one of the first systematic investigations of such natural phenomena and their origins, and his wave theory of earth-shock propagation has become the foundation of modern seismology.[1]

By 1800, the efforts of American clergymen to interpret earthquakes as signs of celestial wrath were being undercut by a growing number of descriptions of these phenomena. Men from all walks of life contributed data on their experiences during such events. Daniel Jones, a Massachusetts farmer, claimed "my herd of cattle were greatly terrified . . . and run together through fear" during a minor tremor (Jones, 1785, p. 315). Governor Winthrop Sargent of the Mississippi Territory submitted a long and detailed account of his and others' experiences during a moderately severe earthquake (Sargent, 1809). By 1820, at least 20 separate descriptive articles on earthquakes had appeared in the various American scientific journals.

In spite of the large number of these accounts available (and the impressive example of John Winthrop), interpretive essays on earthquakes were surprisingly rare in American journals. Two noteworthy works, though somewhat farfetched by modern standards, attempted to explain these phenomena on the basis of systematic observations. Samuel Latham Mitchill was intrigued by the simultaneous occurrence of a comet, several earthquakes, and an unusually severe snowstorm in December of 1810. Mitchill (1815) made careful observations of each of these events, and concluded that the comet caused the tremors and the storm. A seemingly more ambitious project was F.A.A. Williams' "Observations and Conjectures on the Earthquakes of New England" (1785). Closer inspection, though, shows this article to be little more than a restatement of John Winthrop's 1755 lecture. In fact, Williams' only original contribution was the documentation of several late eighteenth-century shocks. It was a dubious tribute to Winthrop that sixty years after its first publication, his work was still worthy of being copied.

While no active volcanoes were found in the United States, American scientists were not ignorant of these phenomena. The first earth-science article published in America was Isaac Jamineau's "Account of the Eruption of Vesuvius," which appeared in the first *Transactions* of the American Philosophical Society in 1771. The French investigator may have stimulated American interest in the subject, for the third *Transactions* contained "An Account of a Hill . . . Supposed to Have Been a Volcano" (T. D., 1793). Caleb Alexander (1785) presented a somewhat fantastic account of a fiery New England volcano in his "Account of Eruptions," and the author's sensationalistic descriptions cast some doubt on the accuracy of this brief notice. All pre-1820 accounts of volcanoes or volcanic remains published in this country were purely descriptive, and no theories were advanced to explain these phenomena.

VERTEBRATE PALEONTOLOGY

In 1739, a group of French explorers discovered a huge deposit of fossil bones at Big Bone Lick in Kentucky, thus providing American scientists with a fascinating opportunity for study and speculation (Simpson, 1943). In view of the fact that the voluminous literature on these and other American vertebrate fossils has been carefully documented and analyzed by George G. Simpson, this essay will simply outline the major contributions by early North American investigators. While Big Bone Lick was by far the largest source of North American ancient vertebrate remains, other significant deposits were found in Pennsylvania by the Susquehanna River (Edwards, 1793); Gay Head, Massachusetts (West, 1793); Western Virginia (Jefferson, 1799); Louisiana (Dunbar, 1804); Wakill on the Hudson River, New York (Annan, 1793); and Hackettstown, New Jersey (Peale, 1802). By 1800, fossil bones had been found near most major American cities.

Many of America's most noted scientific figures were intrigued by these vertebrate fossils at one time or another. Thomas Jefferson (1799) wrote of the discovery of a "Quadruped of the Clawed Kind" (in fact, a giant sloth) in the American Philosophical Society's *Transactions*, and carefully detailed the size and shape of each fossil bone. Jefferson (1964) had earlier pointed to giant American mastodon remains to refute Buffon's theory that American animals were degenerate (smaller in stature than corresponding European varieties). During their respective terms as president of the American Philosophical Society, both Benjamin Franklin and

[1] Hindle (1956, p. 96) notes "Winthrop's recognition of the wave character of earthquakes long preceded its statement by the Reverend John Mitchell who is still often given credit for originating the concept."

David Rittenhouse received donations of fossil bones, and Rittenhouse's discovery of a large fossil (mastodon) tooth precipitated several publications (Hindle, 1964).

Most scientists who studied fossil bones realized the need to reconstruct the "mammoth" and other extinct species. Though Big Bone Lick was too distant for an expedition, several efforts were made on the East Coast. In 1780, workers digging a ditch on the property of the Reverend Robert Annan discovered a tooth and leg bone of some large extinct mammal. Annan then supervised a careful excavation of this almost-complete skeleton, but the bones proved so rotten that only the teeth could be preserved (Annan, 1793). More successful was Rembrandt Peale's New Jersey mammoth project to obtain a specimen for the Peale family museum (Peale, 1802). After several years of work in a peat bog in Hackettstown, New Jersey, three partial mastodon skeletons were removed; from these, an entire specimen was reconstructed and mounted in 1803 (Simpson, 1943). This fine specimen was the world's second restored fossil skeleton.

While most United States investigators were content to describe the size and shape of new fossil finds, Caspar Wistar distinguished himself as America's first physiographic paleontologist. Wistar was born in Philadelphia, received his medical education in London and Edinburgh, and, upon returning to America, became Professor of Anatomy at the University of Pennsylvania. His background in taxonomy and physiography allowed him to interpret an animal's life habits from the configuration of a few bones. For example, Wistar correctly identified a giant sloth from the lower forearm alone (Simpson, 1943). By the year of his death in 1818, Wistar had established himself as America's first vertebrate paleontologist.

Until 1818, the vertebrate fossil remains in the United States were unclassified; neither the relative ages, abundances, nor ranges of the extinct animals were known. The 1818 American edition of Georges Cuvier's *Essay on the Theory of the Earth* established a new direction in the study of extinct animals. As stated in the *Essay*'s "Preliminary Observations":

> It is my object . . . to travel over ground which has yet been little explored, and to make my reader acquainted with a species of remains, which, though absolutely necessary for understanding the history of the globe, have been hitherto almost uniformly neglected. . . . As an antiquarian of a new order, I have been obliged to learn the art of deciphering and restoring these remains . . . (and) reproducing, in all their original proportions and characters the animals to which the fragments formerly belonged, and then of comparing them with those of animals which still live (Cuvier, 1818, p. 4).

Samuel L. Mitchill, the American sponsor and editor of this American edition, followed Cuvier's *Essay* with several of the French naturalist's "Notes" or appendices. Among these was an 80-page outline of some 60 known European fossil vertebrates, arranged by class, order, family, genus, and species. Americans were thus given a model for all future studies of fossil bones. The science of vertebrate paleontology had been introduced to the United States.

INVERTEBRATE PALEONTOLOGY

The study of fossil shells, in contrast to vertebrate paleontology, aroused little interest in pre-1818 American scientific circles. Virtually all naturalists and scientists must have been aware of these curious remains; William Bartram, Thomas Jefferson, David Rittenhouse, and Benjamin Franklin mentioned invertebrate fossils in their letters or travel accounts. Yet marine fossil remains evoked little of the awe associated with the bones of the mammoth or giant sloth. Even those who occasionally described individual shells made little attempt to assign a species, or even genus, to these petrified relics. For example, the prominent American chemist and geologist Parker Cleaveland submitted an "Account of Fossil Shells" to the American Academy of Arts and Sciences *Memoirs* in 1809, but he failed to identify the fossils in any systematic manner (Cleaveland, 1809). He was not, however, in error when he reflected that "the universal existence of marine shells and other fossil bodies . . . satisfactorily prove that very great changes have taken place in the interior part of our earth" (p. 155). With considerable insight, Cleaveland proposed that a systematic map of invertebrate fossil distribution might reveal much about the history of the Earth.

Three Europeans had already accomplished Cleaveland's goal in 1808. William Smith, an English surveyor and geologist, collected suites of fossil specimens from various formations, and noted that each group of fossils was unique to its own formation. The Frenchmen Georges Cuvier and Alexandre Brongniart made the same discovery while collecting near Paris. Arthur Holmes noted that "by 1808 it became possible to correlate the older formations of England with those . . . in France" (Holmes, 1965, p. 152). Americans were presented with an unprecedented opportunity to correlate strata in Europe and North America. Yet only two or three short notices on invertebrate paleontology were published in the United States between 1808 and 1818. Among these, only the Frenchman C. A. le Sueur's "Observations on a New Genus of Fossil Shell" attempted to classify the fossilized organism and compare it with other known genera (le Sueur, 1818).

1818 may be considered a transitional year for invertebrate paleontology in the United States. In apparent desperation from lack of American interest, Alexandre Brongniart published a notice in the first volume of the *American Journal of Science* describing the proper techniques for collecting, labeling, and packing fossil shells. He concluded by supplying his shipping address for those unable to interpret their finds (Brongniart, 1818). Cuvier's *Essay on the Theory of the Earth* (1818) was perhaps more influential in stimulating American interest in fossil shells, for one of its appendices included the Cuvier and Brongniart list of Paris strata and their faunal assemblages. As in the study of vertebrate fossils, French paleontologists pointed the way for American investigators.

MINERALOGY

Americans needed no European encouragement to excel in studying minerals, for the colonies relied upon natural resources for many of their daily necessities. American leaders realized that political independence would depend, in part, on the economic independence provided by developing these resources. Decades before the Revolution in 1775, iron, copper, lead, zinc, and salt were being mined in the colonies. Reports of rich mineral deposits in the American Midwest by the explorers Peter Kalm in 1753 (Benson, 1937), Major Robert Rogers (1765), and Thomas Hutchins (1778) stimulated interest in our nation's mineral wealth (Schneer, 1969). Because inorganic resources also constituted a vital source of drugs and chemicals, mineralogy was a subject of more than passing interest to American doctors and chemists. The constant need for minerals was, in large part, responsible for the active study of these substances by the American scientific community.

Several American journals aided chemists and physicians by including numerous short notes on newly discovered mineral locations or uses. The *Medical Repository* averaged more than five such accounts per year during the period 1798–1818. Minerals with medicinal value were emphasized, but many reports on new species and their localities were included as well. The short-lived *American Mineralogical Journal,* conducted by Archibald Bruce, M.D., was the most ambitious attempt to publish mineral data. Almost fifty essays appeared in its four volumes (1809–1812). The *American Journal of Science,* originally known as *Silliman's Journal,* replaced Bruce's project in 1818 and has remained one of the United States' most respected geological journals. Virtually all other early nineteenth-century scientific or medical journals published occasional mineralogical notes as well.

In order to consolidate and simplify the hundreds of short notices on mineral deposits, several regional mineralogy studies were conducted in the early nineteenth century. Credit must be given to the Hessian doctor Johann David Schöpf who, in 1787, produced the first systematic mineralogy of the United States. However, his great work *Beyträge zur Mineralogischen Kenntniss* was never translated into English, and it is not mentioned in subsequent American works (Schneer, 1969). Despite the fact that Schöpf "opened the field of systematic mineralogy in the United States" (Hindle, 1956, p. 307), it seems unlikely that the German's work had much influence on American researchers. Regional mineralogy reports first appeared in 1804 with Benjamin De Witt's essay on "Mineral Productions of the State of New York" (De Witt, 1804). Sylvain Godon wrote mineral surveys for Maryland (Godon, 1804) and later for Boston (Godon, 1809). The Dana brothers, James and Samuel, expanded on Godon's Boston study in their detailed "Outline of the Mineralogy and Geology of Boston" (Dana and Dana, 1818). In that same year, mineralogical articles on Philadelphia were published by Isaac Lea (1818) and on Virginia and Tennessee by J. H. Kain (1818).

The systematic description and classification of minerals was not an easy task in the early nineteenth century. The periodic table of elements was unknown, and chemists did not possess the techniques necessary to analyze many minerals. Classification schemes were therefore based on a mixture of chemical and physical tests. Because no one system was satisfactory and accepted by all researchers, each author had to devise his own before describing a mineral species. Parker Cleaveland (1822) noted with dismay: "So great . . . has been the diversity of opinion on this subject, that scarcely any two persons have adopted precisely the same division of minerals into species" (p. 78). However, he continued, "Neglecting the minor and unimportant differences between the various methods, we may reduce these to two, which may be called the *mineralogical* and *chemical* methods; the former depending chiefly on external characteristics of minerals, the latter on their chemical composition" (p. 78). Before the publication of Cleaveland's *Elementary Treatise on Mineralogy and Geology,* most Americans appear to have used the "system of Werner," a mixed mineralogical and chemical classification, which divided all minerals into four classes based on external characteristics. This was the scheme modified by the Danas in their description of Boston mineralogy, on which the majority of pre-1818 American mineralogical publications relied.

Parker Cleaveland's "Tabular View of Simple Minerals," as presented in his *Elementary Treatise,* altered the course of American mineralogy. The author rejected the accepted system of Werner in favor of a "division into species . . . as strictly chemical, as the present state of mineralogical knowledge will permit" (p. 97). This 700-page tome was larger by an order of magnitude than any previous American classification scheme, and was correspondingly more detailed and complete. While a period of transition from Wernerian to chemical classification followed Parker Cleaveland's *Treatise,* there can be no doubt that this work was the forerunner of the classic mineralogy textbooks of James Dwight Dana and Edward Salisbury Dana.

GROWTH OF GEOLOGY IN THE UNITED STATES: 1771-1818

The eight journals containing most American contributions to geology between 1771 and 1818 were surveyed to trace the discipline's maturation in North America. All pre-1821 volumes of the American Philosophical Society *Transactions,* the American Academy of Arts and Sciences *Memoirs,* the *Medical Repository,* the *American Mineralogical Journal,* the *American Medical Register,* and the *American Journal of Science,* as well as the single-volume *Transactions* of the Literary and Philosophical Society of New York, and *Journal* of the Academy of Natural Sciences of Philadelphia, were examined. Articles relating to the earth sciences were noted and divided into the following five categories: (1) paleontology (articles on vertebrate or invertebrate fossil remains),

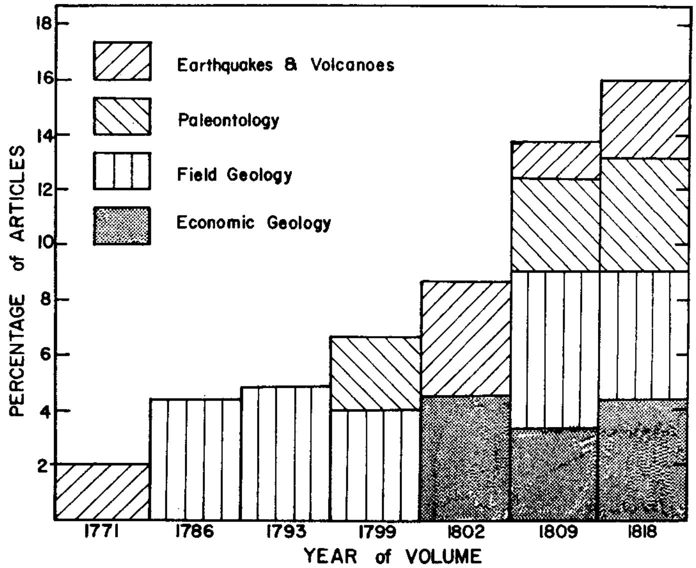

Figure 1. Percentage of earth-science articles in the first seven volumes of the American Philosophical Society *Transactions,* subdivided into five topics.

(2) mineralogy (articles describing chemical or physical properties of minerals), (3) economic geology (articles emphasizing the useful applications of rocks or minerals), (4) field geology (regional studies of rock formations, and detailed studies describing or interpreting individual formations), and (5) earthquakes and volcanoes (articles describing or interpreting these natural phenomena). In order to visualize the growth of geology in the United States, three graphs showing year of article publication versus number (or percentage) of earth-science articles have been prepared. Figure 1 de-

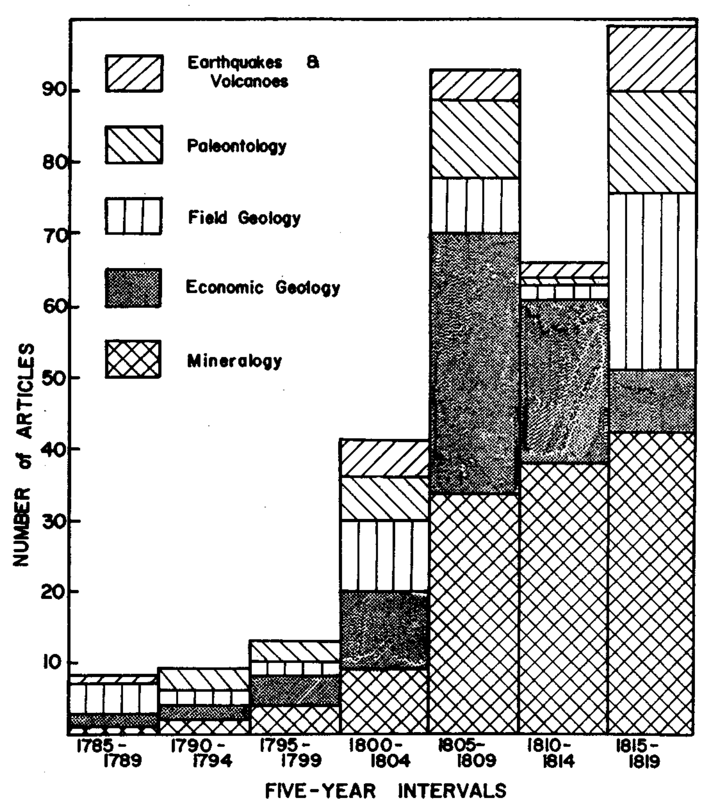

Figure 2. Number of earth-science articles in eight United States journals during five-year intervals from 1785 to 1819, subdivided into five topics.

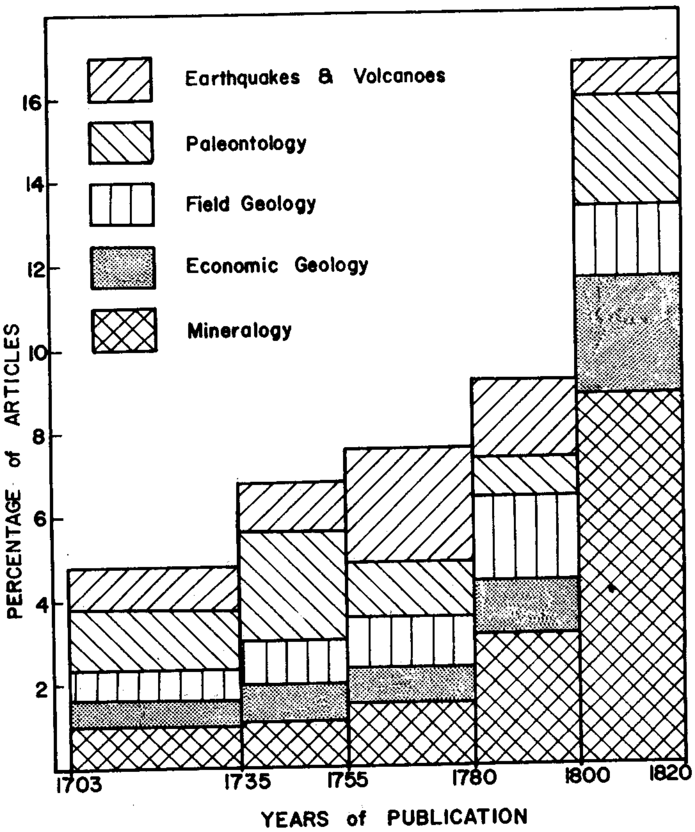

Figure 3. Percentage of earth-science articles in the Royal Society of London *Proceedings* from 1703 to 1820, subdivided into five topics.

picts the percentage of articles on the earth sciences (divided into the five categories) found in the American Philosophical Society *Transactions* for each of the first seven volumes. Figure 2 is a composite of all the above-named journals plotting the number of earth-science articles published by five-year intervals from 1785 to 1820. Finally, a similar chart (Figure 3) for the Royal Society of London *Transactions* from 1703 to 1820 provides a standard for comparison. Although this graph plots percentage of articles concerned with geology, rather than absolute numbers, the total number of articles in any given volume of the Royal Society *Transactions* varied little during this period, and thus the graph also reflects absolute changes in English geological efforts.

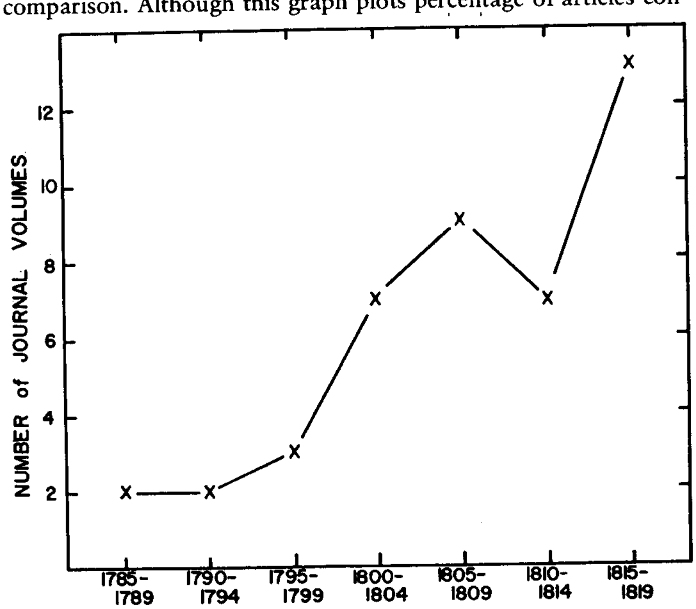

Figure 4. Number of American scientific-journal volumes during five-year intervals from 1785 to 1819.

The most striking feature of these three graphs is the proliferation of earth-science investigations in both England and America during the eighteenth and early nineteenth centuries. Not only did the absolute number of studies increase, but the percentage of earth studies increased with respect to other branches of science. American geological investigations multiplied tenfold between 1785 and 1820, thus doubling every eight years. This rapid growth of the earth sciences in the United States proceeded at an even faster pace in the subsequent decades.

Of the five categories depicted, only mineralogy (and, to a lesser extent, the closely related economic geology) displayed this sharp geometrical rise in number of articles. In America this was partly due to the appearance of the *Medical Repository,* the *American Mineralogical Journal,* and the *American Medical Register.* The relative constancy of paleontology studies reflects the lack of systematic classification in pre-1818 America; however, in the decade following Cuvier's *Essay*, hundreds of paleontological articles were contributed to American journals. Efforts in field geology were similarly sporadic until Maclure's more systematic contributions provided a model for others. It is not surprising that between 1815 and 1820, investigators produced more field studies than the production of the entire 1785 to 1814 period. Finally, natural phenomena such as earthquakes and volcanoes aroused interest only immediately following such events. As these phenomena were of relatively constant frequency during the period in question, related studies were published at a steady pace.

It is interesting to speculate on the gap in the steady growth of geological investigations apparent between 1805–1809 and 1810–1814. The immediate cause for this may be seen by plotting the number of journal volumes (of the eight journals under consideration) during five-year intervals (Fig. 4). The immediate reason for this decrease in the number of articles is clearly a decline in the output of journal volumes. It is intriguing to speculate on the possible effects of the 1812 conflict with England on our nation's scientific development.

CONCLUSIONS

In 1771, the study of earth science in America was limited to a few isolated observations on diverse subjects. Systematic investigation and classification of rocks, fossils, and minerals was unknown, and little progress had been made in understanding the Earth's past. Several European and American scientists recognized the need for a standardized nomenclature and unambiguous identification methods in the earth sciences, and they altered the course of geological investigations. By 1818, through the efforts of Abraham Werner and William Maclure in field geology, Georges Cuvier and Alexandre Brongniart in paleontology, and Parker Cleaveland in mineralogy, systematic classification of geologic materials had been introduced in America. These contributions established the science of geology in the United States, and enabled the next generation of earth scientists to describe fully the natural history and wealth of our expanding nation.

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REFERENCES CITED

Alexander, C., 1785, Account of eruptions and the present appearances in West River Mountains: Am. Acad. Arts and Sci. Mem., v. 1, p. 316–317.

Annan, R., 1793, Account of a skeleton of a large animal: Am. Acad. Arts and Sci. Mem., v. 2, p. 160–164.

Benson, A. B., ed., 1937, Peter Kalm's travels in North America, Vol. 1: New York, Wilson-Erickson, Inc., 400 p.

Brongniart, A., 1818, Notice of M. Brongniart on organized remains: Am. Jour. Sci., v. 1, p. 71–74.

Cleaveland, P., 1809, Account of fossil shells: Am. Acad. Arts and Sci. Mem., v. 3, p. 155–158.

——1822, An elementary treatise on mineralogy and geology designed for the use of pupils (2d ed.): Boston, Mass., Cummings and Hilliard, 818 p.

Cuvier, G., 1818, Essay on the theory of the earth: New York, Kirk and Mercein, 431 p.

D., T., 1793, An account of a hill on the borders of North Carolina supposed to have been a volcano: Am. Philos. Soc. Trans., v. 3, p. 231–234.

Dana, J. F., and Dana, S. L., 1818, Outlines of the mineralogy and geology of Boston and its vicinity: Am. Acad. Arts and Sci. Mem., v. 4., p. 129–223.

De Witt, B., 1804, Mineral productions of the state of New York: Am. Acad. Arts and Sci. Mem., v. 2, pt. 2, p. 73–81.

Dunbar, W., 1804, Extracts of a letter from William Dunbar Esq. of the Natchez to Thomas Jefferson, President of the Society: Am. Philos. Soc. Trans., v. 6, p. 40–42.

Eaton, A., 1818, An index to the geology of the northern states with a transverse section from Catskill Mountain to the Atlantic: Leicester, Mass., H. Brown, 52 p.

Edwards, T., 1793, A description of a horn or bone found in the river Chemung or Tioga: Am. Acad. Arts and Sci. Mem., v. 2, p. 164–165.

Franklin, B., 1793, Conjectures concerning the formation of the earth: Am. Philos. Soc. Trans., v. 3, p. 1–5.

Godon, S., 1804, Observations to serve for the mineralogical map of the state of Maryland: Am. Philos. Soc. Trans., v. 6, p. 319–323.

——1809, Mineralogical observations made in the environs of Boston in the years 1807 and 1808: Am. Acad. Arts and Sci. Mem., v. 3, p. 127–154.

Hindle, B., 1956, The pursuit of science in revolutionary America: Chapel Hill, N.C., Univ. North Carolina Press, 410 p.

——1964, David Rittenhouse: Princeton, N. J., Princeton Univ. Press, 394 p.

Hitchcock, E., 1818, Remarks on the geology and mineralogy of a section of Massachusetts on the Connecticut River, with a part of New Hampshire and Vermont: Am. Jour. Sci., v. 1, p. 105–116 and 436–439.

Holmes, A., 1965, Principles of physical geology (2d ed.): New York, Ronald Press, 1288 p.

Hutchins, T., 1778, A topographical description of Virginia, Pennsylvania, Maryland, and North Carolina: London, J. Almon, 67 p.

Hutton, J., 1795, Theory of the earth with proofs and illustrations: Edinburgh, W. Creech, 3 volumes.

Jamineau, I., 1771, An account of the eruption of Vesuvius in 1767: Am. Philos. Soc. Trans., 1, p. 345–350.

Jefferson, T., 1799, A memoir on the discovery of certain bones of a quadruped of the clawed kind in the western parts of Virginia: Am. Philos. Soc. Trans., v. 4, p. 246–260.

——1964, Notes on the state of Virginia: New York, Harper and Row, 228 p. (reprint of the 1781 version).

Jones, D., 1785, An account of West River Mountain: Am. Acad. Arts and Sci. Mem., v. 1, p. 312–315.

Kain, J. H., 1818, Notes on the mineralogy and geology of the northwestern part of the state of Virginia and eastern part of the state of Tennessee: Am. Jour. Sci., v. 1, p. 60–67.

Latrobe, B. H., 1804, An account of the freestone quarries on the Potomac and Rappahannock Rivers: Am. Philos. Soc. Trans., 6, p. 283–293.

Lea, I., 1818, An account of the minerals at present known to exist in the vicinity of Philadelphia: Jour. Acad. Nat. Sci. Philadelphia, v. 1, p. 462–482.

le Sueur, C. A., 1818, Observation on a new genus of fossil shell: Jour. Acad. Nat. Sci. Philadelphia, v. 1, pt. II, p. 310–312.

Maclure, W., 1809, Observations on the geology of the United States, explanatory for a geological map: Am. Philos. Soc. Trans., v. 6, p. 411–428.

——1818a, Essay on the formation of rocks: Jour. Acad. Nat. Sci. Philadelphia, v. 1, p. 261–275, 285–309, and 327–344.

——1818b, Note on A. Werner: Am. Jour. Sci., 1, p. 387.

——1818c, Observations on the geology of the United States of North America: Am. Philos. Soc. Trans., v. 1, n.s., p. 1–91.

Mitchill, S. L., 1815, A detailed narrative of the earthquake which occured on the 16th day of December, 1811, and agitated the parts of North America that lie between the Atlantic Ocean and Louisiana: Literary and Philos. Soc. New York Trans., 1, p. 281–340.

Ospovat, A. M., 1967, The place of the 'Kureze (sic) Klassifikation' in the work of A. G. Werner: Isis, v. 58, p. 90–95.

Peale, R., 1802, Account of the skeleton of the mammoth, a nondescript carnivorous animal of immense size found in America: London, E. Lawrence, 46 p.

Rogers, Maj. R., 1785, A concise account of North America: London, J. Millan, 264 p.

Sargent, W., 1809, Account of several shocks of an earthquake in the southern and western parts of the United States: Am. Acad. Arts and Sci. Mem., v. 3, p. 350–360.

Schneer, C. J., 1969, Towards a history of geology: Cambridge, Mass., M.I.T. Press, 469 p.

Schöpf, J. D., 1787, Beyträge zur mineralogischen Kenntniss des Östlichen Theils von Nordamerica und seiner Gebürge: Erlangen, J. J. Palm, 194 p.

Simpson, G. G., 1943, The beginnings of vertebrate paleontology in North America: Am. Philos. Soc. Proc., 86, p. 139.

Smith, T. P., 1799, Account of crystallized basalts found in Pennsylvania: Am. Philos. Soc. Trans., v. 4, p. 445–446.

West, S., 1793, A letter concerning Gay Head: Am. Acad. Arts and Sci. Mem., v. 2, p. 147–150.

Williams, F.A.A., 1785, Observations and conjectures on the earthquakes of New England: Am. Acad. Arts and Sci. Mem., v. 1, p. 260–311.

Winthrop, J., 1755, A lecture on earthquakes: Boston, Edes and Gill, 38 p.

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