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ABRAHAM GOTTLOB WERNER AND HIS INFLUENCE ON MINERALOGY AND GEOLOGY

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PREFACE

Although all major modern dictionaries define mineralogy and geology as separate sciences, many geologists consider mineralogy to be a branch of geology. In Werner's time the study of the earth's crust was generally considered to be a branch of mineralogy. Werner himself not only considered "geognosy," or historical geology, to be a branch of mineralogy, but he considered mineralogy to be a branch of mining. Thus when Robert Jameson wrote to him of the many chairs in mineralogy that had been established in Great Britain, he included in the term mineralogy not only the study of minerals, but the general field that we today call geology. With the historical development of these two branches of the earth sciences in mind, I have chosen to regard them as separate but closely related sciences for the purpose of this study.

This work is based largely upon photostatic copies of manuscripts that are at the Bergakademie at Freiberg, Saxony. These manuscripts were used by Karl A. Blöde and Samuel Gottlob Frisch in the early nineteenth century and Richard Beck in the early twentieth, but no thorough examination of them by a historian of science has previously been made.

In this study attention has been focused on Werner's contributions to mineralogy and geology. However, the interrelationship between Werner's geological work and the intellectual and social environment in which it was developed still needs to be investigated. Why was there so much interest in geology at the end of the eighteenth century and the beginning of the nineteenth? why were people from all walks of life attracted to the study of geology? what role did the industrial revolution, the emergence of nationalism, the French Revolution, the enlightenment play in the development of the earth sciences? These questions will have to be answered before Werner's work can be fully evaluated. Studies also need to be made of the introduction of courses of geology at institutions of higher learning as a direct result of Werner's work; of Werner's students and their work, with attention primarily focused on Werner's influence; and of the publications and uses of books, articles, and textbooks of geology which followed Werner's teachings.

We still know very little about Werner's private life. What books, persons, and incidents influenced him in his geological work and in his private life? What were his ideas on science, education, religion, nationalism, and economics? What did he know about chemistry, physics, and other sciences? The answers to some of these questions have been attempted in this study, and it is hoped that they have opened the way for new insights into Werner, the geologist and the man. However, a thorough study will not be possible until more sources are made available and investigated. The Bergakademie at Freiberg is in possession of Werner's library and of much manuscript material, which still await thorough examination.

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CHAPTER I

GEOLOGY BEFORE WERNER

In 1773, while Samuel Adams was organizing Committees of Correspondence, while Frederick the Great was taking inventory of his recently acquired Polish territories, and while the troops of Catherine the Great were ruthlessly crushing the revolt of Russian peasants, a young student at the University of Leipzig was writing a small book which was to bring him fame and recognition in the world of geology and a job as a teacher of mining at the Bergakademie at Freiberg, Saxony. This young man was Abraham Gottlob Werner, one of the founders of modern geology. The book was entitled *Von den äusserlichen Kennzeichen der Fossilien*.

The eighteenth century was the age of enlightenment and the age of reason, and it was also the century that marks the beginning of the industrial revolution. The eighteenth century man believed that the evils of the world are caused by ignorance and superstition. He believed that he was capable of understanding the world he lived in and solving the mysteries of the universe by the use of his intellect. These beliefs, combined with the utilitarian spirit of the eighteenth century rulers, empire builders, and merchants, opened the way for an interplay between science and technology that had never existed before.

The art of mining had been practiced for many centuries, and the interest in ores and minerals has an equally long history. But not until the eighteenth century was it fully realized that the knowledge of our earth's crust, its history and mode of formation, was not an idle pursuit, but an extremely useful one which would improve the search for ores and minerals and also the mining of them. The various phases of modern geology, such as paleontology, stratigraphy, structural geology, economic geology, and mineralogy were molded in the eighteenth and nineteenth centuries into a comprehensive and cohesive whole. But as in all other human endeavors, the accomplishments of the past formed the basis upon which this "new" geology built; and the part that Werner played in this development can be best understood and appreciated after a brief survey of the work done before him and of the state of geological knowledge in 1774, the year that marks the beginning of his long and lasting influence on the geological sciences.

The attention of writers on geology from ancient times to the Renaissance, and even well into the sixteenth and seventeenth centuries, was concentrated upon a few limited subjects which today form only a part of the geological sciences. In antiquity one finds brief references to and speculations about the causes of earthquakes, the origin of mountains, the origin of springs and rivers, the presence of marine fossils far inland, and other similar topics, but no formal treatment of any of them. In the Middle Ages when the ideas of the writers of antiquity once more became available on a large scale and were fused with the contributions of Arabic and Western European writers, the treatment of geological questions took on a different nature. From then on there was a better balance between theory and observation than was to be found in the writings of antiquity. The treatment of geological phenomena became more detailed, and the body of geological knowledge increased. But, despite this change, the Middle Ages, and even the Renaissance and the seventeenth century, failed to produce an organized, formal and systematic treatment of geology as a whole. There was no such thing as a textbook of general geology, but only isolated treatises dealing with a few aspects of geology, which would seem to indicate that geology had not as yet received a definition of its aims and realm of study. Nevertheless, it is possible to separate these disconnected and seemingly isolated treatises into two distinct groups: historical geology and mineralogy.

Mineralogy is primarily concerned with the identification of the individual pieces of the materials which form the earth's crust, and in order to make these identifications the mineralogist must establish relationships between the materials he wishes to identify. This can be done only by arranging these materials in some order, that is, by classifying them. The study of the history of mineralogy is therefore to a large extent a study of the different classification systems put forth by different people at different times.

Among the early Greek writings on mineralogy those of Aristotle (384-322/1 B. C.), and even more so those of his student Theophrastus of Lesbos (c. 372-c. 288 B. C.), deserve particular attention.

Most of what Aristotle had to say on the subject of minerals, or at least what has come down to us, is to be found in the Meteorologica.[1]

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[1]The following editions of the Meteorologica have been used:

In explaining the cause of shooting stars and other phenomena, Aristotle says that there are two kinds of "exhalations," the one being dry and the other moist. These exhalations are the result of the sun's heating of the earth. The moist exhalation, "which rises from the moisture contained in the earth and on its surface is vapour, while that rising from the earth itself, which is dry, is like smoke."[1] Sometimes these exhalations develop underneath the earth's surface, and there they give rise to two kinds of substances: fossils and metals. All stones that cannot be melted Aristotle considered to be fossils, and he uses the term in almost the same sense that it had until well into the nineteenth century, meaning anything that is dug out of the earth. He mentions realgar, ochre, ruddle, sulphur,[2] "and the other things of that kind," which originate in the earth and are caused by the heat of the "dry exhalation." He defines the metals as being "those bodies which are either fusible or malleable such as iron, copper, gold."[3] Aristotle was primarily concerned with the mode of formation of substances which originate in the earth, and therefore he gave a very broad classification of these substances. Whatever Aristotle's ideas about the mineral kingdom

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Aristotle, Meteorologica, with an English Translation by H. D. P. Lee, ("The Loeb Classical Library"; Cambridge: Harvard University Press, 1952); Aristotle, Meteorologica. The works of Aristotle translated into English, ed., W. D. Ross, Vol. 3, trans., E. W. Webster (Oxford: Clarendon Press, 1931).

[1]Aristotle, Meteorologica, I, 4, 341[b], Ross edition, Vol. 3. See also Aristotle, Meteorologica ("Loeb Classical Library"), pp. 29-31.

[2]Aristotle, Meteorologica ("Loeb Classical Library"), p. 287.

[3]Aristotle, Meteorologica, III, 6, 378[a], Ross edition, Vol. 3. See also Aristotle, Meteorologica ("Loeb Classical Library"), p. 287.

may have been, what has come down to us is very scanty, and it seems, as Sarton remarks, as if Aristotle and Theophrastus "had shared the three kingdoms of nature between them,"[1] for Aristotle's surviving writings deal with the animal kingdom and Theophrastus' with minerals and plants.

Theophrastus' treatise On Stones is usually considered to be the first work dealing with minerals and artificial products derived from them.[2] It is a rather short work, and it is not clear whether it is only a fragment of a larger work or whether in its present form it is a separate and complete work.[3] Be that as it may, the work was consulted and quoted by students and scholars for nearly two thousand years. John Hill, who was the first to translate it into English, writes in his preface: "The many References to Theophrastus, and the Quotations from him, so frequent in the Works of all the later Writers of Fossils, would make one believe, at first sight, that nothing was more universally known or perfectly understood, than the Treatise before us."[4]

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[1] George Sarton, A History of Science. Ancient Science through the Golden Age of Greece (Cambridge: Harvard University Press, 1952), p. 559.

[2] Earle R. Caley and John F. C. Richards, Theophrastus on Stones. Introduction, Greek Text, English Translation, and Commentary (Columbus: The Ohio State University, 1956), p. 3. See also Sarton, Ancient Science through the Golden Age of Greece, p. 559.

[3] N. F. Moore, Ancient Mineralogy; or, an Inquiry respecting Mineral Substances mentioned by the Ancients: with occasional Remarks on the Uses to which they were applied (2nd ed.; London: Sampson Low, Son, & Co., 1859), p. 11. See also Caley and Richards, pp. 8-9.

[4] John Hill, Theophrastus's History of Stones. With an English Version, and Critical and Philosophical Notes, Including the Modern History of the Gems, &c. described by that Author, and of many other of the Native Fossils. To Which are added Two Letters: One to Dr. James Parsons, F. R. S. on the Colours of the Sapphire and Turquoise. And the other, to Martin Folkes, Esq; Doctor of Laws, and President of the

Theophrastus seems to have made a limited attempt to classify substances formed in the ground. Excluding metals, which he believed to have come from water,[1] he confines himself to those substances which are made of earth, calling them stones and earths. And these are the two main categories of his classification. However, the distinction between stones and earths is not very clear. It seems to be primarily based on the "power of acting on other substances, or of being subject or not subject to such action."[2] As examples of the power to act on other substances he cites the ability of attraction of the Heraclean stone,[3] and the smaragdos,[4] which "can make the color of water the same as their own, . . ."[5] Some earths also have the power to act on other substances, but they have fewer of these qualities than have stones, and they are more peculiar, as for instance the earth which is mixed with copper, "for in addition to melting and mixing, it also has the remarkable power of improving the beauty of the color."[6] Theophrastus also divides stones and earths into fusible and infusible, combustible and incombustible,[7] and in his description of the various stones and earths he

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Royal Society; upon the Effects of different Menstruums on Copper. Both tending to illustrate the doctrine of the gems being coloured by Metalline Particles (London: Printed for C. Davis, 1746), p. xiv.

[1]Caley and Richards, p. 45.

[2]Ibid.

[3]Ibid., p. 46.

[4]The usual translation for smaragdos is emerald. However, it is not certain that this is the same stone that is today referred to as emerald. For a detailed discussion see Caley and Richards, pp. 45, 97-98.

[5]Ibid., pp. 45-46.

[6]Ibid., p. 55.

[7]Ibid., p. 45. See also Moore, p. 13.

also mentions such properties as density, smoothness, luster, tenacity, and color.[1] It was the last of these properties, color, which he decided to be the most suitable by which to list the earths. "It would also be possible," he writes, "to determine the differences that are naturally adapted for causing earth to turn to stone; for those that are due to locality, which cause different kinds of savors, have their own peculiar nature, like those which affect the savors of plants. But it would be best to list them according to their colors, which painters also use."[2]

Theophrastus' treatise might easily be dismissed as no classification at all and be considered as merely a compilation of descriptions of a few substances from the earth. However, close examination of the work makes it clear that Theophrastus knew far more substances than he mentions[3] and that there is a classification, even though it is a broad and loose one. The distinction between earths and stones is not quite clear, but it is there. Also, the different properties he mentions in describing minerals not only make for easier identification of these substances, but also suggest other possibilities for classification.

Next to Theophrastus' contribution to the geological sciences, that of Pliny the Elder (23-79) is the most important and outstanding of classical times. Books 33 to 37 of his Natural History[4] are devoted to

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[1]Caley and Richards, p. 45. [2]*Ibid.*, pp. 55-56.

[3]In writing about stones from which seals are cut, Theophrastus remarks that there are many stones of this kind, and in another place he says that "there are also many varieties of stones which are obtained by mining," indicating that he knew of stones other than those he mentions.

[4]Editions used are: Pliny, Natural History, trans., H. Rackham

the mineral kingdom. It is not always easy to separate the information from the misinformation, because Pliny, in his effort to include every possible subject, frequently digresses from the topic of mineralogy. Thus, in his treatment of minerals he devotes many pages to painters and sculptors, kings and generals, and structures such as the Pyramids and Labyrinths. Nevertheless we can gain from his writings a fair picture of mineralogical knowledge in his day. Basically his section on minerals is divided along the lines suggested by Theophrastus. He first discusses metals, then the different earths, then stones, and finally precious stones. He begins his treatment of metals with a general condemnation of mining, which he thought was primarily used to seek riches and therefore served to corrupt mankind. "How innocent," he writes, "how blissful, nay even how luxurious life might be, if it coveted nothing from any source but the surface of the earth, . . ."[1] Gold, which of all the metals seemed to Pliny man's worst plague,[2] he put at the head of the list of metals that he wrote about. He mentions its uses and abuses, where it is found, what ores and other minerals are found with it. He describes three ways of obtaining gold: in the detritus of rivers, in the fallen debris of mountains, and by sinking shafts.[3] Silver, "the next madness of mankind,"[4] he treats in much the

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("The Loeb Classical Library"; Cambridge: Harvard University Press, 1947--); Pliny, The Natural History of Pliny, Translated, with copious Notes and Illustrations, by the late John Bostock and H. T. Riley ("Bohn's Classical Library", 6 vols.; London: Henry G. Bohn, 1855-57).

[1]Pliny, Natural History ("Loeb Classical Library"), IX, 5.

[2]Ibid., pp. 5-7.

[3]Ibid., pp. 51-53.

[4]Ibid., p. 73.

same manner as gold. He remarks that silver, unlike gold, is found deep in the ground,[1] and it is most frequently found in association with galena.[2]

In Book 34 Pliny discusses the base metals, that is, copper, iron, lead, and tin, and their ores and alloys. He then passes to the earths in Book 35, to stones in Book 36, and finally to the precious stones in Book 37. His treatment of the different earths is largely an account of paintings and colors. In this too he largely follows Theophrastus, who had classified the earths according to the colors used by painters.

The stones are listed primarily according to their importance in the construction of buildings, public works, and works of art. Pliny first describes the various kinds of marble, which were in such demand in Rome, followed by alabaster,[3] which is used to make plaster of Paris, the various kinds of sands, and the stones which were of exceptional curative power. He closes his treatise on the mineral kingdom with an account of precious stones and gems, their varieties, their uses for medicinal purposes, and their rank among objects of luxury.

Pliny's account is a disorderly assemblage of a wealth of materials gleaned from the writings of others. It is not a systematic treatment of the subject, but a disjointed description of "fossils," that is, of materials dug out of the earth. He includes a great many substances. Some of them he describes at length so that they are identifiable even

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[1]Ibid., pp. 51-53. [2]Ibid., p. 75.

[3]Pliny, The Natural History of Pliny ("Bohn's Classical Library"), VI, 329-330.

today, but he treats others very sketchily. Only in the broadest sense does he classify the substances he mentions, following Theophrastus in dividing them into metals, stones, and earths. For instance, he lists the precious stones partly according to the esteem in which they were held[1] and partly in alphabetical order.[2] What makes Pliny's work of such importance to the historian is that he gives some idea of what kind of minerals were known in his day, how they were obtained, how they were used, and also, by mentioning the sources from which he gathered his material, he preserved for us the views of writers whose works are not extant.

Until the arrival of Greco-Arabic science in the twelfth and thirteenth centuries, Pliny's Natural History represented the major scientific inheritance of the Latin West. The medieval encyclopedias, such as the Etymologies[3] of Isidore of Seville (570-636) and the De Universo[4] of Hrabanus Maurus (776-856), added little to the geological sciences in

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[1]At the beginning of his account of precious stones, Pliny writes: "We will now proceed to speak of the various kinds of precious stones, the existence of which is generally admitted, beginning with those which are the most highly esteemed." Ibid., p. 405. Further on, after having described stones according to the esteem in which they were held, first as determined by the ladies and second, by the men (pp. 417-418), he writes: "Having now described the principal precious stones, classified according to their respective colours, I shall proceed to mention the rest of them in their alphabetical order." Ibid., pp. 439-440. Although Pliny is not very clear about his classification system, it seems that he used "classification according to esteem" and "classification according to color" interchangeably, perhaps assuming that the value of a stone is determined largely by its color.

[2]Ibid., pp. 439-440.

[3]Isidorus, Bishop of Seville, Isidori Etymologiarum opus. Idem de summo bono ([Venice: Bonetus Locatellus, for Octavianus Scotus, after 1500]).

[4][Hrabanus Maurus, Opus De Universo (Strassburg, 1467 or earlier)].

general and especially little to mineralogy. Isidore was primarily interested in the origin and derivations of the names of minerals, and Hrabanus Maurus tried to relate every subject that he dealt with to God and the Holy Scriptures.[1] While these encyclopedias treated mineralogical matters rather briefly, the medieval lapidaries dealt exclusively with metals, stones, and gems; and, though most of them are fairly brief, they represent our best source of mineralogical knowledge in the Middle Ages. The lapidary by Marbode, Bishop of Rennes (1035-1123),[2] was among the best known and is considered by some to be the earliest medieval lapidary.[3] It is written in 734 Latin hexameters, describing sixty stones. The stones are arranged in alphabetical order, and a brief chapter is devoted to each.[4] The length of the descriptions varies, some of them being as short as three lines. Marbode's attention was focused primarily on the names, colors, locations, and powers of the stones that he discusses, and the poem begins with a statement which might be considered the plan and method that Marbode followed in his treatise:

> Evax, king of the Arabs, is said to have written to Nero,
> Who after Augustus ruled next in the city.

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[1]Frank Dawson Adams, The Birth and Development of the Geological Sciences ([New York]: Dover Publications, 1954), p. 138.

[2]Marbode, Bishop of Rennes, De lapidibus pretiosis Enchiridion, cum scholijs Pictorij Villingensis. Eivsdem Pictorii De lapide molari carmen ([Friburg], 1531).

[3]Adams, p. 149.

[4]The printer skipped chapter-number XXVI, so that the last chapter, which deals with the sixtieth stone, instead of being numbered LX, is numbered LXI. Also, number XVII is used twice, once for chapter XVII and once for chapter XVIII. However, the printer caught that mistake and numbered the nineteenth chapter correctly.

How many the species of stones, what names and what colors,
From what regions they came, and how great the power of each one.[1]

The power of the stone is generally given, even though some of the other properties, like color, location, and kind, are left out. Many of the descriptions are so sketchy that the stones cannot be identified or connected with any particular mineral known today.

Marbode's lapidary must have been widely known, for there are over a hundred known manuscripts, and it was translated into French, Danish, Spanish, Hebrew, and Provencal. After the invention of printing, fourteen editions appeared between 1511 and 1740 and still others at later dates.[2]

Another lapidary of importance is the Liber Mineralium[3] of Albertus Magnus (c. 1200-1280), which was written about two hundred years later than Marbode's. The first part of this book deals with stones and gems and the second with metals. The section on stones begins with a general discussion, including such topics as the material of which stones are made, the lucidity of stones, the generation of stones, the virtues of stones, and the refutation of the assertion that there is no virtue in stones. After this treatment of the various properties of stones, Albertus Magnus describes ninety-two stones,[4] which, in the

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[1]Lynn Thorndike, A History of Magic and Experimental Science during the first Thirteen Centuries of our Era, Vol. I (New York: Macmillan and Co., 1923), p. 776. See also Marbode, folio 6.

[2]Adams, pp. 149-150.

[3]Albertus Magnus, Bishop of Ratisbon, Liber Mineralium . . . ([Oppenheym, 1518]).

[4]Sarton writes that there are ninety-five stones listed in the Liber Mineralium. Introduction, Vol. II, Part II, p. 938. Adams says

Oppenheym edition of 1518, are listed in alphabetical order. He borrowed much from Marbode, including many of the stones mentioned by Marbode and giving similar descriptions of them. However, he added much of his own to the descriptions of the powers and virtues of the stones. He paid a great deal of attention to color, but the virtues of stones attracted his greatest attention. Whether or not Albertus did original research, as Adams suggests,[1] the Liber Mineralium is considered to be one of the best and most comprehensive of the medieval lapidaries.[2]

Lapidaries remained popular in Europe as late as the sixteenth century, and they were especially popular in England. There are thirteen known Anglo-Norman lapidaries, three of which go back to the first half of the twelfth century. The earliest known vernacular lapidary of Western Europe is said to be in Old English.[3]

Medieval knowledge of minerals as represented in the lapidaries was based on classical sources, particularly upon the writings of Pliny. The medieval writers knew very little of the composition and physical properties of minerals, and, even though they paid some attention to color, they did not have a fruitful basis for classification. Theophrastus' On Stones provided a very broad scheme of classification, but the writers of the Roman period and the Middle Ages did not elaborate upon it.

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that there are seventy stones mentioned. Adams, p. 145. My own count was ninety-two.

[1]Adams, pp. 144-145. [2]Ibid., p. 144.

[3]Joan Evans and Mary S. Serjeantson, English Medieval Lapidaries (London: Humphrey Milford Oxford University Press, for the Early English Text Society, 1933), p. xi.

On the whole, the interest of the writers of lapidaries was not so much to seek an understanding of the earth's crust through the study of minerals as it was to list and expound the supernatural powers of the stones with which they were acquainted. A change in this attitude was already noticeable in the work of Albertus Magnus, but not until the fifteenth and sixteenth centuries did this concern with the mystic properties of stones abate sufficiently to permit research to be undertaken from a different point of view and with a different purpose in mind. With the work of Agricola (1494-1555) mineralogy enters a new era.

Georgius Agricola, whose original name was Georg Bauer, was born in Glauchau, Saxony. A contemporary of Charles V, Erasmus of Rotterdam, and Sir Thomas More, he lived during one of Europe's stormiest periods, the Reformation. And like Erasmus and Sir Thomas More, he never joined the ranks of Martin Luther but remained a Roman Catholic.[1]

Agricola was educated at the University of Leipzig, where he made his first contact with humanism, a movement of which he was to become one of the outstanding members. After receiving the degree of Bachelor of Arts, he left Leipzig to accept a teaching position at Zwickau and soon published his first written work, a Latin grammar entitled Libellus de prima ac simplici institutione grammatica.[2] As rector of the school he introduced the new humanistic spirit and changed the curriculum

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[1]Helmut Wilsdorf, Georg Agricola und seine Zeit (Georgius Agricola: Ausgewählte Werke, "Gedenkausgabe des Staatlichen Museums für Mineralogie und Geologie zu Dresden," ed., Hans Prescher, Vol. I; Berlin: Deutscher Verlag der Wissenschaften, 1956), p. 10.

[2]Agricola, Georgij Agricolae Glaucij Libellus de prima ac simplici institutione grammatica (Lipsiae: In officina Melchioris Lottheri, 1520). See Wilsdorf, p. 289 and Tafel 37.

drastically by offering Hebrew and Greek in addition to Latin, as well as several practical courses.[1] In 1522 he returned to the University of Leipzig, where he studied medicine,[2] and two years later he went to Italy, where he spent several years, two in the service of the famous printing house of Aldus Manutius at Venice.[3] He returned to his native country in 1526, first settling at Joachimsthal and later, in 1530, at Chemnitz, where he remained for the rest of his life.[4]

At Joachimsthal Agricola had ample opportunity to practice medicine and to pursue his great interest in mining. It was there that he wrote his first geological work, Bermannus sive de re metallica dialogus.[5] This work was followed by others, one being the De natura Fossilium,[6] "the first true handbook of mineralogy."[7]

De natura fossilium consists of ten books. The first of these is of particular interest, because it shows an entirely different approach to the study of minerals from that of the lapidaries. In it Agricola presents a classification of minerals which establishes

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[1]Wilsdorf, p. 109. [2]Ibid., p. 124.

[3]Ibid., p. 136. [4]Ibid., p. 8.

[5]Agricola, Georgii Agricolae Medici Bermannus, sive de re metallica (Basileae: In aedibus Frobenianis, 1530). See Wilsdorf, p. 289 and Tafel 39.

[6]This work was printed together with five other geological works which were published in 1546 under the following title: Georgii Agricolae De ortu & causis subterraneorum lib. v. De natura eorum quae effluunt ex terra lib. iiii. De natura fossilium lib. x. De ueteribus & nouis metallis lib. ii. Bermannus, sive de re metallica dialogus. Interpretatio germanica uocum rei metallicae, addito indice foecundissimo (Basilae: [Per H. Frobenivm et N. Episcopivm], 1546).

[7]Ernst Darmstaedter, Georg Agricola, 1494-1555, Leben und Werk (München: Verlag der Münchner Drucke, 1926), p. 40.

relationships between the different minerals and makes their identification possible. However, he does not depart drastically from the broad categories into which Theophrastus and Aristotle had divided the mineral kingdom.

Agricola's classification of "subterranean bodies" is based on their physical characteristics. He distinguishes first between fluid and vaporous products on the one hand and "fossils" on the other. He calls those fossils which are composed of only one kind of material simple and those which are composed of two or more substances compound. The simple fossils are separated into four classes: earths, congealed juices, stones, and metals. Agricola then defines each of these. "Earth," he writes, "is a simple mineral body which can be worked in the hands when it is moistened and from which mud can be made when it is saturated with water."[1] Congealed juice "is a dry, rather hard mineral body which is either not softened in water but dissolves or, if it softens when sprinkled with water, it differs from an earth in unctuousness or in composition."[2] Stone he defines as "a dry, hard mineral body that may soften a little after standing in water for a long time and is reduced to a powder in fire or is not softened in water and melts in only the hottest water."[3] And of metal he says that it is "a natural mineral body which is either liquid or solid and will melt in a fire."[4]

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[1]Agricola, Georg, De natura fossilium (Textbook of Mineralogy), trans., Mark C. Bandy and Jean A. Bandy (New York: Geological Society of America, 1955), pp. 18-19.

[2]Ibid., p. 18.

[3]Ibid.

[4]Ibid., pp. 18-19.

Agricola divides the compound fossils into two groups: the "mista" and the "composita." In the mista the two or more different substances which constitute the fossil are so intimately mixed that even the smallest particle contains all the substances found in the body as a whole. Furthermore, the different substances cannot be separated from each other except by fire. In the composita, on the other hand, the different substances which make up the fossil are usually recognizable and can be separated from each other by fire, by water, and sometimes even by hand.[1]

Two of the categories of simple fossils, the congealed juices and the stones, are further subdivided. Among the congealed juices Agricola distinguished between the "pingui," or unctuous, such as bitumen and sulphur, and the "macri," or lean, such as salt, chrysocolla, and alum.[2] Among the stones he recognized four genera: common stones, for example, the lodestone and hematite; gems, such as smaragdus, topaz, and diamond; marbles, among which he included basalt, marble, and ophites; and rocks, such as gypsum, limestone, and sandstone.[3]

Agricola's classification of minerals has been conveniently summarized by Adams. Figure 1 is based on his schematic presentation.

In Agricola's taxonomic system the distinction between earths and stones is rather hazy and so are the definitions of earths, stones,

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[1]Agricola, De natura fossilium, p. 187. See also De natura fossilium, trans., Bandy, p. 19.

[2]Agricola, De natura fossilium, pp. 185-186. See also De natura fossilium, trans., Bandy, p. 18.

[3]De natura fossilium, trans., Bandy, p. 18.

1. Fluids and Vapors
2. Fossils
    - A. Simple
        - Earths
        - Congealed Juices
            - a. Unctuous
            - b. Lean
        - Stones
            - a. Common Stones
            - b. Gems
            - c. Marbles
            - d. Rocks (<u>saxum</u>)
        - Metals
    - B. Compound
        - "Mista"
        - "Composita"

Fig. 1. Agricola's Classification of Minerals[1]

congealed juices, and metals. Nevertheless, his system formed the accepted basis for systems of mineralogy until the development of modern chemistry and crystallography. It is a system which is primarily based on physical properties, and external characteristics must of necessity play an important part in it. Agricola recognized this, and he mentions a very large number of external characteristics to be considered in the description and identification of minerals. Among these are color, transparency, luster, taste, smell, touch, hardness, weight, ductility

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[1]See Adams, p. 192.

cleavage, and form. The terms are not arranged in meaningful order, nor are they well defined, so that their actual meaning can only be pieced together from the manner in which Agricola uses them in the descriptions of the various fossils. Despite this deficiency, the mere mention of such a great number of external characteristics is sufficient to earn him the distinction of being "the first who has introduced the proper use of External Characters as applied to the distinction and description of Fossils; . . ."[1] His system is more detailed and complete than those offered before him, making possible better description and identification of fossils; and Agricola identified many new minerals.[2] He gives the location of the fossils that he discusses and their uses; and to a large extent he excludes the mystical properties attributed to stones and gems, which are so prominent in the treatises of those before him.

A somewhat younger contemporary of Agricola was Conrad Gesner, who was born in Zürich in 1516 and died in the same city in 1565.[3] Educated with the help of the Swiss reformer Huldrich Zwingli,[4] and thoroughly imbued with the spirit of humanism, Gesner studied the writings of the Greeks and Romans, learned Hebrew and Greek in addition to several modern languages, and edited several works of Greek and Roman authors. He is best known for his work in biology. He wrote ninety-eight

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[1] Abraham Gottlob Werner, A Treatise on the External Characters of Fossils, trans., Thomas Weaver (Dublin: Mahon, 1805), pp. 10-11.

[2] Adams, p. 195.

[3] J. Mähly, "Konrad Gesner," Allgemeine Deutsche Biographie, IX, 107.

[4] Diethelm Fretz, Konrad Gessner als Gärtner (Zürich: Atlantis Verlag, 1948), pp. 18-19.

complete treatises, seventy-two of which were published during his lifetime.[1] Gesner was not just a compiler of work done by others, as his voluminous literary output might suggest, but relied much on his own observations and research, taking Aristotle for his model.[2]

Among his writings is a small volume, published in 1565,[3] which deals with the mineral kingdom. This work contains many colored illustrations of minerals and gives the German equivalents of the Latin names of many of the fossils mentioned. Furthermore, it offers a comparison with Agricola's classification scheme and shows the difference in approach of two contemporaries to the same problem.

Gesner relied much on the specimens in the mineral collection of Johann Kentmann (1515-1574), a Torgau physician.[4] Like Agricola, whose work he knew, Gesner selected the external characteristics of minerals as the basis of his classification. But unlike Agricola, who had listed a large number of external characteristics which can be detected by the five senses, such as color, taste, smell, touch, and appearance, Gesner

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[1] Mähly, Allgemeine Deutsche Biographie, IX, 118.

[2] Fretz, p. 21.

[3] Konrad Gesner, Conradi Gesneri De rervm fossilivm. Lapidvm et gemmarvm maxime, figuris & similitudinibus liber: non solum medicis, sed omnibus rerum naturae ac philologiae studiosis, vtilis & iucundus futuris . . . (Tigvri, 1565). J. C. Poggendorff in his Biographisch-Literarisches Handwörterbuch zur Geschichte der Exacten Wissenschaften (Leipzig: J. A. Barth, 1863), Vol. I, col. 888, gives the date of publication as 1555. This seems to be an error. I have found no date of publication earlier than 1565 in any of the standard bibliographical sources, such as the U. S. Library of Congress, Bibliotheque Nationale, and British Museum catalogs. The copy in the DeGolyer Collection in the History of Science and Technology at the University of Oklahoma is dated 1565.

[4] Gümbel, "Johann Kenntmann," Allgemeine Deutsche Biographie, XV, 603.

based his classification almost exclusively upon external form, or the similarity he found between the forms of minerals and forms and shapes found in nature outside the mineral kingdom. He distinguished between fifteen different classes, including geometrical forms, forms like heavenly bodies, forms resembling plants or herbs, forms similar to meteors, to things in the sea, to animals and parts of animals.[1] In this respect, Gesner's work is very reminiscent of the lapidaries, and from our point of view it would seem that it was not much of an improvement over them. Agricola's De natura fossilium, on the other hand, is a very practical treatise, strongly influenced by the point of view of the miner. To know what a mineral is, what its relationships and similarities to other minerals are, is still the prime object of the mineralogist, and until the development of modern chemistry and crystallography, mineralogical systems of classification largely followed in the direction pointed out by Agricola.

The dynastic and religious conflicts which plagued Europe in the sixteenth and seventeenth centuries, along with the quest for overseas possessions, increased the importance of the mining industry. In those days, when the economic policies of a country were guided by the concepts of mercantilism, power was measured largely by the amount of bullion in the treasury and by self-sufficiency. The successful search for minerals therefore became a matter of state policy more than ever before. It is not certain what effect this had on the study of minerals, but in the relatively short period from 1647 to 1775, no fewer than twenty-seven systems of mineralogy were proposed by various writers.[2] Among these

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[1]Gesner, De rerum fossilium, praefatio. [2]Adams, p. 200.

were the mineralogical systems of Wallerius[1] (1709-1785), Linnaeus[2] (1707-1778), Gehler[3] (1732-1796), Cronstedt[4] (1702-1765), Valmont de Bomare[5] (1731-1807), and Gerhard[6] (1738-1831).

Linnaeus' classification of minerals, which forms the third part of the 1768 edition of his Systema Naturae is based on physical properties and external characteristics. Linnaeus divides the mineral kingdom into three classes: rocks, minerals, and fossils.[7] Rocks are defined as "steril stones, produced by cohesion from a terrene origin"; minerals are "fruitful stones, produced by crystallization from a saline origin"; and

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[1] Johan Gottschalk Wallerius, Mineralogia, eller Mineral-Riket indelt och beskrifvit af J. G. W. (Stockholm, 1747).

[2] Carl von Linné, Caroli a Linné . . . Systema Naturae per Regna Tria Naturae, secundum Classes, Ordines, Genera, Species, cum Characteribus & Differentiis, Vol. III (Holmiae: Impensis Direct. Laurentii Salvii, 1768).

[3] Johann Carl Gehler, De characteribus fossilium externis (Lipsiae, 1757).

[4] Axel Frederic Cronstedt, Försök til Mineralogie, eller Mineral Rikets Upställning (Stockholm, 1758).

[5] Jacques Christophe Valmont de Bomare, Minéralogie ou nouvelle exposition du Regne Minéral . . . (2 Vols.; Paris: Chez Vincent, 1762).

[6] Carl Abraham Gerhard, Beiträge zur Chymie und Geschichte des Mineralreichs, Vol. I (Berlin, 1773).

[7] Carl von Linné, A General System of Nature, through the three grand Kingdoms of Animals, Vegetables, and Minerals, Systematically Divided into Their Several Classes, Orders, Genera, Species, and Varieties, with Their Habitations, Manners, Economy, Structure, and Peculiarities. Translated from Gmelin, Fabricius, Willdinow, &c. Together with Various Modern Arrangements and Corrections, Derived from the Transactions of the Linnean and Other Societies, as well as from the Classical Works of Shaw, Thornton, Abbot, Donovan, Sowerby, Latham, Dillwyn, Lewin, Martyn, Andrews, Lambert, &c. &c. With a Life of Linné . . . By William Turton, Vol. VII (London: Lackington, Allen, and Co., 1806), p. 15. See also Linné, Systema Naturae, p. 33.

fossils are "neutral stones, and are produced from either one or both of the former."[1] The class Rocks consists of the orders Humose, Calcareous, Argillaceous, Arenate, and Aggregate,[2] all of which are defined by physical properties. The order Humose is combustible and burns into ashes; the order Calcareous is penetrable and becomes even more so when heated; the order Argillaceous hardens and becomes harder and more rigid when heated. The orders of the class Minerals are Salts, which are distinguished by their taste; Sulphurs, which are distinguished by their odor; and Metals, which are known by their appearance. There are three orders in the class Fossils: Petrifactions, which are impressed with the figure of some natural object; Concretes, which are coagulated; and Earths, which are characterized by being pulverous.[3]

Linnaeus' classification of minerals is similar to his classification of plants and animals in that he divides the minerals into classes, orders, genera, and species. The distinguishing marks between these groups and between the members within one group are either their external characteristics or their physical properties. He differentiates between genera and species almost exclusively on the basis of external characteristics. These characteristics are separated into several groups, such as external form, coating, surface, particles, fibers, structure, hardness, and color.[4]

In general, the mineral system of Linnaeus followed what came to

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[1]Linné, System of Nature, p. 16.

[2]Linné, Systema Naturae, p. 35.

[3]Linné, System of Nature, pp. 16-17.

[4]Linné, Systema Naturae, pp. 29-30.

be known as the natural history method of classifying,[1] in which the minerals were arranged, like plants and animals, according to their physical properties and their external characteristics, paying little or no attention to the chemical make-up of the minerals. There were others who took a decidedly different view of how minerals should be classified, insisting that the only proper method is the chemical method[2] and that the true nature of minerals can only be determined by their chemical composition; thus, the external characteristics and physical properties are of secondary importance.

The mineralogical system of Axel Cronstedt, which was published in 1758 under the title Försök til Mineralogie eller Mineral Rikets Upställning, leaned toward the latter point of view. This work was translated into German, French, Italian, Russian, and English,[3] an indication that it was considered to be a significant contribution to the better understanding of minerals. Cronstedt believed that a mineral system must be based upon the constituent parts of minerals, and he divided the mineral kingdom into four classes according to what he believed to be the four principal parts which predominate in the composition of minerals: earths, salts, inflammables, and metals.[4] Earths, according to Cronstedt, are not ductile, are mostly soluble in water and oils, and preserve their constitution when heated red hot; inflammables can be

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[1]Adams, p. 200. [2]Ibid.

[3]Axel Kronstedt, Versuch einer Mineralogie; Aufs neue aus dem Schwedischen übersetzt und nächst verschiedenen Anmerkungen vorzüglich mit äussern Beschreibungen der Fossilien vermehrt von Abraham Gottlob Werner, Vol. I, Part I (Leipzig: Siegfried Lebrecht Crusius, 1780), p.[i].

[4]Ibid., pp. [ii-iii].

dissolved in oil but not in water; salts can be dissolved in water and crystallize again after the water which dissolved them evaporates; and metals are the heaviest of all known bodies. Some metals are malleable and some can be decomposed into their constituent parts and then regain their original form by heating.[1] Classes are divided into orders, determined by the predominant substance in the minerals; genera, according to the ratio of the characterizing substance to the other substances in the mineral; and species and lesser divisions, according to those external characteristics which are characteristic of the genus.[2] The emphasis in Cronstedt's system is on the composition and chemical make-up of minerals.

The systems of Cronstedt and Linnaeus illustrate the two major trends in the classification of minerals in the latter half of the eighteenth century. The nature of these systems is important, for the great advances made in modern geology at the turn of the nineteenth century and thereafter would probably have been impossible without these mineralogical systems upon which to build.

Toward the end of the eighteenth century historical geology was not as far advanced nor considered as important as mineralogy. In fact it is difficult to write of historical geology as such before the eighteenth century because neither its object nor its domain was understood and defined. Nor was it fully realized that the history of the earth's crust is written in the materials of which it consists.

Some aspects of historical geology, however, have stirred men to speculation and study in every age. Thus, the finding of plant and

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[1] _Ibid._, pp. 10-11.

[2] _Ibid._, pp. [iii-v].

animal remains in rocks and marine fossils far inland and on the tops of mountains has aroused the interest of man since the beginning of history. And many men have advanced the idea that the relative position of land and water has changed.

Herodotus of Halicarnassus (c. 484-c. 425) wrote in his History[1] that he believed that the largest part of Egypt had once been covered by water. He had seen the Red Sea and the delta of the Nile, and he reasoned that Egypt had once been two gulfs separated by a narrow strip of land, which had been silted up by the Nile. He wrote:

> I hold that where now is Egypt there was once another such gulf like the Red Sea; one entered from the northern sea towards Aethiopia, and the other, the Arabian gulf . . . , bore from the south towards Syria; the ends of these gulfs pierced into the country near to each other, and but a little space of land divided them. Now if the Nile choose to turn his waters into the Arabian gulf, what hinders that it be not silted up by his stream in twenty thousand years?[2]

Herodotus offers more evidence for his theory by remarking that he had seen sea shells in plain view at the top of mountains and ground covered with salt to the extent of injuring the pyramids.[3]

Aristotle, in the Meteorologica, deals with the origin of rivers and streams, with the cause of earthquakes and of the eruption of volcanoes. He also discusses the relative position of land and sea, of dry land and land that is moist. He gives an explanation for the increase in the land area of Egypt similar to the one given by Herodotus, ascribing it to the workings of the Nile. "For the land of the Egyptians," he writes, "who are supposed to be the most ancient of the human race, appears to be

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[1]Herodotus, Herodotus, trans., A. D. Godley ("The Loeb Classical Library"; London: William Heinemann, 1920-1930), Vol. I.

[2]Ibid., p. 287

[3]Ibid.

all made ground, the work of the river."[1] Aristotle, however, goes further, not confining his discussion to particular areas, but treating the problem in general. He believed that the same parts of the earth are not always wet or dry, but that changes take place in an orderly cycle. In some places the sea recedes from the shore line, while in others it encroaches upon the land. Similarly, when a new river is formed, land once dry becomes wet, and where a river dries up, land once wet becomes dry. Aristotle ascribed these changes to the increase and decrease in heat and cold, which are caused by the sun and its course, because of which "the different parts of the earth acquire different potentialities; . . ."[2] Aristotle was particularly impressed by the immense periods of time involved in these changes, and he remarked that "these changes escape our observation because the whole natural process of the earth's growth takes place by slow degrees and over periods of time which are vast compared to the length of our life, and whole peoples are destroyed and perish before they can record the process from beginning to end."[3]

Theophrastus' views on the question of the eternity of the world, of change, of growth and decay, and of the relative position of land and sea are essentially the same as those of Aristotle.[4] Mountains

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[1]Aristotle, Meteorologica ("The Loeb Classical Library"), p. 117.

[2]Ibid., p. 107. [3]Ibid., p. 109.

[4]Our source for these opinions of Theophrastus is De Aeternitate Mundi, a work attributed to Philo Judaeus, also known as Philo of Alexandria (c. 20 B. C.-c. 40 A. D.). Philo, "On the Eternity of the World (De aeternitate mundi)," Philo, trans., F. H. Colson ("The Loeb Classical Library"; Cambridge: Harvard University Press, 1941), IX, 172-291.

are reduced in height by erosion and raised up by new accretions. The sea which encroaches upon the land in one place recedes from the shore in another, and the submersion of one island is compensated for by the emergence of another. The world is neither created nor destroyed, but there are changes.[1]

According to Theophrastus, the formation of mountains is explained as follows:

> When the fiery element enclosed in the earth is driven upward by the natural force of fire, it travels towards its proper place, and if it gets a little breathing space, it pulls up with it a large quantity of earthy stuff, . . . This earthy substance forced to travel with it for a long distance, rises to a great height and contracts and tapers, and passes finally into a pointed peak with the shape of fire for its pattern.[2]

Theophrastus also believed that the same power which forms mountains holds them together and keeps their main body permanent, preventing their destruction by erosion.[3]

In the *Geography*[4] of the historian and geographer Strabo (c. 63 B. C.-c. 20 A. D.) there are also several comments on geological subjects. Some of these are Strabo's own opinions, others are those of Straton of Lampsacos (fl. c. 288 B. C.), who succeeded Theophrastus as head of the Lyceum, and of Eratosthenes of Cyrene (c. 273-c. 192 B. C.), one of the great geographers of antiquity.

Eratosthenes agreed with the opinions of Straton, who had explained that the presence of the remains of marine life far inland should

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[1] *Ibid.*, pp. 277-279.

[2] *Ibid.*, p. 279.

[3] *Ibid.*

[4] Strabo, *The Geography of Strabo*, trans., Horace L. Jones (8 Vols., "The Loeb Classical Library"; London: William Heinemann, 1917).

be attributed to the drying up of rivers and the receding of the sea from the shore. Straton thought that the Black Sea, the Mediterranean Sea, and the Atlantic Ocean had once been separated from each other by land ridges and that the bottoms of these bodies of water were at different levels. When the waters of the rivers emptying into the Black Sea increased, they forced an opening in the ridge separating the Black Sea from the Mediterranean and permitted water to empty into it. This caused the waters of the Black Sea to recede from its shores and also increased the waters in the Mediterranean to the extent that they forced an opening in the ridge which separated the Mediterranean from the Atlantic. As proof for his theory Straton pointed to the presence of a submarine ridge which stretched across the Strait of Gibraltar.[1] Strabo disagreed with this explanation, maintaining that the rising and falling of the beds of the sea is the cause of the changing levels of the sea. "I reply," he wrote, "that the cause of the rising and falling of the sea, of its inundation of certain tracts of country, and of its subsequent retirement from them, is not to be sought for in the varying levels of the beds of the sea, in that some are lower and others higher, but in the fact that the beds of the sea themselves sometimes rise, and, on the other hand, sometimes sink, and in the fact that the sea rises or recedes along with its beds; for when the sea is lifted up, it will overflow, and when it is lowered, it will subside to its former level."[2] The movements of the beds of the sea Strabo believed to be caused by a central fire, by earthquakes, and by volcanic eruptions.[3]

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[1] Ibid., I, 182-183. [2] Ibid., p. 199.

[3] Ibid.

Among the Roman writings on geological matters other than mineralogy, the Quaestiones Naturales[1] of Seneca (4 B. C.-65 A. D.), the Stoic philosopher, statesman, and scientist, deserves attention. The work deals primarily with meteorology, astronomy, and seismology. However, in the discussion of these subjects Seneca also gives his theories about the structure of the earth. "Be assured," he writes, "that there exists below everything that you see above."

> There, too, there are antres vast, immense recesses, and vacant spaces, with mountains overhanging on either hand. There are yawning gulfs stretching down into the abyss, which have swallowed up cities that have fallen into them, and have buried in their depths their mighty ruins. These retreats are filled with air, for nowhere is there a vacuum in nature; through their empty spaces stretch marshes over which darkness ever broods. . . .[2]

Seneca believed that whatever is beneath the surface of the earth is governed by laws, just as are all things in nature above the earth's surface.

The earthquake of Campania, which occurred in 63 A. D., doing much damage to Pompeii and other cities in that district, seems to have inspired Seneca to write about the causes of earthquakes. After reviewing the opinions of other writers on the subject, he gives his own and concludes that earthquakes are chiefly caused by subterranean winds. As long as the air, which is trapped underground, is not disturbed and remains in the vast underground spaces, "it reposes innocently, giving no trouble to objects round it."[3] But when for any reason it becomes

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[1]Lucius Annaeus Seneca, Physical Science in the time of Nero; being a translation of the Quaestiones Naturales, trans., John Clarke (London: Macmillan and Co., 1910).

[2]Ibid., pp. 128-129. [3]Ibid., p. 247.

compressed and is forced into narrow spaces without any opportunity to escape, "it recoils from the side on which its impact was greatest."

> It is then either distributed through the secret openings which the earthquake of itself causes here and there, or escapes through a new rent. So uncontrollable is this mighty power. No bolt can imprison wind; it loosens every bond, bears with it every weight, and insinuating itself into the smallest crannies wins its release; for by the invincible power of nature it is free, especially when roused, and asserts its right for itself.[1]

The phenomena of earthquakes, volcanic eruptions, the formation of mountains, the relative position of land and sea, and the remains of plant and animal life enclosed in the rocks of the earth's crust, occupied as prominent a place in the writings of the Middle Ages as they did in those of Ancient Greece and Rome. Avicenna (980-1038), the great scientist and philosopher of Islam, dealt with the formation of mountains and rocks and with fossils. The so-called De Mineralibus was one of his most influential scientific writings[2] and is said to have been the "main source of geological ideas of the Christian encyclopaedists of the thirteenth century."[3]

Avicenna believed that the formation of mountains was brought about by an "essential cause" and an "accidental cause." The essential cause he considered to be the thrusting up of large masses of earth by imprisoned subterranean winds, and the accidental cause the work of erosion, which hollowed out some of the raised ground, leaving valleys and mountains. He thought that possibly the entire habitable world had

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[1] Ibid.

[2] G. M. Wickens, ed., Avicenna: Scientist and Philosopher. A Millenary Symposium (London: Luzac & Co., 1952), p. 95.

[3] Sarton, Introduction, I, 711.

once been uninhabited and submerged beneath the sea and that it had then been raised up, exposing the clayey materials of which the floor of the sea largely consists to the sun, which in the course of ages hardened them and transformed them into stone. Some parts of the raised ground, however, consist of materials which do not solidify and are therefore more readily attacked by the forces of erosion. Wind and water were able to cut into these softer stretches of raised ground, and in the course of time formed valleys and left the hardened ground as eminences. The fact that the materials which form mountains were once submerged beneath the sea also explained why the remains of aquatic animals and shells are found in some rocks.[1]

Another way in which mountains might have been formed is described by Avicenna as follows:

> It is also possible that the sea may have happened to flow little by little over the land consisting of both plain and mountain and then have ebbed away from it. . . . It is possible that each time the land was exposed by the ebbing of the sea a layer was left, since we see that some mountains appear to have been piled up layer by layer, and it is therefore likely that the clay from which they were formed was itself at one time arranged in layers. One layer was formed first, then, at a different period, a further layer was formed and a substance of different material, which formed a partition between it and the next layer; but when petrifaction took place something occurred to the partition which caused it to break up and disintegrate from between the layers.[2]

Avicenna's explanation of the origin of mountains is a compromise between the two opinions held by writers of ancient Greece and Rome: one, that mountains are formed primarily by plutonic forces, the other,

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[1]Wickens, pp. 95-99. See also Pierre Duhem, Études sur Léonard de Vinci ceux qu'il a lus et ceux qui l'ont lu, Vol. II (Paris: F. De Nobele, 1955), pp. 302-309; Adams, pp. 333-335.

[2]Adams, pp. 334-335.

that mountains are primarily the result of erosion. Avicenna considered both as parts of the same process, but he attributed more importance to the action of subterranean gases, for he believed that only after these had raised the ground did the forces of erosion begin their work.

Albertus Magnus thought that mountains are formed by either subterranean gases or erosion and that the two processes can work independently. However, he ascribed very little importance to erosive forces as creators of mountains, and he reduced the action of the sea to the formation of sand dunes and coastal deposits.[1]

Agricola, unlike Albertus Magnus, was of the opinion that most mountains were the result of the erosive action of water. This, he thought, could be concluded from the erosion done by brooks, which in only a few years, by washing away the soft surface soil and the harder soil underneath and even moving rocks, cut depressions into level fields and gentle slopes. Over a very long period of time a depression formed in this way becomes deeper and wider and eventually forms a valley with banks of great height on either side of it. In the course of time these banks are altered by the erosive work of rain, wind, and changes in temperature, which tear rocks and soil from their sides and deposit them elsewhere. Two valleys thus formed and running parallel to each other, for instance, would leave high ground between them. This high ground could be further divided into smaller sections by depressions and valleys formed in a similar manner, and in that way isolated hills and mountains would be formed.[2] According to Agricola, then, most mountains are simply

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[1]Duhem, II, 313.

[2]Georgius Agricola, "De ortu et causis subterraneorum libri V,"

the result of erosion changing the relative position of one part of the land to that of another.

In 1669, a hundred and twenty-three years after the publication of Agricola's De ortu et causis subterraneorum, there was published a treatise by Nicolaus Steno (1638-1686) entitled De solido intra solidum naturaliter contento, dissertationis Prodromus, usually known as the Prodromus.[1] At the time he wrote his geological work Steno, the son of a Copenhagen goldsmith by the name of Steen Pedersen, was personal physician to the Grand Duke Ferdinand II of Tuscany. For his services he received a house and a pension and was therefore in a position to pursue his studies in geology as well as medicine. He gratefully acknowledges this patronage in his work, which he wrote in 1668, the same year that he embraced the Roman Catholic faith.

The treatise is divided into four parts.[2] In the first Steno treats fossils and their origin. In the second "is solved a universal problem upon which depends the unravelling of every difficulty, and it is this: given a substance possessed of a certain figure, and produced according to the laws of nature, to find in the substance itself

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trans., Georg Fraustadt, Ausgewählte Werke, ed., Hans Prescher, Vol. III (Berlin: Deutsche Verlag der Wissenschaften, 1956), pp. 125-126.

[1]Nicolai Stenonis, De solido intra solidvm natvraliter contento dissertationis prodromvs. Ad serenissimvm Ferdinandvm II. Magnvm Etrvriae dvcem (Florentiae, 1769).

[2]This discussion of Steno's theories is based upon The prodromus of Nicolaus Steno's dissertation concerning a solid body enclosed by process of nature within a solid; an English version with an introduction and explanatory notes by John Garrett Winter . . . with a foreword by William Hobbs . . . (New York: The Macmillan Company, 1916).

evidences disclosing the place and manner of its production."[1] In the third part Steno investigates different solids contained within solids "in accordance with the laws discovered in the solution of the problem."[2] And in the last portion of the treatise he deals with geological changes in Tuscany and the problem of the "universal ocean."

In the category of solids within solids Steno included not only fossils enclosed in rocks and crystals of minerals enclosed in rocks, but also strata which make up the earth's crust enclosed within other strata. He set forth three propositions which he believed to be sufficient to resolve all the doubtful issues of the inquiry. The first of these is: "If a solid body is enclosed on all sides by another solid body, of the two bodies that one first became hard which, in the mutual contact, expresses on its own surface the properties of the other surface."[3] Thus, he believed that fossils and crystals with smooth surfaces which are found enclosed in earth or rock had already hardened while the earth or rock was still in a fluid state and that the materials in mineral veins were still in a fluid state when the earth and rock which enclose the veins were already hard.

The second proposition is: "If a solid substance is in every way like another solid substance, not only as regards the conditions of surface, but also as regards the inner arrangement of parts and particles, it will also be like it as regards the manner and place of production, if you except those conditions of place which are found time and again in

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[1] Steno, The prodromus of Nicolaus Steno's dissertation, p. 209.

[2] Ibid.

[3] Ibid., p. 218.

some place to furnish neither any advantage nor disadvantage to the production of the body."[1] From this Steno concluded that the strata of the earth, as regards place and manner of formation, are like those which would be deposited from turbid water. Also, bodies dug up from the earth which in every way are like the parts of plants and animals were formed in the same manner and place as living plants and animals.

The third proposition is: "If a solid body has been produced according to the laws of nature, it has been produced from a fluid."[2] The strata of the earth, being solid, are therefore the result of deposits from a fluid. If all the particles in a stony stratum are fine and of the same quality, it must be concluded that the stratum was deposited from a fluid which covered everything at the time of the creation. On the other hand, if a stratum encloses parts of another stratum or parts of animals and plants, this indicates that the stratum was not formed from the fluid which covered all things at the time of the creation, but was deposited at a later time. A stratum which contains the remains of marine animals, flotsam, and other substances of the sea must have been formed while it was covered by the sea, while grass, trunks and branches of trees, and similar objects in a stratum indicate that they were carried to that place by torrents or flooding rivers. Ashes and charcoal in a stratum signify that a fire occurred in the vicinity of the fluid which deposited the stratum.

If the materials of several strata are alike, it proves that they were deposited from the same kind of fluid and were not affected by the fluids of a different character and flowing from other directions at

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[1] _Ibid._, pp. 218-219. [2] _Ibid._, p. 220.

different times. But if the materials of strata found in the same place are different, they must have been deposited from different fluids and at different times, or the materials must have differed in weight and thus settled at different rates. Stony beds enclosed in earthy strata indicate that springs of petrifying waters were in the vicinity.

Steno wrote that four things about strata can be considered as certain: First, every stratum is deposited upon a substance which prevents the further descent of the fine sediment. This substance could be either a solid substance or a fluid of different character from the upper fluid and denser than the solid sediment of the upper fluid. Second, of two strata, the lower one must have been hard at the time the upper one was deposited. Third, a stratum at the time of its deposition was either enclosed on its adjacent sides by a solid substance which limited its extent, or else it extended over the whole surface of the earth. Therefore, in places where the outcrops of strata can be observed, a continuation of these is sure to be found elsewhere. Fourth, since all strata are the result of sedimentation from a fluid, the lowest stratum was deposited before the strata above it existed.

At the time a stratum is produced, its lower surface and its lateral surfaces follow the shape of the surfaces with which they are in contact. The upper surface, on the other hand, is parallel to the horizon. Consequently, the upper and lower surfaces of all but the lowest stratum were horizontal at the time they were produced. Therefore, if strata are found in a position other than horizontal, they must have been moved. Steno thought that this could have been brought about by violent thrusting up of strata or by slipping of the upper strata which had begun to form cracks when the foundation upon which they rested was destroyed.

Steno believed the alteration of the original position of the earth's strata to be the chief cause of the formation of mountains. In support of this theory he mentions broken strata on the opposite sides of hills which, from agreement in their form and content, seem to be parts of the same stratum; strata exposed on the sides of mountains which are inclined at different angles to the horizon; and fragments of broken strata which are found at the foot of the same range, partly piled into hills and partly scattered over the adjoining country. He believed that only a small number of mountains had been formed by volcanic eruptions and erosion. From this theory of the origin of mountains Steno concluded that not all mountains existed in the beginning, that mountains do not grow, but they can be overthrown, that plains can be moved, peaks of mountains raised and lowered, and the surface of the earth opened and closed. The changes in the position of strata, besides forming mountains, also provided repositories for most minerals and avenues of escape for materials issuing from beneath the earth's surface.

Steno thought that much can be learned from the study of rocks that is sought in vain in the study of minerals, and he concludes his section on strata with the following statement: "And these things concerning the strata of the earth I thought ought to be investigated the more carefully, not only because the strata themselves are solids naturally enclosed within solids but also because in them are contained almost all those bodies which gave rise to the question propounded."[1]

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[1] *Ibid.*, p. 236.

The last part of the Prodromus is an application of Steno's general geological principles to a particular problem--the geological features of Tuscany. Steno believed that the geological history of Tuscany had occurred in six stages. At first all things were covered by a watery fluid which was free from plant and animal life and in which a homogeneous substance was held in suspension. This substance slowly settled, forming strata which enveloped the whole earth. The waters then receded. The second stage was "plane and dry."[1] Steno is not very explicit about it, but from his remarks on the other stages, it appears that this second stage was a period in which life developed and huge underground caverns were formed. The third stage was one of great destruction. The position of many strata was changed, making the surface of the earth very uneven and forming mountains. The fourth stage began with the Biblical flood. Once more all things were covered by a watery fluid, but this fluid contained the remains of all life, which it had destroyed, as well as other materials which the flood had torn loose from the earth's surface. The strata deposited from this fluid show the traces of former life and can be found in the highest as well as the lowest places. "If . . . strata which are filled with different bodies are, in certain places, found above the strata of the first fluid," Steno wrote, "from this fact nothing would follow excepting that above the strata of the first fluid new strata were deposited by another fluid, whose matter could likewise have refilled the wastes of the strata left by the first fluid."[2] The waters then receded. The only thing

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[1] Ibid., p. 264.

[2] Ibid.

concerning the fifth stage of which Steno is sure is "that a great amount was carried down every year into the sea . . . , and that the earth thus carried down by the rivers, and added day by day to the shore, left new lands suited for new habitations."[1] The sixth and last stage is the present one, in which the earth's surface is being changed primarily by the forces of erosion and volcanic eruptions.

Steno's work is one of the most significant landmarks in the history of the geological sciences. His postulates of stratigraphy alone earn him a place of rank among the contributors to the geological sciences. But his contribution to historical geology was perhaps his most important achievement, for in the problem which he proposed he stated the object of historical geology: to find in the earth's crust itself evidences of its origin--"given a substance possessed of a certain figure, and produced according to the laws of nature, to find in the substance itself evidences disclosing the place and manner of production."[2] Steno's work was not given recognition in his own time, however, and seems to have been almost forgotten until its rediscovery by Elie de Beaumont and Alexander von Humboldt early in the nineteenth century.[3] The effective contribution of Steno, therefore, is not clearly established.

John Strachey (1671-1743) made a contribution to historical

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[1] Ibid., p. 267. [2] Ibid., p. 209.

[3] Karl Alfred von Zittel (1839-1904) wrote: "The writings of this keen scientist [Steno] unfortunately remained without any significance whatsoever for the development of geology; they were given hardly any attention by his contemporaries, fell into oblivion, and were first given deserved recognition in this century by Élie de Beaumont and Alexander von Humboldt." Ibid., p. 204 (translation by the author).

geology when an account of the different strata he had encountered in coal mines[1] was published in the Philosophical Transactions. He explained that the earth consists of a series of strata formed from materials which were once in a soft and fluid state. While in this state, these materials revolved about a common center and simultaneously settled toward it, and as a result of the centripetal motion, they formed strata which took on the shape of pages in a rolled up magazine. And just as the ends of the rolled up pages are exposed at different places, so the outcrops of the different strata reach the earth's surface at different places. Furthermore, all the strata of which the earth consists appear at the surface in some place. For this reason, Strachey believed, it is possible to find strata consisting of light materials covered by strata which consist of heavier materials. "Every one of these Strata," he wrote, "tho' they each reach the Center, must, in some Place or other, appear to the Day; in which Case there needs no specifick Gravitation to cause the lightest to be uppermost, etc. for every one in its Turn, in some Place of the Globe or other, will be uppermost; and, were it practicable to sink to the Center of the Earth, all the Strata, that are, would be found in every Part, . . ."[2] Strachey's article is short, but it is a good example of the combination of observational and theoretical work being done in geology in the early part of the eighteenth century, and his theory suggested useful applications, since it is possible to infer from it that series of strata similar to those which he had

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[1]John Strachey, "An Account of the Strata in Coal-Mines, &c.," Philosophical Transactions, XXXIII (1724-1725), 395-398.

[2]Ibid., p. 398.

observed could be found in other parts of the world.

Ever since man has pondered geological phenomena, there has been a diversity of opinion as to which is the more important factor in the formation and alteration of the earth's geological features, fire or water. In antiquity these divergent views lacked the support of detailed observational work, and perhaps for that reason they do not seem to us an adequate treatment of the problem. As more detailed studies of the geological features of different parts of the globe were brought forth, the controversy grew more heated. In 1740 and 1756 two notable works were published, the first supporting what later came to be known as "vulcanism" and the second supporting what came to be known as "neptunism."

Anton Lazarro Moro (1687-1764) in his De Crostacei e degli altri marini Corpi che si truovano su' Monti[1] asserted that originally the whole earth was covered by water and that all islands, mountains, and level lands had been raised up from the bottom of the ocean by subterranean fires. In arriving at this theory Moro had perhaps been influenced by Newton's hypothesis that "to the same natural effects we must, as far as possible, assign the same causes"[2] and by knowledge of the emergence of a

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[1]Anton Lazarro Moro, De Crostacei e degli altri marini corpi che si truovano su' monti (Venezia: S. Monti, 1740). The explanation of Moro's theories is based upon the German translation of the work: Neue Untersuchungen der Veränderungen des Erdbodens, nach Anleitung der Spuren von Meerthieren und Meergewächsen, die auf Bergen und in trockener Erde gefunden werden, trans., D. Ehrhard (Leipzig: B. C. Breitkopf, 1751).

[2]Isaac Newton, Mathematical Principles of Natural Philosophy and His System of the World, translated into English by Andrew Motte in 1729. The translation revised, and supplied with an historical and explanatory appendix, by Florian Cajori (Berkeley: University of California Press, 1947), p. 398. See also Moro, Neue Untersuchungen der Veränderungen des Erdbodens, pp. 228, 229, 258, 259, 290.

volcanic island in the Aegean Sea in 1707. Moro reasoned that continents are nothing but large islands and that they must have been formed in the same way as the new island which had been thrust out of the sea. He used the present as the key to the past, and his statement that "nature acts according to laws and rules which are so uniform and constant that it maintains the course it has once taken exactly and without change[1] presents the principle later to be known as uniformitarianism.

Moro's theory is of interest not only because of the "plutonist-neptunist" views, but also because of its religious implications. According to Genesis, God created dry land by gathering together the waters under the heavens unto one place,[2] presumably thereby uncovering land submerged in the waters. But this is not the way Moro interpreted the verse in Genesis. Instead, Moro assumed that on the third day of the creation God kindled subterranean fires, which broke open the smooth stony outer layer of the earth which underlay the waters. The tremendous force of the subterranean fires then raised huge masses of this stony outer layer and heaped them up until they protruded from the surface of the water, thus forming land and mountains. While raising these stony masses, the force created by the fires also ejected different materials, such as earth, sand, clay, and metals, from the interior of the earth. Some of these materials were deposited near and about the tops of the mountains which had been first formed from the earth's outer layer; some of the materials flowed down the sides of the mountains and settled at the bottom of the sea, where they formed a new layer above the original

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[1] Moro, Neue Untersuchungen der Veränderungen des Erdbodens, p. 228 (translation by the author). See also pp. 249, 274, 315.

[2] Genesis I:6.

stony surface. The fires continued to burn, forming more mountains by ejecting more materials from the interior of the earth, as well as by disrupting the newly deposited layers, which they heaped up in large masses. This process went on repeatedly, forming more mountains and depositing more strata. Through the addition of different minerals the originally pure waters were able to support living things, and marine life began to develop. The deposition of fertile land on top of the stony masses which had formed the first dry land made the development of plant life possible. This in turn made the appearance of terrestrial animals possible, which was followed by the advent of man.[1] Moro explained the presence of marine fossils in mountains without resorting to a flood by asserting that mountains formed from strata which contained marine life would necessarily contain their fossils. According to Moro, all mountains were the result of the action of fire. He did, however, distinguish between two classes of mountains: unstratified and stratified mountains, and he believed these to have been formed in two successive periods.[2]

Moro's work was probably the most completely plutonistic work ever written, and his extreme views helped to attract more attention to the neptunist-plutonist arguments. His recognition of *primary* and *secondary* mountains was an important contribution to the understanding of the history of the earth's crust, and his work also contained the principles of uniformitarianism.[3]

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[1] Moro, *Neue Untersuchungen der Veränderungen des Erdbodens*, pp. 460-462.

[2] *Ibid.*, p. 296.

[3] See *ibid.*, pp. 249, 274, 315.

Moro's work did not go unchallenged: in 1756 Johann Gottlob Lehmann (d. 1767) presented a neptunistic theory of the origin of the earth in his Versuch einer Geschichte von Flötz-Gebürgen.[1] Lehmann divided all mountains into three classes, which he believed to have been formed successively during widely separated periods. To the first class belong all mountains which were formed at the time of the creation, to the second, all those which resulted from a general change of the earth's surface, and to the third, those which are formed from time to time by accidental causes, such as local floods, earthquakes, and volcanic eruptions.

Lehmann thought that in the beginning the materials which constitute the earth's crust had been dissolved and held in suspension in a universal ocean. At the time of the creation the heavier particles settled first and formed the innermost layer of the earth, and the lighter particles settled at a slower rate and formed the earth's crust. The earth's surface, however, was not smooth, because the atmosphere which God had created when he separated the waters and made the firmament agitated the waters of the universal ocean, causing the sediments to settle faster in some places than in others, thereby forming mountains and plains. The mountains thus formed are what Lehmann called "uranfängliche,"[2] or primitive, mountains. They are characterized by their steep slopes, by

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[1]D. Johann Gottlob Lehmann, Versuch einer Geschichte von Flötz-Gebürgen, betreffend deren Entstehung, Lage, darinne befindliche Metallen, Mineralien und Fossilien, gröstentheils aus eigenen Wahrnehmungen, chymischen und physicalischen Versuchen, und aus denen Grundsätzen der Natur-Lehre hergeleitet (Berlin: Klütersche Buchhandlung, 1756). The discussion of Lehmann's theories is based upon this edition.

[2]Ibid., p. 99.

their great height, by their internal structure, and by the minerals which are found in them. As far as their internal structure is concerned, the primitive mountains consist of few different kinds of rocks, and their strata are either perpendicular or greatly inclined, of great thickness, and extend into unknown depths.

After the formation of the primitive mountains, the waters receded into the center of the earth. The earth's surface dried out, and life began to develop on the fertile topsoil. The earth's surface suffered few changes until a universal flood occurred, once more covering everything, including the highest mountains. The waters dissolved much of the clayey and calcareous earth and held it in suspension for a time. Then gradually these materials settled, forming new strata, particularly in the valleys and plains between the mountains. As the waters receded they became more turbulent, tearing loose rocks and trees, stripping the mountains of their fertile cover and carrying with them the remains of plants and animals. These settled when the waters became calm and formed new strata. The waters receded until they occupied the present oceans, leaving the earth's surface to become dry once more.

The mountains and series of strata between the primitive mountains, formed in this manner, are the Flötz-Gebirge, or stratified mountains and formations. They are characterized by their gentle slopes, their low height, and particularly by the numerous horizontal strata, which consist of many different kinds of rocks and which contain many fossils. After this period, no general changes occurred in the earth's surface, only some of a local nature caused by local floods, earthquakes, and volcanoes.

After giving his theory of the origin and major alterations of the earth, Lehmann devoted the rest of his book to the Flötz-Gebirge. He explained that the reason for the difference in number, size, and contents of the strata of the various stratified formations can be attributed in part to the position of the adjacent primitive mountains, in part to the dissolved materials in the second universal ocean, and in part to the degree of turbulence of the waters. He considered folded, inverted, and highly inclined strata in Flötz-Gebirge to be anomalies, and he firmly believed that most floetz strata are horizontal. He reminded his readers that in order to study a Flötz-Gebirge one must begin his investigations at the lowest stratum, which is immediately next to the primitive formations, and finish where the strata merge into the plains. Furthermore, it is necessary to determine what the different materials of the different strata are, for "through this," he wrote, "one is in the position to recognize the reasons why one stratum settled before another."[1]

Lehmann recognized that the earth's crust has undergone a series of changes, that these changes occurred in widely separated periods, and that these could be traced in the rocks of the earth's crust. He distinguished among three classes of mountains; he presented a theory of the earth, very similar to Steno's but more elaborate, and he attacked the study of the earth's crust not only with the view of determining the origin and sequence of the rock masses which form it, but also of determining the details of the various strata.

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[1] Ibid., p. 156 (translation by the author).

By the eighteenth century both mineralogy and historical geology had long histories, but whereas historical geology had yet to achieve the status of a scientific discipline, mineralogy was comparatively far advanced. Mineralogy and the art of mining are very intimately connected, and this interplay between science and technology, between the desire to understand the nature of minerals and the desire to extract them from the earth in order to make use of them, had deeply influenced the study of minerals. By the end of the eighteenth century it was clearly recognized that the prime function of mineralogy was the identification of minerals. As yet, however, no general agreement had been reached as to what constitutes identification and what is the best method for the purpose of identification.

Historical geology, not having had the stimulus of being recognized as useful, had developed much more slowly. Although the origin of the earth and its history have aroused the curiosity of many writers of all times, it was not until the importance of historical geology to the finding of minerals was recognized that it assumed its place among the sciences and began to make the great advances that it has made ever since. By the eighteenth century many problems which eventually became a part of historical geology, such as the relative position of land and water, the occurrence of fossils in rocks, the difference in the materials of different strata, and the relative position of strata, had been formulated and some effort had been made to solve them; but these problems were yet to be synthesized into a unified field of endeavor and a unified body of scientific knowledge. The object and the realm of historical geology were yet to be understood and defined.

CHAPTER II

ABRAHAM GOTTLOB WERNER: A BIOGRAPHICAL SKETCH[1]

On September 25, 1749,[2] Abraham Gottlob Werner was born in the little village of Wehrau, eighty-five miles east of Dresden and a little more than a hundred miles east of Freiberg. Along the east side of the town flows the river Queiss, a narrow stream, too small to carry much

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[1]There are only three important printed works on Werner's life: Karl August Blöde, "Kurzer Nekrolog Abraham Gottlob Werners," Auswahl aus den Schriften der unter Werner's Mitwirkung gestifteten Gesellschaft für Mineralogie zu Dresden, II (1819), 252-304; D. Samuel Gottlob Frisch, Lebensbeschreibung Abraham Gottlob Werners (Leipzig: F. A. Brockhaus, 1825); and Traugott L. Hasse, Denkschrift zur Erinnerung an die Verdienste des in Dresden am 30. Juni 1817 verstorbenen K. S. Bergrath's Werner und an die Fortschritte bei der Bergakademie zu Freiberg, nebst einer übersichtlichen Nebeneinanderstellung der Mineralsysteme Werners und seiner Nachfolger bei dieser Akademie. . . . Auch einige Beiträge im Bezug auf mittelbare Folgen der Wernerschen Wirksamkeit (Dresden: Arnoldische Buchhandlung, 1848). In addition I have had available copies of manuscripts from the Bergakademie at Freiberg, hereafter referred to as OW (see Bibliographical Note, pp. 232-233, below).

[2]The most important and extensive biographical works on Werner are Blöde's "Kurzer Nekrolog Abraham Gottlob Werners" and Frisch's Lebensbeschreibung Abraham Gottlob Werners. Both Blöde and Frisch were personal friends of Werner; according to their own statements they used virtually the same sources for their biographies; yet they differ on Werner's birth date. Blöde based his fifty page article on Werner's own handwritten notes, on official records, and on communications from Werner's only sister. The date that he gives for Werner's birthday is September 25, 1749, the same date that Werner himself gave in a note found among his personal papers, in which he stated, "I was born the 25th of September, 1749, at Wehrau on the Queiss, five miles from Görlitz in Upper Lusatia." OW 370002, "Biographische Notizen" (all translations from the Oklahoma Werner sources are by the author). Frisch gives Werner's birthyear as 1750, and since his work is the only booklength

traffic, but large enough to furnish water to the towns which lie along its course and to turn the wheels of the machinery in the mines which were located near it. The geology of the surrounding territory is relatively simple, consisting primarily of sandstone of the upper chalk formation and of diluvial strata, all of which are sedimentary rocks, typically neptunistic formations.[1]

Shaded by large trees, the house in which Werner was born was still standing as late as 1917. Over the entrance was a plaque with the inscription Te saxa loquentur.[2]

Little is known of Werner's ancestry, especially on the maternal side. What is known consists largely of the few things that Werner's only sister could remember. Werner's mother must have died when he was very young, for nowhere does he mention her. Even as a young girl, his sister had to keep the books of the household, and in her old age she still remembered how terrified she had been when she could not account for two thaler in the monthly balance and how her father, after mildly

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biography of Werner, it was more widely known than Blöde's. Thus, the date 1750 was long accepted as the correct one--so much so that a Werner Fest commemorating his hundredth birthday was held in Freiberg in 1850, and a Festschrift was issued entitled Die Bergakademie zu Freiberg. Zur Erinnerung an die Feier des hundertjährigen Geburtstages Werners am 25. September 1750 (Freiberg: Gerlachsche Druckerei, 1850). Regarding this celebration the Mitteilungen des Freiberger Altertumsvereins of 1910 inserted the following note: "Concerning the date of the celebration, it should above all be mentioned that the then current assumption that the year 1750 was Werner's birthyear was erroneous; it has since been found that Werner first saw the light of day in 1749." XLVIII, 121 (translation by the author).

[1]Richard Beck, "Abraham Gottlob Werner. Eine kritische Würdigung des Begründers der modernen Geologie. Zu seinem hundertjährigen Todestage," Jahrbuch für das Berg- und Hüttenwesens in Sachsen, 1917, p. 4.

[2]Ibid., p. 5.

admonishing her, had made her carry the shortage in the books for a whole year as a reminder of her mistake.[1] Almost all that is known of their mother is that she was born in Bunzlau, a somewhat larger town than Wehrau about eight miles east of it by the river Bober, and that her maiden name was Schilling.[2] When she was born when she died, what kind of mother and person she was is not known.[3]

A little more is known of Werner's paternal ancestors, whom his sister was able to trace back to the beginning of the sixteenth century. Almost all of them were connected with the iron industry, either as the owner of a hammermill or foundry or as a worker or official in an iron-works belonging to someone else. Johann Christoph Werner was the most distant ancestor in the memory of the family. He lived near Weida in Vogtland, where he owned an ironworks.[4] He willed his property to his only son, Christoph, who in turn passed it on to his only son, Georg. Georg also had only one son, Christoph, and Christoph was the last owner of the ironworks at Weida, for in 1661 an unusually violent storm destroyed the whole property, forcing him to leave the family home. He

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[1]Frisch, pp. 5-6. [2]*Ibid.*, p. 6.

[3]There is one item of interest about one of her ancestors recorded in Gottfried Arnold's *unparteyische Kirchen- und Ketzer-Historie, vom Anfang des Neuen Testaments biss auff das Jahr Christi 1688 . . .* (4 Theile; Francksfurt am Mayn, 1700-1715). It is reported that M. Wenzeslaus Schilling was a *Läugner der Vernunftsreligion*, against which the universities of Helmstadt and Wittenberg had declared themselves. In 1636 he was a preacher at Kochberg in the district of Rudolfstadt, and during a service which he was conducting a group of Croats entered the church and mortally wounded him. On the orders of the Duke of Schwarzburg he was taken to Rudolfstadt, where he died of his wounds a few days later. Frisch, pp. 6-7.

[4]Blöde, *Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden*, II (1819), p. 254.

decided to move to the Ore Mountains, and within a few years he was the lessee of several ironworks. He had three sons, the youngest, Johann Christoph, being Werner's grandfather. The family must have been fairly wealthy, for the oldest of the three became the owner of a hammermill, and the youngest bought a similar establishment at Ludwigstadt, a town not far from Wehrau, and later built an ironworks at Dober.

Werner's father, Abraham David Werner, was born at Ludwigstadt on March 31, 1708.[1] Werner liked to talk about him and even left a brief character sketch of him among his personal papers. At the time Werner was born, his father was inspector of the Duke of Solm's ironworks at Wehrau and Lorenzdorf,[2] a small town on the Queiss five miles north of Wehrau. We do not know what his salary was, but he seems to have been well off. Possibly he carried on some private business, or perhaps he had inherited some money. At any rate, he had enough money in 1754, two years before the outbreak of the Seven Years War, when he was an overseer of the Duke of Promnitz's ironworks at Wehrau,[3] to make a substantial loan to an Ensign Tempsky of the du Moulinx regiment.[4] As late as 1793 Werner's father was still trying to get a court judgment against the

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[1] Ibid.

[2] OW 370002, "Biographische Notizen."

[3] OW 170001-0080, "Vollkommener Verlauf der Rothlachner Streitsache."

[4] Ernst Gottlob von Tempsky had inherited several pieces of property which he could not claim until the mortgage against them had been paid off. Being a friend of the family, he asked Werner's father for a loan of six thousand Reichsthaler in gold. The elder Werner was able to lend Tempsky the money, giving it to him in pieces of Friedrich d'or, Louis d'or, and Braunschweig Charles d'or, each piece counted at the exchange rate of five Saxon thaler, a currency which was very much affected by the current political situation. Ibid.

Tempskys, who had refused to repay the loan and interest in gold rather than in relatively worthless Saxon currency. The letters written by Werner's father at the advanced age of eighty-five indicate that he was a man of keen mind and certainly a steady hand.[1]

Werner described his father as "a man of clear intellect, restless activity, unlimited sense of justice and selflessness, obliging and tractable in his dealings with others but of some severity with his children, and of very strict religious principles."[2] He was a devoted father and his children's first teacher.[3] A deeply religious man, he assembled his family every day for a prayer, encouraged his children to read the Bible diligently, and set them an example which was to influence them for the rest of their lives.

Like many children, Werner was much interested in what his father did, and even as a little boy he became acquainted with some of the machinery of an ironworks, particularly after his father bought him a model of a stamping mill, which the mining people carved in their spare time and sold on the market to supplement their wages.[4] When there was something in his toy that he could not understand, his father would explain it to him and even show him a full scale working model at the plant. Not only did this early acquaintance with the machinery of an ironworks further his interest in its workings, but it was also to stand

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[1]OW 17 contains photostats of a number of letters written by Abraham David Werner.

[2]OW 370014, "Biographische Notizen."

[3]Werner wrote: "The principal intellectual training of my youth I received from my father, . . ." OW 370014, "Biographische Notizen."

[4]Frisch, p. 7. See also Hasse, p. 3.

him in good stead when he was a student at the Bergakademie at Freiberg and, later, a teacher of mining at the same institution.

As a boy Werner was an ardent rock collector, and he brought home pocketfuls of specimens from his walks in the country. With the help of his father he learned the names of the various stones he had collected, their uses and usual locations, and what kind of minerals are associated with them. His father, recognizing the great interest his son showed in the mineral kingdom, encouraged him and even prepared a special box of more select minerals than those Werner himself had collected. In later life Werner wrote of his early interest and training in mineralogy. He could remember what minerals his father had collected for him and that among them there were some about which his father knew nothing, not even their names.[1]

Werner's father was his first teacher not only of religion and mineralogy, but also of reading and arithmetic. According to Werner's own recollections, he was able to read at the age of four and to write and solve some arithmetic problems at the age of five. At the ages of five, six, and seven he spent a great deal of time reading books.[2] Among his favorites were two handbooks, one a mineral and mining lexicon, Minerophilo, and the other a lexicon of a more general nature known by the short title of Hübner's Berg-Gewercks- und Handlungs Lexicon.[3]

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[1]OW 370008, "Biographische Notizen."

[2]Ibid.

[3]Minerophilus, Neues und wohleingerichtetes Mineral- und Bergwercks-Lexicon, worinnen nicht nur alle und iede beym Bergwerck, Schmeltz-Hütten, Brenn-Hause, Saiger-Hütten, Blau-Farben-Mühlen, Hammerwerken etc. vorkommende Benennungen, sondern auch derer Materien, Gefäsze, Instrumenten und Arbeitsarten Beschreibungen enthalten, alles nach der

Minerophilo deals with mining and mineralogical terms exclusively, giving their definitions, many of which have made their way into modern geology. Hübner's is more encyclopedic, containing terms from many walks of life.

Many changes of great importance to future generations occurred during Werner's childhood. In America the wars between the French and the English began in 1754, eventually resulting in the complete expulsion of the French from the North American continent. In 1756 the Third Silesian War began, being little more than the European phase of the struggle for colonial supremacy and a continuation of the struggle between Austria's Maria Theresa and Prussia's Frederick the Great for control of the Germanies.

Maria Theresa had lost Silesia to Frederick in 1745, and she wanted it back, not only because of the great mineral wealth of Silesia, but also because the loss of it upset the balance among Teutonic, Slavonic and Magyar elements in the Hapsburg lands, and Silesia afforded a dangerous entry up the Oder River into the heart of these lands. The matter was further complicated by the designs of Count Brühl, advisor to

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gebräuchlichen Bergmännischen Mundart, so wohl aus eigener Erfahrung, als auch aus den bewehrtesten Schriftstellern mit besondern Fleisz zusammengetragen und in Alphabethischer Ordnung zu sehr bequemen Nachsehungen gebracht, andere und vielvermehrtere Ausgabe (Chemnitz: Johann Christoph und Johann David Stöszeln, 1743); Johann Hübner, Curieuses und Reales Natur-Kunst-Berg-Gewerck-und Handlungs-Lexicon. Darinne nicht nur die in der Physic, Medicin, Botanic, Chymie, Anatomie, Chirurgie und Apothecker-Kunst, wie auch in der Mathematic . . . sondern auch alle im Handel und Wandel, ingleichen im Jure und vor Gerichten vorfallende, und aus allerhand Sprachen genommene, unentbehrliche Wörter, den Gelehrten und Ungelehrten zu sonderbarem Nutzen gründlich und deutlich erkläret, . . . Welches als der zweyte Theil des Realen Staats-Conversations-und Zeitungs-Lexici mit grossem Vortheil zu gebrauchen. Neue Auflage, verbessert und mit einer Vorrede versehen von Georg Heinrich Zincken (Leipzig: J. F. Gleditsch, 1755). OW 370008, "Biographische Notizen."

the Elector of Saxony, who hoped that Saxony might get some of the spoils while others were doing the fighting. Silesia and Saxony therefore became the major battlegrounds of the Third Silesian War. In 1756 Frederick invaded Saxony with 67,000 men and took Dresden, and all Saxony was interested in the daily news. Later Werner was to remember how, as a little boy of seven, he read the newspapers to his father, a practice that may have been the source of his later interest in politics, military strategy, and history, an interest which he kept for the rest of his life.

After his father, Werner's first teacher was a candidate for the ministry named Rothe, who was then residing at Thommendorf, about three miles from Wehrau.[1] We do not know the exact nature of the instruction that Werner received from Rothe, but it is safe to assume that, in addition to the instruction in reading, writing, and arithmetic, he received a good deal of religious instruction. As a teacher Werner never failed to stress the importance of practicing the teachings of the Bible.

When Werner was nine years old Rothe was admitted to the ministry and left Thommendorf, whereupon Werner was sent to Bunzlau, his mother's birthplace.[2] Bunzlau, in Poland today and called Boleslawiec, was the closest town of any size to Wehrau. Probably some of Werner's mother's relatives lived there, and, above all, it did have at least one school, the Waisenhausschule. It is not very likely that this school was restricted to orphans only, even though it was the school of the orphanage, as the name implies. Werner remained at Bunzlau until after his

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[1]Frisch, p. 6.

[2]Ibid., pp. 6-7. See also OW 370002, "Biographische Notizen."

confirmation in 1764, when he returned to Wehrau to become an assistant to his father in the ironworks, his official position being that of a Hüttenschreiber.[1]

The duties of a Hüttenschreiber were never very well defined, but he seemed to be something of a combination bookkeeper, secretary, and payroll clerk. His most important function was to assay the ores which were delivered during each week. At the end of the week the Hüttenschreiber would take samples of all the ores and determine the nature and proportion of the ingredients.[2] How much of this Werner, as a boy of fifteen, had to do we do not know, but the various functions of a Hüttenschreiber were among the many things he later taught in his course on mining.[3] Organization and orderliness were two things which Werner learned very early in life. These were impressed upon him by his father, by his collecting and sorting and arranging of rocks and minerals, and by his duties as a Hüttenschreiber.

In 1767 Werner got his first glimpse of Freiberg, then the most important mining town in Saxony. He had been sick for some time, and despite the doctor's efforts, he was not able to recuperate fully. His father therefore arranged for him to go to Carlsbad, then as now one of the best known spas of Europe. He was traveling with a certain Rat

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[1]OW 370002, "Biographische Notizen."

[2]Minerophilus, p. 309. See also Johann Friedrich August Breithaupt, Die Bergstadt Freiberg im Königreiche Sachsen, in Hinsicht auf Geschichte, Statistik, Kultur und Gewerbe, besonders auf Bergbau und Hüttenwesen, skizziert (Freiberg: Craz und Gerlach, 1825), p. 114.

[3]OW 080265, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1790."

Krumpe, and on their way to Carlsbad they stopped at Freiberg. Krumpe introduced his young companion to several of the mining officials at Freiberg and also saw to it that he would be permitted to visit a few of the numerous mines in the outskirts of Freiberg. The officials who conducted him on the tour of the mines were so impressed with Werner's knowledge of mining and mineralogy that they asked Krumpe to persuade Werner's father to send his son to the newly established mining academy at Freiberg.[1]

Whatever plans Werner's father may have had for him--there is reason to believe that he wanted him to become a metallurgist--[2] he obliged the mining authorities, and accompanied his son to Freiberg in 1769. They arrived shortly after Easter in the midst of great festivities in honor of Frederick Augustus III, Elector of Saxony.[3]

The festivities lasted several days, and the elder Werner remained with his son until the Bergakademie opened its doors after the holidays. Werner was the fifty-second student to be admitted to the Bergakademie,[4] and according to the application for admission which he

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[1] Frisch, pp. 9-10.

[2] Jean François D'Aubuisson de Voisins, "Suite de la Lettre . . . à M. Berthollet, sur les travaux de M. Werner, en minéralogie," Annales de Chimie, LXIX (1809), 241-242.

[3] Frederick was only thirteen years old when his father, the Elector Frederick Christian, died in 1763. His uncle Xavier therefore became his guardian and took over the administration of the government. However, because of some difficulties with the nobility, Xavier was forced to resign, and Frederick, then only eighteen years old, was officially declared of age and assumed the Electorship of Saxony. One of his first acts was to remove the imposts ordered by his uncle and to reduce the armed forces. Flathe, "Friedrich August III," Allgemeine Deutsche Biographie, VII, 786-789. See also Gustav Eduard Benseler, Geschichte Freibergs und seines Bergbaues (Freiberg: Engelhardt, 1843-53), II, 1192.

[4] Festschrift zum hundertjährigen Jubiläum der Königl. Sächs.

had sent to Freiberg ahead of his arrival there, he was a student "auf eigene Kosten," that is, he paid his own expenses and did not have a stipend.[1]

In 1769 the Bergakademie was still in its infancy. Only a few subjects were offered at that time, and the student who wanted to learn more than what was required to complete the course of study had ample time and opportunity to do so on his own. Werner spent much time continuing his study of languages, including Latin and Greek, and of German literature, which he had begun at the Waisenhausschule in Bunzlau. In later life he liked to tell how in the evenings he would read the writings of various German authors to his landlady, who would often call his attention to the intended meaning of a piece of literature which otherwise might have escaped him.[2]

Of great importance to Werner's education and of lasting influence in his life was his relationship with the curator of the Bergakademie, Karl Eugen Pabst von Ohain. Von Ohain had a very excellent mineral collection, a good library, and a wide knowledge of the literature and the various branches of mineralogy, all of which he put at Werner's disposal. In the introduction to his Ausführliches und sistematisches Verzeichnis des Mineralien-Kabinets des . . . Pabst von Ohain, Werner wrote: "I acknowledge with pleasure and feelings of gratitude that the

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Bergakademie zu Freiberg am 30. Juli 1866 (Dresden: C. C. Meinhold & Söhne, 1866), p. 224.

[1]Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 257.

[2]Frisch, p. 17.

mineralogical knowledge which I gathered from oral instruction during the time of my first scientific training I owe largely, if not exclusively, to this scholar; . . ."[1]

But Werner did not spend all of his time reading and studying the minerals in the cabinets of the academy and of Pabst von Ohain, for he was particularly attracted to the mines in the country around Freiberg and in the Ore Mountains. In these mines he had an excellent opportunity to study not only mining, but also geology and mineralogy. As an assistant to his father he had had opportunity to visit mines in Lusatia and Silesia, and in his capacity of Hüttenschreiber he had also acquired much practical knowledge, so that when he visited the mines of Freiberg and the Ore Mountains he knew what kind of questions to ask of the various officials and workers in the mines. By the time he left Freiberg in 1771, there was little that Werner did not know about the operation of a mine. He had learned about the different methods used in extracting ores from the different kinds of rocks, what tools were used in hard rock and in soft rock, and how the different tools were used. He had been instructed in the mechanism of the various machines, such as conveyors and hydraulic machines, and in how to operate them. Later, as a teacher at the Bergakademie, he was to make use of all of this knowledge.

Many of the mines in the Freiberg mining district were quite deep, some of them going as much as 1450 feet below the surface of the earth.[2]

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[1]Abraham Gottlob Werner, Ausführliches und sistematisches Verzeichnis des Mineralien-Kabinets des Herrn Karl Eugen Pabst von Ohain (Freiberg: Crazische Buchhandlung, 1791-1793), I, iv (translation by the author).

[2]Breithaupt, Die Bergstadt Freiberg, p. 177.

The rocks exposed in the shafts of the mines offered an excellent opportunity to study the inner structure of rock formations, since they exposed the various layers of rock, much as mountains do above the surface of the earth; and Werner combined the study of rock formations in the mines with the knowledge of rock formations that he had gained from books. He wasted little time on frivolities during his two-year stay at Freiberg, but pursued his studies systematically, always combining the practical with the theoretical. This relationship between the practical and the theoretical is apparent in all Werner's later teachings and writings.

Werner could have stayed on at Freiberg and entered the mining service, for Pabst von Ohain in his official capacity as Berghauptmann, or mining director, had offered him a job. But Werner turned down the offer.[1] According to the rules and regulations of the mining service of Saxony, nobody was permitted to reach a position of high rank without university training, specifically, training in jurisprudence.[2] Werner therefore decided to leave Freiberg, and in 1771 he enrolled as a student of law at the University of Leipzig.[3]

Werner left a detailed account of the courses that he took during his second, third, and fourth semesters at Leipzig, that is, from the fall of 1771 to Easter of 1773. Most of the subjects that he enrolled in dealt with law, the only exceptions being a course in physics, one in

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[1]OW 370002, "Biographische Notizen."

[2]Frisch, p. 17.

[3]OW 370002, "Biographische Notizen."

Latin, one in Italian, and lectures on Tacitus and Livy. He did not neglect his interest in the sciences, however, and together with several friends he arranged to hold meetings to discuss problems in psychology, astronomy, and mineralogy.[1] Among the members of the group were Johann Samuel Traugott Gehler (1751-1795), who later became well known for his dictionary of physics; Friedrich Anton Gallisch (1754-1783), a doctor, professor of medicine, and amateur poet; and Nathanael Gottfried Leske (1751-1786), professor of economics at the University of Leipzig and later at the University of Marburg.[2]

After Easter, 1773, Werner's studies took a different direction. He gave up the study of law and devoted his time primarily to the study of modern languages, philosophy, and mineralogy. He attended meetings of the Italian language club, at which the members conversed in Italian, and he studied French, English, and other languages. According to his own notes, in 1775 he intended to take private lessons in Latin and French, and during the summer of 1774 he attended lectures on anthropology, Horace, and Tasso.[3]

After Werner had decided to give up the study of law, he translated into German a book on the external characteristics of minerals written in Latin by Gehler's brother. He intended to publish this translation with notes and explanations but was advised against it by a friend, who suggested that he write a work of his own instead, since

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[1]OW 370004-0007, "Biographische Notizen."

[2]Frisch, pp. 18-19.

[3]OW 370004-0007, "Biographische Notizen."

Gehler himself was not very well satisfied with his work and since it was not a very complete treatment of the external characteristics of minerals.[1] Werner accepted the advice of his friend and began work on his treatise which was published a year later, in 1774, under the title Von den äusserlichen Kennzeichen der Fossilien.

Werner left Leipzig in the same year that his book was published and returned to his home at Wehrau. He did not even bother to go to Freiberg to inquire about the possibility of getting a job there, believing that the authorities there had forgotten him and that without a law degree he would not have much chance of getting a good job.[2] But he had not counted on the success of his little book. When it was brought to the attention of his friend and former teacher Pabst von Ohain, he recommended that Werner be hired as a teacher of mining and mineralogy and curator of the various collections at the Bergakademie.[3] Von Ohain's recommendation was accepted by the authorities, and in February of 1775 Werner "very unexpectedly"[4] received the offer to become a teacher and curator at the Bergakademie at an annual salary of one hundred Reichsthaler.[5] Werner accepted the offer and began his teaching duties after

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[1]Frisch, pp. 19-20; Hasse, p. 4.

[2]OW 370002, "Biographische Notizen."

[3]In recommending Werner for this position, Pabst von Ohain referred to him as "the same Werner who some time ago mastered the various branches of mining . . . as a student at Freiberg and afterward further pursued his studies at Leipzig, and who, a short time ago, published a timely treatise on the external characteristics of minerals." Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 261 (translation by the author).

[4]OW 370003, "Biographische Notizen."

[5]Blöde and Frisch wrote that Werner was hired at the annual

Easter in 1775.[1]

Werner remained at the Bergakademie of Freiberg until his death in 1817. Through his writings and through his students he gained recognition for his school and for himself, and his name became familiar to students of geology and mineralogy everywhere. Saxony recognized his service, and in 1799 he was elevated to the rank of Councillor of Mines and named a member of the Board of Mines. In 1816 he was given the knight's cross of the Orden für Verdienst und Treue.[2]

From paintings and from descriptions given by Frisch and Hasse, we have some detail of Werner's appearance. His portrait was painted by several artists, and two of these portraits, one by Müller of Weimar[3] and the other by Kügelgen,[4] are still in the Bergakademie at Freiberg.

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salary of 300 thaler. Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 261; Frisch, p. 27. However, Werner in several communications to the Bureau of Mines wrote that he was hired at the salary of 100 thaler. OW 080300, "Werner's Report for 1793-1794." It is possible that Werner was referring only to his salary for teaching the course on mining, the only lectures for which he was paid, and did not include his salary as curator of the various collections in the Bergakademie. His salary was increased to 300 thaler in 1792, when he was promoted to the rank of Edelsteininspektor und Berg-Commissionsrath. OW 110007-0009, "Letter in the name of the Elector Friedrich August to the Oberbergamt at Freiberg, March 24, 1792."

[1] OW 130036, "Draft of a Letter from Werner to the Oberbergamt, 1795."

[2] Hasse, p. 6.

[3] Johann Christian Ernst Müller (1766-1824) was a protege of Goethe and of Johann Gottfried Herder. "Müller, Christian (Joh. Ch. Ernst)," Allgemeines Lexikon der Bildenden Künstler von der Antike bis zur Gegenwart, XXV, 222.

[4] Franz Gerhard von Kügelgen (1772-1820) was a famous painter in his day. He painted portraits of Alexander I of Russia, Goethe, Queen Luise of Prussia, and others. C. v. Kügelgen, "Kügelgen, Gerhard (Franz G.) von," Allgemeines Lexikon der Bildenden Künstler von der Antike bis zur Gegenwart, XXII, pp. 51-53.

A third portrait, which Werner presented to a friend in Dresden, was painted in 1800. Frisch thought that the portrait by Kügelgen was the best of the three, even though he felt that the artist had failed to show Werner's mildness and friendliness and had made him appear pompous and polite. Werner himself remarked that the sittings for the painting were held in a cold studio, that he was freezing all the time, and that the artist had conveyed his being cold to the canvass.[1]

Werner was of average height, his body well proportioned, his chest wide. His forehead was high, his eyebrows thick and curved up at the bridge of the nose. His nose was straight and rounded at the tip. He had a well formed mouth, with lips somewhat protruding, and a round chin with a dimple. His eyes were blue and not very big, and his hair was of a flaxen color. His cheeks had a healthy color.[2] But despite his rugged build and healthy look, Werner suffered from his early youth from abdominal disorders and was always extremely susceptible to colds. This susceptibility to colds was aggravated by the frequent trips to the mines which he had to make as an official of the Saxon Bureau of Mines to check on mining practices and conditions of the mines and as a teacher at the Bergakademie to take his students on field trips.

These trips proved to be very exhausting to Werner, who suffered much from the heat and closeness of the mines. He took all kinds of precautions to prevent illnesses, and his concern about his health increased as the years went by. He kept his room heated in summer and winter, so that there would not be much difference between the temperature of his

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[1]Frisch, p. 236.

[2]*Ibid.*, pp. 234-235; Hasse, p. 14.

room and the temperature in the mines. When on trips in winter he asked the hotels at which he intended to stay to heat his room for several days before his arrival. He always dressed warmly, and in cold weather he would wear two or three vests, a coat and overcoat, and two sets of underwear.[1] His poor health together with a tendency to be something of a hypochondriac and his acquaintance with doctors in Freiberg and Leipzig increased his interest in medicine. He tried to be his own doctor as well as the diagnostician of his friends, and to cure different diseases he worked out a system which was based on the assumption that the constitution of a human being is either acidic or alkaline.[2] Accordingly, he diagnosed his own maladies and made up his own diet. But his diets and precautions were not enough. He was ill frequently--in his correspondence with the authorities of the Bergakademie and the Bureau of Mines he often excused his absences from class or official meetings on the ground of illness.[3] Several times he was unable to finish a course of lectures because of illness and was forced to continue the course the next semester. His stomach troubles led him to the spas of Europe, and during the last forty-two years of his life he spent forty-one summers or autumns at Carlsbad.[4]

Werner usually spent two or three months at Carlsbad. Sometimes he would go there as soon as classes were dismissed in July, but very

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[1]Frisch, p. 245. [2]Ibid., p. 244.

[3]OW 080124, "Werner's Report dated February 19, 1781"; OW 130036, "Letter dated October 1, 1800."

[4]OW 120023, "Copy of an Article in the Dresdener Abendzeitung, 1817, No. 198"; Frisch, p. 215; Hasse, p. 20.

often he would remain in Freiberg to take care of business connected with the Bureau of Mines and would not arrive at Carlsbad until November. The season was by no means over at Carlsbad even that late in the year. Another visitor who often came there in the autumn was Johann Wolfgang von Goethe. He and Werner became well acquainted with each other and spent many an hour together. Goethe was always delighted to be in Werner's company,[1] for Werner was a good conversationalist, a man of many interests, who could talk on many subjects outside his special field. He actually tried to avoid discussions dealing with geological matters, often much to the annoyance of Goethe, who as an owner of mines and a student of the natural sciences was very much interested in what an authority like Werner had to say about various geological phenomena.[2] On their walks to the springs to take the waters Werner explained to Goethe his theory of the origin of the mineral springs and the different rock formations in the vicinity of Carlsbad,[3] which lies in the midst of the Ore Mountains, but when they visited each other Werner usually turned the conversation away from geology. When Werner visited Goethe on the evening of September 1, 1807, for instance, the conversation started with a discussion of the sandstone by the river Eger (whether it was a chemical or a mechanical deposition), moved to a discussion of Nicolas Joseph Jacquin (1727-1817), professor of chemistry and botany at the University of Vienna, to Vienna itself, and finally to the current world situation.[4] But Werner liked almost nothing better

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[1]Johann Wolfgang von Goethe, Die Schriften zur Naturwissenschaft, ed., Günther Schmid (Weimar: H. B. Böhlaus Nachfolger, 1947), pp. 325, 356.

[2]Ibid., pp. 325-326. [3]Ibid., p. 289. [4]Ibid., p. 322.

than to talk about linguistics. He was interested in the origin, derivation and kinship of words and languages. Goethe describes how Werner carried a number of books dealing with linguistics in a small cardboard box, which he would pull out whenever a problem came up during a discussion or differences of opinion had to be resolved.[1]

Frequently Werner would not return from his vacation directly to Freiberg, but would travel to other parts of Germany and Austria. He visited Prague, Vienna, Munich, Augsburg, Regensburg, and other places, some of them several times. Dresden, with its fine art galleries, had a special attraction for him, and often he would remain there so long that he would have to skip the other cities which he had intended to visit.[2]

According to Robert Hunt, Werner visited England, being drawn there by the work of Joseph Carne (1782-1858).[3] Carne had a unique mineral collection and had done work on the granitic veins of Mont-Saint-Michel and the vein-like lines of porphyritic rocks known as "elvans." "After studying the formation of mineral veins," Hunt wrote, "he [Carne] in 1818 communicated to the Geological Society of Cornwall a paper 'On the relative Age of the Veins of Cornwall.' The celebrated Werner was drawn by it into Cornwall, and he visited the mines of the county in company with Carne."[4] It is possible that Werner visited

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[1] Ibid., p. 326. [2] Frisch, p. 232.

[3] Robert Hunt, "Carne, Joseph," Dictionary of National Biography, III, 1045-1046.

[4] Ibid., p. 1045. See also Robert Hunt, British Mining. A Treatise on the History, Discovery, Practical Development, and Future Prospects of Metalliferous Mines in the United Kingdom (London: C. Lockwood & Co., 1884), p. 333.

Cornwall and other parts of England, for he had long been interested in the geology of England, but he certainly did not visit the mines of Cornwall after 1818, for he died in 1817.

Werner also traveled to various parts of Prussia on business matters, as, for instance, in 1800, when the Prussian government asked him to appear as an expert in a lawsuit concerning mineral rights in the mining district of Wettin.[1]

Of all his travels, Werner enjoyed his visit to Paris most. What the occasion of his trip was we do not know with certainty. Possibly he went to Paris just for a visit, but it is more likely that he went there in connection with his election by the Institut National as a Correspondent in the physical and mathematical section of the society. He was very cordially received in the capital of France, and everything was done to make his stay as pleasant as possible. He was taken to the École des Mines, where he amazed Descostils,[2] who conducted him through the school, with his ability to assay ores. Descostils told how he handed Werner several pieces of iron ore. Werner carefully examined them and weighed them in his hand, then announced the quantity of metal that each of the pieces would yield; and, according to Descostils, his estimates were almost the same as those indicated by the results of

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[1]OW 020001-0002, "Lawsuit against the Board of Mines of Wettin."

[2]Hippolyte Victor Collet-Descostils (1773-1815), Ingénieur-en-chef and professor of chemistry in the Corps Royal des Mines. He was the chemist of Napoleon's expedition to Egypt. J. C. Poggendorf, ed., Biographisch-Literarisches Handwörterbuch zur Geschichte der Exacten Wissenschaften enthaltend Nachweisungen über Lebensverhältnisse und Leistungen von Mathematikern, Astronomen, Physikern, Chemikern, Mineralogen, Geologen u.s.w. aller Völker und Zeiten (Leipzig: Johann Ambrosius Barth, 1863), Vol. I, col. 464.

assays.[1] Werner was also shown the points of interest in Paris and introduced to many members of the learned world and of society and government circles. Probably the highlight of his visit was a dinner given in his honor by Jean Jacques Réges de Cambacérès (1753-1824). Cambacérès was one of the most prominent men of France at that time. In 1795 he had been a member of the Committee of Public Safety, in 1799 he became second consul, and in 1802 he was very instrumental in assuring Napoleon of the consulship for life. He also helped to draw up the Civil Code and was later appointed arch-chancellor of the empire and president of the Senate in perpetuity. In 1808 he was made a prince of the empire and given the title of Duke of Parma.[2] Unfortunately we do not know who was present at the dinner which he gave in Werner's honor, but the guest list must have been impressive. It may have been at this dinner that Werner was introduced to Napoleon. Whatever the occasion, this was one meeting which Werner remembered with some distaste, for Napoleon in the manner of a politician on a campaign tour greeted him with the remark: "I know you, you have been of great service to chemistry."[3]

Werner met many people on his travels in Europe as well as in Freiberg, where many persons of importance in public life came to study under him or just to meet him. The mineralogist and physician Franz Ambrosius Reuss (1761-1830), who wrote the most complete treatise on

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[1]D'Aubuisson de Voisins, Annales de Chimie, LXIX (1809), 226.

[2]"Cambacérès (Jean-Jacques-Regis DE)," Nouvelle Biographie Générale depuis les temps les plus reculés jusqu'a nos jours, avec les renseignements bibliographique et l'indication des sources à consulter; . . . , Vol. VIII, cols. 289-294. See also Frisch, p. 233.

[3]Hasse, p. 13.

Werner's geological teachings, was never his student, but he did occasionally come to Freiberg to discuss points of common interest with him.[1] The poet and writer Johann Gottfried Seume (1763-1810) walked, despite a sore foot, from Dresden to Freiberg to meet Werner in person and to deliver to him a piece of rose quartz which the governor-general of Finland had asked him to give to Werner in appreciation for the kindness that Werner had shown the governor's wife when she visited Saxony.[2] Freiherr vom Stein (1757-1831), who was to become Prussia's foremost reformer of the early nineteenth century, who abolished serfdom in Prussia, reorganized that country's financial system and liberated Prussian industry from its burdensome restrictions, spent a year in Freiberg (1782-83) studying the mining industry and attending Werner's lectures. He must have admired Werner, for he sent him a box of minerals and kept an iron bust of him in his Nassau library.[3] Franz Benedict von Baader (1765-1841), philosopher, mining engineer, and inventor of a method of glass making, was also one of Werner's students, studying under him for five years, from 1787 to 1792.[4] Julius Wilhelm von

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[1]Franz Ambros Reuss, Neues mineralogisches Wörterbuch oder Verzeichnis aller Wörter welche auf Oryctognosie und Geognosie Bezug haben, mit Angabe ihrer wahren Bedeutung nach des Herrn Berg-Commissions-Rath Werners neuester Nomenclatur in alphabetischer Ordnung in Deutscher, Englischer, Russicher und Ungarischer Sprache. Nebst einer tabellarischen Uebersicht der mineralogisch einfachen und gemengten Fossilien (Hof: G. A. Grau, 1798), pp. [x-xi].

[2]Johann Gottfried Seume, "Mein Sommer 1805," Prosaische und poetische Werke (Berlin: Gustav Hempel, n.d.), II, 97. See also Frisch, p. 225.

[3]Freiherr vom Stein, Briefe und Amtliche Schriften, ed., Erich Botzenhart, Vol. I (Stuttgart: W. Kohlhammer Verlag, 1957), p. 154.

[4]Friedrich Hoffmann, "Baader: Franz Benedict von B.," Allgemeine Deutsche Biographie, I, 713-725. See also Festschrift 1866, p. 232.

Oppel (1766-1832), son of one of the founders of the Bergakademie, who was director of finances of Saxony when that country came under Allied control in 1813 and accompanied Prince von Hardenberg, the Prussian minister, to the Congress of Vienna, was not only Werner's student, but practically his ward.[1]

A pioneer in the romantic movement, the poet and novelist Friedrich Leopold, Freiherr von Hardenberg (1722-1801), better known by his pen name, Novalis, was another of Werner's students who made their mark outside the world of geology. Novalis came to Freiberg in 1797, being the 493rd student to enroll officially at the Bergakademie,[2] and, according to his own statement, Werner gave him direction and purpose in life. He wrote: "The acquaintance with Werner resulted in a new vitality and direction of my activities. It is entirely due to Werner that I can apply with a clear conscience for a practical position."[3] Novalis perpetuated Werner in two of his novels. In Lehrlinge zu Sais he portrayed him as the teacher and in Heinrich von Ofterdingen as the old miner.

Werner never married, and very little is known of the women in his life or his relationship with women. A note found among his papers suggests that he had at least one love affair in his youth, but no details of this affair are known, not even the name of the girl.[4] Frisch

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[1]Schumann, "Oppel: Julius Wilhelm v. O.," Allgemeine Deutsche Biographie, XXIV, 390-392. See also Festschrift 1866, p. 229.

[2]Festschrift 1866, p. 238.

[3]Novalis, Novalis Schriften, ed., Paul Kluckhohn (Leipzig: Bibliographisches Institut A. G., 1928), IV, 280.

[4]Frisch, p. 231.

speculates that Werner had too little money to consider marriage in his youth, but that in later life he regretted that he had not married.[1] He enjoyed the company of educated women, and apparently they enjoyed his company,[2] but we do not know what educated women he knew. We do know that the friend in Dresden to whom he gave the portrait painted in 1800 was a Mrs. Salzmann, the wife of a physician.[3] But what their relationship was is not known, nor even the circumstances under which Werner gave her the portrait.

Werner was a welcome guest wherever he went, not only because he was a famous teacher and a ranking official of the Saxon Bureau of Mines, but also because he was a man of wide interests, well read and able to converse on many subjects. He could discuss the merits of a painting or a poem, and he was able to speak with authority on history, military strategy, numismatics, linguistics, and many other topics.

His interest in many of these subjects was a direct result of his interest in mineralogy and geology, to which he tried to relate virtually all human endeavors and achievements. His interest in archaeology, for instance, was largely due to his curiosity about the minerals and stones of which some of the sculptured masterpieces and buildings of ancient Greece and Rome were made. With the help of his archaeologist friend Böttiger,[4] he examined statues in museums and studied Homer and

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[1] _Ibid._

[2] _Ibid._, p. 230.

[3] _Ibid._, p. 237.

[4] Karl August Böttiger (1760-1835) was the author of many books on archaeology, editor of the _Journal des Luxus und der Moden_ from 1795 to 1803 and of the _Neuer deutscher Merkur_ from 1797 to 1809. Urlichs, "Böttiger: Karl August B.," _Allgemeine Deutsche Biographie_, III, 205-207.

Pliny for archaeological evidence. He read Millin's Minéralogie Homérique[1] and discussed the nature and significance of Murrhine vases.[2]

His study of linguistics was also in part the outcome of his work in mineralogy. He did not think that the German and English translations of a Swedish book on mineralogy were satisfactory, and so he decided to learn Swedish and make his own translation.[3] The study of Swedish led him to the study of other Scandinavian languages, and through these he hoped to learn more about Gothic. Comparative linguistics became one of his greatest interests outside the field of geology and mineralogy, and, according to Frisch, he left more treatises on linguistics among his personal papers than on nearly any other subject.[4] Many of these papers deal with the development of the German language, its relationship to other languages, and the borrowings from Greek and Latin. Werner also developed a theory that words beginning with the sounds sp, st, and sh are usually words of action, strength, and creativity. To support this view he compiled lists of words beginning with these sounds.[5]

Werner was always interested in the relationship of one subject to another. In the last few years of his life he became fascinated by

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[1]Millin de Grandmaison (Aubin Louis), Minéralogie Homérique, ou essai sur les minéraux dont il est fait mention dans les Poèmes d'Homère (Paris, 1790).

[2]Frisch, p. 197.

[3]This was Axel Cronstedt's Försök til Mineralogie eller Mineral Rikets Upställning. See above, p. 22 and footnote 5, same page. Werner's translation of the first part of this work with commentaries was published in 1780.

[4]Frisch, p. 199.

[5]Ibid., p. 200.

numismatics. But he did not just collect coins for the joy of collecting. He studied them so that he could compare the likenesses of gods and emperors on the coins with their respective characters, their deeds, and their governments. He would speculate about the origin and development of art and artistic taste as reflected in the craftsmanship of the coins, and he bemoaned the decline in artistic taste and feeling after the second century A. D.[1]

Werner's interest in history went back to his early youth, and with the years this interest grew stronger. He liked to talk about the influence of geology and geography on the course of history, and he made a special study of the Völkerwanderung.[2] He explained the movement of peoples from the highlands to the more fertile lowlands, the settlements near rivers, and the destruction of empires by migrating peoples largely on the basis of geology and geography.[3]

Werner's ability to carry on conversations in several languages made him an especially welcome guest in many houses during the French wars, when armies of various countries passed through Freiberg. During the Napoleonic wars, when Freiberg was under French occupation, his company was eagerly sought by officers of the French General Staff, and often generals and members of their staffs would call on Werner to hear him expound on military strategy.[4] He pointed out to the officers

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[1] Ibid., p. 201.

[2] D'Aubuisson de Voisin, Annales de Chimie, LXIX (1809), 244.

[3] Frisch, p. 195.

[4] Ibid., p. 204. In his plan for an ideal university, Werner included an elaborate curriculum in military science. OW 380032-0041, "Plan for a University."

mistakes in strategy which might have been avoided through a better knowledge of geography and geology, and he often amazed his visitors with his ability to give accurate descriptions of regions which he had never seen. He also liked to predict the turn of military events, basing his predictions primarily on his knowledge of history, geology and geography, and he was particularly proud that he had been able to predict the exact route which the Russian general Suvorov took in 1799 when he retreated from Italy across the Alps.[1]

Although he was much interested in the military campaigns of the wars of the French Revolution, Werner was even more interested in the revolution itself and its results in France and elsewhere. After Bastille Day he became an ardent supporter of the revolution and the principles for which it stood, often to the dismay of some of his friends. He talked about it at his own dinners, at functions to which he was invited, and indeed almost anywhere that he happened to be. Some of his friends tried to avoid the topic, and a few even avoided his company.[2] As the revolution progressed, Werner's ardor abated somewhat, but not his admiration for what he regarded as the enlightened attitude of the new French government toward education and science.[3]

It is not difficult to explain Werner's enthusiasm for the French Revolution. As one who was always much concerned about the lot of his fellow man, he saw in France the hope for a better France and a better world, and as a German nationalist who dreamed of abolishing

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[1]Frisch, pp. 196-197.

[2]*Ibid.*, p. 246.

[3]*Ibid.*, p. 247.

serfdom and particularism, he saw in France a new hope, a hope which he had believed to have vanished with the death of Frederick the Great. Frederick was to Werner the epitome of the enlightened ruler, the man who could have brought about German unification. Among Werner's papers there are a few sheets which he dedicated to the dead ruler of Prussia. These show not only his admiration for Frederick, but also his German nationalism. He wrote:

> Most highly esteemed shadow! Shadow of the Frederick who is gone forever. At the death of the greatest king, permit a deeply grieved German to bring you an offering, one which his German spirit demands, but which, in a way, is prevented by his grief. The thought saddens his heart every time that it occurs--Frederick is no more! The pride of your fatherland is gone! . . . Glorious king! You were not just a sovereign, restless, active and wise, inspired with love for the fatherland, an untiring, brave leader of armies, but also--which gives a special luster to your other attributes--a connoisseur, a warm admirer of learning and the sciences, and even a scholar. You were a new--indeed the strongest--proof that learning, when it enlightens whole nations, makes man wise and great, . . .[1]

However strong Werner's feelings were for Frederick the Great and German nationalism, he can hardly be thought of as belonging to the school of Johann Gottlieb Fichte (1762-1814).[2] He agreed with Fichte's idea that the individual can best live up to his potentialities in the group which forms his nation and that nationalism is a healthy cultural force, but he had too much of the cosmopolitan spirit of Goethe[3] to

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[1]OW 110103, "Some Comments on Frederick the Great."

[2]Fichte insisted that the individual has no real existence outside the group and that the individual can best realize himself in the group. Frederick Hertz, Nationality in History and Politics. A Study of the Psychology and Sociology of National Sentiment and Character (New York: Oxford University Press, 1944), pp. 338-339.

[3]Goethe welcomed national unification only insofar as it was in the interest of security, commerce and trade. He had no wish for political centralization and an increase of central power. Ibid., pp. 332-333.

accept Fichte's idea of nationalism.[1]

Werner's cosmopolitan and international spirit can perhaps best be seen in his ideas on economics. He believed that man must look at the whole world as one estate and learn economics from it. States must realize, he said, that the attainment of all their goals is possible only through cooperation, that they must work closer together and form systems of alliances, which will bring them closer to an international government.[2] Werner's nationalism, therefore, was only a means rather than an end in itself. The goal that he had in mind was enlightenment, education and better economic conditions for all mankind.[3]

Werner was a deeply religious man, although he seldom attended church services except on Good Friday and those occasions on which his attendance, as an official of the Saxon government, was required.[4] Although he believed strongly in religious education for the young and urged his young students to attend church services,[5] he himself was more interested in inner conviction and devotion to Christian ideals in daily behavior than in demonstrations of piety. He was subjected to much criticism for his failure to attend church, but those who knew him well always defended him, for they recognized him as a truly religious man. The correctness of their interpretation is shown in the following outline, found among his notes, of Werner's view of what it means to be a

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[1]OW 390002-0008, "The Value of Germany and German Art."

[2]Novalis, III, 302-303.

[3]OW 380004, "Ideas on Education."

[4]Frisch, p. 253.

[5]Hasse, pp. 16, 21.

Christian:

> The purpose and intent of Christian righteousness and the duties which it imposes upon us:
>
> I. Purpose and intent
> 1. the fulfillment of the will of God with obedience and submission
> 2. to become similar to God
> 3. the pleasure of God in the next life
>
> II. Duties
> 1. the inner self should be the same as the outer self
> 2. we should be God fearing, not from compulsion, but because of principle
> 3. we should always strive to be virtuous until we become righteous
> 4. we should not practice only single virtues, but the whole should be our object.[1]

In another place Werner wrote:

> To the heart and soul, the most exalted part of our holy books is that place where it is written:
>
> And God created man in his own image; in his own image created he him.
>
> It embraces everything that leads to a more noble humanity.[2]

Frisch, a minister, wrote that Werner was a religious man in the true spirit of Christ.[3]

Werner was much concerned with the behavior of his students: in every one of his annual reports to the Bureau of Mines he discussed the Sittlichkeit (morality) of his students during the past academic year.[4] And in his own life he demonstrated a constant spirit of helpfulness and charity. When fire destroyed an amalgamating plant a few miles

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[1]OW 370019, "Biographische Notizen."

[2]OW 370022, "Biographische Notizen."

[3]Frisch, p. 250.

[4]OW, various annual reports. See also C. A. Böttiger, "Über Werner's Umgang mit seinen Schülern," Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 322, 325.

outside of Freiberg, he was the first to think of sending food to the workers. When he found out that the soldiers at the main guardhouse had no part in the celebrations of the king of Saxony's return from captivity on July 7, 1814, he sent them food and drink so that they would not feel left out. And in 1813, after the battle of Lützen, when wagonload after wagonload of wounded Prussian soldiers were brought to Freiberg, he hurried to help take care of them bandaging their wounds and performing all the duties of a nurse.[1]

Werner was an ardent Protestant, mainly because he believed that much freedom of thought was possible under Protestantism.[2] He had studied the Bible, both with his father and by himself, and he believed that everyone should be permitted to read and interpret Scripture for himself. His own library contained the writings of anti-trinitarians, Socinians, and deists.[3] He could not be considered anti-Catholic, however, for he believed that Christians should emphasize their similarities rather than their differences, and he spoke respectfully of the Roman church as the "mother church." He had little patience with the minute quarrels of the different Protestant sects,[4] and one of his fondest hopes was that the two major Protestant denominations would become united before the three hundredth anniversary of the Reformation in 1817.[5] Thinking of the approach of this day, Werner wrote:

> The highest and holiest holiday of the Protestant church is approaching, the three hundredth anniversary of its founding. . . . May all

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[1]Frisch, pp. 257-285.

[2]*Ibid.*, pp. 251-253.

[3]*Ibid.*, p. 251.

[4]Hasse, p. 14.

[5]Frisch, p. 252.

> the congregations of this church celebrate this holiday in brotherly love, hand in hand. May they raise their hearts and voices together in festive songs of praise and loud prayers of thanks to God the giver of all good for all that he has given them in that span of time. Lutheran and Reformed, you of the brother congregations of the old and new confederation, we all consider the revealed word of God as the pure source of our holy religious teachings. We are already united whenever, with hearts raised to God, you read your church song: we all believe in one God. Then you speak out loudly that in the most essential teachings of the Christian religion you are united with our most honored mother church, the Roman, and with the highly esteemed Greek church and her daughters, which are even closer to us in some customs. We are all brothers in spirit.[1]

The wide range of Werner's interests is indicated by his library. Of the total of approximately 20,500 items, all but 2,000 were books, the others being tracts and pamphlets. The library was fairly complete in the earth sciences and the subjects related to what Werner taught. It also contained a very good collection of books on the history of the Reformation and on the history of Saxony. Among the writings on the Reformation were several rare pamphlets, sermons and lampoons of the period, and two original editions of the Confessio oder Bekenntniss des Glaubens christlicher Fürsten und Städte. Ueberantwortet zu Augsburg 1530. In world history Werner's holdings were less extensive, but according to Rüdiger, who catalogued part of the library, he had most of the major works.[2] As might be expected, Werner's library was especially strong in the field of linguistics. It contained virtually all the dictionaries and treatments of linguistics that were available at the time, including a copy of Hickes' Thesaurus Linguae Anglo Saxonicas, which Werner had bought for sixty thaler not long before his death. In the

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[1] OW 370017-0018, "Biographische Notizen."

[2] Frisch, p. 208.

classics Werner had numerous current editions of Greek works, and his collection of books by Roman writers was even more extensive and contained many old editions. Among these were a 1478 edition of the writings of Seneca, a 1491 edition of Solinus, a 1494 edition of Ciceronis Rhetor, a 1504 edition of Cicero de Officiis, a 1505 printing of Terence, and no less than twenty-two editions of Pliny's Historia naturalis, one dated 1472, as well as several German and French translations of it. Werner's library also contained several old editions of the Digest, or Pandecta, of Justinian's Code, a large number of books on archaeology and numismatics, and several treatises of homiletic and ascetic content.[1] It was rich in literary and philosophical works, including many works by foreign authors as well as German. Among these were the works of Alexander Pope, Milton's Paradise Lost and Paradise Regained, and Thomson's The Seasons; translations of Burke's Reflections on the Revolution in France and Condorcet's Esquisse d'un tableau historique des progrès de l'esprit humain; and the writings of Kant, Berkeley, Hume, Locke, Descartes, Voltaire, Montesquieu, Rousseau, and Leibnitz.[2] Werner's collection of exegetic writings and Holy Scriptures was comparatively small, but he did have a collection of Bibles in Slavic languages and also Walton's Polyglot, the Lord's Prayer in most living and dead languages, and several translations with commentaries of the Book of Job. According to Frisch, Werner studied the Book of Job and the Mosaic writings in connection with his study of the history of

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[1] Frisch, pp. 205-210.

[2] "Werner Bibliothek." A partial list of Werner's books now in the library of the Bergakademie at Freiberg.

mineralogy, and in one of his Bibles each mineral and stone mentioned was underlined.[1]

Besides his library and his coin collection, which consisted of 6650 pieces,[2] Werner had several mineral collections. Together, these collections took far too much space to be housed in his own quarters, so that Werner had to rent several rooms in which to store them. Many of the pieces in his mineral collections had been given to him by his students, particularly his foreign students, who sent him specimens from their own countries and from countries which they had visited. The greatest contributor to Werner's mineral collections was the Englishman John Hawkins (1758?-1841), who came to Freiberg in 1786 to study under Werner. After leaving Freiberg, Hawkins traveled to all parts of the world and sent Werner whole sets of minerals from all the countries that he visited.[3] Werner's collection of precious stones--polished and unpolished--included diamonds, zircons, hyacinths, sapphires, beryls, chrysoberyls, and others and was valued at approximately 20,000 thaler.[4] The oryctognostic collection, the largest of Werner's mineral collections, was stored in 249 drawers. It had complete suites of almost all the simple minerals in Werner's mineralogical system. Another collection was designed to demonstrate all the external characteristics of minerals as defined by Werner. A collection of rocks, including a suite of meteorological specimens, filled sixty drawers, and the geographic

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[1] Frisch, p. 209. [2] _Ibid._, p. 202.

[3] OW 130046, 130044, "Draft of a letter from Werner to the Oberbergamt, 1795."

[4] Frisch, p. 214.

collection, which filled eighty drawers, was made up of rocks from Italy, Greece, Spain, England, France, Hungary, and other European countries, arranged according to their geographic location. There was also a collection of petrifactions, comprising forty drawers, a fairly large collection of conchylia, and a collection of zoophites, corals, and other marine animals. All these collections together were appraised for tax purposes at 56,164 thaler and 8 Groschen.[1] From England Werner received an offer of 50,000 thaler for them,[2] but he decided to keep them in Saxony. In 1814 he sold them to the Saxon government for 40,000 thaler.[3] The conditions of the sale were that Werner was to receive 7,000 thaler in cash. He was to receive five per cent interest on the balance of 33,000 thaler as long as he lived. After his death, the interest on 17,000 thaler was to be paid to the Bergakademie, and the interest on the remaining 16,000 thaler was to be paid to Werner's sister. After her death, all the interest was to be paid to the Bergakademie.[4]

No provisions were made for the disposal of Werner's library and other possessions until very shortly before his death. In 1817 he suffered a great deal from his intestinal disorders, and, as though he knew that he did not have much longer to live, he worked harder than

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[1] General-Gouvernements-Blatt für Sachsen, Vol. III (Dresden: Redaction des General-Gouvernements-Blatts für Sachsen, 1814), pp. 629-630.

[2] Frisch, p. 213.

[3] Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 284.

[4] Ibid.

ever, doubling the number of his lectures to make sure that he would finish the course by the end of the semester. As soon as classes were dismissed, he hurried to Dresden to seek the advice of specialists, but to no avail. His intestinal troubles, augmented by pneumonia, drained his strength very rapidly. His illness caused much concern in Saxony. In a letter to Werner Frederick August, Duke of Saxony, wrote: "My concern for your illness . . . is due not only to my high esteem for you as a man of science and of character, but also to my love for the fatherland, whose greatest blessing it would be for heaven to keep you among us for a long time to come."[1] But Werner did not improve. He sensed it, and his friends knew that death was near.

Since he had not made a will, the delicate question of what should become of his library and other belongings arose. The Counsel of Mines, Freiherr von Herder, was selected to approach Werner and discuss the matter with him--not an easy task. But when Herder mentioned the subject to him, Werner, without misgivings or hesitation, had Herder call in a notary to draw up a will. He specified that "all his remaining collections of books, geographic maps, plans, coins, assortments of minerals and rocks, etc., as well as all his literary remains, should go to the Freiberg Bergakademie for a sum of 5,000 thaler, which is to be paid to his only sister and heir."[2] The next day, June 30, 1817, at 8:30 in the evening, Werner died.[3]

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[1]Frisch, pp. 228-229 (translation by the author).

[2]Ibid., p. 216 (translation by the author). See also Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), p. 285.

[3]OW 120018-0077, "Various Papers relating to Werner's Death and Funeral." See also Hasse, p. 15; Frisch, p. 259.

All Saxony mourned his death. The newspaper announcement of his death was followed by a list of nearly two hundred friends and admirers, among whom were members of the royal family, members of the diplomatic corps, officials from the various branches of the armed forces and other governmental agencies, as well as many members of the learned world.[1] The king decreed that Werner be given a state funeral and ordered that the funeral procession, which was to take the body from Dresden to Freiberg during the night of July 2, "should be conducted with all the honors worthy of such a distinguished state official, scholar, teacher, and man."[2]

Werner was buried in the vaulted cross-aisle of the Domkirche at Freiberg. Over his grave his sister erected a monument of sandstone. At the top of the monument there was a six-pointed star made of bronze, and at the bottom there were two torches, one, under which was inscribed Werner's birth year, pointing up, the other, under which was inscribed the year of his death, pointing down. The inscription read: "Hier ruhet Abraham Gottlob Werner. Dieses Denkmal errichtete ihm schwesterliche Liebe. Ein bleibenderes Er sich selbst."[3]

Werner died a famous man. During his lifetime he had been elected to twenty-three learned societies, among which were the Academy of Sciences of Berlin, the Royal Society of Edinburgh,[4] the academies of

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[1]OW 120018-0077, "Various Papers relating to Werner's Death and Funeral"; Frisch, pp. 260-261; Hasse, pp. 17-18.

[2]Hasse, p. 17 (translation by the author).

[3]Ibid., p. 26.

[4]Memoirs of the Wernerian Natural History Society, Vol. 1, for the years 1808, 1809, 1810 (Edinburgh: Bell and Bradfute, 1811), xiii.

sciences of Stockholm, Wilna, and Munich, and the Geological Society of London.[1] In 1808 the Wernerian Society of Edinburgh had been formed and Werner made the first honorary member. He was the first president of the Mineralogical Society of Dresden, and after his death it was decided that no new president would be elected but that instead a bust of Werner would occupy the place of honor at the meetings of the society.[2]

Werner was known wherever there were people interested in geology and mineralogy. Among his papers an envelope was found addressed simply: To Werner in Europe.[3]

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[1]Hasse, p. 6; Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 275. See Appendix IV, pages 258-259, below, for a complete list of the organizations to which Werner belonged.

[2]Hasse, p. 22.

[3]Frisch, p. 225.

CHAPTER III

WERNER AT THE BERGAKADEMIE AT FREIBERG

Freiberg owes its existence to mining,[1] and ever since its founding in about 1185,[2] its citizens and the people in the country about Freiberg, or Vriberc,[3] as it was called, have depended upon the mining industry for their livelihood. During its long history the importance of Freiberg to the Electorate of Saxony increased steadily, until the Freiberg mining district became the most important in Saxony.

The necessity of training people for the mining industry was already recognized by the Elector Maurice (1547-1553) when he commissioned Georg Agricola to put his mining experience and research on paper.[4] In 1702, August II, Elector of Saxony and King of Poland, decreed that a sum of money be set aside each year for the training of young miners in surveying and assaying.[5] To the training in these two subjects Johann Friedrich Henkel (1679-1744) added courses on metallurgical chemistry and mineralogy, which he taught at his house in Freiberg. Henkel's house became a regular place of training for mining officials, and Saxons and foreigners alike came to study under him. But as yet no school was

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[1] Breithaupt, Die Bergstadt Freiberg, p. 2.

[2] Ibid., p. 6.

[3] Ibid., p. 2.

[4] Ibid., p. 129.

[5] Ibid.

established.[1] After Henkel's death in 1744, the Saxon government felt that a complete course of subjects on mining should be made available to promising young people interested in mining, particularly since the art of mining was becoming so intricate that greater skill and knowledge were required to exploit profitably the numerous old mines, as well as the newer ones, all of which were constantly being extended deeper into the earth. In 1746 a certain Zimmermann drew up a plan for an academy of mining,[2] but nothing was done about it until 1765. On November 13 of that year, Prince Xavier, uncle and guardian of the young Elector Friedrich August, was at Freiberg, where he entertained members of the Dresden Court. And on that occasion it was decided that a public school of mining should be established at Freiberg.[3]

The selection of Freiberg as the site of the new school was not surprising. In the surrounding countryside there were approximately a hundred mines, in which the student could learn about virtually all the phases of mining then practiced anywhere. Almost every year a new mine, or an important addition to an old one, was undertaken, providing opportunities for instruction in the building of new mines as well as in the maintenance of old ones. In the eighty miles of passable underground tunnels and two hundred mine shafts, the student could learn the various methods used in extracting minerals from the different kinds of rocks and also about timbering and masonry walling of mines. The water necessary to drive many of the machines used in the mines was stored in seventeen

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[1] _Ibid._, pp. 129-131

[2] _Ibid._, p. 131.

[3] _Ibid._, pp. 132-133. See also _General-Gouvernements-Blatt für Sachsen_, III, 602-603.

large ponds and conveyed to the different mines through an intricate system of surface and underground canals, which totaled some eighty miles in length. The student would therefore have the advantage of studying the various phases of water-supply relative to mining. Only a few miles from Freiberg there was a large amalgamating plant, and the Freiberg mining district had twenty-five furnaces in which the ores were roasted and melted.[1]

The charter of the school was signed on March 22, 1766.[2] It provided a fund of 1200 thaler, which was to pay the salaries of teachers and stipends for promising students who could not afford to pay their own expenses. The same fund was also to pay for further training for exceptional students at the University of Leipzig and in the mines of foreign countries and for the minerals and models necessary for instruction. To the 1200 thaler were added an annual fund of 262 thaler and 12 groschen and a tax of six pfennig on every mark of silver mined in the Freiberg mining district. These were to help pay for the purchase of books, instruments, maps, and other teaching aids. Forty thaler was set aside for prizes which were to be given to the outstanding students of each academic year.[3] The Bergakademie was put under the direction of the ministry of finances, but the immediate supervision of the school was left to the chief superintendent of mines in concurrence with the Board of Mines. From time to time the Board of Mines met with the faculty of the

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[1]Breithaupt, <u>Die Bergstadt Freiberg</u>, pp. 131-132.

[2]<u>Ibid.</u>, p. 133.

[3]<u>General-Gouvernements-Blatt für Sachsen</u>, III, 603.

Bergakademie to discuss business concerning the school and its students.[1]

Originally it had been decided to use the Freiberg Castle as quarters for the academy, but because of the dilapidated state of the castle, the academy was housed in a building belonging to Friedrich Wilhelm von Oppel.[2] Von Oppel, later chief director of mines, who had been very instrumental in the establishment of the school, was so interested in the success of the new Bergakademie that he refused to accept the annual rent of fifty thaler for the use of part of his house.[3] The original quarters of the Bergakademie were three rooms on the ground floor of von Oppel's three story building. The largest of the three rooms was used for lectures and general examinations. The adjoining rooms housed the mineral collection, the library, the collection of models of various machines used in mining, and the maps and instruments.[4]

After Easter in 1766 the Bergakademie was ready to receive its first students. The faculty consisted of five people: Christlieb Ehregott Gellert, who was to teach metallurgical chemistry, Johann Friedrich Charpentier, who was to teach mathematics and physics, two other instructors, who were to teach mine surveying and assaying, and an inspector of the Bergakademie, who was in charge of the various collections.[5] The inspector was also to give instruction in mining, which consisted largely

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[1] Ibid., p. 606. [2] Ibid., p. 604.

[3] Festschrift 1866, pp. 71-72.

[4] Ibid. See also OW 130021-0031, "Werner's Proposal to the Board of Mines to buy the von Oppel House, 1791." The house became the property of the Saxon government in 1792. Festschrift 1866, p. 72.

[5] General-Gouvernements-Blatt für Sachsen, III, 603.

of explaining the workings of mining machinery with the help of the models in the collection of the Bergakademie and of some field trips to the mines. However, there was no coordination between the class instruction and the visits to the mines.[1] The inspector was also required to set aside the hours from two to five of two afternoons each week to discuss the various minerals in the Bergakademie collection with all those interested.[2] This instruction in mineralogy, however, was not considered to be part of the curriculum of the Bergakademie, but was offered only as a public service.[3] This was the faculty and curriculum available when Werner came to Freiberg in 1769 to enroll as a student at the Bergakademie.

In 1771 the inspector, Lommer, resigned from his job,[4] and the vacancy was not filled for several years. As a consequence, the course on mining was taught by Professor Charpentier,[5] and the semi-weekly demonstrations of minerals were discontinued. In 1775 it was felt that the position of inspector and teacher of mining should be filled, and, upon the recommendation of Pabst von Ohain, Werner was hired for the job.[6]

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[1] OW 130036, "Werner's Draft of a Report to the Board of Mines, 1795." See also OW 370009-0013, "Biographische Notizen."

[2] General-Gouvernements-Blatt für Sachsen, III, 603.

[3] OW 130046, "Werner's Draft of a Report to the Board of Mines, 1795." See also Festschrift 1866, p. 44; General-Gouvernements-Blatt für Sachsen, III, 603, 605.

[4] Festschrift 1866, p. 9.

[5] OW 080011, "Werner's Report to the Board of Mines for the Academic Year 1775-76, May 12, 1776."

[6] See above, p. 63, note 2.

When Werner returned to his alma mater, the curriculum was still the same as it had been in his student days, and metallurgical chemistry, physics, mathematics, mine surveying, assaying, and mining were the only courses for which the teachers were paid by the state.[1]

Werner's first year as a member of the faculty of the Bergakademie was a busy one. He spent much of his time in rearranging the mineral collection and familiarizing himself once more with the library and the map and model collections, which he had not seen for several years.[2] As inspector of the Bergakademie, it was his job to enlarge the collections, to buy and catalog books and journals, and to keep a running account of the expenses involved in the various purchases and in the upkeep of the collections.[3] Like his predecessor, he was also to set aside sufficient time for discussion and demonstration of minerals, and he was to be available to visitors who might want to see the school and its collections of minerals and mining models. And he was to offer one course, in mining. He was therefore a combination librarian, curator of collections, bookkeeper, teacher, and building superintendent. The school authorities, realizing that he would need some time to become familiar with the job, excused him from teaching the course on mining during his first year at the Bergakademie, and Charpentier was asked to lecture on that subject

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[1] General-Gouvernements-Blatt für Sachsen, III, 605. See also OW 130035-0047, "Werner's Draft of a Report to the Board of Mines, 1795."

[2] OW 08011, "Werner's Report to the Board of Mines for the Academic Year 1775-76, May 12, 1776."

[3] OW 080029-0031, "Werner's Report to the Board of Mines for the Academic Year 1776-77, April 13, 1777." See also General-Gouvernements-Blatt für Sachsen, III, 605.

during the academic year of 1775-76.[1] Werner had only to give the instruction on minerals which was open to the public. Five students took advantage of this public service,[2] but four of them were also enrolled in a course on mineralogy which Werner was offering privately and for which he was collecting an honorarium. He could not collect his fee from two of the twenty-five students who signed up for this course, since the Board of Mines had assigned them to his lectures.[3] He expressed some displeasure at this, and in several communications to the Board of Mines he tried to make it clear that he would admit students assigned to him by the Board free of charge, but only because of his generosity and not because the students were entitled to it.[4] He always distinguished between the course on mineralogy which he offered privately and the instruction that he gave as a public service, calling his own course "mineralogie privativa" and the other "mineralogie publica."[5]

From the beginning of his career at the Bergakademie until his death, Werner worked for the improvement of the school. He introduced new methods of teaching; he enlarged the curriculum, improved the library and mineral collections, and established better coordination between the practical and theoretical instruction in courses taught by others as well

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[1]OW 080011, "Werner's Report to the Board of Mines for the Academic Year 1775-76, May 12, 1776."

[2]Ibid.

[3]OW 080006-0008, "Letter from the Board of Mines to Werner, June 21, 1775."

[4]OW 080010, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, May 12, 1776."

[5]OW 080025-0026, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1777."

as in his own. He suggested that all students be required to keep a journal in which they should enter all their experiences connected with their training and that these should be made available to the instructors upon demand or at a fixed time.[1] This suggestion was accepted by the Board of Mines, who agreed with Werner that writing is an aid to learning, that it improves the memory, and, since the keeping of such a journal requires time, it also helps to keep the students out of mischief.[2]

As curator of the library Werner seldom had sufficient funds to buy the books and journals that he considered absolutely necessary for the education of the students, and in 1777 he proposed to the Board of Mines that each student be charged an enrollment fee and that the money be used for the purchase of books and journals. This proposal was accepted.[3]

More important were the changes in the curriculum introduced by Werner. Many of the courses which Werner taught were added to the curriculum only after he had offered them privately for several years, charging an honorarium from those who could afford it and admitting many without charge.[4] In the academic years of 1789-90 and 1796-97 he taught

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[1]OW 080174, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 10, 1784."

[2]OW 080041-0042, "Letter in the Name of Frederick August, Elector of Saxony, to the Board of Mines at Freiberg, May 31, 1777."

[3]OW 080023-0025, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1777."

[4]See Appendix I, pp. 253-254, below, for a list of courses taught by Werner during his tenure at the Bergakademie and the official curriculum of the school in 1825.

a course on metallurgy of iron (Eisenhüttenkunde);[1] in 1797-98 he offered a course entitled Enziklopädie der Bergwerkskunde,[2] in which he gave a very general treatment of all subjects connected with mining, including geology and mineralogy, so that the student could become familiar with the whole field of mining. This course was repeated in 1799-1800.[3] In the academic year of 1800-01 he gave a course on the history of the Saxon mining industry, which he said "would arouse in the students more interest in mining and the study of mining, as well as their patriotism."[4] In the same year he also offered a course dealing with the Freiberg mining district.[5] In the academic year of 1802-03 he taught a course on the literature of mineralogy, and in 1813-14 he offered courses in mining economics and the duties of mining officials.[6]

In 1788 Saxony experienced a shortage of wood and as a result began a concentrated effort to find more combustible materials. Consequently Werner inaugurated a geologic survey of Saxony, mapping not only coal, but all minerals. This survey was not concluded until after his

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[1] OW 080265, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1790"; OW 080475, "Lektions-Tabelle auf das mit Ostern 1797 eintretende 31ste akademische Lehrjahr, für den Unterricht in der Bergbaukunst und Mineralogie, eingereicht von Abraham Gottlob Werner. Freiberg den 5ten May 1797."

[2] OW 080498, "Announcement by Werner of Courses he will teach in the Academic Year 1797-98, June 7, 1797."

[3] Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 270.

[4] OW 140015, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, May 26, 1801."

[5] Ibid., 0014-0015.

[6] Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 270-271. See also General-Gouvernements-Blatt für Sachsen, III, 605.

death.[1]

It was due to Werner's influence that a course in German composition was introduced at the Bergakademie,[2] and he was also the chief mover in the building of a chemical laboratory, completed in 1797, and the importation of a man to teach the "new chemistry" of Lavoisier.[3] The official register of the Bergakademie and the rules of conduct, a list of which was given to each academist at the time of enrollment, were other innovations introduced by Werner.[4]

In these innovations, as in many other aspects of Werner's life, we see the combination of the practical with the theoretical. Although he was well aware of the necessity of training his students, he was also firmly convinced of the necessity of educating them. He was strongly dedicated to the idea of learning, believing that it makes those who have it "humane and therefore truly beneficent, loved and honored by others."[5] Among his notes there is the following statement:

> Learning ennobles princes. With what dignity does history present to us Marcus Aurelius, illumining his memory into the most distant generations. Would we know the age of Augustus as the golden age of the Roman Empire if this great emperor had not fostered, protected, and admired the sciences and the arts?
> . . . .
> Learning frees nations from the oppressive shackles with which superstition enchains them, degrading them to infamous servitude. . . . It . . . has changed mad barbarians into peaceful, industrious, inventive and noble citizens. . . .[6]

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[1]Breithaupt, Die Bergstadt Freiberg, pp. 149-150. See also OW 070001-0112, "Verordnungen und Rescripte die geognostischen Landes untersuchungen betr. von 1791-1815."

[2]Beck, p. 17.

[3]Festschrift 1866, p. 72. See also Frisch, p. 170.

[4]OW 080023-0025, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1777."

[5]OW 380002, "Werner on Learning." [6]Ibid., 0003-0004.

Of all the branches of learning, Werner believed science to be the most important. He wrote: "If anything deserves the earnest, ardent consideration of the enlightened and thinking citizen concerned for the good of the world and his country, it is surely the furthering of science, which pushes enlightenment further and further."[1]

It is not surprising that a man so convinced of the value of learning should make his mark in the world as a teacher. And Werner's lasting fame in the world of geology was achieved largely through the courses that he taught at Freiberg and the influence that he had upon the students who came to attend them. Chief among these courses were mineralogy and the first part of his course on mining, which he later called geognosy.

Werner considered his course on mineralogy a prerequisite to all courses dealing with the history and composition of the earth's crust, and for that reason he offered it almost every year. However, it did not become an official part of the curriculum of the Bergakademie until 1788.[2] Werner divided this course into two parts. The first dealt primarily with explanations of the different characteristics of minerals, and for this he used his own work Von den äusserlichen Kennzeichen der Fossilien as a text. The second part of the course was devoted to a systematic presentation of minerals, for which he used a German translation of Axel Cronstedt's Försök til Mineralogie eller Mineral Rikets Upställning as a text. But more than anything else, he used the minerals themselves. He always made sure that every student had adequate opportunity to examine

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[1] Ibid., 0006.

[2] General-Gouvernements-Blatt für Sachsen, III, 605.

the minerals used to illustrate the lectures.[1]

In 1788 Werner changed the name of the course to oryctognosy,[2] because he wanted to give the term mineralogy a broader meaning, including in it all subjects dealing with the mineral kingdom. The nature of the course did not change, however, since he defined oryctognosy as the study of the identification of minerals.[3]

During the many years that Werner taught the course he attracted students from all corners of the world. Some of them were already famous by the time they came to Freiberg; others were beginners, many of whom later became well known in the field of mineralogy or in some other field. Among those who attended Werner's lectures on mineralogy was the well known chemist and Fellow of the Royal Society of London Robert Chenevix (1774-1830), who had received the Copley gold medal "for his various chemical papers printed in the Philosophical Transactions"[4] before he came to Freiberg in 1804.[5] Other students were the royal Portuguese

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[1]OW 080009, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, May 12, 1776."

[2]OW 080233-0234, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 5, 1788." In this report Werner referred to the course as Mineralogie oder vielmehr Oryktognosie; in subsequent reports he referred to the course only as Oryktognosie. See OW 080244, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 20, 1789."

[3]OW 450002, "Notes taken in Class in Werner's Course on Geognosy, 1808." Since OW 45 consists entirely of these class notes and is very voluminous, it will be referred to hereafter by number only. For a fuller discussion of the theories and systems presented in Werner's course on mineralogy, or oryctognosy, see Chapter IV, below.

[4]Robert Hunt, "Chenevix, Richard," Dictionary of National Biography, IV, 186.

[5]OW 130015, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, June, 1805."

chargé d'affaires at Berlin, Piñehiro, and professors Gmelin from the University of Tübingen, Zimmermann from the University of Magdeburg, Paraga from the University of Madrid, and Sinerowitch from the University of Vilna.[1] In 1792 the man who was later to become the principal founder of Brazilian independence, Bonifacio José de Andrada (1765-1838) enrolled at the Bergakademie[2] after attending the lectures of Lavoisier and Haüy in Paris.[3]

Among those who received their first training in mineralogy from Werner and later became well known in the field was Carl Friedrich Mohs (1773-1839). Mohs came to Freiberg in 1798, where he studied under Werner for two years. After Werner's death in 1817, he was invited to teach mineralogy at Freiberg, and during his tenure at the Bergakademie he wrote his famous work on mineralogy, Die Charakteristik der Klassen, Ordnungen, Geschlechter, und Arten der Mineralien,[4] in which he based his mineralogical system primarily on crystal form.[5] Mohs was also the inventor of a hardness scale by which the relative hardness of minerals is determined by pushing a pointed corner of one firmly across the flat surface of the other. This hardness scale is still used today and is often referred to as the Mohs hardness scale.

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[1] Ibid.

[2] Festschrift 1866, p. 235.

[3] Ferdinand Denis, "Andrada E Sylva (Bonifacio Jozé DE)," Nouvelle Biographie Générale, Vol. II, cols. 539-545.

[4] Friedrich Mohs, Die Charaktere der Klassen, Ordnungen, Geschlechter und Arten; oder, die Charakteristik des naturhistorischen Mineral-Systems (Dresden: Arnoldische Buchhandlung, 1820).

[5] Gümbel, "Mohs: Friedrich M.," Allgemeine Deutsche Biographie, XXII, 76-79. See also Festschrift 1866, p. 44.

In his second year at the Bergakademie Werner offered his course on mining for the first time. He met his class of twenty-four students twice a week, using von Oppel's revised edition of Kern's Bericht vom Bergbau[1] as a syllabus for the course. Even as a student at the Bergakademie he had been dissatisfied with the way the course was taught. He thought that the lectures had been unintelligible, that the method used was not suitable for the purpose in mind, and that because of the lack of coordination between the lectures and the field trips to the mines much time was wasted.[2] Furthermore he believed that two hours a week was not sufficient time for a course that included so much material. In his very first annual report on the teaching of mining he made several proposals which he believed would improve the course, as well as other courses.

Werner suggested to the Board of Mines that all students who attended the Bergakademie on a stipend should be required to write a paper to be handed in at the end of the academic year, and before the student applied for another stipend. He thought that first year students could be asked to write a lesser report and that more advanced students might be asked to write descriptions of various mining operations, such as ore dressing or the conveying of ores from the mines. Students who were nearing the end of their training, he suggested, should be required to write a description of a whole mining district, including the natural

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[1]Johann Gottlieb Kern, Bericht vom Bergbau, revised edition by Friedrich Wilhelm von Oppel (Leipzig: Siegfried Lebrecht Crusius, 1774). See OW 080020-0021, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1777."

[2]OW 130036, "Werner's Draft of a Report to the Board of Mines, 1795." See also OW 370009-0013, "Biographische Notizen."

and political history of the district, or to write opinions as to the feasibility of introducing certain mining procedures into a mine, or to prepare a financial statement for a mine.[1] Werner's suggestions were accepted,[2] and he began to assign papers to all of his students, always taking into consideration the ability and inclination of the student. In a report written in 1787 he stated that "this time too I made no assignments except on materials on which I had lectured in the course just finished. Furthermore, I chose short topics suitable to the abilities, occupation, and chosen career of the student, . . ."[3] In the preparation of these yearly papers Werner gave his students very little help, considering the reports as a test in which the student would have an opportunity to show his talents and diligence. He took a similar position on final examinations, testing the students only on materials that he had discussed in class, but giving them no hint of the nature of the questions or how to prepare for the examination. He hoped that this would force the students to review the whole course and would give each one another chance to show his talents.

Werner also introduced a writing laboratory which he called Elaboratorium practicum, because he found that "almost all academists were lacking in the ability to write mining reports."[4] Every week he met with

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[1]OW 080026-0029, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1777."

[2]OW 080042, "Letter in the name of Frederick August, Elector of Saxony, to the Board of Mines at Freiberg, May 31, 1777."

[3]OW 080230, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, 1787."

[4]OW 080023, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 13, 1777."

his students for two hours, during which time he instructed them in the preparation of reports, read the pages that they had already written, and made comments and corrections.[1] Thereby he not only helped the students but also became more intimately acquainted with them.

Werner gave a very detailed course on mining, including much of the current literature on the various related subjects. He taught his students how to use a miner's compass and how to determine the strike and dip of beds of minerals. He lectured on searching for minerals, how to judge whether or not a certain district or rock formation might be worth mining, how to determine whether an old mine was worth continued exploitation, how to lay out a new mine, and how to lay out canals to convey water to and from the mines. He demonstrated the use of various mining tools, such as the miner's sledge hammer, and showed the students how to bore and blast. He explained the differences in hardness in rocks, about which he wrote an article entitled "Von den verschiedenen Graden der Festigkeit des Gesteins . . .,"[2] and he lectured on the different ranks of miners and their wages, on timbering and walling of mines, on the mechanism of the various machines employed in mines and how to operate them, on ore dressing, and on ventilation of mines.[3]

As a consequence of the detailed instruction in virtually all the phases of mining, Werner was seldom able to finish his course by the end

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[1]OW 080061, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 4, 1778.

[2]"Von den verschiedenen Graden der Festigkeit des Gesteins, als dem Hauptgrunde der Hauptverschiedenheiten der Häuerarbeiten," Bergmännisches Journal, I (1788), pp. 4-21.

[3]OW 080076-0078, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, April 4, 1778."

of the year. In 1778 he got no further than the second part of the text and had to lecture on the remainder of the course in the following year. He very soon realized that he could not possibly handle all of the material in one course. In his annual report dated April 4, 1778, he announced that he would treat the first part of the course on mining separately. This part of the course dealt with the earth's surface and the rocks and rock formations which form the earth's crust. In the Bericht vom Bergbau this subject was covered in only thirty-eight pages, but Werner made a two hour course of his material, meeting his students twice a week for an hour. He named the course Lehre von den Gebirgen.[1]

It was this course which was developed from his course on mining, and which he was later to call geognosy, that established Werner's fame in the world of geology and attracted students from all over the world. Although Werner was not the first to work in this field, he was, as Keferstein writes, "the first to bring this knowledge to the academic lecture, to treat it as a separate science, to try to define all related subjects and give a clear understanding of them; and thus he shaped a science of material which had long been at hand."[2] It was the course on geognosy that made possible the statement of Cuvier: "It is thus that within a few years the small school at Freiberg, founded only for the purpose of training some mining experts for Saxony, reproduced the spectacle of the Middle Ages in that students from all civilized countries flocked there and in the most distant countries men already advanced in

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[1] Ibid.

[2] Christian Keferstein, Geschichte und Litteratur der Geognosie (Halle: Johann F. Lippert, 1840), pp. 66-67 (translation by the author).

age and renowned as scholars hastened to study the German language solely to prepare themselves to go and listen to the great oracle of geology."[1]

And men did come from all parts of the world to attend Werner's lectures. In the official enrollment sheets of the Bergakademie and in Werner's own reports are listed students from Russia, Poland, Sweden, Norway, Denmark, Brazil, Spain, France, Mexico, Italy, England, Scotland, Ireland, and several other foreign countries as well as from practically every state in Germany. Werner himself believed the course on geognosy to be especially important. In a lecture given near the end of his career he said of geognosy:

> No science deserves more to be taught everywhere than ours. It will come to pass that lectures such as mine will be arranged and prepared elsewhere. Then it will become the object of the teachers of geognosy to train their students in geognostic investigations and practices, and this will lead us to a general, concrete knowledge of our solid earth.[2]

In spite of the ultimate importance of the course, Werner had considerable difficulty in introducing it. The first time that he offered it he had enough students, because he admitted everyone who was taking his course on mining that year.[3] When he offered it again in the academic year of 1780-81, however, he could find no students interested enough to take the course. He tried again in 1781-82, a year in which he also

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[1]Georges Cuvier, Recueil des Éloges Historiques lus dans les séances publiques de L'institut Royal de France (Paris: F. G. Levrault, 1819), II, 310-311.

[2]Beck, pp. 20-21.

[3]OW 080075, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, March 6, 1779."

offered a course on mineralogical geography, but with no more success than in the previous year. In the academic year of 1782-83 he scheduled a course in which he combined his Lehre von den Gebirgen with mineralogical geography, and, late in the year, he was able to find a few students. Werner must have become discouraged with the lack of interest in a course which he considered so important, for he did not schedule it for two years. He tried once more in 1785-86, but still without success. Finally in the academic year of 1786-87 he offered the course as Gebirgslehre or Geognosy, and this time he found enough students to enroll in it.[1] From that year on the course was offered every year.

The course was divided into two parts and lasted for about nine months, the class meeting twice a week.[2] The first part of the course was a general treatment of geognosy, and the second part was a detailed study of the various rocks and rock formations which compose the earth's crust.

Werner defined geognosy as that part of mineralogy which familiarizes us systematically and thoroughly with the conditions of our solid earth--the sum total of all minerals--with its relationship to all known natural bodies outside it, with the circumstances of its internal and external formation, the differences between them and the reasons for the

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[1]OW 080124-0125, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, February 19, 1781"; OW 080149-0150, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, March, 1782"; OW 080161, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, March, 1783"; OW 080216-0217, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, [1787]."

[2]In 1813 Werner lectured four times a week and covered the material in less than three months, January 14 to March 27, 1813. See OW 460001-0278, "Lecture Notes taken by August Breithaupt."

differences.[1] Werner began his course on geognosy with this definition.[2] He then proceeded to a discussion of the place of geognosy within the realm of the earth sciences.

According to Werner geognosy was one of the five branches of mineralogy, the other four being oryctognosy, mineralogical chemistry, mineralogical geography, and economic mineralogy. He considered oryctognosy, which deals with the recognition of the external characteristics of minerals, and mineralogical chemistry, which deals with the chemical composition of minerals, to be prerequisites to the study of geognosy, because a knowledge of the mineral composition of rocks is necessary to the study of the relationships between different rocks and rock formations. On the other hand, he believed that mineralogical geography should be studied together with geognosy, because both deal with large mineral masses, mineralogical geography in a concrete way, geognosy in an abstract way. He considered the study of fossils a subdivision of geognosy and the history of individual minerals, the literature of mineralogy, and the history of mineralogical literature subsidiary branches of geognosy.

Werner emphasized that the chief concern of geognosy is the study of the external and internal formation of the earth.[3] Geognosy is also

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[1]OW 450002.

[2]Werner gave the following reason for his use of the word geognosy instead of geology: "The name geognosy is composed of the Greek words geo and gnosis and actually means knowledge, that is, abstract knowledge, of the earth. However, some mineralogists say geology instead of geognosy, but this is wrong, because logos has a generic meaning, and geology would therefore include geography, geogeny, and mineralogical geography as well as geognosy." OW 450006-0007. See also OW 460007, "Lecture Notes taken by August Breithaupt, 1813."

[3]OW 450002-0004.

concerned with the shape of the earth and with the different forms of the earth's surface, such as mountains, hills, valleys, rivers, and plains. Furthermore it is a history of our earth, since it explains how the earth's surface developed. "Geognosy," said Werner, "is a history of the events of our solid earth, which leads us into the most distant past, in contrast to which written history is only a point in time. It has an advantage over written history in that it leads us to undeniable truth."[1] Geognosy aids the study of history, for it by itself sets forth an important part of the history of nations.

Werner thought that the study of geognosy was useful and important in many walks of life. The miner, he said, cannot succeed without some knowledge of geognosy. Even if he does not have scholarly training in it, he must have empirical knowledge of it, "because he has to know what the different kinds of rocks which he intends to work are, so that he will know what useful minerals he can expect, since these occur in different places but always in a distinct way. He must know where the different mineral deposits occur, so that he will know where to look for them and so that he will be able to build mines in such a way that they will be suitable for the object in mind." Geognosy is also extremely important to the economy of the state: "those who guide the destiny of a nation must be concerned with the extraction of that wealth within the earth which will make the country prosperous; though culture and agriculture bring wealth, the effusion of wealth from mining is far greater; because of it many countries have been able to gain great strength for

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[1]OW 450010.

great undertakings."[1]

Werner told his students that every thinking and educated person should have the desire to learn about the earth on which he lives, "about those things which, when we leave our homes, are touched by our feet and seen with our eyes." He believed that the student should not only have the desire to learn about the earth but should "consider this science as the one that will fill a void in our knowledge which no one had ever imagined that it would be possible to fill."[2]

According to Werner, geognosy is based on principles which the geognost arrives at through his own experience or derives from mineralogical geography. It is based on theorems taken from various other sciences, such as physics, biology, and chemistry. Furthermore geognosy also includes corollaries which the geognost derives from these theorems and principles. And finally geognosy is based on common sense. He added that the geognost tries to avoid all conjectures, does not build on hypotheses, and is always careful to mark hypotheses as such.[3]

Werner concluded the introductory part of his course with a discussion of the physical and mental qualities that the student of geognosy should have and what other subjects he should have studied before undertaking the study of geognosy. He believed that the student must be in good enough physical condition to be able to do field work; that he must have the ability to observe; that he must be inquisitive and love to do research; and that he must have a good memory. The student of

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[1]OW 450011-0012.

[2]OW 450009-0010.

[3]OW 450008-0009.

geognosy, he thought, should also have an imagination that is vivid but at the same time reflective, "for if his imagination is too vivid, it will result in more images than are necessary, and whatever he might establish will not be according to nature."[1] The student must have a good sense of judgment in order to distinguish between the true and the false, the certain and the uncertain; thus he will be able to bring together his experiences, compare them with each other, and draw conclusions from them. These conclusions are the most essential part of geognosy. The geognost must be able to synthesize, "otherwise his work and the results of his work will be disconnected and fragmentary,"[2] and he must have a love of truth, "because many have too great a love for their own premature and worthless systems, which they do not like to abandon even though nature contradicts them."[3]

Besides having training in oryctognosy and mineralogical chemistry, Werner thought, the student of geognosy should have some knowledge of other sciences. Training in zoology and botany is useful, because the remains of organisms in the earth are extremely important objects in the study of the earth. Some knowledge of atmospherology is helpful, since water, air and fire are agents which are responsible for important changes in the earth. A knowledge of chemistry is important, "because nature's effects on the mineral kingdom are to a large extent chemical."[4] Since astronomy sheds some light on the formation of the earth, some knowledge of it is useful, and Werner believed that the

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[1]OW 450014.

[2]OW 450014-0015.

[3]OW 450015.

[4]OW 450016.

geognost is benefited by some training in mathematics. What can be learned from books and from experts is not enough, however; the student must combine classroom knowledge and what can be learned from books with the study of nature itself.[1]

Werner began the next section of the course with "some general remarks about our solid earth, which every educated man can readily observe." "When we cast a glance at our solid earth," he began, "it appears to us as a solid body or a solid mass which floats in the universe."[2] He tried to make his students aware of the immensity of the universe, pointing out to them the infinitely large number of the heavenly bodies which are dispersed in space. From the heavens, which are at a great distance from the earth, Werner passed on to a brief discussion of the atmosphere, which is immediately next to the earth and completely surrounds it. He pointed out the effects of the atmospheric bodies--air, water, and fire--on the earth, such as weathering and erosion, and then went on to consider in a very general way and very briefly the inner structure of the earth. He remarked that the earth consists primarily of earth and rock masses; that these are deposited in layers one above the other; and that the most elevated regions usually consist of rock masses, while the lower regions are made up largely of earth, sand, and gravel. A closer investigation of the rock masses, he said, reveals that there is a gradation of the materials of which they consist as one proceeds from the higher to the lower elevations. The rock masses which occupy the highest points consist largely of siliceous and argillaceous materials, while those which occur in the lower regions

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[1]OW 450020. [2]*Ibid.*

are more calcareous and argillaceous. There is also a gradation in the structure of the rocks, those which make up the highest points of the earth's surface being crystalline, then becoming less so as the rocks become more calcareous and argillaceous. The lower regions of the earth consist largely of layers of sandstones and conglomerates, which frequently alternate with layers of limestone. Furthermore, there is an abundance of organic remains in these stratified rock masses, the remains of marine life predominating in the higher regions, the remains of plant life in the lower regions.[1]

Considering these general remarks, Werner formulated a number of questions. How did the earth get its spherical shape, which it has in common with the other heavenly bodies and with a drop of water? What caused the unevenness and the ruggedness of the earth's surface? What is the reason for the differences in the masses which form our solid earth? What causes the rocks which form the highest points of the earth's surface to be crystalline in nature? What is the reason for the occurrence of large number of organic remains in rocks?[2] He believed that the answers to these questions would shed much light upon the formation and alteration of the earth.

Werner believed that astronomy might provide the answers to some of these questions, and therefore he devoted considerable time to a discussion of various aspects of it. He explained to his students the nature of the solar system, the movements of the planets, the earth, and comets. He discussed Newton's theory of gravitation, using it to explain the paths of the different heavenly bodies. He gave his students the

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[1]OW 450027-0029. [2]*Ibid.*

sizes of the different planets and their distances from the sun, remarking that "seemingly in the very beginning of the universe, the larger heavenly body took possession, so to speak, of the smaller ones, since the latter are guided solely by the attraction of the sun."[1] He lectured on the size, shape, and surface forms of the moon and pointed out what seemed to him to be similarities between the moon and the earth. He believed that there are fires, similar to volcanoes, on the moon, that the moon has an atmosphere, that the depressions which can be seen on the surface of the moon are filled with a fluid, and that some parts of the moon are denser than others.[2]

Werner ended his discussion of the moon by remarking that it can be supposed "that those mighty forces which guide the planets about the sun must be the reason for the spherical form of these bodies, and also for the spherical form of the earth."[3] He gave the then current proofs for the spherical shape of the earth. He spoke of the circumference of the earth at the equator and at the poles, pointing out that "these measurements, . . . , confirmed Newton's theory, and at the same time established as an undeniable truth that our earth must have been formed from a fluid mass--one of the most important principles which follow from it."[4]

After discussing the path of the earth around the sun and the reasons for the different seasons,[5] Werner finished the section on astronomy by giving his students a brief list of readings on the subject,

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[1]OW 450034.

[2]OW 450036-0038.

[3]OW 450038.

[4]OW 450045.

[5]OW 450048-0050.

including Bode's Allgemeine Betrachtungen über das Weltgebäude, Anleitung zur allgemeinen Kenntniss der Erdkugel, and Von den neu entdeckten Planeten and Gehler's Physikalisches Wörterbuch.[1] This list indicates that Werner was informed concerning current scientific literature, since the edition of Bode's Allgemeine Betrachtungen über das Weltgebäude which he recommended to his students was published in the same year in which the lecture was given.

Werner followed his discussion of astronomy with some very general remarks about the distribution and presence of organic bodies on the earth and then compared the occurrence of living organisms with the occurrence of organic remains in the crust of the earth. He noted that in the seas, rivers, and lakes we find few true plants and a very large number of animals, but on land the reverse is true. In the waters we find a tremendously large number of fish, but none on land. On land we find all the birds, and none in the sea. In the waters crustacea are far more abundant than on land, and insects, which form the largest group of animals, are more abundant on land. The amphibians, which are the mean between land and aquatic animals, belong to the land as much as to the waters, but more live in fresh water than in the sea. There are numbers of "worms"[2] in the waters, but relatively few on land. The largest group

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[1] Johann Elert Bode (1747-1826), Allgemeine Betrachtungen über das Weltgebäude (3rd edition; Berlin: Knechtische Buchhandlung, 1808), Anleitung zur allgemeinen Kenntniss der Erdkugel (Berlin, 1786), Von den neu entdeckten Planeten (Berlin: Dümmler, 1784); Johann Samuel Traugott Gehler, Physikalisches Wörterbuch oder Versuch einer Erklärung der vornehmsten Begriffe und Kunst der Naturlehre in alphabetischer Ordnung, 4 Vols. (Leipzig: 1787-1791). OW 450050.

[2] In the English translation of Gmelin's last edition of Linné's Systema Naturae, worms is the sixth class of the animal kingdom. The

of living organisms in the seas are zoophytes, which form the transition from plant to animal life. Werner then spoke briefly about the effects of climatic conditions on the distribution of different plants and animals, and he pointed out that there is a greater abundance of living things in the temperate zones than in the tropical and polar regions.[1]

In comparing the present distribution of animals and plants with the distribution of organic remains as they are found in the rocks of the earth's crust, Werner remarked that in some rock masses no organic remains are found and that most organic remains are found in those rock masses which are of a newer origin; that the remains of land animals are fewer than those of water animals; that the organic remains always occur in a certain order, so that one stratum includes an entirely different species of organic remains than does the stratum beneath it or above it. From this Werner concluded that the places where we find organic remains were once the natural habitats of these plants and animals. Furthermore, since the remains of water organisms occur in much greater abundance than remains of land organisms, it follows that most rock formations which include organic remains were formed from water. Werner also remarked that the climatic conditions of the world must once have been very different, because remains of tropical plants and animals are found in parts of the

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animals of this class are described as of "slow motion, soft substance, able to increase their bulk and restore parts which have been destroyed, extremely tenacious of life, and the inhabitants of moist places. Many of them are without distinct head, and most of them without feet. They are principally distinguished by their tentacula or feelers." They are divided into five Orders: I. Intestina. II. Mollusca. III. Testacea. IV. Zoophyta. V. Infusoria. Linné, System of Nature, IV, 3-4.

[1]OW 450052-0055.

world which no longer have climates suitable for such plants and animals.[1]

Even though Werner lectured only very briefly on organic remains in his course on geognosy, he considered them important enough that he said in one of his lectures that "it is the immediate province of geognosy to consider petrifactions in their most interesting relations, which, when viewed in a proper light, tend greatly to illustrate the history of the Earth, as indicating the various, and successive general, and partial, catastrophes, to which it has been subject."[2] In the academic year of 1799-1800 he offered lectures on petrifactions as a supplement to his course on geognosy, meeting his geognosy class on Wednesday and Saturday afternoons from two to three o'clock and the class on petrifactions on the same days from three to four o'clock.[3] He offered the course on petrifactions again in the academic year 1802-03, but he could find no students interested in the course.[4] But he never failed "to fix the attention of his pupils on the relations that exist between certain fossils and the formations of different ages."[5]

At least one of Werner's students made the study of paleontology his life work and became one of the outstanding pioneers in that field.

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[1]OW 450055-0060.

[2]Abraham Gottlob Werner, A Treatise on the Characters of Fossils, trans., Thomas Weaver (Dublin: Mahon, 1805), pp. 137-138.

[3]OW 130131, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, May, 1800."

[4]OW 130138, "Werner's Annual Report of Subjects Taught and Proposed Schedule for the Coming Year, 1803."

[5]Alexandre de Humboldt, A Geognostical Essay on the Superposition of Rocks, in both Hemispheres, trans. unknown (London: Longman, Hurst, Rees, Orme, Brown, and Green, 1823), p. 67.

It has been said of him that "he can be considered the founder of a new scientific treatment of petrifactions in Germany."[1] This student, Ernst Friedrich, Freiherr von Schlotheim (1764-1832), enrolled at the Bergakademie in 1791[2] and studied at that school for two years. During that time he attended Werner's lectures on geognosy,[3] and it was possibly from them that he acquired his great interest in the study of fossils. In 1791 Werner included a report by von Schlotheim in his book Neue Theorie von der Entstehung der Gänge, remarking that von Schlotheim's investigations in Thuringia concerning the occurrence of petrifactions in mineral veins were the best on the subject and that he knew that he could rely on the work of his student.[4] It was not until 1792, however, that von Schlotheim decided to make the relations between fossils and rock formations the principal object of his study, much to the delight of Werner.[5] Von Schlotheim's first monograph, Beiträge zur Flora der Vorwelt, was published in 1804.[6] In 1820 he published his most extensive work, Petrefactenkunde auf ihrem jetzigen Standpunkte, to which he

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[1]Gümbel, "Schlotheim: Ernst Friedrich Freiherr v. S.," Allgemeine Deutsche Biographie, XXXI, 551.

[2]Festschrift 1866, p. 234.

[3]Humboldt, A Geognostical Essay on the Superposition of Rocks, in both Hemispheres, p. 67.

[4]Abraham Gottlob Werner, Neue Theorie von der Entstehung der Gänge (Freiberg: Gerlachische Buchdruckerei, 1791), pp. 76-77.

[5]Humboldt, A Geognostical Essay on the Superposition of Rocks, in both Hemispheres, p. 67.

[6]Ernst Friedrich Freiherr von Schlotheim, Beiträge zur Flora der Vorwelt, oder Beschreibung merkwürdiger Kräuter Abdrücke und Pflanzen-Versteinerungen (Gotha: Becker'sche Buchhandlung, 1804).

added supplements in 1822 and 1823.[1] In the 1823 supplement he included an account of the characteristics of fossils in the Thuringian Muschelkalk (shell limestone) which is considered to be of fundamental importance to the study of the subject. The plates which are included in this work show all types of animal life, "which were, for the first time in Germany, named according to the binomial nomenclature."[2]

Werner's remarks on petrifactions were followed by a lengthy discussion of the inequalities of the earth's surface. Werner considered this an important part of the course, since he believed that the geognost must be able to recognize the boundaries between one mountain range and another, between mountain ranges and mountainous land, between hilly country and plains, in order to be able to set the boundaries for a geognostic investigation of a district or region. He devoted seven lectures to the differences in the earth's surface, defining every term, no matter how simple. He explained the differences between highland and lowland, between a mountain range (Gebirge) and mountainous country (Bergiges Land), between a plateau and a plain, as well as the differences between the more specific parts of a mountain or a mountain range, such as slopes, peaks, and mountain ridges. A highland he defined as a region at least five hundred miles long and of similar width

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[1]Ernst Friedrich Freiherr von Schlotheim, Die Petrefactenkunde auf ihrem jetzigen Standpunkte durch die Beschreibung seiner Sammlung versteinerter und fossiler Uberreste des Thier-und Pflanzenreichs der Vorwelt erläutert (Gotha: Becker'sche Buchhandlung, 1820); Nachträge zur Petrefactenkunde (Gotha: Becker'sche Buchhandlung, 1822, 1823).

[2]Karl Alfred von Zittel, History of Geology and Palaeontology to the End of the Nineteenth Century, trans., Maria M. Ogilvie-Gordon (London: Walter Scott, 1901), p. 126.

consisting of mountain ranges, groups of mountains, and hilly country which gradually passes into lowland. A mountain range is a very uneven region of considerable elevation, several miles in length and of comparable width, in which the inequalities are arranged in a series so that they form a cohesive whole. According to their length Werner divided the mountain ranges into three groups. Those which are 150 miles or more long he called major mountain ranges (Hauptgebirge); those between 50 and 150 miles in length he called medium mountain ranges (Mittlere Gebirge); and those less than 50 miles long he called minor ranges (Kleinere Gebirge). He classified a mountain range more than 6000 feet high as high (Hohes Gebirge), one between 3000 and 6000 feet high as a medium range (Mittleres Gebirge), and one between 600 and 3000 feet high as low (Niederes Gebirge). Anything below 600 feet high he considered as hilly country or plains. Mountainous country reaches the

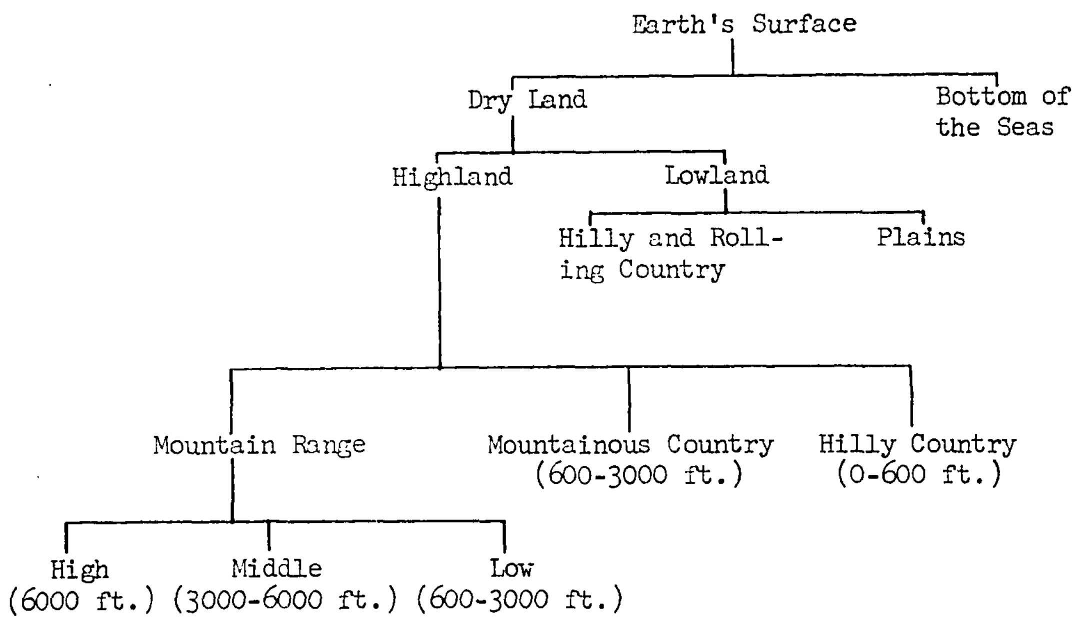

Fig. 2. Schematic presentation of Werner's division of the earth's surface.

same height as low mountain ranges, that is, 600 to 3000 feet. The main difference between a mountain range and mountainous country, however, is that the latter consists of small groups of mountains or single isolated mountains which do not form a cohesive whole, like a mountain range. Werner also taught his students how to determine the direction and size of mountain ranges; he discussed the relations between mountain ranges and valleys; and he treated briefly the inequalities of the lowlands.[1]

In the next section of the course Werner considered what he called "atmospheric bodies"--water, fire, and air--with regard to geognosy. He began by describing how these substances act and then discussed their effects on the earth's crust. Of the three atmospheric substances, he considered water to be the most important; and the largest portion of the discussion was devoted to it. He put the various forms in which water is precipitated into three categories: vaporous, fluid, and dry.[2] He described the movements of the waters in the seas, distinguishing between continuous and periodic movements and between general and partial movements. Thus he considered ocean currents to be continuous and general, since they occur constantly and are worldwide, but ebb tide and flood tide he considered to be periodic and general. River currents at the mouth of a river are examples of continuous and partial movements, since they are ever present but affect only a relatively small area of the sea into which the river empties; and partial and periodic movements of the seas are caused by various kinds of air currents, such as cross currents, trade winds, whirlwinds, and various kinds of storms. "Usually,"

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[1] OW 450060-0095.

[2] OW 450099.

he said, "we think of the waters in the universal basin, that is, in the seas, as being calm; but this is not true: on the contrary they are subject to all kinds of movements."[1]

Having finished the discussion of the movements of the waters and the kinds of precipitation, Werner took up the contents of the waters of land and sea, remarking that water is almost never found in nature in a pure state--that is, consisting solely of hydrogen and oxygen.[2] Usually water contains many foreign bodies, he said, and these can be separated into four groups: earths, salts, combustibles, and metals.[3]

Werner considered fire to belong partly to the atmosphere and partly to the earth itself.[4] He considered subterranean fires important because of their destructive and constructive effects, and, according to the manner in which they manifest themselves, he divided all subterranean fires into earth fires and volcanoes. Earth fires, he said, burn very slowly and may last for hundreds of years. Their presence can be detected in heat on the surface of the earth, in cracks and fissures in that surface, in rising vapors, and sometimes even in the appearance of flames. They usually occur in low regions; and a place where an earth fire has been can be recognized by the presence of such materials as earth slag and porcelain jasper. Werner called such rocks, which he considered to have been altered by earth fires, pseudo-volcanic rocks.[5]

Volcanoes seemed to Werner to be of far greater importance than earth fires,[6] since their destructive and constructive effects are more

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[1]OW 450104.

[2]See below, p. 153.

[3]OW 450111.

[4]OW 450121.

[5]OW 450123.

[6]_Ibid._

significant and pronounced. They can be recognized, he said, by their conical shape, by their craters, by their violence in ejecting lava and other stones, and by the earthquakes which usually accompany active volcanoes.[1] Volcanoes frequently raise hills and small mountains. Werner attributed the temperature of hot springs to underground combustible materials, especially smoldering beds of coal.

The discussion of the nature of the atmospheric bodies was concluded with a few remarks about earthquakes. These are of three kinds, Werner said. The most violent ones, which are caused mostly by volcanoes and subterranean explosions, result in a vibrating motion of the earth, either to and fro or circular. The second kind result from cave-ins and make themselves felt in an up-and-down movement of the earth. Werner believed that a third kind of earthquake is caused by "some kind of electricity."[2]

In discussing the effects of air, water, and fire on the earth's crust, Werner separated these into destructive and constructive effects, which he treated in turn according to whether they are caused by chemical or mechanical action. He thought that the most telling effect of air is weathering, that is, a transition in the consistency of a mineral from a solid to a friable or earthy state. This, he explained, is the result of a chemical change in the mineral brought about by hot, cold, humid, and dry air. Felspar is the most important mineral affected in this manner.[3] Far more important, however, is the action, particularly the mechanical action, of water. Most valleys, Werner said, have been eroded

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[1] OW 450124.

[2] OW 450136.

[3] OW 450139.

by continuously running waters, such as brooks, streams, and rivers. Water also causes landslips, particularly in mountainous regions. Many cave-ins result from the absorption of large quantities of water by some rocks, increasing their weight to a point where the rocks on which they rest can no longer support them. The expansion of rock masses brought about by freezing of water in the rocks is another destructive effect of water which Werner believed to be of some importance. The effects of the sea along the coast and also eddies and whirlpools belong to the mechanically destructive forces of water.[1]

Werner believed that the constructive and destructive effects of water work hand in hand, for rock masses which are broken up in one place are deposited in another. The harder and larger pieces are carried the shortest distance from their original place, the softest and smallest the farthest, so that a progression from large to small pieces and from hard to soft ones can be noticed in rock masses which are the result of the mechanical constructive effects of water. Werner also pointed out that water frequently combines with organic materials to form turf and coal and that there is a progression from the newest sod, through pitchpeat, to brown coal and anthracite, "so that in each formation we can recognize that it is a mineral formed by water from the vegetable kingdom."[2]

After discussing the effects of earth fires and volcanoes,[3] Werner ended his discussion of the atmospheric bodies by giving a list of characteristics by which to determine whether a rock or mineral was formed

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[1]OW 450141-0150.

[2]OW 450155-0156.

[3]OW 450158-0162.

by fire or by water.[1]

In the final portion of the first, or general, part of the course on geognosy, Werner dealt with the internal structure of the earth, discussing the structure of rocks, rock masses, and rock formations, the structure of the earth's crust as a whole, and the relations of the internal structure of the earth's crust to its external structure.[2]

Werner divided all rocks into two large groups: the simple, or homogeneous, rocks and the compound rocks. By definition, simple rocks are composed of one single mineral; thus when other minerals are occasionally found in them, these are regarded as only accidental occurrences. Compound rocks are composed of more than one mineral, being either cemented or aggregated.[3] The aggregated rocks were further divided into several categories, depending upon the internal structure of the rocks.[4]

Under the heading of Struktur der Gebirgsmassen, Werner discussed stratification and jointing of rock masses. He considered the study of stratification especially important, "because the determination of rock formations is based on it, and at the same time it is also the clue to the study of the formation of the earth."[5] If a rock mass consists of layers of the same rocks, he called the layers strata; but if the rock mass consists of an alternation of different rocks, he called the layers beds. He discussed the position and shapes of strata and beds and how

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[1]For a summary of these characteristics, see Chapter IV, pp. 167-168, below.

[2]OW 450169-0285.

[3]OW 450172.

[4]OW 450172-0181.

[5]OW 450181-0182.

to determine their extent and direction. "All strata," he said, "are separate precipitations. . . ,"[1] and he pointed out that this can best be recognized where layers of different rocks are found deposited one above the other. He divided his discussion of jointing into three categories: columnar jointing, as in basalt; globular jointing, which he said can sometimes be seen in granite; and tabular jointing, which can be found in porphyry.

"By a rock formation," Werner said, "we understand those rock masses which were formed in one period."[2] A rock formation may be composed of only one kind of rock, as is usually the case with granite formations, or it may consist of several kinds of rocks, as, for instance, in a clay slate formation, where beds of whetslate, alum slate and others occur along with clay slate. Similar rocks may be repeated in different periods. Each of these depositions is a rock formation, and the whole is called a series, or suite, of formations.[3]

In dealing with the different stratigraphic relations of the rock masses which compose the earth's crust,[4] Werner took into consideration the following relations: the original extent of the formations, the present extent of the formations, the relations of the strata of one formation to those of the underlying formation, and the relation of the outcrops of the strata of one formation to the outcrops of the formation upon which it rests.[5] He believed that most rock formations were universally deposited, that is, that they at one time covered the whole earth.

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[1]OW 450186.

[2]OW 450195.

[3]OW 450195-0199.

[4]OW 450195-0225.

[5]OW 450201.

A few formations, however, are isolated and very different from all universal formations. These, he said, must be considered exceptions, and he called them partial or anomalous formations.[1] The present extent of a rock formation is often quite different from its original extent. Different causes, such as the mechanical and chemical action of the atmosphere and water, have brought about the destruction of parts of original deposits so that parts of originally universal formations are often found in isolated portions of little extent, resembling partial formations. Werner distinguished between broken formations and partial formations on the basis of the frequency of occurrence of the isolated parts and their stratigraphic relations.[2]

Next Werner discussed the relations of the strata of a rock formation to those of an underlying formation. If the strata of both formations have the same direction, they are conformable; if their directions are different, they are unconformable. Werner distinguished between several kinds of unconformities. He then compared the outcrops of the strata of two superimposed rock formations, talked briefly about rock fissuring, and then presented a lengthy discussion of the relation of the internal structure of the earth to its external structure.[3] He finished the general part of the course with a discussion of the various changes to which the solid earth has been subjected.[4]

The second part of the course was devoted to a detailed

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[1]OW 450202.

[2]OW 450201-0211.

[3]OW 450225-0235.

[4]OW 450235-0285. Werner's theories on the internal structure of the earth are discussed in Chapter IV.

investigation of the different rock formations of which the earth's crust is composed and a discussion of mineral deposits. It ended with a lecture on the applicability of geognosy to mineralogical geognostic investigations.[1]

Much that Werner included in his course on geognosy was neither new nor significant, particularly when the different parts of the course are considered by themselves without reference to the course as a whole. There was nothing very startling in his remarks about astronomy, for instance, for what he taught was only current theory. Likewise, his discussion of the topography of the earth's surface included little that was not known before. What is significant is the course itself when considered as a whole--what he included in the course, how he arranged his materials, and how he correlated them with each other and with the study of the earth's crust. Werner recognized that the study of earthquakes, physical geography, stratigraphy, fossils, petrography, dynamic geology and many branches of practical geology taught today are part of the study of the earth. How clearly he grasped the object of some of these studies can be seen in his thorough and logical arrangement of the materials on atmospheric bodies, for instance. From the lectern of the small Bergakademie of Freiberg, a systematic treatment of the study of the earth was presented for the first time in the history of geology, bringing students from virtually all the countries in Europe and from all walks of life to Freiberg to study with Werner. Among them were students who later became ministers, lawyers, businessmen, statesmen,

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[1]The theories which Werner put forth as the basis for this part of the course are discussed in Chapter IV.

artists, bookdealers, and writers. Counts, barons, and sons of nobility sat side by side with mining officials and sons of poor miners. In 1787 James Watt, son of the inventor, enrolled at the Bergakademie, as did Dr. Heinrich Struve, professor of chemistry at the University of Lausanne. Freiherr von Spillner, later an officer in the Saxon army, attended Werner's classes together with John Hailstone, Woodwardian professor of geology at Trinity College, Cambridge; Jens Esmark from Denmark, later professor of mining and mineralogy at the University of Christiana; and José Bonifacio D'Andrada, liberator of Brazil. Alexander von Humboldt came to Freiberg to study under Werner in 1791, the year in which von Schlotheim first enrolled.[1]

Many of Werner's students became famous in the field of geology. Besides von Humboldt, von Schlotheim, Esmark, and Hailstone, there were Diedrich Ludwig Karsten, Andrés Manuel Del Río, Leopold von Buch, Johann Carl Freiesleben, Henrik Steffens, Jean André Marie Brochant de Villiers, Jean François d'Aubuisson de Voisins, Robert Jameson, Friedrich August Breithaupt, Carl Friedrich Naumann, and many others.[2]

And so within the forty-two years of Werner's tenure at the Bergakademie it grew from a small local school offering only a few courses in mining and mineralogy to an internationally known institution offering a complete curriculum in geology. This growth can be attributed mainly to the efforts and reputation of Werner. Between 1771 and 1814, 108 students from countries outside the Germanies were officially

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[1] Festschrift 1866, pp. 232, 234-235.

[2] Ibid., pp. 221-249. For a discussion of the work of some of Werner's students, see Chapter V.

enrolled at the Bergakademie at Freiberg.[1] Only two of these came before 1775, the year that Werner began his teaching career, and only fifteen before 1786, the year in which the course on geognosy became firmly established. As the fame of the Bergakademie grew, other schools became interested in the science of geology; and it came to pass, as Werner predicted, that other teachers prepared lectures such as his and geology became an accepted academic discipline.

And just as Werner was important to the Bergakademie, the little school became the most important part of his life. On the occasion of the negotiations in 1814 by which he left his mineral collections and other property to the school, he wrote:

> This day is one of the happiest of my life. It is the day on which . . . I leave the largest part of my property to the royal Bergakademie. Thus I bequeath the dearest part of my possessions to that scientific institution through which I have made all my contribution to mineralogy, which is dear to me above all things, and which I have fostered with the greatest zeal for almost forty years. In the evening of my life I am filled with joy to see the scientific seed which I have sown over all the countries of Europe, nay almost over the whole world, bearing fruit. . . .[2]

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[1] Ibid. See also General-Gouvernements-Blatt für Sachsen, III, 604.

[2] OW 370015, "Biographische Notizen." See also Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 284-286.

CHAPTER IV

WERNER'S MINERALOGICAL AND GEOLOGICAL THEORIES

Although Werner is known today primarily for his work in geognosy, he first gained recognition for his work in mineralogy. It was the success of his book on the external characteristics of minerals that gained him his teaching position at Freiberg and thus paved the way for all his subsequent work in both mineralogy and geognosy. And although his mineralogical theories were less far-reaching in their ultimate influence than his geognostical theories, they were widely known and used in his own day and in many respects offered real improvement over those of his predecessors.

Mineralogy is the science which deals with the classification and description of minerals, mineralogical classification being primarily concerned with determining relationships between minerals, whereas the prime object of mineralogical description is the identification of minerals. Identification, however, particularly in the absence of rigid standards of description, depends to a large extent on classification, since a classification, in which objects are arranged in some kind of sequence, affords a means of comparison.

At the time Werner's book Von den äusserlichen Kennzeichen der Fossilien was published, mineralogists were divided in their opinions as to the best method of classifying minerals, some believing that the natural history method was the best, others that the chemical method was most suitable. In the former, the minerals were arranged in much the same way that plants and animals are arranged in biological classifications, according to their external characteristics; in the latter, the minerals were arranged according to their chemical properties and affinities in their chemical make-up. The mineralogists of these two schools of thought sometimes lost sight of the twofold aim of mineralogy, the work of the adherents of the chemical method being devoted almost entirely to classification and that of the adherents of the natural history method almost entirely to description. This raised the question of whether mineralogy was an academic pursuit designed solely to demonstrate the relationships among the different parts which form the earth, whether it should be solely a practical study designed to aid the miner, or whether it should satisfy both the student of natural history and the man interested in the extraction of mineral wealth from the earth. For it is one thing to identify a mineral by its chemical properties and chemical reactions and quite another to give a description of it based upon direct sense perception.

The state of the development of chemistry and the absence of a universally understood terminology added to the difficulties of late eighteenth century mineralogists. Accurate analysis of the chemical composition of minerals was not possible, and communication between mineralogists was difficult. What, for instance, was meant by describing a mineral as green, hard, and of a granular texture in which the grains are large? There are many shades of green and different degrees of hardness, and "large" is a vague and indeterminate term. The lack of a universally understood terminology affected not only the description of minerals but also the names of minerals, which differed in many instances from country to country and from author to author. Finally, there were no commonly accepted definitions of a mineral species or even of a mineral.[1]

In the introduction to his book on the external characteristics of minerals, Werner wrote that "every science has its value; only in this do they differ, that one is of wider use and more closely related to everyday life than another." Of all the sciences, mineralogy is "one of the most generally useful, and to civilized society almost indispensable."[2] And the function of mineralogy, Werner thought, is the classification and description of minerals. "When I open a work on mineralogy in order to learn something from it," he wrote, "I do so to acquire a general knowledge of that science, to obtain a complete conception of some mineral which I know only by name, or to find out the name of some mineral which I have found and know by its external appearance, and what place it occupies in the system of minerals."[3] But he considered the accurate description of minerals to be by far the most important function of mineralogy. "I would rather have a mineral badly classified and well described," he wrote, "than well classified and badly described."[4]

It seemed to Werner that there were two prime obstacles to the

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[1]Compare, for instance, Linné's _System of Nature_, Vol. VII, and Cronstedt's _Försök til Mineralogie_.

[2]Abraham Gottlob Werner, _Von den äusserlichen Kennzeichen der Fossilien_ (Leipzig: Crusius, 1774), p. 13 (translation by the author).

[3]_Ibid._, p. 15 (translation by the author).

[4]_Ibid._, p. 31 (translation by the author).

progress of mineralogy. One was that many mineralogists, confounding their subject with other sciences, included in their treatments matters that did not properly belong to mineralogy, neglecting things that are important to it. The other obstacle, which Werner believed to have more serious consequences in the development of mineralogy, was the tendency of the mineralogists of his day to base the whole science either upon external characteristics or upon the chemical make-up of minerals. He pointed out that mineralogists who adhere to one system to the exclusion of the other forget that it is one thing to place a mineral in a system and another to know a mineral from its external appearance, and that both methods must be used if both ends are to be accomplished.[1]

Werner was of the opinion that mineralogy should combine the study of chemical characteristics and external characteristics of minerals, for the reason for the differences among minerals lies in their chemical composition, and these differences are expressed in the external characteristics. He wrote that "minerals down to their species must be classified according to their composition (Mischung),"[2] since that is the most accurate way to determine the natural succession or sequence of minerals. Once this has been established, then the external characteristics may be used to identify the minerals. Werner also pointed out that the methods used to classify plants and animals are not applicable to the mineral kingdom. Plants and animals consist of different parts, that is, of different organs, and the reason that one plant or animal

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[1] Ibid., pp. 16-18.

[2] Ibid., p. 20 (translation by the author).

differs from another lies in the differences of their parts and, above all, in the different aggregation and arrangement of these organs. In minerals, on the other hand, the reason for the essential differences must be sought in their chemical constitution, and not in the aggregation of the parts, for no matter how many times we divide a mineral mechanically, the smallest part still has all the characteristics of that mineral. If a plant is cut up into small pieces, the pieces can no longer be considered a plant, but cinnabar, for instance, ceases to be cinnabar only after it has been chemically decomposed into mercury and sulphur.[1] Werner then formulated this question: "Since it is certain that whenever minerals change in their chemical composition they also change in their external appearance, could not the order or succession of minerals be found in their external characteristics just as they can be found in their chemical composition?" And he answered: "It is possible to perceive through the external characteristics of minerals the different relations of their chemical composition, provided both have been previously determined; however, the sequence of these relations cannot be discovered in them; . . ."[2] Wherever possible Werner used the chemical analyses of minerals of the leading chemists of his day, particularly those of Martin Heinrich Klaproth (1743-1817).[3]

In his book Von den äusserlichen Kennzeichen der Fossilien, however, Werner was primarily concerned with the external characteristics

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[1] Ibid., pp. 20-29.

[2] Ibid., p. 26 (translation by the author).

[3] See Carl August Siegfried Hoffmann, ed., "Mineralsystem des Herrn Inspektor Werners mit dessen Erlaubnis herausgegeben . . . ," Bergmännisches Journal, I (1789), 369-398.

of minerals, which he believed to be the easiest to use and most reliable means by which to describe a mineral.[1] In this book Werner explained what external characteristics are, gave each characteristic a denomination, defined every term, giving examples to convey a better understanding of them, and arranged all the characteristics according to what he called a natural order. The book therefore also provides a classification of the external characteristics of minerals.

Werner listed seven common (allgemeine) characteristics, arranging them in the order in which he thought they present themselves to our senses: color, cohesion, touch, temperature, weight, smell, and taste.[2] The specific characteristics, being merely "the differences or varieties of a generic character," were arranged in the order "in which the generic character varies and in which they pass one into another." The varieties of the specific characteristics were also arranged in this manner.[3]

Werner listed eight principal colors that are common to minerals,[4] and for each of the eight he gave their variations, fifty-four in all.[5] The following is a typical Wernerian definition of a color:

> Mountain green [Berggrün] is a light bluish-green color which seems to be mixed with a little gray. Celadon-green also belongs to this variety. Its name is borrowed from that artist's color with which

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[1] Ibid., p. 43.

[2] Ibid., 1ste Tafel, facing p. 86.

[3] Ibid., p. 84 (translation by the author).

[4] Ibid., 2te Tafel, facing p. 128.

[5] In a table of the external characteristics of minerals which Werner sent to his student Robert Jameson, he listed eighty-four color varieties. Robert Jameson, A Treatise on the External Characters of Minerals (Edinburgh: Printed at the University Press for Bell & Bradfute, Guthrie & Tait, and W. Blackwood, 1805), pp. 1-4.

> it agrees. Examples which are found among minerals are green hornstone, green talc-earth, and aquamarine; however, in the last it is very pale.[1]

This definition may seem crude, but in the absence of any standards, it was a great improvement over the mere naming of a color, which was the practice in other treatises on mineralogy of that time. Werner was attempting to establish standards of some kind that could be easily understood by both students of mineralogy and miners.

Besides giving variations of the different principal colors, Werner also included intensity of color (Höhe der Farbe)--dark, clear, light, and pale--and variegated colors.[2] In later years he added to these play of color, mutation of color, and delineation of color, such as dotted, spotted, nebulous, and striped.[3]

The section on the common generic character cohesion is by far the most elaborate part of Werner's treatise. Under this heading minerals were divided into solid, friable, and fluid minerals, and under each of these headings were listed a large number of particular generic characteristics. For example, external form, external surface, external luster, internal luster, fracture, and the form of the fragments are all particular generic characteristics of a solid mineral, and crystallization is a specific characteristic of the particular generic characteristic external form.[4]

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[1]Werner, Von den äusserlichen Kennzeichen der Fossilien, p. 112 (translation by the author).

[2]Ibid., pp. 95-98.

[3]Werner, A Treatise on the External Characters of Fossils, pp. 68-72. See also Jameson, A Treatise on the External Characters of Minerals, p. 5.

[4]Werner, Von den äusserlichen Kennzeichen der Fossilien, 1ste Tafel, facing p. 86.

The interesting feature of Werner's whole treatment of external characteristics is not only the great number of characteristics listed, but the fact that there is a definition of some kind for each of these, that all are arranged in a system, and that the definitions given are such that they convey an image from everyday life, so that the uneducated, the practical geognost, and the student of natural history could all understand what was meant by each term. Such terms as coralliform (zackig), kidney-form or reniform (nierenförmig), cellular, perforated (durchlöchert), corroded (zerfressen), rough, smooth, and streaked are familiar to most people even without a definition, but they become even clearer when they are accompanied by explanations and examples from the mineral kingdom.

Werner believed that much confusion existed in mineralogy because of the lack of quantitative definitions. In the section of Von den äusserlichen Kennzeichen der Fossilien that dealt with the size of crystals, he remarked that as long as parts of the human body, such as the hand, arm, foot, and thumb, are used as standards, there has to be much variation. But since no one of the several measures used in different countries can be imposed upon the public as a universal standard, he wrote, ". . . I have endeavored to discover some kind of general measure for the determination of the magnitude of crystals, which is so much the more necessary in that the sizes cannot be very accurately determined otherwise."[1] With this view in mind Werner tried to combine in his definition those things which he believed to be familiar to all mineralogists, regardless of where they lived. He gave seven sizes of mineral

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[1]Ibid., p. 191 (translation by the author).

crystals, deriving their relations from the magnitude of crystals themselves. "These I have determined not only by mentioning the crystallizations to which they principally belong," he wrote, "but also by showing what approximate relation they bear to our customary measures in common life."[1] The seven sizes were: uncommonly large, very large, large, middling, small, very small, and minute. These measures apply to the length, breadth, and thickness of the crystal. The following is a typical definition:

> Very small includes all those crystals from an eighth of an inch down to the smallest size in which the form can be distinguished with the naked eye. Very small corneous silver-ore cubes, very small tinstone grains, very small green uran-mica cubes are of this size.[2]

It is difficult to say how much of an improvement this definition of a very small crystal was, but it does represent an attempt to introduce quantitative standards that would be intelligible to mineralogists everywhere. By giving examples and an approximate size based on the magnitude of crystals themselves, Werner provided a means of comparison that was perhaps more widely understood in 1774, the year his book was published, than a definition which gave only a linear measure such as an ell or a foot.

Although Werner's work on the external characteristics of minerals was very detailed, it did not form the basis of his mineral system, which was founded "on the natural differences and alliances among the minerals," which Werner believed depended "on the quality, quantity, and

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[1] *Ibid.*, pp. 191-192 (translation by the author).

[2] *Ibid.*, p. 193 (translation by the author).

combination of the constituent parts."[1]

Werner defined minerals "as those independent, mechanically simple, chemically compounded inorganic natural bodies which together make up the solid earth and which are found in and under the surface of the earth."[2] By the qualification "which together make up the solid earth and which are found in or under the surface of the earth," Werner hoped to exclude air, water, fire, ice, and snow from the mineral kingdom. But he had some difficulty with mercury and petroleum, since both are fluids and therefore do not strictly help to make up the solid earth.[3]

Werner divided all minerals into four classes: earths, salts, combustibles, and metals, considering these as the fundamental constituent parts of all minerals.[4] In the last revision of his mineral system,

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[1]Robert Jameson, System of Mineralogy, comprehending Oryctognosy, Geognosy, Mineralogical Chemistry, Mineralogical Geography, and Oeconomical Mineralogy, Vol. I (Edinburgh: A. Constable, 1804), p. xxiii.

[2]Excerpt from Werner's "Classificationslehre," quoted in Frisch, p. 53 (translation by the author). The efforts of the author to obtain a copy of this important work have so far been unsuccessful. The facts of the publication of this treatise are of some interest. In 1814 Werner had prepared a manuscript entitled "Abhandlung über Klassifikazion überhaupt und über mineralogische Klassifikazion insbesondere." Through the intercession of his friend Böttiger, Werner hoped to have the work published by Cotta in Tübingen as soon as he could prepare some tables to accompany the manuscript. Somehow the editor of the monthly Hesperus, Christian Karl André, came into possession of the manuscript and, without Werner's permission, published it in the September, October, and November issues of Hesperus. When Werner learned of this he was very much annoyed and was unable to explain how André had obtained the manuscript. Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 282-283.

[3]Frisch, pp. 54-55.

[4]Werner, Verzeichnis des Mineralien-Kabinets des Pabst von Ohain. See also "Mineralsystem des herrn Inspektor Werners mit dessen

the class of earthy minerals included nine genera, the salts four genera, the combustibles four genera, and the metals twenty-two genera. In all there were 317 species.[1] The genus was determined "by the predominating or characterizing earthy, saline, inflammable, or metallic matter."[2] Werner, however, was not very strict in adhering to his definitions, a good example being his classification of the diamond among the earths. He was fully aware that chemists had analyzed the diamond as a form of carbon, but he did not pay any attention to the analysis or to his own dictum that all minerals down to their species[3] should be classed according to their constituent parts. He wrote:

> The diamond, this so remarkable and still so little known mineral, is by nature, according to its exterior, characterized wholly as an earthy mineral, as a stone. Its geognostic occurrence also speaks for its place among the earths, because the diamond, as far as is known, occurs only with and among other stones, and not among combustible minerals, among which it has recently been classed. All uses which are made of it are as a stone. And finally, its identification is not helped in any way by placing it, in lectures and mineral collections, among earth pitch, the three coal species, graphite, and so forth; but it is helpful to place it with the far

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Erlaubnis herausgegeben von C. A. S. Hoffmann," Bergmännisches Journal, I (1789), 369-398. In this mineral system 181 species were listed.

[1]Abraham Gottlob Werner, Abraham Werner's letztes Mineralsystem. Aus dessen Nachlasse auf oberbergamtliche Anordnung herausgegeben und mit Erläuterungen versehen (Freyberg: Craz und Gerlach, 1817).

[2]Jameson, System of Mineralogy, I, xxv.

[3]According to Werner all those minerals that agree in external characteristics and internal composition belong to the same species. He explained that "in the animal and vegetable kingdoms each plant and animal constitutes a whole, possesses a determinate form, each individual exhibits an essential difference, and is capable of definition. In the mineral kingdom each fossil cannot be considered as an individual, but merely as a part of that immense individual, the globe; hence it is evident that, accurately considered, there exists but one mineral species or individual, which is the globe." Ibid., p. xxvi.

> more similar zircon and the other gems. Let the mineralogical chemist regard this stone as one of the coals and place it among them; but he should permit the oryctognost to act according to the purpose he has in mind when placing the diamond in an oryctognostic system.[1]

Werner did not pretend "that his arrangement shall always correspond with the experiments of the chemist; for it is only when chemical results agree with the natural alliances of the mineral that he gives them a place in his system."[2]

Werner tried to combine the best features of both methods of classifying minerals, that is, the natural history method and the chemical method, and he was constantly guided by the practical aspects of both and by his conviction that science must be related to everyday life. In the absence of standards and accurate analyses, the emphasis in his "mixed method" of classification was on external characteristics.

Besides making use of the external and chemical chracteristics of minerals, Werner also used physical characteristics, such as responses to rubbing or heating and the effects shown by a mineral when touched by a magnet; geognostic characteristics, which show the association of minerals in the field and which Werner believed threw some light on the chemical make-up and chemical properties of minerals; and geographic characteristics, which are determined from the place of origin or local situation of minerals. "All these four mentioned characteristics chemical, physical, geognostic, and geographic ," he wrote, "can at least be considered and used as supplementary and adjunctive in the determination

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[1]Frisch, pp. 62-63 (translation by the author).

[2]Jameson, System of Mineralogy, I, xxiv.

of mineral species."[1]

The first sketch of Werner's mineral system appeared in the first part of his translation of Cronstedt's Försök til Mineralogie in 1780. In that work he made many additions and corrections, thus giving the first glimpse of his own system. Anything that he added to the original text was printed in smaller type, to enable the reader to distinguish between what was Cronstedt's and what was Werner's. This edition of Cronstedt's work was to be published in two volumes, but the second was never published. The remainder of the translation was found in manuscript form among Werner's literary remains.[2]

In 1791 Werner published the first volume of a catalog of the mineral collection of Pabst von Ohain, his friend and benefactor. In it Werner presented his concept of a mineral system, including all the steps of his classification and the different characteristics which he thought necessary for a complete classification and description of a mineral. The second volume of the catalog was published in 1794.

Werner was very cautious in making additions to his system, often waiting several years and examining the works of other mineralogists with great care to make sure that a mineral was thoroughly described before incorporating it into his system. In spite of this caution, however, his work on the external characteristics of minerals and his mineral system did not remain unchanged, for he was constantly adding new minerals and finding new characteristics by which to describe them. This is reflected

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[1]Werner, Von den äusserlichen Kennzeichen der Fossilien, pp. 33-34 (translation by the author).

[2]Frisch, p. 164.

in the work of his student Robert Jameson,[1] which gives a far greater number of external characteristics of minerals than Werner had given in Von den äusserlichen Kennzeichen der Fossilien. By the time of the publication of Jameson's work, which includes a tabular view of external characteristics provided by Werner, Werner had added a whole new section dealing with distinct concretions, defining them as "those masses into which certain minerals are naturally divided, which can be separated from one another without breaking through the solid or fresh part of the mineral."[2] The section on crystallization was much enlarged; and in the tabular arrangement of all the external characteristics of minerals, eleven pages out of a total of thirty-two are devoted to crystallization.[3] Werner was aware of the work of the Frenchmen René Just Haüy (1743-1822) and Jean Baptiste Louis Romé de l'Isle (1736-1790) in crystallography and called the attention of his students to this important branch of mineralogy. However, he considered crystallography to be a special branch of mineralogy, believing that the principles upon which it is based are not applicable to the entire mineral kingdom and therefore could not form the basis for a system that would include all minerals.[4]

Although he leaned heavily upon external characteristics in his own work, Werner was convinced of the importance of chemistry in the study of minerals. He encouraged his students to study chemical analysis, and at the time of the founding of the Dresden mineralogical society he

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[1] A Treatise on the External Characters of Minerals.

[2] Ibid., pp. 70-71. [3] Ibid., pp. 1-32.

[4] Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 300-301.

made it Blöde's duty to see to it that several chemists would always be permitted to become members of the society.[1]

Werner probably thought of himself primarily as a mineralogist, and he considered mineralogy the most important branch of the earth sciences because "it forms the foundation of geognosy and mineralogical geography."[2] But because of the wide renown of his theories of the formation of the earth's crust, brought about largely by his own fame as a teacher and the conviction and devotion of a large number of his students, he was to be remembered by posterity chiefly for his work in the field of historical geology, the field that he called geognosy.

As we have seen, thought on the origin of the earth has revolved about two fundamentally different ideas since classical antiquity: one that the earth was formed by the deposit of materials which were suspended in a universal ocean, the other that the earth's crust was primarily the work of subterranean fires which melted the various materials making up the core of the earth and then ejected them, forming islands, continents, and the various layers of the earth's crust. In the eighteenth century these divergent views were represented by the works of Lehmann and Moro, and in earlier times in the works of Agricola, Steno, Albertus Magnus, Avicenna, Theophrastus, and others. Beginning with Agricola, observation began to play a more important role in discussions of these theories until, toward the end of the eighteenth century, very elaborate systems were worked out to give support to these hypotheses.

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[1] Ibid., p. 301.

[2] Werner, Von den äusserlichen Kennzeichen der Fossilien, p. 14 (translation by the author).

Of all the work done on the subject, no more detailed and far-reaching system was offered for either of the two theories than the one worked out by Werner, for Werner explained virtually every structure of the earth's crust, from the hand specimen to the largest rock formation, on the basis of the two major postulates of neptunism: that the earth was once covered by a universal ocean, and that the materials of which the strata of the earth's crust consist were at one time dissolved or suspended in that ocean.

Using the two postulates as a starting point, Werner proceeded to develop his theory to explain how the rocks which compose the solid earth's crust were formed and in what sequence they were deposited. He theorized that in the period during which the first rocks were formed the earth was uninhabited. Nothing living existed, and therefore no organic remains are found in these first precipitates, which he called uranfängliche, or primitive.[1] The ocean which covered the earth being very deep and calm at that time, the first precipitates were chemically pure and crystalline.[2] The rocks formed in this period consist primarily of siliceous and argillaceous minerals. These first precipitates formed granite, which is the most abundant rock. Werner believed that granite forms the foundation for all other rocks[3] and that it is found at the lowest as well as the highest points of the earth's crust.[4] After granite was formed, the waters of the ocean began to recede, so that gneiss, mica-slate, and clay-slate, which were subsequently formed, show an ever-falling level of their outcrops, but their strata are conformable. The difference

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[1] OW 450263.

[2] OW 450265.

[3] OW 450287.

[4] OW 450235.

in age among the rocks formed in the primitive period can be determined from the stratigraphic relations and the degree of crystallization of these rocks, the older ones being more crystalline than the newer ones.

Werner explained the occurrence of other rocks, limestone for instance, in gneiss, mica-slate, and clay-slate formations by the assumption that "the contents of the universal ocean must have varied from time to time."[1] In his book Von der Entstehung der Gänge, he wrote that "at different periods the universal solvent contained mixtures as various as the different precipitates and the universal waters held in solution at one time one substance, and at another, another; in short, from time to time, different substances have entered into and been retained in this solution."[2]

Werner theorized that, after the original waters receded, they rose again but without reaching their previous level. They were still calm, but not so calm as they had formerly been. The rocks which were deposited while these waters were receding show some signs of the mechanical action of water; their outcrops show a falling level; and their strata are conformable with respect to the strata of the rocks deposited from these same waters, but relative to the older rock strata, they are in unconformable or unconformable and overlying stratification.

Thus the first, or primitive, period of the earth's history had two parts, the first characterized by the falling of the original waters and the second by the rising and subsequent falling of the same waters. Werner listed the following rock formations as belonging to the primitive

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[1]OW 450253.

[2]Werner, Von der Entstehung der Gänge, p. 122 (translation by the author).

period: granite, gneiss, mica-slate, clay-slate, primitive limestone, primitive trapp, serpentine, porphyry, syenite, primitive quartz, topaz, flinty slate, and primitive gypsum.[1]

According to Werner's theory, the next period was one of transition. The relatively low-standing waters of the last part of the primitive period were calm at first, but gradually they became more stormy and violent. The rocks precipitated while the waters were still relatively calm were fairly crystalline and were deposited in a conformable position with the older rocks, at the feet of the mountains which these older rocks had formed. As the waters became more violent, however, their action destroyed many previously formed rocks as well as some living organisms, which had just begun to develop near the end of the primitive period. Part of the rocks formed from these stormy waters are chemical depositions and part of them are mechanical depositions. "It was during the transition period that the first, chaotic state gradually changed into a state capable of supporting life," Werner wrote, "and it is in the rocks of this period that we discover the earliest organic remains."[2] According to Werner, the transition rocks are far less extensive than the rocks of the primitive period, because they were formed long after the primitive rocks were deposited, from relatively low-standing waters. The transition rocks contain only three formations: transition limestone, transition trapp, and gray-wacke.[3] Of the three, gray-wacke is the most important, both because of its wide distribution and because of the ores which are found in it.[4] It is also

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[1]OW 450287-0288. [2]OW 450263.

[3]OW 450367-0368. [4]OW 450377.

the first distinct mechanical precipitate. The transition rocks form the connecting link between the primitive period and the floetz period.[1]

Werner's floetz period is characterized by storms and violence. While violent storms were raging in the low-standing ocean, life was developing in great abundance in those regions of the earth which were no longer under water. The fury of the waters destroyed much of the new life as well as many previously formed rocks.[2] Werner's student Leopold von Buch writes of this period:

> On walking upon the floetz rock formations, one finds himself, to his amazement and horror, among the ruins of a rich organic creation, whose existence in that period of formation one could hardly have dared imagine. There[among the primitive rocks] upon each step, newly formed and newly forming substances--here, the fury of destruction, which, as it seems, wanted to throw back all the forces which had given life into their previous state of inactivity. In the first period of formation a new nature seems to be forming, in this one only ruins. The germs of our present organic world saved themselves with effort, under the protection of the primitive rocks.[3]

Werner believed that the waters of the floetz period receded rather rapidly, leaving much of the material which they had destroyed behind. Some of these materials were deposited at the tops of mountains and some on the slopes, but most of them were deposited at the feet of the primitive mountains and in the valleys, giving the country a hilly, undulating appearance.

After the waters of the floetz period had abated, they rose once more, this time reaching a level higher than that reached by any previous waters.[4] At first these waters also were stormy, but not so stormy as the

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[1]OW 450386. [2]OW 450263-0264, 0386.

[3]Leopold von Buch, Geognostische Beobachtungen auf Reisen durch Deutschland und Italien, Vol. I (Berlin: Haude und Spener, 1802), pp. 84-85 (translation by the author).

[4]OW 450455-0457.

previous ones, and gradually they grew calmer. The deposits from them are therefore more regular and conformable. However, with respect to the depositions from the first waters of the floetz period, they are unconformable and overlying. The earlier depositions, because of the still stormy waters, were mechanical, but gradually, as the waters became calmer, the depositions became chemically purer, even showing some crystallization. Werner thought that these waters again became stormy as they receded, destroying some of the rocks which had been deposited from them, and this, he thought, was the reason for the broken stratification of these rock formations. The following rock formations were formed in the floetz period: sandstone, floetz-limestone, floetz-gypsum, salt, coal, and floetz trapp. Several of these, however, were deposited at various times during the long-lasting floetz period, as for instance the first, second, and third sandstone formations,[1] so that the geological column for this period takes the following form:

Chalk formation

Floetz trapp formation--consisting of basalt, wacke, porphyry slate, floetz greenstone, amygdaloid, graystone, floetz trapp-porphyry, sand, gravel, clay, coal, particularly brown coal, and clay-ironstone

Coal formation--consisting of black and glance coal, clay-slate, soft sandstone, conglomerate, hardened clay, porphyry, marl, limestone, and clay-ironstone

Third floetz gypsum formation, an example being the Montmartre region near Paris

Third sandstone formation--including quader sandstone

Muschelkalk formation, or second floetz limestone

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[1]OW 450397.

Second floetz gypsum formation--contains much clay, and the gypsum is frequently of a red color

Second sandstone formation, or variegated sandstone--containing roestone and sandstone slate

Rock salt formation--rock salt with clay, gypsum, stinkstone, and limestone

First floetz gypsum formation--contains stinkstone, alternating with layers of gypsum and selenite

First, or old, floetz limestone formation--including Kupferschiefer and Rauchwacke

First sandstone formation--also known as the old red sandstone.[1]

According to Werner, the rocks formed during the primitive, transition, and floetz periods were the only ones deposited from a universal ocean. The gradual receding of this ocean, which began in the primitive period and continued through the transition and floetz periods, was disrupted by two general inundations, or risings of the waters. One occurred in the primitive period and the other in the floetz period. Besides these general floods, there also occurred inundations of a more local nature, which were primarily caused by storms which raged at various times during the three periods and by local floods. The rocks which were deposited from the universal ocean were, generally speaking, put down in layers one above the other, much like the layers of an onion. But this is only a very much simplified version of Werner's theory:

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[1]The sources for the order and composition of the various formations in this geological column are as follows: chalk, OW 450461; floetz trapp, OW 450443-0445; coal, OW 450435-0436; third floetz gypsum, OW 450428; third sandstone, 450403; Muschelkalk, OW 450427; second floetz gypsum, OW 450427; second sandstone, OW 450400; rock salt, OW 450430; first floetz gypsum, OW 450425-0426; first floetz limestone, OW 450411; first sandstone, OW 450398-0400.

because of the differences in the contents of the ocean at different times and even in different places at the same time, and because of the stormy conditions, which did not always occur everywhere at the same time nor with the same intensity, there is a considerable variation in the depositions and in the sequence in which the rocks were deposited. For instance, the first, second, and third gypsum formations do not occur everywhere, and therefore we do not find the same rocks everywhere deposited one above the other. Werner does not even pretend that the depositions are universally identical in every respect.[1]

Werner saw two major problems connected with his theory of the universal ocean. One was to give an explanation of what had become of the immense quantities of water that had formed an ocean deep enough to cover even the highest mountains of our earth. The other was to explain the occurrence of two universal floods, especially since "when comparing the universal flood with present times, we are not aware of such changes, at least not in short periods of time."[2]

In explaining what had become of the water, Werner rejected the idea that the earth is hollow and that the waters disappeared into empty space beneath the surface of the earth.[3] Instead, he thought that he had found the answer in the then relatively new discovery that water is a chemical compound of hydrogen and oxygen.[4] "Fortunately," he wrote,

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[1]OW 450203. [2]OW 450244.

[3]OW 450239. This was the idea advanced by Lehmann. See Chapter I, p. 46, above.

[4]The chemical composition of water was discovered between 1781 and 1783. Joseph Priestley (1733-1804), Henry Cavendish (1731-1810), Antoine Lavoisier (1743-1794), and James Watt (1736-1819) have all been

Waters	Activity of the Waters	Nature of the Precipitates	Stratification	Rock Formations	Period
Third	Calm	Crystalline	Conformable	Floetz-trapp	Floetz
	Stormy	Mechanical	Unconformable and overlying	Floetz-trapp	
Second	Stormy	Mechanical (destroyed primitive and transition rocks)	Conformable, with sinking level of the outcrops	Floetz	Floetz
	Stormy	Fairly mechanical	Unconformable	Transition	Transition
	Less calm	Less crystalline	Conformable		
	Less calm	Less crystalline	Interrupted, unconformable and overlying	Newer Primitive	Primitive
First	Calm	Crystalline	Conformable	Older Primitive	Primitive

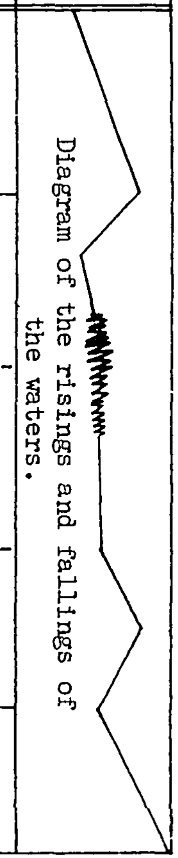

Fig. 3. A summary of the activity and the precipitates of the waters of the different periods.

"about twenty years ago, we learned what the chemical composition of water is and the nature of the process of its composition and decomposition. The two components are hydrogen and oxygen, which together form water, which in turn can be decomposed by various methods into these two substances. There is no doubt that nature used a large part of the universal ocean to form the atmosphere."[1] Werner remarked further that "other less significant causes may have contributed to the diminution of the waters, such as the translation of decomposed water in the communication of the heavenly bodies."[2]

Werner considered the two universal inundations as "exceptions to the rule,"[3] that is, to his general view that the waters had receded gradually and continuously. When we add even small quantities of sand to a container filled with water, he said, the water will soon run over because it has been displaced by the sand. Since large quantities of destroyed rocks and organic bodies are daily carried to the seas without appreciably raising the level of the oceans, it must be assumed that "there must occur a continuing diminution of the waters." On the other hand, there is much evidence, in stratigraphic relations and in destroyed rocks and organic remains in large quantities, to indicate that a flood occurred, and "we must assume its occurrence."[4] However, Werner could not explain the source of the waters which caused the two floods.

The fallings and risings of the universal ocean were a necessity

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given credit for the work. See Henry Cavendish, "Experiments on Air," Philosophical Transactions, LXXIV (1784), 119-153.

[1]OW 450241; OW 460194, "Lecture Notes taken by August Breithaupt."

[2]OW 450242. [3]OW 450245. [4]OW 450244.

to Werner's system, for they provided the highly flexible mechanism by which it was possible to explain the stratigraphic relations among the different kinds of rocks and their formations. Werner was convinced, for instance, that the most important porphyry formation belonged to the primitive period and that it was of aqueous origin.[1] He found no organic remains in it; he found it to be universal in extent and to contain very few mechanical depositions, being largely crystalline. But this formation occurs in an unconformable and overlying stratification, covering some of the older rocks of the primitive period. If porphyry was to be counted among the primitive rocks deposited from a universal ocean which was gradually receding, its strata should show an ever-falling level of their outcrops; but such is not the case. Werner's way of explaining porphyry's unconformable and overlying stratification while still adhering to the belief that it was formed during the primitive period and is of aqueous origin was to resort to a universal flood.

Stratigraphic relations played a very important part in Werner's theory and in the substantiation of his postulates. As a starting point he used the axiom that all mineral deposits which are still in their place of origin are always of more recent formation than the deposit upon which they are superimposed;[2] and his interpretations drawn from the position and form of strata are based on the assumption that strata are usually found in their original position. He knew that rock strata are found in different positions, some vertical, some horizontal, some inclined; his problem was to give explanations of these occurrences consistent with his neptunistic theory of the formation of rocks. He

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[1]OW 450342-0349. [2]OW 450200.

supposed that the position of the strata had been determined partly by the shape of the ground on which they had been deposited and partly by the nature of the material deposited. Thus the primitive strata, which he generally found in a vertical or steeply inclined position, and as in the case of granite, showing little sign of stratification, he thought to have been chemically dissolved in the ocean and, when first deposited, to have taken the position in which he found them because they had been hastily crystallized following the contours of the base on which they were deposited. According to John Murray,[1]

> the opinion maintained in the Neptunian theory . . . is that they [the precipitates] had been chemically dissolved, and had separated and concreted by a species of crystallization. These crystalline deposites would be in large irregular masses, as granite, the rock of primary foundation, is; and the fluid still continuing to deposit matter by crystallization, this matter, in conformity to the laws of that process, would crystallize on the sides of the masses already produced; and thus the appearance of the vertical strata would be formed; or the division of these might even be determined by the process of crystallization itself.[2]

The position of the rock strata of later periods, Werner believed, was also determined by the base on which these strata were deposited and by the nature of the materials precipitated. According to this theory,

> . . . crystallization always commences from the solid surface in contact with the fluid; to this the solid mass adheres, taking of course more or less perfectly its figure or position. In this manner it is conceived by Werner, that the positions of the inclined strata have been determined; they have been deposited by an imperfect crystallization, mingled sometimes with a mechanical subsidence, and have adhered to the sides of the primitive strata on which they are incumbent. And from the same cause, any bending which

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[1]See Chapter V, p. 197, below, for Murray's place in the development of geology.

[2]John Murray, A Comparative View of the Huttonian and Neptunian Systems of Geology: in answer to the illustrations of the Huttonian theory of the earth, by Professor Playfair (Edinburgh: Ross and Blackwood, 1802), p. 108.

> they have, different from that of the base on which they rest, may be explained. Hence we find, in conformity to this theory, that the secondary strata are more inclined in the neighbourhood of the primitive vertical mountains; and, as they recede from these, are more horizontal, in proportion as they are mechanical deposites.[1]

On the assumption, then, that the rock deposits are generally found in their original position and with the belief in the so-called Law of Superposition, Werner compared the superimposed strata with the older strata on which they rest.[2] If he found them conformable, it meant to him that they had been formed in the same general period of formation. As an example of this Werner cited gneiss, mica-slate, and clay-slate in the Ore Mountains, which are all in conformable stratification. He added that further proof that they were all formed during the same period can be found in the fact that gneiss gradually changes into mica-slate and mica-slate into clay-slate.[3] If he found two rock formations which were unconformable, that is, with the strata within each formation conformable with each other but not with the strata of the other formation, he interpreted this to mean that a disturbance had occurred after the older strata had been deposited but before the newer ones had, and perhaps even that the waters from which the older rocks had been deposited had receded and then risen again, depositing the newer rocks. Werner distinguished between two kinds of unconformities. In one case the newer strata envelop the older ones completely, and in the other, only partially. The second kind of unconformity usually occurs when the lower strata are not horizontal, so that their outcrops frequently appear at the surface.[4]

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[1] Ibid., pp. 110-111.

[2] OW 450211-0213.

[3] OW 450212-0213.

[4] OW 450213.

Werner also compared the level of the outcrops of the superimposed strata with those of the strata on which they rest. When he observed that the outcrops of the newer strata were at a lower level than those of the older strata, he concluded that the rocks had been precipitated from a calm ocean while it was gradually receding. This is what he calls stratification with a sinking level of the outcrops.[1] He remarked that sometimes the strata of the newer rocks extend over the strata of the older rocks--they overlap. This phenomenon he explained by a rising of the ocean at some time after the older rocks had been deposited, when part of them had perhaps been worn away, so that the newer rocks are in an unconformable stratification in addition to the overlap. As an example of this stratigraphic relation he cited the floetz-trapp formation. In that formation, he explained, we usually find beds of gravel, sand, sandy clay, wacke, and so forth and also thick beds of bituminous fossils, especially wood.

> From the consideration of this, the following result becomes evident: sand and clay and those scattered trunks of wood can only be the doing of a tremendous flood. If this condition can be found in all parts of the world, the flood must have been a universal one. First it acted destructively, hence the masses of gravel, sand, wood, etc., which settled during the first disturbance. After the waters became calm, the precipitation of wacke, basalt, porphyry slate, greenstone, etc. followed, so that we find the crystalline rocks last.
> . . . .
> The fact that the floetz-trapp formation occurs rather high in the primitive formations and in unconformable and overlying stratification, covering the newest floetz-trapp formation, proves that this formation was formed from a suddenly appearing universal flood, which at first acted destructively, and then constructively, making mechanical and finally chemical and fairly crystalline deposits.[2]

Besides investigating stratigraphic relations, Werner also examined strata without reference to the strata on which they rest. He

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[1] OW 450237, 450214. [2] OW 450246-0248.

believed that the direction and shape of the strata indicate the different activities of the waters of the universal ocean. In this as well as in his examination of stratigraphic relations, he made use of the miner's practice of observing the dip (the downward slope of the stratum) and the strike (the direction of the stratum with regard to the points of the compass).[1] Strata which completely enclose a pre-existing mountain he called buckelförmig, or hump-shaped.[2] If the mountain was elongated, he called the strata sattelförmig, or saddle-shaped. If the older rocks protruded so that the newer rocks only surrounded them but did not cover them completely, he called the strata mantelförmig, or mantle-shaped.[3] He theorized that the mantle-shaped strata came about either because the newer rocks, having once completely covered the older ones, had been partially destroyed, or because the waters which deposited the newer rocks had never reached the height of those which deposited the older ones.[4] Strata that are concave he called muldenförmig, or basin-shaped.[5] The outcrops of both concave and convex strata form circles. When the strata are concave, the ones forming the outermost, largest circle are the oldest; when they are convex, those forming the outermost circle are the newest.[6] Hump-shaped, saddle-shaped, and mantle-shaped strata are all convex. If the mantle formed by newer rocks covering older ones is incomplete so that the newer rocks are found deposited along the slopes of the older ones in isolated portions, Werner called them schildförmig, or shield-shaped.[7] In all these explanations of the

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[1] OW 450184-0186. [2] OW 450213.

[3] OW 450218. [4] OW 450232-0233.

[5] OW 450213. [6] OW 450234. [7] OW 450206.

different shapes of strata Werner endeavored to use terms that would convey a mental image of familiar objects and thus be easy to remember.

In considering the relation between the original extent of rock formations and their present extent and continuity, Werner distinguished between two kinds of original formations: universal formations and partial formations.[1] Universal formations extend around the whole globe, although not necessarily without interruption. One reason for the lack of continuity in some of these formations, Werner believed, was the falling of the level of the universal ocean, which left some of the first rock deposits above the surface of the waters like islands, so that later deposits are interrupted by these previously formed rocks, which protruded above the water level. He thought that most of the primitive, transition, and floetz formations were universal depositions.[2] Partial formations, that is, those which are found only here and there, he believed to be the result of local inundations. Thus he explained that a particular rock deposit at Wehrau, consisting of limestone, sandstone, bituminous shale, and iron-clay resting on loose sand, had been formed by a partial flood.[3]

According to Werner, the present extent of rock deposits is often quite different from their original extent. He believed that different causes, such as the mechanical and chemical action of the atmosphere and water, brought about the destruction of parts of original deposits, so that parts of originally universal formations are often found in isolated portions of little extent, resembling partial

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[1]OW 450202. [2]OW 450204.

[3]OW 450202-0203.

formations.[1]

From the frequency of occurrence of these isolated parts and their stratigraphic relations, he distinguished between broken formations and partial formations. Detached portions occurring on the summits of hills, such as basalt caps, are examples of what Werner believed to be the remains of a once continuous formation. "Werner attached great importance to these concepts which he first introduced, because he used the occurrence of these stratigraphic relations not only to convey a clear idea of the spatial relations of rock masses and to define them, but also to elucidate his views on the rising and falling of the waters and to show the original unevenness of the earth's crust."[2]

The various activities of the waters, the storms and the calms, also served to explain some of the structural differences of rocks. Werner divided the compound rocks[3] into rocks of granular, slaty, porphyritic, amygdaloidal, and conglutinated structure. He thought that rocks of a granular structure are the result of chemical precipitation, that their constituent parts are imperfect crystals of contemporaneous origin, and that they were formed primarily in the primitive period.[4] Rocks of slaty structure, he thought, were also the result of chemical precipitation and formed primarily in the primitive period.

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[1]OW 450206-0207.

[2]Friedrich Hoffmann, Geschichte der Geognosie, und Schilderung der Vulkanischen Erscheinungen. Vorlesungen gehalten an der Universität zu Berlin in den Jahren 1834 und 1835 (Berlin: Nicolaische Buchhandlung, 1838), p. 89 (translation by the author).

[3]See Chapter III, p. 123, above.

[4]OW 450173.

In rocks of a porphyritic structure, one or more of the constituents are dispersed through a groundmass in the form of grains and crystals. Werner thought that the porphyritic rocks are the result of chemical precipitation, but that this precipitate was chemically far less pure than the precipitates which formed the rocks of granular and slaty structure,[1] and to him this was an indication that the porphyritic rocks are in general newer than the granular and slaty ones.

Rocks which have an amygdaloidal structure are characterized by a groundmass containing vesicles which are empty, filled, or partially filled.[2] Werner attributed the formation of the cavities in the groundmass to the release of gases which had been trapped in it while it was still in a fluid or soft state.[3] Von Humboldt writes:

> If we assume heat producing precipitates from a universal and chaotic solution, then--especially if the temperature is greatly increased--a great amount of vapors must be produced; the solution itself reaches a stage of effervescence, the traces of which are recognizable as much in the form and direction of the rock masses as in their thickness. Wherever earth masses are precipitated, vapors try to escape; the still soft mass puffs up, forming partly vesicles and small apertures and partly wide ruptures which we call caves. . . .[4]

Werner believed that the vesicles had been filled by different minerals which filtrated through the groundmass after it had solidified, the materials adhering to the walls of the cavities and thus gradually filling them. According to this theory, the material found in the center of

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[1]OW 450176. [2]OW 450174-0175.

[3]OW 450177-0178.

[4]Cited in Franz Ambrosius Reuss, Lehrbuch der Mineralogie nach des Herrn O. B. R. Karsten mineralogischen Tabellen (Leipzig: Friedrich Gotthold Jacobaer, 1801-1805), Part III, Vol. II, pp. 19-20 (translation by the author).

such a vesicle would be newer than that found near the walls.[1]

Conglutinated, or cemented, rocks consist of fragments of older rocks which have been broken up and the pieces then transported to their present location, where they were agglutinated by a cement, which is usually of a different nature and later formation than the fragments. Werner considered rocks of cemented structure to be the result of mechanical precipitation.[2] These rocks made their first appearance in the transition period but occur most frequently in the floetz period.

According to Werner, by far the largest part of the rocks which form the earth's crust were formed during the primitive, transition, and floetz periods, being deposited from a universal ocean. There are some rocks, however, which were formed in later periods: the alluvial rocks and the volcanic rocks.

The alluvial rocks are the result of local floods and are largely mechanical depositions.[3] "The alluvial rocks," Werner wrote, "which lie one above the other in horizontal beds of extremely different thicknesses, consist almost entirely of parts of destroyed primitive and floetz, sometimes even of volcanic, formations."[4] They occur mostly in the lowlands, but they are also found in mountainous regions, where they were deposited either on high plateaus or in the valleys. The largest

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[1]OW 450178.

[2]OW 450172, 0178, 0180.

[3]OW 450277.

[4]Alexander M. Ospovat, "The Kurze Klassifikation und Beschreibung der verschiedenen Gebirgsarten of Abraham Gottlob Werner" (unpublished Master's thesis, Department of History, University of Oklahoma, 1958), p. 83. At the time the Kurze Klassifikation was published, Werner divided all rocks into four classes only: primitive, floetz, alluvial, and volcanic.

valleys, Werner remarked, are often filled with alluvial rocks to a depth of several fathoms. Alluvial formations occurring in the mountainous regions consist largely of "sand [Grus], siliceous pebbles [Kieselgeschiebe], clay and loam."[1] In the lowlands and "flat hilly country" the alluvial formations consist mostly of "sand, clay, rubble, and beds of flint [Kiesellager],"[2] all of which are mechanical precipitates. There are, however, two chemical precipitates which occur in the lowland alluvial formations: calc-tuff and turf. Werner divided the lowland alluvial formations into calc-tuff, sandland, clay, or loamland, and moorland formations.[3] The sandland formations consist primarily of sand, rubble, and gravel. "Beds of clay and loam," Werner wrote, "occur only occasionally. At times the sand layers are already converted into true sandstone. In some regions the sandland also contains embedded shellfish. Occasionally beds of alum earth (so-called earthy alum ore) are found in it, . . ."[4] The loamland formations "consist almost entirely of various kinds of loam and clay beds which are more or less sandy and sometimes even alternate with thin sand beds."[5] The moorland formations are made up of all kinds of peat and bituminous earth, which sometimes alternate with thin beds of sand or even with beds of clay.[6] Werner thought that there is an uninterrupted transition from peat to moor-coal and from moor-coal into the other species of coal.[7] The

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[1]OW 450464. [2]OW 450465.

[3]OW 450466; OW 460263, "Lecture Notes taken by August Breithaupt."

[4]Ospovat, pp. 84-85. [5]*Ibid.*, p. 85.

[6]*Ibid.*

[7]OW 460264-0265, "Lecture Notes taken by August Breithaupt."

calc-tuff formations occur in layers of different density, some being earthy and others porous.[1] The stratification is usually horizontal, and the layers of tuff often alternate with beds of brown coal. Amber is very common to this formation.

The volcanic rocks play a relatively unimportant role in Werner's geognostic system, constituting a very small fraction of the rocks which form the earth's crust. But because of his great emphasis upon the formation of rocks from a universal ocean, Werner felt it necessary to have a theory of the origin of volcanoes which would help to support his neptunistic theories.

Differing with many other mineralogists of his day, Werner had advanced the theory that basalt is of aqueous rather than volcanic origin. In 1789 he published an article[2] in which he pointed out that one of the reasons often given for believing that basalt is a volcanic rock stems from the frequent occurrence of hornblende crystals in volcanic lavas as well as in basalt and wäcke. It was difficult for him to imagine that the hornblende crystals in basalt could have been formed by water and those in lava by fire; and he had long been convinced of the aqueous origin of basalt and consequently also of the aqueous origin of the hornblende crystals in basalt.

Werner then proceeded to delineate a theory of the origin of volcanoes which he believed was congruent with his theory on basalt. He writes that the concept of volcanoes resulting from the inflammation of

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[1]Jameson, System of Mineralogy, III, 210.

[2]Abraham Gottlob Werner, "Versuch einer Erklärung der Entstehung der Vulkanen durch die Entzündung mächtiger Steinkohlenschichten, als ein Beytrag zu der Naturgeschichte des Basalts," Magazin für die Naturkunde Helvetiens, IV (1789), 240-254.

coal beds is an old one but that the elaboration of this concept and the proofs which he offers to support it are new. Three conditions have to be fulfilled to produce a volcano according to his theory: (1) the presence of immense beds of coal, (2) rocks covering these beds of coal which are of such nature as to yield a material from which lava can be produced, and (3) the rushing in of water as the immediate cause of the eruption of the volcano. He then offers the following arguments that the conditions necessary for making a volcano do exist. (1) Immense masses of coal exist in some places, and beds of coal occur in many parts of the globe. (2) Burning beds of coal are not rare, and it is generally accepted that these fires are sometimes started by spontaneous combustion. (Here he casually remarks that besides the inflammation of large beds of coal and a high, solid cover over the coal beds, a communication with the sea or some other waters is also necessary, but he gives no further explanation of how water might get to the place of the potential volcano). (3) Coal usually occurs in those places where volcanoes are found, namely, in the plains and hilly country, as is the case with Vesuvius, Aetna, Hecla, and others. The fact that some volcanoes reach great heights is to be attributed to the heaping up of the materials produced by them. (4) The distribution of several volcanoes throughout a region, as in Chile, Iceland, and, to a certain extent, the region about Vesuvius, would seem to suggest, or even necessitate, the presence of widely extended but not very deep rock beds, and beds of coal are of that nature. Also the occurrence of several volcanoes in one area would indicate that the seat of these volcanoes is not so deep as has been supposed, because great rock masses above would tend to direct the eruptive forces to the already existing openings instead of creating new ones. (5) Sulphur and sal ammoniac are produced during the burning of beds of coal. (6) The occurrence of coal under basalt, the geognostic and oryctognostic affinity of lava to basalt, and the almost certain aqueous origin of basalt and wacke seem to prove not only that coal furnishes the inflammable material for volcanoes, but also that the covering is basalt and wacke. As examples of basalt covering coal he gives the Faroe Islands, the Meissner in Hesse, the Westerwald in Westphalia, and the basaltic mountains in Bohemia.

Having given these arguments for his theory, Werner proceeded to describe how he imagined the eruption of a volcano to come about.

> Suppose an immense bed of coal on fire, the ends, or outcrops, of this coal bed sealed, viscous rocks such as basalt and wacke (especially when they are mixed with calcspar and zeolite as is often the case) immediately above the bed of coal, and several hollows formed by the burning of the inflammable materials; would not the viscous rocks just mentioned melt? Now only water in sufficient quantities is needed to rush in and reach the large quantities of melted material, and one has an eruption, and with it the volcano.[1]

Werner placed great emphasis upon the viscosity of melted basalt to further support his theory that basalt is of aqueous origin and that the hornblende crystals found in lava were originally embedded in the principal mass of basalt. The flow of lava is rather thick; therefore, Werner reasoned, it is self evident that the very viscous principal mass of basalt is melted by the volcanic fire, but not the embedded refractory hornblende crystals, these being only slightly burned. This explains the difference in color and fracture between hornblende crystals

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[1]Werner, "Entstehung der Vulkanen," Magazin für die Naturkunde Helvetiens, IV (1789), 249 (translation by the author).

found in basalt and those found in lava. The hornblende crystals which occur in lava are green or even yellow, and their fracture is imperfectly foliated. Hornblende crystals found in basalt are black and their fracture is perfectly foliated.

A corollary to Werner's theory that volcanoes are the result of burning coal deposits is that volcanic rocks are of very recent origin. Coal is an organic product, and in Werner's system it was not formed until the floetz period. All volcanoes, therefore, had to be formed still later.

Werner's theory of the origin of volcanoes was an indirect support of his neptunistic theories. For in showing that volcanoes are of very recent origin and of a local nature, Werner also showed that most rocks are of aqueous origin and that the aqueous rocks are older than the volcanic rocks. He composed a list of criteria, eleven in all, by which to judge whether a mineral or rock is of aqueous or volcanic origin, showing in many cases why a particular rock or mineral cannot be of volcanic origin: (1) A rock mass consisting of pebbles and pieces resembling pebbles, such as sandstone, gravel, and sand, is a mechanical precipitation from water. (2) All masses consisting of tenacious minerals which become brittle in fire, such as clay and wacke, are indisputably of aqueous origin, because fire cannot form tenacious minerals. (3) Masses whose constituents can be consumed by fire cannot have been formed by fire. (4) Minerals or rock masses which contain water of crystallization or carbon dioxide must be of aqueous origin, since water of crystallization and carbon dioxide would have been driven out by fire. (5) Mineral or rock masses which contain petrifactions, especially marine bodies, cannot have been formed by fire. (6) All those mineral or rock masses which occur in thin, widely distributed strata or beds cannot be volcanic products; and they certainly cannot be lavas, for lava flows are several feet thick and extend only a short distance from their place of origin. (7) Rock masses consisting of several different minerals of contemporaneous origin, such as greenstone, granite, and syenite, must be of aqueous origin, since fire brings about an immediate, uniform decomposition and destruction of the constituent parts. (8) Minerals which contain vesicles filled with minerals of later origin cannot be of volcanic origin, because minerals formed by fire contain only empty vesicles. (9) Minerals which have a distinctly foliated fracture cannot be of volcanic formation. (1) True volcanic formations contain no distinct concretions, especially in the large masses. (11) If mineral masses which are similar to those of volcanic origin are found in equal combination and alternation with minerals which are known to be precipitates from water, then these apparently volcanic minerals are also of aqueous origin.[1]

Having determined what he believed to be the origin of rocks and having arranged the rocks in a fivefold classification, that is, primitive, transition, floetz, alluvial, and volcanic rocks, Werner arranged the same rocks in formation suites. He believed that, despite the apparent diversity in the rocks which form the earth's crust, only a limited number of substances form all the rocks of all the different periods: a few rock-forming substances occurred again and again in modified forms--in states of greater or lesser chemical purity or mechanical alteration--

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[1]OW 450163-0167; OW 460154-0156, "Lecture Notes taken by August Breithaupt."

in the rocks of all the different periods of formation. Thus, according to their analogous mineral and chemical composition, he arranged the rocks in several series, or formation suites--such as limestone, slate, trapp, gypsum, salt, and porphyry--extending through all the periods of formation. Jameson, following Werner, wrote of the formation suites:

> In a series of this kind, all the members have general characters of agreement, and the individual members bear characters expressive, not only of the period of their formation, but also the circumstances under which they were formed. By contrasting the old and the new members of such a series, the differences will be found to be so great, that we can with difficulty recognise them as members of the same formation suit: on the contrary, the immediately preceding or following members are so much alike, that it is equally difficult to distinguish the one from the other. This shows how much the prevailing circumstances that existed during the time of their formation, were alike in the members of the same age, and differed in those of a different age.[1]

The classification according to period of formation (the fivefold classification) and the one according to analogous mineral and chemical composition (the formation suites) are based upon the same theories, and they supplement each other.

Werner's theory of the origin of mineral veins is also based upon the neptunistic postulates that the earth was once covered by a universal ocean and that the materials of which the earth's crust consists were at one time dissolved or suspended in that ocean. Werner lectured on mineral veins from the time he began to teach at Freiberg in 1776. He devoted several lectures to them in his course on geognosy, and in 1791, after "almost thirty years of study," he published his ideas on the subject in a book entitled Neue Theorie von der Entstehung der Gänge. In the introduction to this book he wrote that the idea that mineral veins fill former rock fissures is an old one but that he presents a more

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[1]Jameson, System of Mineralogy, III, 87-88.

precise account of the causes of the formation of veins and better proofs for the process of formation itself.[1]

Werner defined veins as "particular mineral depositories of a tabular shape, which in general traverse the strata of rocks, . . . and are filled with mineral masses differing more or less from the rocks in which they occur." He remarked that it would be even more accurate to describe veins as "rents which have been formed in rock masses and have, after their formation, been filled up by minerals more or less differing from the rock masses."[2]

Werner thought that the rents were primarily the result of compaction of the rock masses, which were wet at first and not solidified, and the simultaneous loss of the support of the high-standing waters when these receded. This permitted large rock masses to separate from the rest of the deposition and fall to the lower-lying regions. The rents, he believed, might also be the result of the drying up and subsequent contraction of the wet rock masses, or the result of earthquakes.[3]

"The same precipitation from water that formed the beds and strata of rock masses, and among these produced many ore-bearing ones," Werner wrote, "also formed the lode stuff; this took place during the time when the solution which contained such substances was standing above the already existing rents, which were wholly or partly open."[4] He thought that he had found verification of this theory when he found petrifactions

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[1]Werner, Von der Entstehung der Gänge, pp. xviii-xix.

[2]Ibid., pp. 2-3 (translation by the author).

[3]Ibid., pp. 49-50.

[4]Ibid., p. 52 (translation by the author).

in veins, which he believed must either have been in the strata before they fissured or introduced at a later time from above. Other evidences which he presented were the following: Rents and fissures in rock masses which are very similar to those spaces now filled by veins are still forming in our own day. Druses, and the small crystals which line their walls, are nothing but parts of veins which were not completely filled, the remainder of once completely empty spaces. Certain veins are filled with rolled masses and water-transported stones. Fragments of rocks found in veins are often confusedly arranged, indicating that they fell into an empty space from above or separated from the sides of the open space. Werner also cited the presence of breccia and of rock salt and coal, substances of very recent formation, in veins; the stratigraphic relations of veins to the rock masses in which they occur; and the interior structure of veins that are composed of different kinds of minerals as further proofs of his theory.[1]

Werner's elaboration of an old theory of the formation of veins was consistent with the general neptunistic theory of the formation of the earth's crust. Indeed, his whole geognostic system was built upon the two neptunistic postulates of the formation of rocks.[2] The stratigraphic position, the shape and form of strata, the extent--past and present--of rock formations, the structure of rocks, his theory of the formation of veins--all were formulated into a coherent and interlocking system in which each part supported and was supported by every other part. Thus, the assumption that a high-standing ocean had gradually receded was supported by the ever-sinking level of the outcrops of

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[1] _Ibid._, pp. 61-88, _passim_. [2] See above, p. 145.

superimposed rock masses. Likewise the degree of crystallinity attests to the age of the crystalline rocks and the relative calm of the waters, while crystallinity in general shows that those rocks had been precipitated from an ocean and that that ocean was fairly calm.

There were some "exceptions to the rule" in Werner's system, such as the first and second inundations and local floods. But these were needed to make possible an explanation of stratigraphic relations consistent with the general theory. The universal and the local floods were, in a sense, mere adjustments to the theory that a universal ocean had existed and that it had receded gradually and continually.

Werner could not explain where the waters came from, nor could he explain the source of the substances held in solution. But he remarked that the inability to explain a phenomenon does not prevent a person from recognizing its existence with all its consequences. "In all researches into effects and their proximate and remote causes," he wrote, "we arrive at last at the investigation of ultimate causes, beyond which we cannot proceed."[1]

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[1]Werner, Von der Entstehung der Gänge, p. 115 (translation by the author).

CHAPTER V

WERNER'S INFLUENCE ON MINERALOGY AND GEOLOGY

Werner's influence in his own time, at home and abroad was very great. His mineralogical system was followed in most of the universities of Germany and Spain and to a large extent in England, Denmark, Portugal and France.[1] In the German speaking world, Wernerian books dominated the geological scene. In 1809 Jean François d'Aubuisson de Voisins wrote that more than a hundred works following Werner's system had appeared in German and that he thought that he was not exaggerating when he said "that the number of books published on the Wernerian mineralogy exceeds that of all the other existing works in mineralogy."[2] Many of these works were written by men who had never been Werner's students. In 1791 Johann Georg Lenz published a handbook of mineralogy based on Werner's system,[3] which was widely enough read to demand several editions. In 1792 an anonymous author published a book entitled Oryctognosie, oder Handbuch für die Liebhaber der Mineralogie, which has been attributed to

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[1]D'Aubuisson de Voisins, Annales de Chimie, LXIX (1809), 235-237.

[2]Ibid., p. 235 (translation by the author).

[3]Johann Georg Lenz, Mineralogisches Handbuch, durch weiter Ausführung des Wernerschen Systems (Hildburghausen: Johann Gottfried Hanisch, 1791).

Werner.[1] Franz Joseph Anton Estner wrote a three volume work entitled Versuch einer Mineralogie für Anfänger und Liebhaber, nach . . . Werner's Methode which was published during the years 1797-1804.[2] Between the years 1801 and 1805 Franz Ambrosius Reuss published in seven volumes one of the most complete treatises on Werner's mineralogy and geognosy, his Lehrbuch der Mineralogie.[3] And in 1812 Franz Reichetzer wrote a textbook for the imperial-royal mining academy of Austria carrying the title Anleitung zur Geognosie insbesondere zur Gebirgskunde. Nach Werner. . . .[4] Among the works on mineralogy and geognosy written in German by Werner's students are Widenmann's Handbuch des oryctognostischen Theils der Mineralogie,[5] Emmerling's Lehrbuch der Mineralogie,[6] Steffens' Vollständiges Handbuch der Oryktognosie,[7] and Hoffmann's Handbuch der Mineralogie.[8]

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[1]Deutsches Anonymen Lexikon, 1501-1850. Aus den Quellen bearbeitet von Dr. Michael Holzmann und Dr. Hanns Bohatta (Weimar: Gesellschaft der Bibliophilen, 1905), III, 244.

[2]Franz Joseph Anton Estner, Versuch einer Mineralogie für Anfänger und Liebhaber, nach . . . Werner's Methode (3 Parts, 5 Vols.; Wien: Beck, 1794-1804).

[3]Franz Ambrosius Reuss, Lehrbuch der Mineralogie nach des Herrn O. B. R. Karsten mineralogischen Tabellen (3 Parts, 7 Vols.; Leipzig: Friedrich Gotthold Jacobaer, 1801-1805).

[4]Franz Reichetzer, Anleitung zur Geognosie insbesondere zur Gebirgskunde. Nach Werner für die K. K. Berg-Akademie (Wien: Camesinasche Buchhandlung, 1812).

[5]Johann Friedrich Wilhelm Widenmann, Handbuch des oryctognostischen Theils der Mineralogie (Leipzig: Siegfried Lebrecht Crusius, 1794).

[6]Ludwig August Emmerling, Lehrbuch der Mineralogie (Giessen: G. F. Heyer, 1793-1797).

[7]Heinrich Steffens, Vollständiges Handbuch der Oryktognosie (4 Theile; Halle, 1811-1824).

[8]Carl August Siegfried Hoffmann, Handbuch der Mineralogie (4 Parts in 5 Vols.; Freyberg: Craz und Gerlach, 1811-1817).

The last two works are truer to Werner's system than any others.[1]

In Spain a translation of Widenmann's handbook was used as a text in courses on mineralogy taught at Madrid.[2] In Mexico Werner's system was made known through the work of his student Manuel Del Río, who wrote a treatise designed for the use of students at the Real Seminario de Minería de México entitled Elementos de orictognosia ó del conocimiento de los fósiles, dispuestos según los principios de A. G. Wérner, . . .[3] Carlo Antonio Napione, inspector of mines in Piedmont, published a mineralogical treatise according to Werner's system in which he referred to Werner as "the new Socrates of mineralogy."[4] In England Richard Kirwan published a mineralogical treatise according to Werner's principles,[5] and Thomas Thomson based the mineralogical part of his System of Chemistry[6] on Werner's classification, nomenclature, and mode of description of the external characteristics of minerals. Werner's student Thomas Weaver

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[1]Blöde, Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, II (1819), 298, 302.

[2]D'Aubuisson de Voisins, Annales de Chimie, LXIX (1809), 235.

[3]Andrés Manuel Del Río, Elementos de orictognosia ó del conocimiento de los fósiles, dispuestos según los principios de A. G. Wérner, para el uso del Real Seminario de Minería de México (México: Don Mariano Joseph de Zúñiga y Ontiveros, 1795-1805).

[4]Carlo Antonio Napione, Elementi di Mineralogia, esposti á norma delle più recenti osservazioni e scoperte (Torino, 1797). Quoted in d'Aubuisson de Voisins, Annales de Chimie, LXIX (1809), 236.

[5]Richard Kirwan, Elements of Mineralogy (London: Printed for P. Almsly, 1784).

[6]Thomas Thomson, A System of Chemistry (4 Vols.; Edinburgh: Bell & Bradfute, 1802). See also d'Aubuisson de Voisins, Annales de Chimie, LXIX (1809), 236.

translated his work on the external characteristics of minerals into English, and Charles Anderson made a translation of Werner's Neue Theorie von der Entstehung der Gänge.[1] But no one did more to spread Werner's teachings in Great Britain than Robert Jameson, whose System of Mineralogy is largely based upon the lecture notes that he took while attending Werner's courses at the Bergakademie in Freiberg. In Denmark Werner's work became known through his student Jens Esmark and through Gregers Wad, professor of natural history at the University of Copenhagen, who published a Latin and Danish translation of Werner's terminology.[2] In 1790 a translation of Werner's book on the external characteristics of minerals by Madame Guyton de Morveau appeared in France.[3] It did not arouse much interest among mineralogists, however, and it was largely through the works of Brochant de Villiers, d'Aubuisson, Vanberchem, and Struve that French geologists became acquainted with Werner's system and theories. In 1795 Vanberchem and Struve published a work entitled Principes de minéralogie ou exposition succincte des caractères extérieurs des fossiles, d'après les leçons du Professeur Werner, . . .[4] Both authors

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[1]Abraham Gottlob Werner, New Theory of the Formation of Veins; with its Application to the Art of Working Mines, trans., Charles Anderson (Edinburgh: Encyclopedia Britannica Press, 1809).

[2]Gregers Wad, Tabulae synopticae terminorum systematis oryctognostici Werneriani, latine, danice et germanice . . . (Hafniae: Fr. Brummer, 1798).

[3]Abraham Gottlob Werner, Traité de caractères extérieurs des fossiles traduit de l'Allemand par le traducteur des mémoires de chimie de Scheele (Madame Guyton de Morveau) (Dijon, 1790).

[4]J. P. Vanberchem-Berthout and Henri Struve, Principes de minéralogie, ou exposition succincte des caractères extérieurs des fossiles, d'après les leçons du professeur Werner, augmentées d'additions manuscrites fourniés par cet auteur, . . . (Paris: Reynier, 1794).

studied under Werner between 1787 and 1789 and had the benefit of Werner's advice during the preparation of the work.[1] A more complete treatment of Werner's system was written by Brochant de Villiers, his Traité élémentaire de minéralogie, suivant les principes du professeur Werner, . . .[2] And d'Aubuisson's works did as much to spread Werner's teachings in France as Jameson's did in Great Britain. D'Aubuisson translated Werner's book on mineral veins and wrote a treatise on the Freiberg mining district. His Traité de géognosie is to a large extent based on Werner's lectures.[3] Horace-Bénedict de Saussure (1740-1799), "the first geologist who made a prolonged study of the Alps,"[4] thought that he made a notable advance in mineralogy as a result of becoming acquainted with Werner's doctrines, and in the third volume of his famous work Voyages dans les Alpes he mentions Werner frequently. In the preface to this volume Saussure wrote that in describing minerals he followed "the language of the celebrated Werner, which should be made universal as soon as possible."[5]

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[1]Hoffmann, "Einige litterarische Notizen über die Verbreitung des Wernerschen Systems der Mineralogie im Auslande," Bergmännisches Journal, III (1802), 487-488.

[2]André Jean François Marie Brochant de Villiers, Traité élémentaire de minéralogie, suivant les principes du professeur Werner, . . . redige d'après plusieurs ouvrages allemands . . . (Paris: Villier, 1800).

[3]Abraham Gottlob Werner, Nouvelle théorie de la formation des filons. Application de cette théorie a l'exploitation des mines . . . Ouvrage traduit de l'Allemand et augmenté d'un grand nombre de notes (Freiberg: Craz und Gerlach, 1802). D'Aubuisson de Voisins, Des mines de Freiberg en Saxe et de leur exploitation (3 Vols.; Leipzig: P. P. Wolf, 1802); Traité de Géognosie, ou Exposé des connaissances actuelles sur la constitution physique et minérale du globe terrestre (2 Vols.; Strasbourg: F. G. Levrault, 1819).

[4]Adams, p. 387.

[5]Horace-Bénedict de Saussure, Voyages dans les Alpes, précédés

Werner and his work were so well known to his contemporaries and followed and imitated by such a large number of geologists that Thomson could write with little fear of contradiction that in the neptunist-vulcanist controversy almost all mineralogists agreed with Werner.[1] Werner's teachings were made known more through the works of his followers than through his own works, but we do not need to believe, as some historians of geology aver, that Werner was averse to writing.[2] This opinion undoubtedly stems from the relatively small number of publications by Werner. Yet he left behind him thousands of pages of unpublished manuscripts on various geological and other subjects, some of them book-length. His failure to publish these appears to have been due to the sheer pressure of official duties. That his duties as a member of the Board of Mines and as a teacher and official of the Bergakademie were very time consuming is attested by the thousands of pages of reports that he wrote and by his being excused by the Board of Mines from participating in board meetings other than those that dealt with theoretical matters concerning mining, mineralogy, the ironworks in the Freiberg mining district, and the Bergakademie. In view of his duties, it is not surprising that Werner did not publish as much as some other scholars

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d'un essai sur l'histoire naturelle des environs de Genève (4 Vols.; Neuchatel: Chez Louis Fauche-Borel, 1779-1796), III, i (translation by the author).

[1] Thomas Thomson, History of the Royal Society, from its Institution to the End of the Eighteenth Century (London: Printed for Robert Baldwin, 1812), p. 185.

[2] See Adams, p. 215; Archibald Geikie, The Founders of Geology (2nd ed.; London: Macmillan and Co., 1905), p. 234.

did. Since his works in oryctognosy, geognosy, and other subjects were never prepared for the press, however, Werner's students and admirers took it upon themselves to make his teachings known to the rest of the geological world by publishing transcripts of their notes taken in class. Werner was much concerned about this, for he felt that many of these publications misrepresented his views, as might be expected from works based upon class notes. He complained rather bitterly about such activities in his Neue Theorie von der Entstehung der Gänge:

> And now I take this opportunity to turn some of my friends from an error that is damaging to me and may become more so. Some of them hold a peculiarly wrong idea--and even state it openly: that I myself will never publish any more of my many carefully planned works on mineralogy, mining, and ironworks metallurgy. Out of regard for me and my scientific works they believe, I am almost sure, that they do science no small service when they take it upon themselves to publish such works as soon as possible. . . . I gladly overlook what has already been done. But since I hear that not only the introductory part of my oryctognosy, but also my work on ironworks metallurgy, are to be published, I feel that I owe it to myself and to science to disapprove of it publicly.[1]

His friends and students turned out to be right, however, for he never published a complete treatment of either his oryctognostic or his geognostic teachings. In spite of this, the bibliography of his publications includes twenty-eight articles and books, two of which were published posthumously. However, only four were published after 1792, the year that he was appointed to the Board of Mines.

Werner's published works are fairly evenly divided between mineralogical and geological topics. Of the mineralogical works, the most important are Von den äusserlichen Kennzeichen der Fossilien, Versuch

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[1]Werner, Von der Entstehung der Gänge, pp. xxv-xxvi (translation by the author).

einer Mineralogie, which is an edited translation of Cronstedt's Försök til Mineralogie, and his two volume catalog of Pabst von Ohain's mineral collection. In the absence of a complete treatise by Werner on his mineral system, these three works taken together formed the best substitute for such a treatise. By helping to explain his system to his contemporaries, they helped to shape the development of mineralogy. His "Classificationslehre,"[1] which explains in detail his principles of classification, was not widely known and was therefore less influential.

Among Werner's geognostic writings, his Kurze Klassifikation und Beschreibung der verschiedenen Gebirgsarten was the first to appear in print. This very brief work, which was first published in 1786 as an article and a year later as a pamphlet,[2] has become a classic in the history of the geological sciences. It is not clear whether or not Werner himself was responsible for its publication, but he did later claim it as his own. The Kurze Klassifikation is a sketch of Werner's classification of rocks, which at the time this work was published was only fourfold, not including the class of transition rocks. The basis of the classification is barely mentioned, and the different periods of formation are only briefly outlined. The stratigraphic relations are barely alluded to, giving a decidedly petrographic emphasis to this classification. The rocks, or Gebirgsarten, are those which Werner at that time considered to be the only ones occurring in masses large enough to form

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[1]See p. 139, note 2, above.

[2]Abraham Gottlob Werner, "Kurze Klassifikation und Beschreibung der verschiedenen Gebirgsarten," Abhandlungen der Böhmischen Gesellschaft der Wissenschaften (1786); Kurze Klassifikation und Beschreibung der verschiedenen Gebirgsarten (Dresden: Waltherische Hofbuchhandlung, 1787).

formations; and in the absence of an explanation of what he considered to be a Gebirgsart, a full understanding of the work was almost impossible except to those acquainted with his theories and terminology. The Kurze Klassifikation does not explain Werner's geognostic system other than to say that most rocks are of aqueous origin and that there are four classes of rocks. Despite its shortcomings, the Kurze Klassifikation was important in the development of geology. It gives, for the first time, clear definitions of rocks as well as a classification of them based on Werner's theories. It had the virtue of providing a point of reference for further investigations; and the writings which Werner's students and followers based on this classification helped to stimulate work by others, those who disagreed with Werner's classification as well as those who agreed with it.

In the Neue Theorie von der Entstehung der Gänge Werner published his knowledge and theories concerning mineral veins, which he had studied for almost thirty years. This 296-page book was written in only three months, going to the printer a few sheets at a time as soon as they were written. It was translated into French and English, and even those who disagreed with Werner's theory of the origin of veins gave him credit for demonstrating that veins could be classified according to their relative age and that their relative age can be determined from their direction and manner of intersection.[1] Veins of an ore, for instance, when considered to be depositions from an aqueous solution, can be assumed to have been deposited from the same solution in different places at the

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[1]Geikie, p. 309.

same time; therefore the division of veins according to relative age and materials makes possible prediction of the level and location of similar materials.

A very general view of Werner's theory of the formation of the earth's crust is contained in a paper which he read before the Dresden mineralogical society shortly before his death. This paper was published posthumously in the first volume of the transactions of that society under the title "Allgemeine Betrachtungen über den festen Erdkörper."[1] It contains little more than what Werner told his students in the introduction to his course on geognosy. Since it is the only printed piece by Werner which presents a synopsis of his theory, however, it is of some importance historically.

Of all of Werner's writings, none was of greater consequence than a short article on the origin of basalt, for it set off the great debate which divided the geological world for several decades and which has not been completely settled to this day. Toward the end of the eighteenth century and at the beginning of the nineteenth, no other geological question was debated with more fervor than that of the origin of basalt. The geologists of Werner's time felt that the answer to this question would establish the validity of either the neptunistic or the vulcanistic theory of the formation of the earth's crust.

Basalt is a widely distributed rock. Agricola in the Natura Fossilium wrote of the most famous basalt mountain in Saxony, the one

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[1]Abraham Gottlob Werner, "Allgemeine Betrachtungen über den festen Erdkörper," Auswahl aus den Schriften der . . . Gesellschaft für Mineralogie zu Dresden, I (1817), 38-56.

at Stolpen.[1] The Scheibenberger Hügel was familiar to many who had visited the Ore Mountains. The Vogelberg in Hesse, the basalt columns in the valley of the Rhine, the Giants' Causeway in Northern Ireland, the basalts in the Western Islands of Scotland, and many basalt mountains in Italy were known to geologists of the eighteenth century. As more basalt formations were found, it became clear that basalt is a rock of universal distribution. And it was the wide distribution of this stone that made its origin seem so important to geologists.

In 1752 Jean Etienne Guettard (1715-1786) presented a paper to the French Academy of Sciences in which he made known the results of his trip to the heart of France, the Auvergne.[2] In this paper he reported that he had detected a number of craters in the Auvergne, which led him to believe that there had once been active volcanoes in that region.[3] He also thought that he had found evidence that the volcanoes of the Auvergne were the result of the burning of large deposits of combustible materials, such as coal and petroleum, beneath the surface of the earth and that these underground fires had created a temperature capable of melting and vitrifying the most intractable substances.[4] Guettard believed basalt to be an aqueous rock, "a species of vitrifiable rock, formed by crystallization in an aqueous fluid, . . ."[5] He explained that

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[1]Agricola, De natura fossilium, p. 315. See also De natura fossilium, trans., Bandy, pp. 149-150.

[2]Jean Etienne Guettard, "Mémoire sur quelques montagnes de la France qui on été des volcans," Histoire de l'Académie Royale des Sciences. Année MDCCLII. Avec les mémoires de mathématique & de physique pour la même année, tirés des registres de cette académie, Mémoires, pp. 27-59.

[3]Ibid., p. 31. [4]Ibid., pp. 52-53. [5]Geikie, p. 135.

the basalt found among volcanic masses had probably existed in the position in which it is found before the eruption of the volcano, or that it was deposited upon the lavas after they had solidified. The importance of Guettard's paper, however, lies primarily in the fact that he was the first to ascertain that there had once been active volcanoes in central France. Thus he led others to investigate the same region and helped to provide observational evidence for the basalt controversy which ensued several decades after his paper was published. The Auvergne became one of the most important proving grounds for the neptunistic and vulcanistic theories of the formation of the earth's crust.

In 1763, another Frenchman, Nicholas Demarest (1725-1815), made a trip to the Auvergne and detected basalt in association with lavas.[1] Like Guettard, he was convinced that there had once been active volcanoes in the Auvergne, but unlike Guettard, he believed that the basalt columns which he had seen were of igneous origin. "On the return from the Puy de Dome," he wrote, "as I was following the rocky crust in which the prisms had been separated, I recognized the character of compact and fine-grained lavas."

> Considering afterward the thinness of the crust which was resting upon a bed of scoria, which originated at the feet of mountains whose form and materials give evidence of volcanic chimneys and which covers a mass of granite not altered by fire, it presented itself suddenly to my mind as the product of a flow that had issued from a neighboring volcano. After this first idea, I determined the lateral limits and farthest extremities; thus I found again the prisms which presented to me in its thickness their faces and their angles, and on its surface showed me their bases, quite distinct from each other. I was very much inclined to believe that prismatic

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[1]Nicholas Demarest, "Mémoire sur l'origine et la nature du basalte à grandes colonnes polygones, déterminées par l'histoire naturelle de cette pierre, observée en Auvergne," Histoire et mémoires de l'Académie Royal des Sciences, for the year 1771, Mémoires, pp. 705-768.

> basalt could be a volcanic product and that that constant and regular form was the result of the former state of fusion where the lava had been.[1]

Demarest made comparisons between the basalt of the Auvergne and that of the Giants' Causeway,[2] and concluded "that in general these assemblages of polygonous columns are an infallible proof of an ancient volcano, provided that the stone which composes the prisms has a compact texture dotted with brilliant points and a black or gray color."[3] He believed that the materials which had been melted by volcanic fires to form basalt were granites.[4]

Others were also beginning to have doubts about the aqueous origin of basalt. Johann Jacob Ferber (1743-1790), professor of natural history at Mitau, writing of his travels through Italy during the year 1772, remarked that it was possible that some basalts were formed by an aqueous crystallization, which may have been the case with the basalts of Saxony and Bohemia, but he was convinced that the Paduan, Vicentine, and Veronese basalt hills had once been "parts of volcanoes, and that they are composed of the same lava as their other parts; one side of these hills commonly being columnar, and the other consisting of rude, unformed, lava masses."[5] Sir William Hamilton (1730-1803), who was

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[1] _Ibid._, p. 707 (translation by the author). For an example of the distortion of which nineteenth century vulcanists were sometimes capable, see Geikie's translation of this passage (pp. 151-152).

[2] _Ibid._, p. 709.

[3] Ibid. (translation by the author).

[4] _Ibid._, p. 723.

[5] John James Ferber, _Travels through Italy, in the Years 1771 and 1772. Described in a Series of Letters to Baron Born, on the Natural History, particularly the Mountains and Volcanos of that Country. Trans-_

considered to be an authority on volcanoes,[1] thought that basalts found near Vesuvius had been ejected by that volcano.[2] August Ferdinand, Graf von Veltheim (1741-1801), Barthélemi Faujas de St. Fond (1741-1819), and Rudolf Erich Raspe (1737-1794) were among those who accepted the theory that basalt was a volcanic product,[3] and it seemed that the ranks of the vulcanists were growing stronger. In 1775 even Werner had his doubts about the origin of basalt. In his Kurze Klassifikation he wrote:

> When I returned to Freiberg in 1775, I found the system of the vulcanists, and in it, among other things, the volcanic origin of basalt, generally accepted. The novelty and interest of this theory along with the superior art of persuasion of its defenders and, to a certain extent, the persuasive appearance of the matter itself soon procured for it an unusual number of adherents. If from the very beginning it seemed paradoxical to me, I had too much respect for the reputations of most of the mineralogists who adhered to the theory to at once declare myself against it. For the time, until I myself could make observations concerning it, I considered the correctness of the theory to be established. But in the summer of the following year, 1776, I visited and observed the most famous Saxon basalt mountain, the one at Stolpen. Here I found not even a trace of volcanic action or the least sign of volcanic origin. Indeed the entire interior structure proved completely to the contrary. Now for the first time I dared maintain publicly and prove that not all basalt, at least, could be of volcanic origin and that the Stolpen, among others, undoubtedly was not. As great and as formidable as the opposition which I at first encountered was, several people soon agreed with my opinion. My opinion received excellent support from the observations which I made in 1777 of the old earth fires in the coal formations surrounding the basalt and porphyry-slate mountains of the Bohemian Mittelgebirge and of the pseudo-volcanic formations

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lated from the German; with Explanatory Notes, and a Preface on the present State and Future Improvements of Mineralogy. By R. E. Raspe (London: Printed for L. Davis in Holbourn, 1776), p. 62.

[1]OW 450128.

[2]Johann Friedrich Wilhelm Widenmann, "Beantwortung der Frage. Was ist Basalt? ist er vulkanisch oder ist er nicht vulkanisch? Eine gekrönte Preiszschrift," Magazin für die Naturkunde Helvetiens, IV (1789), p. 170.

[3]Ibid., pp. 172, 175, 177.

which originated from them. Since in the future I will present my reasons against the volcanic origin of basalt, as well as several other rocks, in detail, I discontinue for the time being; but I do want to say here very briefly that, after further mature investigation and reflection, I am of the opinion that no basalt is of volcanic origin, but that all of it is of aqueous origin, just as all other primitive and floetz rocks are.[1]

In the spring of 1787 Werner took several of his students to the Scheibenberger Hügel, a basalt hill in the Ore Mountains, to demonstrate to them in the field what he had told them in the classroom about the origin of basalt.[2] And on this field trip he found what he believed to be proof of the aqueous origin of basalt. He published these findings in the Jenaischen allgemeinen Litteraturzeitung under the title "Neue Entdeckung."[3]

What had impressed Werner about the Scheibenberger Hügel were the layers of sand, clay, and wacke below the basalt. The layer of sand was undermost; above it was a layer of clay, and above the clay a layer of wacke, on which the basalt rested. It seemed to Werner that there was a transition from sand to clay to wacke and finally to basalt. The

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[1]Werner, "Kurze Klassifikation," Abhandlungen der Böhmischen Gesellschaft der Wissenschaften (1786), p. 294 (translation by the author).

[2]Abraham Gottlob Werner, "Werner's Bekanntmachung einer von ihm am Scheibenberger Hügel über die Entstehung des Basaltes gemachte Entdeckung, nebst zweyen zwischen ihm und Herrn Voigt darüber gewechselten Streitschriften; alle dreye aus dem Intelligenzblättern der allgemeinen Litteraturzeitung genommen, und von ihm noch mit einigen erläuternden Anmerkungen, wie auch einer in den noch besonders angehängten weitern Ausführung seiner letztern Schrift begleitet," Bergmännisches Journal, II (1788), 847. The students who accompanied Werner on this trip were: Obergamtssekretär Johann Friedrich Wilhelm Widenmann from Stuttgart, Dr. Franz Baader from Munich, one of the von Oppel brothers, and Johann Ludwig Gerhard from Berlin. Ibid.

[3]Ibid., p. 846.

sand, he noted, became finer from the bottom of the layer to the top, where it merged into clay; the clay in turn, being fairly sandy at the bottom of the layer, became progressively more clayey toward the top, where it merged into wacke; and the wacke, through various gradations, merged into basalt.[1] This excited Werner very much, for he saw in it evidence that these rocks were precipitates from a universal ocean. "Here," he wrote, "ideas pressed upon me . . . fast and irresistibly: this basalt, wacke, clay and sand are all of one formation; all were precipitated from one and the same ocean, which at one time covered this region; the waters which once covered this region precipitated first sand, then clay, and gradually changed their precipitate into wacke and finally into basalt."[2] It was this transition from one rock to another that prompted Werner to write the short article and to assert that "as concerns basalts in general I am now fully of the opinion that all basalt is of aqueous origin and of one formation, and a very new one at that, that all basalt at one time constituted one single tremendously wide-spread thick bed (covering various primitive and floetz formations), which was in time for the most part destroyed and of which all basalt caps are remainders." He triumphantly remarked: "Now what are most of our mineralogists who have a strong bias in favor of the volcanic origin of basalt going to say to this?"[3]

He was soon to find out what one vulcanist had to say about his

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[1] Ibid., pp. 850-852.

[2] Ibid., pp. 852-853 (translation by the author).

[3] Ibid., p. 855 (translation by the author).

new discovery. Only three issues after the one that carried his article the same newspaper published a reply by one of his former students, Johann Karl Wilhelm Voigt (1752-1821), entitled "Berichtigung. Ueber die neue Entdeckung von dem Herrn Akademieinspektor Werner, im Intelligenzblatt der allgemeinen Litteraturzeitung, Jahrg. 1788, N. 57."[1] Voigt began his article by saying: "What will the majority of mineralogists, who have a strong bias in favor of the volcanic origin of basalt, say about this new discovery? I can tell you at once that it is not going to weaken the conviction of a single one of them in the least."[2] He then went on to say that Werner was wrong in assuming the aqueous origin of basalt from what he had seen at the Scheibenberger Hügel and that it was his opinion that the basalt had flowed over the layers in a molten state. The fact that wacke merges into basalt seemed to Voigt to be proof that it too had been in a molten state at the same time as the basalt.[3] Voigt explained the difference between the wacke and the basalt by saying that the lavastream had probably flowed over the still wet ocean bottom, and therefore the lava at the bottom of the lavastream took on a different appearance than the lava at the top of the lavastream, the lower part forming wacke, the upper part forming basalt. Voigt thought that if the rock masses had not been altered since the waters receded, we would still be able to recognize the craters of former volcanoes. Furthermore, he added, there is nothing new about the discovery, since he had seen a lava flow over sandstone before. He then gave an example of basalt

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[1]Ibid., pp. 856-871.

[2]Ibid., p. 856.

[3]Ibid., pp. 857-858.

covering a layer of bituminous wood and ended his article with an excerpt from a book by Gratet de Dolomieu (1750-1801) entitled Mémoires sur les iles Ponces.[1]

Less than a month later, on December 19, 1788,[2] Werner wrote an answer to Voigt's article which was published in the same newspaper that had published the other articles. This reply was also published in the Bergmännisches Journal together with Werner's original article, a reprint of Voigt's article annotated by Werner, and a conclusion in which Werner stated more fully his objections to the volcanic origin of basalt.[3] Werner's annotations and reply were rather sharp, for he felt that Voigt had assumed a very righteous position in calling his article Berichtigung and in making himself the spokesman for all vulcanists. He wrote that he was not concerned with a person's manner as long as he was not unjust, but that Voigt, in writing mere opinion, in criticizing only the conclusions but not the observations from which the conclusions had been drawn, was not trying to get at the truth of the matter.[4] He was even more

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[1]Déodat Guy Silvain Tancrède Gratet de Dolomieu, Mémoire sur les iles Ponces, et catalogue raisonné des produits de l'Etna; pour servir a l'histoire des volcans: suivis de la description de l'éruption de l'Etna, du mois de Juillet 1787. Par M. le Commandeur Déodat de Dolomieu, . . . Ouvrage qui fait suite au voyage aux iles de Lipari, . . . (Paris: Chez Cuchet, 1788). Voigt cited the pages by Dolomieu in which he had written that volcanic materials found on isolated hills which are not volcanoes are the remainders of a lavastream, parts of which have been destroyed by erosion. As an example Dolomieu gave a basalt hill near Toulon. Werner, "Werner's Bekanntmachung einer von ihm am Scheibenberger Hügel über die Entstehung des Basaltes gemachten Entdeckung," Bergmännisches Journal, II (1788), 866-871. See also Dolomieu, Mémoire sur les iles Ponces, pp. 16-20.

[2]Werner, "Werner's Bekanntmachung einer von ihm am Scheibenberger Hügel über die Entstehung des Basaltes gemachten Entdeckung," Bergmännisches Journal, II (1788), 872.

[3]Ibid., pp. 845-907.

[4]Ibid., pp. 872-873.

convinced of Voigt's injustice by the fact that Voigt had paid very little attention to his main support for his argument, that is, the transition from sand to clay to wacke to basalt.[1] Werner also criticized Voigt for the choice of evidence that he had cited in support of the volcanic origin of basalt, particularly the example of a bed of basalt covering bituminous wood or coal. He could not understand how a flow of hot lava, which Voigt supposed basalt to have been at one time, could fail to set bituminous deposits on fire,[2] and he sarcastically called people who cite such examples while at the same time believing basalt to be a volcanic product "philosophical mineralogists."[3] He thought that Voigt's contention that nature has changed the topography of some areas where basalt is found to the extent that it is no longer possible to recognize the presence of an old volcano was a weak argument in support of the vulcanistic theories.[4]

Werner was still further convinced of Voigt's insincerity by his contention that he knew of the wacke Werner had written about only through the writings of Werner's student Karsten.[5] In his reply Werner cited pages in a book by Voigt in which he had discussed the same wacke.[6] Summing up Voigt's Berichtigung Werner wrote: "Everything that he has said against my observations and my proposition I consider as nothing."[7] He ended his reply by saying that he hoped that Voigt would keep his

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[1] Ibid., pp. 875-876.

[2] Ibid., p. 882.

[3] Ibid., p. 865.

[4] Ibid., p. 861.

[5] Ibid., p. 854.

[6] Ibid., pp. 877-878.

[7] Ibid., p. 884.

promise and further defend and support the volcanic origin of basalt and that he for his part would also try to get at the truth of the matter, whatever it might be.[1] In his Schluss-Anmerkung,[2] in which he listed his objections to the volcanic origin of basalt, Werner once more challenged Voigt and all others to an open discussion of the origin of basalt.[3]

A few months later the Bergmännisches Journal printed two articles by Werner. In the first, entitled "Ueber das Vorkommen des Basalts auf Kuppen vorzüglich hoher Berge,"[4] Werner explained that mountain caps of basalt, which are frequently found even in high mountainous regions, are the remainders of a once continuous universal formation, parts of which have been destroyed and washed away, leaving these isolated basalt peaks. In the second article,[5] Werner dealt with the question of basalt covering bituminous deposits. Such a deposit, described in an article by a Dr. Faust, had been used by Voigt in his reply to Werner as support for his theory that basalt was once part of a lava flow. Werner annotated the same report and used it to show that basalt covering bituminous wood and coal could not possibly have been part of a lava flow.

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[1] Ibid., p. 886. [2] Ibid., pp. 887-907. [3] Ibid., p. 904.

[4] Abraham Gottlob Werner, "Ueber das Vorkommen des Basaltes auf Kuppen vorzüglich hoher Berge," Bergmännisches Journal, I (1789), 252-260. The Bergmännisches Journal was a monthly journal. Werner's article appeared in the March issue.

[5] Abraham Gottlob Werner, "Herrn Doktor Fausts Nachricht von dem auf dem Meiszner in Hessen über Steinkohlen und bituminösem Holze liegendem Basalte. (Aus dem August-monate des 1784er Jahrgangs des Journals von und für Deutschland entlehnt, und mit einer Vorbemerkung, wie auch einigen erläuternden Anmerkungen versehen)," Bergmännisches Journal, I (1789), 261-295. This article too appeared in the March issue.

In the following issue of the Bergmännisches Journal Werner annotated a letter by Bergrat Eversmann,[1] who had visited Scotland and found that the famous basalt mountain King Arthur's Seat shows the same transition from sand to clay to wacke to basalt that Werner had observed in the Scheibenberger Hügel. The last article that Werner published in the basalt controversy appeared in 1789 in the Magazin für die Naturkunde Helvetiens. This article dealt with his theory of the origin of volcanoes.[2] In the same issue of this journal two essays appeared which had been entered in a contest advertised by the editor, Albrecht Hoepfner, on October 1, 1787. The contest question was "Was ist Basalt? Ist er vulkanisch; oder ist er nicht vulkanisch?" The deadline for the entries was October 31, 1788,[3] only eleven days after Werner's article on the Scheibenberger Hügel was to appear. Two essays were published in 1789.[4] One was by Voigt and the other by Johann Friedrich Wilhelm Widenmann, one of the students who had accompanied Werner on the field trip to the Scheibenberger Hügel. Widenmann won the prize, but, according

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[1]Abraham Gottlob Werner, "Schreiben des königlich preussischen Bergraths Herrn Eversmann an den Herrn Inspektor Werner über eine von ihm an dem berühmten Basaltberge König Arthurs-Sitz bey Edinburgh in Schotland gemachte ganz conforme Beobachtung mit der des letztern am Scheibenberger Hügel; von dem Herrn Inspektor Werner mit einer Vorbemerkung und einigen erläuternden Anmerkungen, wie gehörigen Beobachtungen begleitet," Bergmännisches Journal, I (1789), 485-526. This article appeared in the May issue of the journal.

[2]Werner, "Entstehung der Vulkanen," Magazin für die Naturkunde Helvetiens, IV (1789), 239-254. The article is dated January 12, 1789.

[3]Johann Georg Albrecht Hoepfner, ed., "Nachrichten," Magazin für die Naturkunde Helvetiens, III (1788), 440.

[4]Altogether there were six papers submitted in the contest. "Preisaustheilungen," Bergmännisches Journal, I (1789), 198.

to Hoepfner, neither essay had helped to solve the problem.[1]

The timing of the contest was unfortunate, because it coincided with the quarrel between Werner and Voigt, thus giving the impression that the editor of the journal had caused the quarrel. Hoepfner wrote that he had hoped to stimulate research toward the solution of the problem of the origin of basalt but that, instead, the contest had brought him only grief and unpleasantness.[2] Apparently its involvement in the controversy proved the ruin of the Magazin für die Naturkunde Helvetiens, for the 1789 issue of the journal was the last one ever published.

At approximately the same time that Werner and Voigt were arguing the origin of basalt, the same question was being discussed in Great Britain, where James Hutton's (1726-1797) "Theory of the Earth" had aroused some interest. Hutton's paper, which he had read to the Royal Society of Edinburgh in 1785, was published in 1788 in the first volume of the Transactions of that society.[3] Hutton set forth the theory that "all the strata of the earth, have had their origin at the bottom of the sea, by the collection of sand and gravel, of shells, of coralline and crustaceous bodies, and of earths and clays, variously mixed, or separated

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[1]Magazin für die Naturkunde Helvetiens, IV (1789), 136. For the full title of Widenmann's article, see p. 186, note 2, above. Voigt's article was entitled "Beantwortung der Preiszfrage. Was ist der Basalt? Ist er vulkanisch oder ist er nicht vulkanisch? Welche das Accessit erhalten hat." Magazin für die Naturkunde Helvetiens, IV (1789), 213-232.

[2]Magazin für die Naturkunde Helvetiens, IV (1789), v-vii.

[3]James Hutton, "Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Globe," Transactions of the Royal Society of Edinburgh, I (1788), 208-304.

and accumulated."[1] Hutton thought that these materials had been carried to the bottom of the ocean by the forces of erosion, but he does not explain where the materials came from originally. After the eroded materials were deposited in horizontal layers at the bottom of the ocean, he thought, they were consolidated by heat from the interior of the earth. The subterranean heat which fused the materials also caused them to expand, resulting in various kinds of folds and unconformities.[2] The expansive force applied directly under the materials at the bottom of the sea, Hutton thought, was sufficient to raise these materials above the surface of the sea, thereby forming land.[3] According to his theory, volcanoes "are natural to the globe,"[4] being primarily safety valves. "A volcano," he wrote, "should be considered a spiracle to the subterranean furnace, in order to prevent the unnecessary elevation of land, and fatal effects of earthquakes; . . ."[5] Hutton did not mention basalt in his paper, but he said that trapp is a subterranean lava and that the difference between "subterranean lavas" and "erupted lavas" results from the fact that a subterranean lava "only came to be exposed to the light in a long course of time, after it had congealed under the compression of an immense load of earth," and after being affected in a manner "proper to the mineral region," while the erupted lavas were emitted to the atmosphere in a fluid state.[6] In Werner's system of geognosy, basalt is the most important rock of the floetz-trapp formation, and thus Hutton's view in this instance, as in many others, was

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[1]*Ibid.*, p. 221

[2]*Ibid.*, p. 265.

[3]*Ibid.*, p. 262.

[4]*Ibid.*, p. 274.

[5]*Ibid.*, p. 275.

[6]*Ibid.*, p. 280.

diametrically opposed to the views of the neptunists. Hutton's theory was soon assailed in a series of letters by Jean André DeLuc (1727-1817)[1] and in a paper read before the Royal Irish Academy by Richard Kirwan (1733-1812). Kirwan, a well known scientist in his day,[2] was a great admirer of Werner and a staunch supporter of the neptunistic theory of the earth. His paper was published in the Transactions of the Royal Irish Academy under the title "Examination of the Supposed Origin of Stony Substances."[3] Kirwan not only criticized Hutton's theories, but also implied that they were atheistic.[4] Possibly as a result of this attack Hutton felt it necessary to give a more detailed account of his theories, for in 1795 he published an enlarged version of his original paper under the title Theory of the Earth, with Proofs and Illustrations.[5] After Hutton's death in 1797, his friend John Playfair (1748-1819) wrote a one volume condensation of this work entitled Illustrations of the Huttonian Theory of the Earth,[6] which was published in 1802. John

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[1]Jean André DeLuc, "Fourth Letter to Dr. James Hutton, F. R. S. Edinburgh, On the Theory of the Earth," Windsor, August 29, 1791. See also Geikie, p. 296.

[2]Agnes Mary Clerke, "Kirwan, Richard (1733-1812)," Dictionary of National Biography, XI, 228-230.

[3]Geikie, p. 296. See also Richard Kirwan, Geological Essays (London: Printed for D. Bremner, 1799), pp. 433-499.

[4]John Playfair, Illustrations of the Huttonian Theory of the Earth (Edinburgh: Printed for Cadell and Davies, London, and William Creech, Edinburgh, 1802), pp. 120-121.

[5]James Hutton, Theory of the Earth, with Proofs and Illustrations, In four Parts (Edinburgh: Printed for Messrs. Cadell, Jr., and Davies, London, and William Creech, Edinburgh, 1795). The work was never completed; the two volumes contain only two parts.

[6]See note 4 above.

Murray (d. 1820), a well known lecturer on natural philosophy, chemistry, medicine, and pharmacy at Edinburgh,[1] wrote that in Playfair's work Hutton's theory "is so ably supported, its principles are placed in so advantageous a point of view, the arguments which appear to favor it are so forcibly urged, and objections so ingeniously, and often successfully obviated, that it has given to the discussion of this subject an interest and form in a great measure new." To Murray, Hutton's theories appeared "visionary and inconsistent with the phenomena of Geology,"[2] and thus Playfair's able explanation of them prompted him to write a treatise in which he tried to state the arguments of both the Huttonians and the neptunists. His book, A Comparative View of the Huttonian and Neptunian Systems of Geology: in Answer to the Illustrations of the Huttonian Theory of the Earth, by Professor Playfair, was published in 1802, the same year that Playfair's work had appeared. The Huttonians, in the meantime, were receiving support from Sir James Hall (1761-1832), geologist, chemist, and later president of the Royal Society of Edinburgh.

The argument was carried on with even greater ardor after 1804, for in that year Robert Jameson (1744-1854), one of Werner's most loyal students and an ardent exponent of Werner's theories, was appointed regius professor of natural history at the University of Edinburgh,[3]

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[1]Bernard Barham Woodward, "Murray, John (d. 1820)," Dictionary of National Biography, XIII, 1285-1286. See also George P. Fisher, Life of Benjamin Silliman, M. D., LL. D., Late Professor of Chemistry, Mineralogy, and Geology in Yale College. Chiefly from his Manuscript Reminiscences, Diaries, and Correspondence (New York: Charles Scribner and Company, 1866), I, 166.

[2]Murray, p. iii.

[3]George Simonds Boulger. "Jameson, Robert (1744-1854)," Dictionary of National Biography, XXIX, 234-235.

where Playfair was professor of mathematics. And in 1805 Playfair exchanged his chair in mathematics for a professorship of natural history.[1] We can imagine the excitement of the situation in which two men in the same department, two of the fiercest advocates of the two different systems, offered lectures on the same subject. No wonder that Edinburgh became the center of the great debate between the vulcanists and the neptunists, between the Huttonians and the Wernerians.

Although the Huttonians were ultimately to assume the favored position, for a long time the Wernerians held the upper hand. An example of the pervasive influence of Werner and the neptunistic system is to be found in early American geological investigations and publications.

Early American geology was largely practical in accordance with the feelings of Thomas Jefferson, who wrote in 1826:

> . . . to learn, as far as observation has informed us, the ordinary arrangement of the different strata of minerals in the earth, to know from their habitual collocations and proximities, where we find one mineral, whether another, for which we are seeking, may be expected to be in its neighborhood, is useful. But the dreams about the modes of creation, enquiries whether our globe has been formed by the agency of fire or water, how many millions of years it has cost Vulcan or Neptune to produce what the fiat of the Creator would effect by a single act of will, is too idle to be worth a single hour of any man's life.[2]

Consequently, American geologists never became significantly involved in the theoretical controversy; but their work was guided by the Wernerian system. One need only open a book or journal dealing with geological

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[1]Bernard Barham Woodward, "Playfair, John (1748-1819)," Dictionary of National Biography, XV, 1299-1300.

[2]Thomas Jefferson, "Letter to Doctor John P. Emmet, May 2, 1826," The Writings of Thomas Jefferson, ed., Andrew A. Lipscomb (Washington: The Thomas Jefferson Memorial Association of the United States, 1905), XVI, 171.

matters, or a textbook of geology published in the United States during the first few decades of its independence, or even the reports of various expeditions which the United States government sent out to explore the West, to find out that Werner's terminology, Werner's theories and Werner's teachings were familiar to American geologists.

One famous American geologist who adopted Werner's classification of rocks as well as Werner's nomenclature was William Maclure, who published the first geological map of the United States, which earned him the title "father of American geology."[1] Maclure's map together with an article entitled "Observations on the Geology of the United States, explanatory of a Geological Map," was published in 1809 in the _Transactions of the American Philosophical Society._[2]

Maclure has been said to have studied under Werner, but this is not known with certainty. There are indications, however, that he did: during his extensive travels in Europe he visited Saxony,[3] and among the many books which he gave to the Academy of the Natural Sciences of Philadelphia was von Oppel's revised edition of Kern's _Bericht vom Bergbau_, which Werner used as a text in his course on mining and in the

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[1]George P. Merrill, _Contributions to the History of American Geology_ (Washington: Government Printing Office, 1906), p. 217.

[2]William Maclure, "Observations on the Geology of the United States, explanatory of a Geological Map," _Transactions of the American Philosophical Society_, VI (1809), 411-428.

[3]William Maclure, _Observations on the Geology of the United States of America; with Remarks on the Effect produced on the Nature and Fertility of Soils, by the Decomposition of the Different Classes of Rocks; and an Application to the Fertility of every State in the Union, in Reference to the accompanying Map. With two Plates_ (Philadelphia: Printed for the author by Abraham Small, 1817), p. 40.

introductory part of his course on geognosy.

Whether or not he had studied with Werner, Maclure understood Werner's theories. And although he wrote that in adopting Werner's nomenclature he did not mean to enter into the discussion of the origin of the different materials which compose the earth's crust nor into the relative periods of time in which modifications of the earth's crust may have occurred,[1] he also wrote that the geology of the United States might "perhaps be found to be the most correct elucidation of the general exactitude of that [Werner's] theory, as respects the relative position of the different series of rocks."[2] Maclure had little use for anything that was not useful, but he could not completely separate a classification of rocks from the theory on which it was based.

Maclure's map is clearly based upon Werner's system, which he thought to be "the most perfect and extensive in its general outlines."[3] It shows four classes of rocks: primitive, transition, secondary (Werner's floetz), and alluvial. The alluvial rocks occupied the area beginning with Long Island, extending southward and westward, roughly following the fall line, to the eastern border of Texas, and from there northward along the Mississippi River somewhat beyond the point where the Illinois River flows into it. In other words, the alluvial class formed approximately what is known from the physiographic standpoint as the Coastal Plain. The primitive rocks occupied most of the New England States, extended southward to Long Island and from there to the fall line,

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[1]Maclure, "Observations on the Geology of the United States," Transactions of the American Philosophical Society, VI (1809), 427.

[2]Ibid., p. 412.

[3]Ibid., p. 411.

where the western limit of the alluvial class formed its eastern border. It extended as far south as the Alabama River, its western limit being the Appalachians. To the west of the primitive class ran a narrow belt of transition rocks, from Albany, New York, to the Tombigbee River in Alabama; and between the alluvial rocks which followed the Mississippi River and the transition rocks, lay the floetz, or secondary, rocks.

Maclure defended Werner's addition of a class of transition rocks to his classification on the ground that the rocks of that class could otherwise only be placed either in the primitive or in the secondary class. Since they contain pebbles and organic remains, however, they had to be excluded from the primitive class; and their hardness, their almost crystalline structure, and the nature of their stratification excluded them from the secondary class.[1] Maclure showed no volcanic rocks on his map, remarking "that no volcanic productions have yet been found east of the Mississippi, is not the least of the many prominent features of distinction between the geology of this country and that of Europe; and may perhaps be the reason why the Wernerian system so nearly accords with the general structure and stratification of <u>this</u> continent."[2]

While Maclure did not wish to go into the origin of rocks nor the relative periods of formation, he fully accepted the idea of geological succession, which has a central and fundamental position in Werner's theories. In studying the arrangement of rock strata, in acquiring a knowledge of the original structure of the strata, Maclure thought that one

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[1]Maclure, Observations on the Geology of the United States of America, pp. 17-19.

[2]Ibid., p. 33.

should begin with the great outlines, tracing "the limits which divide the principal classes of rocks, and their relative situations and extents; leaving the examination of the vast variety, contained in each class, to be regulated by the general principles previously acquired,"[1] and he believed that geology "must rest, more upon relative positions, than upon the constituent parts of rocks."[2]

The basic unit of a geological map is the formation, and in his definition of a formation Maclure follows Werner very closely. "All that I mean by a formation," he wrote, "is, a mass of substances (whether adhesive, as rocks, or separated as sand and gravel) uniform and similar in their structure and relative position, occupying extensive ranges with a few or no interruptions of the rocks belonging to another series, class, or formation; and when such partial mixture apparently takes place, a careful examination will seldom fail to explain the phenomenon, without injuring the general principle, or making it a serious exception to the rule."[3]

In 1818 Maclure published an Essay on the Formation of Rocks,[4] in which he attempted a rock classification of his own, but he did not depart drastically from Werner's classification. The basis of his classification is the origin of rocks. However, by "origin of rocks" Maclure did not mean the coming into existence of rocks, but only "the last

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[1]Ibid., pp. 11-12. [2]Ibid., p. 46.

[3]Ibid., p. 59.

[4]William Maclure, Essay on the Formation of Rocks, or an Inquiry into the Probable Origin of their Present Form and Structure (Philadelphia, 1818).

change which produced their present form, and the agents that nature employed to give them that form, or effectuate that change."[1] With this definition of origin Maclure hoped to have a classification that would be based primarily upon observation, one in which some of the uncertainties of the classifications of the neptunists and vulcanists would be avoided. But he did not quite succeed. He encountered the same difficulties that all classifiers of rocks have met, and his classification did not turn out to be any less speculative than others. He retained Werner's terminology and Werner's explanations of the various rocks, even including transition neptunian rocks in his classification.[2]

In 1822 Maclure wrote that geologists did not know the origin and formation of the primitive rocks, but as far as the volcanic, alluvial, secondary and transition rocks are concerned, "we have either caught nature in the act of aggregating or forming such rocks, or rocks that from direct analogy are so similar in their construction, relative situation, &c. &c. as to warrant a deduction that they were most probably formed after this manner. Water appears to be the principal agent in changing the form of the earth's surface, . . ."[3] Maclure disagreed with some of Werner's views, but essentially he was always a Wernerian.

A very significant landmark in the history of American geology was the appointment in 1802 of Benjamin Silliman (1772-1864) to the professorship of chemistry and natural science at Yale University. Silliman

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[1] Ibid., p. 9. [2] Ibid., p. 29.

[3] William Maclure, "Some Speculative Conjectures on the Probable Changes that may have taken place in the Geology of the Continent of North-America east of the Stoney Mountains," The American Journal of Science, VI (1823), 98.

had been educated in law and did not have even the most rudimentary knowledge of the sciences he was to teach. To prepare himself for the task, therefore, he went to Philadelphia to attend lectures on chemistry. He arrived there in November of 1802, shortly after the city had had an epidemic of yellow fever and "the streets were quiet, and an air of anxiety was visible in the aspect of the remaining citizens."[1] At Mrs. Smith's boardinghouse he met with gentlemen of "brilliant intelligence," learned to drink port, and by the end of his stay in the City of Brotherly Love had "made some progress towards incipient gout."[2] But he also attended lectures by Dr. James Woodhouse (1770-1809) at the Philadelphia Medical School, Dr. Benjamin Rush (1745-1813), physician, scientist, and one of the signers of the constitution, and Dr. Caspar Wistar (1761-1818), at whose house he met Joseph Priestley. In 1805 he went to England and Scotland, his trip being financed by his salary from Yale and a five per cent commission which he received for acting as agent in the purchase of ten thousand dollars worth of books for the Yale library.[3]

In England Silliman visited the mines in Derbyshire and Cornwall and met James Watt and Sir Joseph Banks (1743-1820), president of the Royal Society. After several months in England he went to Edinburgh, where Jameson and Murray on the one hand and Hall and Playfair on the other were arguing their case. In 1805-06 there was no distinct course in geology offered at the University of Edinburgh. The geological discussions "were held in the midst of the chemical lectures, being

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[1]Fisher, Life of Silliman, I, 97.

[2]Ibid., p. 99. [3]Ibid., p. 128.

introduced in connection with the elementary and proximate constitution of rocks and minerals."[1] At that time Silliman was still a novice in geology, having received the elements of geological and mineralogical instruction primarily in the mines and mineral districts of England.[2] He was therefore able to listen to both sides without much prejudice for one or the other of the two theories, although he admitted that "as far as I had any leaning, it was towards the Wernerian system."[3] He was swayed by the arguments of both the Wernerians and the Huttonians, being in "a state of mind to yield to evidence," but he finally emerged with the conviction that Werner's system was more correct than Hutton's. He wrote:

> I was a diligent and delighted listener to the discussion of both schools. Still the igneous philosophers appeared to me to assume more than had been proved regarding internal heat. In imagination we were plunged into a fiery phlegethon, and I was glad to find relief in the cold bath of the Wernerian ocean, where my predilections inclined me to linger.[4]

The fact that Silliman had become a Wernerian was important to early American geology because he was to teach the subject to many Americans, not only at Yale but also in popular lectures throughout the eastern states. In 1829 he published an Outline of the Course of Geological Lectures given in Yale College,[5] in which he wrote:

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[1] *Ibid.*, p. 167.

[2] *Ibid.*, pp. 167-168.

[3] *Ibid.*, p. 168.

[4] Benjamin Silliman, "Address before the Association of American Geologists and Naturalists, assembled at Boston, April 24, 1842," *The American Journal of Science*, XLIII (1842), 229-230.

[5] Benjamin Silliman, *Outline of the Course of Geological Lectures, given in Yale College* (New Haven: Hezekiah Howe, 1829).

> The arrangement implied in the following sketch is . . . founded upon the great outlines of the Wernerian plan. Whatever may be the errors and imperfections of that system, (for it undoubtedly has both,) its great outlines still appear to be founded in truth, and to the present the best clew to conduct the young pupil through the labyrinths of geology. It has become fashionable to decry Werner; but, without being his blind admirer, I may be permitted to ask, who has done more for geology, and who has done it better?[1]

While Silliman exerted great influence upon early American geology through his teaching, he was perhaps even more influential as editor of the American Journal of Science, also known as Silliman's Journal, which he founded in 1818, the first issue appearing in 1819. The title page of the first volume reads: "The American Journal of Science, more especially of Mineralogy and Geology, and the other branches of Natural History." In the second volume the title was changed to The American Journal of Science and Arts, but the strong emphasis upon geology and mineralogy remained. For this reason the American Journal of Science has been called "one of the greatest influences in American geology."[2]

Silliman wrote articles, reviewed books, and prefaced many letters and articles written by others. Although not a blind follower of Werner, he was always one of his admirers. In the introductory remarks to a letter by William Maclure he wrote: "The name of Werner will always be venerated as long as geological science shall be cultivated, for geology owes more to him than to any other man. . . ."[3]

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[1] Ibid., p. 4.

[2] Charles Schuchert, "A Century of Geology.--The Progress of Historical Geology in North America," The American Journal of Science, 4th Series, XLVI (1918), 45.

[3] William Maclure, "Hints on some of the Outlines of Geological Arrangement, with particular Reference to the System of Werner, in a Letter to the Editor, dated Paris, 22d August, 1818, with Introductory

Silliman was also the founder of the first geological society in America, the American Geological Society, which held its first meeting at Yale College on September 6, 1819, and ceased to function in 1830. William Maclure was the president of the society and Silliman the second vice president, one of several offices that he held during the life of the society.

The widespread interest in mineralogy and geology in the United States and the teaching of these subjects in schools of higher learning created a demand for a textbook, and in 1816 the first one by an American was published in the United States. This was Parker Cleaveland's (1780-1858) An Elementary Treatise on Mineralogy and Geology.[1] By far the largest portion of the work is devoted to mineralogy, only fifty-five pages of a total of more than six hundred and fifty being devoted to geology. In his treatment of minerals Cleaveland adopted Werner's classification and definitions of the external and physical characteristics of minerals, combining these with the systems of Alexandre Brogniart (1770-1847), based primarily upon the chemical composition of minerals, and Haüy, based largely upon the crystal form of minerals.[2] In the portion of the text devoted to geology Cleaveland followed Werner almost exclusively, remarking that the "classification of rocks has been

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Remarks by Benjamin Silliman," The American Journal of Science, I (1819), 211.

[1]Parker Cleaveland, An Elementary Treatise on Mineralogy and Geology, being an Introduction to the Study of these Sciences, and designed for the Use of Pupils,--for Persons, attending Lectures on these Subjects,--and as Companion for Travellers in the United States of America. Illustrated by six Plates (Boston: Cummings and Hilliard, 1816).

[2]Ibid., pp. v-x.

effected by Werner with as much accuracy, perhaps, as the nature of the subject permits, in regard to all those rocks, which have fallen under his observation."[1] The demand for Cleaveland's work was great enough that a second edition was published in 1822.[2] No doubt this book did much to spread Wernerian teachings in the United States.

In 1818 J. Freeman Dana (1793-1827) and his brother Samuel L. Dana (1795-1868) published a brief description and map of the mineralogy and geology of Boston and its vicinity,[3] employing not only Werner's classification of rocks, but also his colors for the different minerals shown on the geological map and his definitions of mineralogical terms. In the same year Samuel L. Mitchill (1764-1831), statesman, educator, and one of the outstanding scientists in America, published his "Observations on the Geology of North America," which was appended to Robert Jameson's edition of Cuvier's Essay on the Theory of the Earth.[4] Mitchill believed that water was the most important agent in the formation and alteration of the earth's crust, and in his theories and terminology he

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[1] Ibid., p. 587.

[2] Parker Cleaveland, An Elementary Treatise on Mineralogy and Geology, designed for the Use of Pupils,--for Persons, attending Lectures on these Subjects,--and as a Companion for Travellers in the United States of America. Illustrated by six Plates (2 Vols., 2nd ed.; Boston: Cummings and Hilliard, 1822).

[3] J. Freeman Dana and Samuel L. Dana, Outlines of the Mineralogy and Geology of Boston and its Vicinity, with a Geological Map (Boston: Cummings and Hilliard, 1818).

[4] Georges Cuvier, Essay on the Theory of the Earth. With Mineralogical Notes, and an Account of Cuvier's Geological Discoveries, by Professor Jameson. To which are now added, Observations on the Geology of North America; illustrated by the Description of various Organic Remains, found in that Part of the World, By Samuel L. Mitchill (New York: Kirk & Mercein, 1818).

followed Werner. His biographer writes that "examination of the Doctor's work in these two sciences [mineralogy and geology] fails to disclose any theories of the earth's formation out of harmony with Werner. . . ."[1]

Amos Eaton's (1776-1842) first important geological publication, An Index to the Geology of the Northern States,[2] which he had prepared for the geological classes at Williams College, Northampton, Belchertown, Leicester and Worcester, Massachusetts, also appeared in 1818. Eaton had studied under Silliman and was a Wernerian. His definition of geology was essentially the same as Werner's definition of geognosy, and he wrote that "geology treats of the relative position of the different rocks, their formations, their imbedded mineral substances, their changes, and the soils resulting from their disintegration."[3] He classified all rocks as primitive, transition, secondary, superincumbent, and alluvial, and lik Werner, he attributed little importance to volcanoes. The definitions of the different classes of rocks are the same as Werner's, the superincumbent rocks being Werner's floetz-trapp formation. In 1820 a second edition of the work was published[4] under the auspices of the Troy Lyceum at Troy, New York, where Eaton was then lecturing. This particular

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[1]Courtney Robert Hall, A Scientist in the Early Republic. Samuel L. Mitchill 1764-1831 (New York: Columbia University Press, 1934), p. 72.

[2]Amos Eaton, An Index to the Geology of the Northern States, with a transverse section from the Catskill Mountains to the Atlantic, Prepared for the geological Classes at Williams College, Northampton, Belchertown, Leicester and Worcester, (Mass.) (Leicester: Printed by Hori Brown, 1818).

[3]Ibid., p. 9.

[4]Amos Eaton, An Index to the Geology of the Northern States, with transverse sections, extending from Susquehanna River to the Atlantic, crossing Catskill Mountains. To which is prefixed a Geological Grammar (2nd ed.; Troy, New York: Wm. S. Parker, 1820).

edition had been examined by a committee appointed by George Gibbs, first vice president of the American Geological Society, which recommended it as "an Authentic Record of Geological Facts," for adoption by the American Geological Society "as a system of North American Geology."[1] This edition was much enlarged, but Eaton still followed Werner in his classification, in his terminology, and in his theories. He wrote: "With respect to the theoretical part, as far as I have given in to any theory, it is to that of Werner, with the improvements of Cuvier and Bakewell."[2] In his Geological Nomenclature for the United States,[3] Eaton used Werner's system and terminology and retained his original classes.[4] In 1830 his Geological Text-book,[5] which he had prepared for his lectures on North American geology, was published. In it he remarked that Werner's "classification of facts must ever form the basis of all future geological enquiries."[6] It certainly formed the basis of Eaton's geological work.

While at Albany in 1818, Eaton was invited by Governor De Witt Clinton to deliver a course of lectures on chemistry and geology before the members of the legislature of New York.[7] Because of this he became

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[1] Ibid., p. ii. [2] Ibid., p. vi.

[3] Amos Eaton, A Geological Nomenclature for North America; founded upon Geological Surveys, taken under the Direction of the Hon. Stephen van Rensselaer. Prepared for Rensselaerean Schools (Albany: Packard and Van Benthuysen, 1828).

[4] Ibid., p. 9.

[5] Amos Eaton, Geological Text-book, prepared for Popular Lectures on North American Geology; with Applications to Agriculture and the Arts (Albany: Websters and Skinners, 1830).

[6] Ibid., p. 13.

[7] Schuchert, The American Journal of Science, 4th Series, XLVI

acquainted with important men and was in a position to arouse their interest in geology and to influence their geological concepts.

The United States had learned early in its history that it could not depend upon the whims of European statesmen such as Pitt the Younger and Napoleon Bonaparte if it wished to survive and remain independent. The War of 1812 convinced many statesmen that the nation must develop its own resources and dominate the country from ocean to ocean. The phrase "manifest destiny" had not yet been coined, but the spirit of it already existed during the Era of Good Feelings. It was in this spirit that Secretary of War John C. Calhoun instructed Major Stephen H. Long in 1819 to explore the Missouri and Arkansas rivers, the Mississippi River above the mouth of the Missouri, and the Red River. In his instructions to the geologist of the expedition, Long wrote that he was to report the "geology, so far as it relates to earths, minerals, and fossils, distinguishing the primitive, transition, secondary, and alluvial formations and deposits . . . without regard to the theories or hypotheses that have been advanced by men of science."[1] On the whole the geologists of the expedition, Augustus Edward Jessup and Edward James,[2] adhered to the instructions issued and did not get involved in geological theories. But they could not refrain from doing so occasionally. Thus, when in

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(1918), 56.

[1]Reuben Gold Thwaites, ed., Early Western Travels 1748-1846, Vol. XIV: Part I of James's Account of S. H. Long's Expedition, 1819-1820 (Cleveland: The Arthur H. Clark Company, 1905), p. 42.

[2]Jessup remained with the expedition during the first season only, then was replaced by James. James was a student of Amos Eaton and Dr. John Torrey, and he joined the expedition "fresh from the tutelage of these men." *Ibid.*, pp. 13, 40.

July 1820 the party arrived at the base of the Rocky Mountains and observed the sandstone formations, James remarked that "it is difficult, when contemplating the present appearance and situation of these rocks, to prevent the imagination from wandering back to that remote period, when the billows of an ocean lashed the base of the Andes, depositing, during a succession of ages, that vast accumulation of rounded fragments of rocks, alternating with beds of animal remains, which now extends without interruption from the base of this range to the summits of the Alleghany mountains; and endeavouring to form some idea of that great subsequent catastrophe, by which this secondary formation has so changed its elevation, in relation to the primitive, that its margin has been broken off and thrown into an inclined or vertical position."[1] Nor could they refrain from giving their opinion as to the origin of amygdaloid, a rock whose origin was much disputed, some maintaining that it is a volcanic rock, others that it is not, which Werner had classified among the transition and floetz rocks.[2] When the expedition, in the midst of a violent storm, crossed "a long and inconsiderable elevated ridge of amygdaloid," its singular disposition suggested to everyone in the party the idea "that the mass had once been in a fluid state; . . ."[3] Some theory was also introduced in the accompanying drawings of the report, for in the profile, or vertical, section of the region drained by

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[1]Thwaites, Vol. XV: Part II of James's Account of S. H. Long's Expedition, p. 287.

[2]Ospovat, p. 64.

[3]Thwaites, Vol. XVI: Part III of James's Account of Long's Expedition, p. 91.

the Mississippi, on the thirty-eighth parallel the supposed level of the primitive ocean is indicated.

In his report to Calhoun, Major Long wrote that the Mississippi Valley from a geological point of view "is constituted of three varieties of formations, which characterize the surface throughout; viz. transition, secondary and alluvial."[1] Jessup in a report to Major Long, drawn up at Smithland, Kentucky, in January 1820, noted that the secondary formations along the eastern base of the Rocky Mountains rest immediately upon the primitive granite, transition forms are entirely lacking, and sand and gravel rest on the sandstones which cover the great desert. He remarked that the sandstones which are entirely mechanical aggregates and consist of rounded fragments of rocks formerly constituting a part of the primitive mountains "would seem to have been deposited at a very remote period, when the waters of the primeval ocean covered the level of the great plain and the lower regions of the granitic mountains."[2] Thus it seems clear that Werner's theories were known to the geologists of the Long expedition, for his classification and terminology were used by them.

In the 1823 and 1824 issues of the American Journal of Science, Edward Hitchcock's "Geology, Mineralogy and Scenery of the Connecticut,

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[1]Thwaites, Vol. XVII: Part IV of James's Account of Long's Expedition, "A General Description of the Country Traversed by the Exploring Expedition. Being the Copy of a Report of Major Long to the Hon. J. C. Calhoun, Secretary of War. Dated Philadelphia, Jan. 20, 1821," p. 104.

[2]Ibid., "Observations on the Mineralogy and Geology of a Part of the United States West of the Mississippi. Extracted from Jessup's MS Report to Major Long," p. 212.

with a Geological Map and Drawings of Organic Remains,"[1] appeared. The coloring of the map and the classification were not strictly Wernerian, but Hitchcock did not depart far from Werner's system. J. W. Webster in his account of the geology of Boston and its vicinity wrote that Prospect Hill, which toward its northwest extremity is covered by a mass of trapp, "exhibits that gentle acclivity and rounded summit so common in the transition formation of the Wernerians."[2] And Ebenezer Emmons in his Manual of Mineralogy and Geology,[3] which was first published in 1826, used the same classification of rocks as did Eaton, primitive, transition, secondary, superincumbent, and alluvial, a classification which is very much like Werner's.

George P. Merrill, in his Contributions to the History of American Geology, names the early period in American geology for William Maclure and Amos Eaton, calling the period from 1785 to 1819 the Macclurean Era and the period from 1820 to 1829 the Eatonian Era.[4] Considering Werner's influence on these men as well as many other American geologists, it would not be inappropriate to call this period the

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[1]Edward Hitchcock, "A Sketch of the Geology, Mineralogy, and Scenery of the Regions contiguous to the River Connecticut; with a Geological Map and Drawings of Organic Remains; and occasional Botanical Notices. Read before the American Geological Society at their Sitting, Sept. 11th, 1822," The American Journal of Science, VI (1823), 1-86; VII (1824), 1-30.

[2]Merrill, pp. 283-284.

[3]Ebenezer Emmons, Manual of Mineralogy and Geology: designed for the Use of Schools; and for Persons attending Lectures on these Subjects, as also a Convenient Pocket Companion for Travellers, in the United States of America. Adopted as Text-book in the Rensselaer School (Albany: Websters and Skinners, 1826).

[4]Merrill, p. 193.

Wernerian Era of American geology.

At the end of the eighteenth century and the beginning of the nineteenth, the figure of Werner dominated the geological world. This period was the Wernerian Era of geology not only in America, but all over the civilized world. This is even more remarkable considering that Werner wrote comparatively little, that he did not publish a complete treatment of either his mineralogical or his geognostic system, and that he did not take part in the great neptunist-vulcanist controversy after his feud with Voigt. Werner exerted his influence from the lecturn of the Bergakademie at Freiberg. There he expounded to his students his theories and his mineralogical and geognostic systems; there he gave them a framework within which to work and taught them how to investigate the earth's crust. He was not "the dogmatic theorist, intolerant of the opinions different from his own," as Geikie has called him.[1] He was a scientist convinced of his theories and convincing to his students, whom he taught to go out into the world and combine their classroom learning with the teachings of nature itself. It is no wonder that Wernerian theories spread over most of the civilized world, for Werner's students taught in many schools in widely scattered places. Dietrich Ludwig Gustav Karsten (1768-1810) taught at the Mining Institute at Berlin, Heinrich Struve (1751-1826) at the University of Lausanne, Andrés Manuel Del Río (1765-1849) at the School of Mining in Mexico City, Vicenzo Ramondini (1758-1811) at the University of Naples, Henrik Steffens (1773-1845) at the universities of Kiel, Halle, and

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[1]Geikie, p. 202.

Berlin, Friedrich Wilhelm Lempe (1783-1850) at the University of Warsaw, Robert Jameson at the University of Edinburgh, Moritz von Engelhardt (1779-1842) at the University of Dorpat in Estonia, and John Hailstone (1759-1847) at Trinity College, Cambridge. Petrus Ilman was vice-director of the Russian Imperial School of Mining, and Carl Haberle (1764-1832) taught at the University of Pest.

Never in the history of geology, and seldom in the history of any science, has there been another teacher who gathered around him so many students who later gained fame and recognition in their field. In the introduction to his course on geognosy Werner told his students that they must be able to judge, to draw conclusions, and to synthesize, and above all they must have a love for truth. How well he taught them is demonstrated by the fact that it was his own students, some of whom had lived in his house and were his friends as well as his students, who ultimately did more to stem the tide of his theories than anyone else.

One of Werner's students who left Freiberg a convinced neptunist and later changed his views was Leopold von Buch (1774-1853), whom his fellow student Alexander von Humboldt (1769-1859) described in his Kosmos as "the greatest geognost of our time."[1] Von Buch was only sixteen years old when he came to Freiberg to study with Werner. His parents put him under Werner's personal care,[2] and during his three year stay at Freiberg he lived most of the time at Werner's house. Through

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[1]Alexander von Humboldt, Kosmos. Entwurf einer physischen Weltbeschreibung (Stuttgart: J. G. Cotta'scher Verlag, 1845), I, 26.

[2]Leopold von Buch, Leopold von Buch's Gesammelte Schriften, eds., J. Ewald, J. Roth, H. Eck (Berlin: Georg Reimer, 1867), I, vii.

his classroom and close personal contact with Werner he became thoroughly imbued with Werner's theory of the formation of the earth's crust and with his whole geognostic system. This is reflected in his early writings in geognosy, which show little deviation from Werner's teachings. In one of the earliest of these, Versuch einer mineralogischen Beschreibung von Landeck,[1] von Buch tried to interpret his observations on the basis of Werner's theories, explaining the distribution and composition of the rocks in Landeck by giving directions of flow to the floods which had deposited these rocks.[2] And commenting on the origin of basalt, he wrote: "Werner's merits extend further than the more accurate determination of this rock; one can boldly assert that, through the exposition of his opinion, light was spread in geognosy over that which had been hidden in darkness."[3]

Three years later, in 1800, von Buch published the first volume of his two volume work Geognostische Beobachtungen auf Reisen durch Deutschland und Italien, which he dedicated to Werner. In this work von Buch began to show some doubts about Werner's theories; in writing of the basalt in the Schneegrube he said that its occurrence cannot be satisfactorily explained by either the neptunistic or the vulcanistic theory.[4] The difficulties von Buch had in turning away from the teachings of his master can be seen in his statement in a letter to Freiherr

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[1]Leopold von Buch, Versuch einer mineralogischen Beschreibung von Landeck (Breslau: Johann Friedrich Korn, 1797).

[2]Ibid., pp. 50-51.

[3]Ibid., p. 50 (translation by the author).

[4]Von Buch, Reisen durch Deutschland und Italien, I, 122-123.

von Moll: "There is hardly anyone who is as convinced as I am that basalt is not volcanic; and yet I am just now finishing an essay in which I try to show . . . that the leucites which are found in the greatest splendor in the plains of Rome . . . were formed in a mass which flowed from a volcano."[1] Von Buch also began to have doubts about Werner's theory that volcanoes are the result of burning coal deposits. He wrote: "In vain we seek near Vesuvius and in the whole adjacent region places where beds of coal might be deposited."[2]

In April of 1802 von Buch visited the Auvergne, and after five weeks of investigations he came to the conclusion that granite, through a series of operations, had changed into lava and that the seat of the Auvergne volcanoes is in the granite itself. This was a drastic departure from Werner's teachings, and yet von Buch still found it difficult to accept the vulcanists' position that all basalts are of volcanic origin. He cautioned the vulcanists not to dare consider the results of his investigations as applicable to all basalts and not to consider the basalts of Germany to have originated from granite in the way that those of the Auvergne had.[3]

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[1]Von Buch, "Briefe gerichtet an den Freiherrn von Moll," Leopold von Buch's Gesammelte Schriften, I, 99 (translation by the author). The origin of a number of basalt-like masses in southern Italy was being disputed by vulcanists and neptunists. Leopold von Buch's Gesammelte Schriften, I, xxvii. Von Buch's essay, in asserting that rock masses containing leucites were of volcanic origin, supported the position taken by the vulcanists and helped to place many of the disputed rock masses among the volcanic rocks.

[2]Von Buch, Reisen durch Deutschland und Italien, II, 166 (translation by the author).

[3]Ibid., p. 311.

Two years later, in 1804, von Buch went to Freiberg to visit Werner. He was somewhat apprehensive about meeting Werner, who had heard of his writings and opinions about the rocks of the Auvergne, but he was soon relieved of his fears, for Werner received him very cordially and insisted that he stay at his house just as he had done on previous visits. He did, however, oppose von Buch's views and categorically declared himself against the assumption that granite had changed into lava.[1]

Von Buch continued his research on the origin of volcanoes, traveling to many parts of the world. He visited Italy in the company of von Humboldt and Joseph Louis Gay-Lussac,[2] to further study the volcanoes of that peninsula and traveled to the Canary Islands, where he formulated his theory of "craters of elevation" with which he explained the different forms of volcanic mountains. In 1810 he published his Reise durch Norwegen und Lappland,[3] in which he described the geographic and geognostic features of a region which until that time had been studied but little. He found that the geological succession on the whole agreed with that of Werner's formations, though he did find near Oslo a granite deposit immediately above limestone. His suggestion that fossils might be found in that granite seems to indicate that, at that time, he still considered granite a sedimentary rock.[4]

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[1]Von Buch, Leopold von Buch's Gesammelte Schriften, I, xliii.

[2]Ibid., p. xlv.

[3]Leopold von Buch, Reise durch Norwegen und Lappland (2 Vols.; Berlin: G. C. Nauck, 1810).

[4]Von Buch, "Reise durch Norwegen und Lappland," Leopold von Buch's Gesammelte Schriften, II, 183-184.

Von Buch did not easily give up his neptunistic views, and much of his work in the Canary Islands, in the Alps, in Scandinavia, and in other parts of the world was stimulated by his desire to find evidence for the theories that he had learned at Freiberg. He did not discard Werner's system but modified it, rejecting that which he could no longer substantiate with his observations and retaining what he could confirm.

One year after von Buch came to Freiberg, Alexander von Humboldt enrolled at the Bergakademie. During part of his nine months stay in Freiberg von Humboldt lived in Werner's house, and like von Buch, became his friend as well as his student. Werner gave him very intensive instruction in geognosy, since he knew that von Humboldt had accepted a position with the Prussian mining service and would not be able to stay in Freiberg very long. To make von Humboldt's stay as beneficial as possible, Werner also assigned Johann Carl Freiesleben to be his guide and instructor in practical mining matters. Von Humboldt became a close friend of Freiesleben and also of von Buch, and the friendship among these three students of Werner's endured for the rest of their lives.[1]

Von Humboldt, who is best known for his work Kosmos, in which he tried to present a synthesis of all nature, did most of his geological work on the nature of volcanoes and earthquakes. At the time he came to Freiberg he had already written a treatise entitled Mineralogische Beobachtungen über einige Basalte am Rhein,[2] in which he agreed with Werner

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[1]Alfred Dove, "Humboldt: Friedrich Wilhelm Heinrich Alexander v. H.," Allgemeine Deutsche Biographie, XIII, 360-361.

[2]Alexander von Humboldt, Mineralogische Beobachtungen über einige Basalte am Rhein. Mit vorangeschickten, zerstreuten Bemerkungen über den Basalt der ältern und neuern Schriftsteller (Braunschweig: In der Schulbuchhandlung, 1790).

that basalt is an aqueous rock, and during his stay at Freiberg he became fully convinced of the correctness of Werner's theories and system. He never abandoned the bulk of Werner's ideas, despite the fact that he differed with Werner in many details. This can best be seen in his Essai géognostique sur le gisement des roches dans les deux hémisphères,[1] which he wrote in 1822 for the Dictionnaire des sciences naturelles,[2] and published separately in 1823. At that time von Humboldt no longer believed that volcanoes were of little importance in the formation of the earth's crust, as Werner had taught, nor that basalt is a rock of aqueous origin. But he still followed Werner in many respects, used much of his classification of rocks, and believed what Werner had expressed in his Kurze Klassifikation, that despite the apparent diversity of rocks in the earth's crust in different parts of the world, "the rocks of even the remotest countries agree in general with those that are known to us."[3] Like Werner, von Humboldt did not believe in "unorganized nature." He asserted that the independence of a formation, that is, its immediate superposition on rocks of a different nature, "in no manner excludes uniformity or concordance of position; it rather excludes the oryctognostic passage between two superposed formations."[4] He searched for correlation between the rocks of the New World and the

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[1]Alexander von Humboldt, Essai géognostique sur le gisement des roches dans les deux hémisphères (Paris: F. G. Levrault, 1823).

[2]Alfred Dove, "Humboldt," Allgemeine Deutsche Biographie, XIII, 373.

[3]Werner, "Kurze Klassifikation," Abhandlungen der Böhmischen Gesellschaft der Wissenschaften (1786), p. 272 (translation by the author).

[4]Von Humboldt, A Geognostical Essay on the Superposition of Rocks in both Hemispheres, p. 7.

Old World, and he found it. "My attention," he wrote, "was particularly directed, during my travels, to the position and succession of formations, . . . In South America . . . I was struck by the conformity of superposition exhibited in the two continents."[1] In 1811, after his return from America, von Humboldt met Werner in Vienna and discussed with him the "geognostic constitution of the Cordilleras, of the Andes, and of Mexico."[2]

Certainly, Werner must have disagreed with some of the views of his former students, particularly those concerning the classification and origin of certain rocks. But, von Humboldt wrote, Werner was "conscious that his real glory was rather founded on the discovery of the principles of the science, and on the means of research, rather than on the results obtained at a particular epoch. Werner showed no less regard for such of his pupils as differed from him on the subject of the relative age, and the origin of some formations."[3]

Von Humboldt, although he disagreed with some of the details of Werner's system and although he had contributed much to the establishment of the importance of volcanic action in the formation of the earth's crust, could still write in 1823:

> The first views of Werner, even those which that illustrious man had formed before the year 1790, possessed a justness that is still remarkable. The learned of every country, even those who show no predilection for the school of Freiberg, have preserved them as the basis of geognostic classifications; and yet what was known, however, in 1790, of primitive, transition, and secondary formations, was founded almost entirely on Thuringia, on the metalliferous mountains of Saxony, and those of the Harz, on an extent of country not 75 leagues in length.[4]

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[1] Ibid., p. 20.

[2] Ibid., p. 77.

[3] Ibid., p. 82.

[4] Ibid., pp. 80-81.

In 1797, a few years after von Buch and von Humboldt had left Freiberg, Jean François d'Aubuisson de Voisins came to study at the Bergakademie. At first rather skeptical about Werner's theories and teaching, d'Aubuisson was soon won over by Werner, and during his five year stay at Freiberg he became an ardent supporter of the neptunistic theories of the formation of the earth's crust. After his return to France, d'Aubuisson did not hesitate to support the theory that basalt is an aqueous rock. Despite the fact that in France the work of Demarest and Dolomieu, of Faujas de St. Fond, and others had done much to establish basalt as a volcanic rock, d'Aubuisson read a paper before the Institut National in which he maintained that all basalts, be they of Saxony, the Germanies, or elsewhere, are of aqueous origin.[1] Haüy and Louis Francois Elisabeth Ramond de Carbonnières advised d'Aubuisson to visit the Auvergne and see the basalts in that region. Only a year later d'Aubuisson read another paper to the Institut National admitting that he had been wrong in assuming that basalt is of aqueous origin.[2] Like von Buch and von Humboldt, d'Aubuisson rejected Werner's theory that volcanoes were of little importance in the formation of the earth's crust and that basalt is of aqueous origin, but he retained much of what he had learned from Werner. Nothing shows d'Aubuisson's adherence to much of Werner's teachings better than his Traité de géognosie.[3] Even

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[1]Jean François d'Aubuisson de Voisins, Mémoire sur les basaltes de la Saxe, accompagné d'observations sur l'origine des basaltes en général. Lu a la classe des sciences-physiques et mathématiques de l'Institut National, en frimaire an 11 (Paris: Chez Courcier, 1803).

[2]Jean François d'Aubuisson de Voisins, "Sur les volcans et les basaltes de l'Auvergne," read to the Institut National in 1804. Published in 1819 in the Journal de Physique. Geikie, p. 244.

[3]Jean François d'Aubuisson de Voisins, Traité de géognosie, ou

though it was published in 1819, fifteen years after d'Aubuisson had accepted the opinion of Demarest and Dolomieu, the two volume work was still one of the best texts on Wernerian geology. It won wide popularity in France, and a second edition was printed between 1828 and 1834. In its arrangement it follows Werner's lectures very closely, and it did much to spread Wernerian ideas in France. Karl A. von Zittel wrote in his History of Geology and Palaeontology that "the excellent work of d'Aubuisson de Voisins is the only one which merits the name of a text-book for teaching purposes."[1]

The work of von Buch, von Humboldt, and d'Aubuisson clearly indicates that they rejected and revised only parts of Werner's system, accepting what they believed to be correct in both the Wernerian and Huttonian systems.

Werner, like other scientists, built on the work done by others before him, adding much of his own. His contribution to the geological sciences, however, lies not only in the additions which he made to geological knowledge, but in his synthesizing that which already existed and pointing the way for future work. Whether Werner's theories were right or wrong is of little consequence, for the value of scientific work in the development of science can be determined only by its fruitfulness. And the work of few geologists has been more fruitful than Werner's.

Werner put order into mineralogy, which was in a state of confusion at the time he wrote his book on the external characteristics of

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Exposé des connaissances actuelles sur la constitution physique et minérale du globe terrestre (2 Vols.; Strasbourg: F. G. Levrault, 1819).

[1]Zittel, p. 144.

minerals. He clearly recognized the shortcomings of the different systems, pointed out the object of mineralogy and combined in his own system the best features of the systems of other mineralogists. He used the mixed system because he believed that it was the most useful in the identification of minerals, and according to his own dictum the value of a science depends upon the extent of its usefulness.

Werner invented a terminology for the description of minerals, gave definitions for every term, and attempted to introduce qualitative and quantitative standards which could be readily understood and used by mineralogists everywhere. And his system of external characteristics introduced a standard method by which to describe minerals.

By his difinition of a mineral he excluded from mineralogy rocks, petrifactions, fluids, and gases, thus setting stricter limits to the realm of mineralogy. His work in this field was extremely influential, since it was adopted in all parts of the world, and it was fruitful in that it aided the understanding of minerals.

Werner's geological system was detailed, consistent, and universally applicable. On the basis of the neptunistic theory of the formation of the earth's crust, Werner classified every rock known to him, defined their composition, determined stratigraphic relations, and explained their structure, occurrence and origin. When he classified granite among the primitive rocks and defined it as being composed of felspar, quartz, and mica; when he maintained that granite is the oldest rock and the foundation of all other rocks; and when he asserted that granite is a universal formation and that it can be found in the highest as well as the lowest places of the earth's crust, he made it possible for other geologists to investigate the validity of his system, to go out into the field and determine whether what he had said was according to nature.

Geology is primarily the history of the earth's crust, and therefore it has much in common with history. The geologist who goes out into the field and sees folded strata of rocks which he believes to be sedimentary assumes that these rocks were deposited in a horizontal position and this position was later changed by certain forces, such as heat and thrusting. He did not see it happen, but on the basis of a certain theory agreed upon by geologists, he believes that it happened in such and such a way. Likewise, historians do not know the causes of the French Revolution. But on the basis of certain manuscripts and books which are agreed upon as evidence, and working from the basic theory that all human beings are basically the same and will at all times react in similar ways to similar conditions, that human beings have always striven for freedom and wished to be free from hunger and persecution, historians have agreed that certain political, economic and social conditions were the causes of the French Revolution. The nature of geological theory and the nature of historical theory do not differ greatly. Werner's theory, the theory of uniformitarianism, or any other geological theory, is not much different in its aims and origin from historical theories, such as that of Max Weber (1864-1920).[1] All such theories try to explain what has happened in the past; they do not tell

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[1]Weber believed that science, commerce, and virtually every human endeavor in seventeenth century England flourished because the pioneers of modern capitalism were spurred on by their belief in the Calvinistic Augustinian doctrine of predestination.

us much about the future. But this does not detract from their usefulness. Werner's theory, the theory of uniformitarianism, Weber's theory --all have stimulated much work which has led to a better understanding of the past and, perhaps, even of the future.

Werner's system was new, even though most of the individual parts were not. The basic principle of the neptunistic theory, that the earth was once enveloped by a universal ocean in which the materials that make up the earth's crust were at one time dissolved or suspended, was known to others before him. His classification of rocks was very similar to Lehmann's, and his theory of the origin of volcanoes was much like Guettard's. The proposition that mineral veins fill former rock fissures was, as Werner himself wrote, old. The Law of Superposition was known to Steno; that some rocks are crystalline, and others are not, and that some are more crystalline than others was also known. What was new in Werner's system were the interpretations that he gave to observed phenomena, the consistency of his interpretations with the neptunistic postulates, and the way in which these interpretations complemented each other; the relation between the ever-falling level of the outcrops of strata as evidence for the degree of turbulence of the ocean and the conformity or unconformity of rock formations as evidence for the level and action of that ocean as well as for the period of deposition of the different rock masses. In short, the establishment of relationships between geological phenomena and their arrangement into a highly coherent and thoroughly interlocking system was what was new about Werner's work. As Keferstein wrote, "he shaped a science of materials which had long been at hand." And this is what is new in most important scientific work.

Werner's theory was a highly flexible one. By introducing the fallings and risings of the ocean Werner was able to explain the stratigraphic relations among the different kinds of rocks and their formations without resorting to a mechanism in conflict with the neptunistic theory. And the assumption that "the contents of the universal ocean must have varied from time to time" made it possible to explain virtually every variation in the succession of the rock formations in the different periods of formation. Today we reject Werner's theory not because it is too flexible, but because we are no longer able to believe that there once existed an ocean that stood higher than the Rocky Mountains and the Himalayas, that there could have been an ocean which held in suspension or solution enough materials to form the earth's crust.

Werner's system was fruitful. Werner emphasized that geognosy is the history of the earth's crust and that the stratigraphic relations form one of the best clues in the interpretation of the earth's history. The doctrine of geological succession found no stronger advocate than Werner and guided the work of many of his followers as well as the work of other geologists; the stress Werner put upon the mineralogical and petrographical side of geology has played an important part in geological investigations ever since.

Probably no other single occurrence in the history of geology stimulated more work than the basalt controversy. Werner's insistence that volcanoes played a relatively unimportant part in the formation of the earth's crust and that basalt is of aqueous origin gave rise to a great number of geological investigations, by his students and followers on the one hand and his opponents on the other. Zittel's statement that

Werner's influence retarded progress in Germany in the study of volcanoes could not be less correct.[1] Nowhere was the reaction in favor of accurate investigations of volcanoes keener than in Germany, where Werner's students stood on the forefront of these investigations.[2] It was because of Werner that so much work was done in the study of volcanoes. There had been differences of opinion as to the importance of volcanoes for centuries, but only after Werner developed his system and only after his system was accepted by many geologists, did this difference of opinion grow into a controversy. Werner's system forced the issue because it had explanations for virtually all geological phenomena, and his followers were therefore able to argue against all other theories. Hutton's theory of the earth did not attract much attention until it was attacked by the Wernerian Kirwan. This attack caused Hutton to write an enlarged version of his theory, which in turn led Playfair to write an abridgment and Murray to write an answer to Playfair. The controversy did not settle the issue, for there is still disagreement as to the relative importance of fire and water in the formation of the earth's crust,[3] but it stimulated much theoretical and observational work. As regards geological theory, therefore, Werner's influence was not, as Geikie wrote, disastrous to the higher interests of geology;[4] on the contrary it was highly beneficial. For all we know, Charles Lyell might have turned to

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[1]Zittel, p. 255. [2]*Ibid.*

[3]See Charles H. Hapgood, *Earth's Shifting Crust. A Key to some Basic Problems of Earth Science*. With the collaboration of James H. Campbell. Foreword by Albert Einstein ([New York]: Pantheon Books, [1958]), pp. 82-84.

[4]Geikie, p. 203.

another field of study if it had not been for the interest in geology that had been stimulated by Werner, his students, and his opponents.

Werner helped to establish geology as an academic discipline. He decided which materials should be included in the study of the earth's crust, brought these materials together, and presented them to his listeners in a systematic and well organized manner. He showed the relationships of these materials to each other and to the study of the earth's crust, and he related the whole study of geognosy to man and the universe. He found in geognosy explanations for migrations, wars, and prosperity, and he showed that geognosy is important to man's understanding of nature, his own history, and his development. In the spirit of the enlightenment, Werner considered geognosy to be important to man's well being and progress. His lectures served as models for his students and followers and were copied by many others. At the time Werner first offered his course on geognosy, mineralogy was the only earth science to be considered as an academic pursuit. At the beginning of the nineteenth century geognosy was offered in many institutions of higher learning. Only a few days before Werner's death, his student Robert Jameson wrote to him:

> The society which bears your name is flourishing. The Geological Society of London [founded in 1807] and . . . the Society of Cornwall are adding much to the unexampled zeal in mineralogy which now prevails on our island. At Oxford, Cambridge, London, Glasgow, York, Dublin, and Belfast chairs in mineralogy have recently been established, and soon there will be no place of note in Great Britain which will not have a professor of mineralogy.[1]

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[1]Quoted in Frisch, p. 223 (translation by the author). See "Preface," p. iii, above for an explanation of Jameson's use of the term mineralogy.

A direct result of the widespread interest in geology which had been stimulated by Werner was the emergence of textbooks of geology and manuals of geology, the first of which were written by Werner's students. These fulfilled the important function of bringing together current geological knowledge, of making this knowledge readily available, and of serving as a point of reference for further work.

Through his writings and his teaching Werner exerted a great influence on the later development of the geological sciences as well as on the mineralogy and geognosy of his own day. In the words of Cuvier:

> It is to his influence that the learned world owes those hard working authors who have described with such care the different natures of minerals and those indefatiguable observers who have torn from the globe almost its last veils. The Karstens, the Wiedemans [sic] in the study; the Humboldts, the von Buchs, the Daubuissons, the Hermanns, the Freyeslebens at the summit of the Cordilleras, in the midst of the flames of Vesuvius and Aetna, in the deserts of Siberia, in the depths of the mines of Saxony, Hungary, Mexico, Potosi--they have been guided by the spirit of their master and have brought back to him the honor of their labors. Of him can be said what has never before been truthfully said of any but Linnaeus: that all nature was interrogated in his name.[1]

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[1]Cuvier, Recueil des éloges historiques, II, 329-330 (translation by the author).

BIBLIOGRAPHICAL NOTE

Through the efforts of the author and with the cooperation of the University of Oklahoma Library, the E. DeGolyer Collection in the History of Science and Technology is now in possession of photostatic copies of Werner sources housed in the historical division of the Mineralogical Institute of the Bergakademie at Freiberg, Saxony. The purchase of these photostats was made possible through the kind cooperation of Professor Dr. Oelsner, Rector of the Bergakademie, Dr. Albert Bernstein, Curator of Collections of the Institut der Mineralogie und Lagerstättenlehre der Bergakademie, Professor L. Pfeiffer of the Bergakademie, and Dr. Friedrich Leutwein, formerly Rector of the Bergakademie.

This particular group of manuscript sources comprises approximately 8,000 sheets and has been arranged at Freiberg under fifty headings. Among these are part of Werner's literary remains, official correspondence between Werner and the authorities concerning the Bergakademie and the geognostic survey of Saxony, annual reports of courses taught in the past academic year, schedules of courses offered, class notes taken in Werner's courses on geognosy and mining, the minutes of the Verein Wernerischer Schüler, biographical notes, correspondence with Professor Nathanael Gottfried Leske (1751-1786) of the universities of Leipzig and Marburg, opinions and reports on technical matters concerning the Freiberg mining district, and Werner's reports to the authorities concerning the progress of his students.

Each group of manuscripts has been assigned a number by the Bergakademie at Freiberg. The University of Oklahoma Library has assigned a six digit number to each sheet, the first two digits being the manuscript number assigned at Freiberg, the last four numbers being used for the individual sheets within each of the fifty Freiberg groups. For example, class notes taken by Friedrich August Breithaupt in 1813 have a Freiberg number "46." There are 278 sheets of these notes. Therefore, the numbers assigned by the University of Oklahoma Library to this group begin with 460001 and end with 460278. To distinguish these photostats from the originals at Freiberg, the letters OW, signifying "Oklahoma Werner," have been prefixed to each number. The author has assigned descriptive titles to most of the manuscripts used.

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APPENDIX I

LIST OF COURSES OFFERED BY WERNER DURING HIS TENURE AT THE BERGAKADEMIE AND THE OFFICIAL CURRICULUM OF THE SCHOOL IN 1825

List of Courses offered by Werner during his Tenure at the Bergakademie[1]

Mining

Oryctognosy

Elementary Mineralogy

Geognosy

Mineralogical Geography

Ferrous Metallurgy (Eisenhüttenkunde)

Petrifactions

The Literature of Mineralogy

The History of Mining in Saxony

Mineralogical Geography of Hungary

Mining Economics

Study of a Mining District (Revierkunde)

Preparation of Mining Reports

Preparation of Geognostic Reports

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[1]Compiled from Werner's annual reports on courses and schedules.

Enziklopädie der Bergbaukunst

The Official Curriculum of the School in 1825[1]

Mining

Mathematics

a. Higher mathematics
b. Applied mathematics
c. Pure mathematics

Mine Surveying

Mineralogy

a. Oryctognosy
b. Elementary mineralogy

Geognosy

Physics

Chemistry

a. General chemistry
b. Chemical analysis of minerals
c. Metallurgy
d. Practical assaying

Mining Law

Mining Business Composition

Mining Engineering

Drawing

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[1]See Breithaupt, Die Bergstadt Freiberg, pp. 136-138.

APPENDIX II

THE FIELD OF MINING AS WERNER UNDERSTOOD IT

Werner divided the field of mining into six parts: mineralogical, technological, economical, mathematical, juridical, and historical. Each of these parts was subdivided as follows:[1]

A. Mineralogical

1. oryctognosy
2. mineralogical chemistry
3. geognosy
4. mineralogical geography
5. economic mineralogy

B. Technical

1. miner's work
2. installation of a mine
3. ore extraction
4. machine work
5. ore dressing
6. foundry work

C. Economical

1. mine management
2. foundry management
3. mining stylistic
4. mining bookkeeping
5. mining commerce
6. mining finance

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[1]Werner, ed., Kleine Sammlung mineralogischer Berg-und Hüttenmännischer Schriften (Leipzig: Friedrich Christian Wilhelm Vogel, 1811), pp. 161-176.

D. Mathematical

1. mine surveying
2. mining mechanics
3. mining engineering

E. Juridical

1. mining law
2. interpretation of mining laws
3. writing of mining laws

F. Historical

1. history of mining
    a. political history of mining
    b. the literature of mining
2. mining geography
    a. geography in its narrow meaning
    b. mining statistics

APPENDIX III

SEQUENCE OF EVENTS IN THE BASALT CONTROVERSY

Werner's trip to the Scheibenberger Hügel, spring, 1787.

Announcement of the prize essay question "Was ist Basalt?" October 1, 1787.

Werner's article "Neue Entdeckung," dated October 20, 1788, published in the Jenaische allgemeine Litteraturzeitung.

Deadline for the entries in the prize essay contest, October 31, 1788. Six essays were entered, among them Widenmann's and Voigt's.

Voigt's reply to Werner, dated November 23, 1788.

Werner's reply to Voigt, dated December 19, 1788.

Werner's article "Über das Vorkommen des Basaltes auf Kuppen vorzüglich hoher Berge," printed in the March, 1789, issue of Bergmännisches Journal.

Werner's article "Herrn D. Fausts Nachricht von dem Meiszner in Hessen," printed in the March, 1789, issue of Bergmännisches Journal.

Werner's article "Schreiben des Herrn Eversmann," dated May 29, 1789, printed in the May, 1789, issue of Bergmännisches Journal.

Prize essay by Widenmann printed after September 9, 1789, in Vol. IV of Magazin für die Naturkunde Helvetiens.

Voigt's contest essay printed after September 9, 1789, in Vol. IV of Magazin für die Naturkunde Helvetiens.

Werner's article "Von der Entstehung der Vulkanen," dated January 12, 1789, printed after September 9, 1789, in Vol. IV of Magazin für die Naturkunde Helvetiens.

APPENDIX IV

LIST OF LEARNED SOCIETIES TO WHICH WERNER BELONGED

According to the diplomas found among his papers, Werner was admitted to the following learned societies:

1. Honorary member of the Leipziger Ökonomische Gesellschaft (1770).

2. Honorary member of the Gesellschaft naturforschender Freunde zu Berlin (January 28, 1777).

3. Member of the Oberlausitzische Gesellschaft der Wissenschaften zu Görlitz (August 24, 1779).

4. Foreign member of the Böhmische Gesellschaft der Wissenschaften zu Prag (December 2, 1786).

5. Member of the Leipziger Ökonomische Gesellschaft (October 10, 1797).

6. Honorary member of the Jenaische mineralogische Societät (December 8, 1797).

7. Member of the Gesellschaft der Wissenschaften und Kunst zu Mainz (1801).

8. Corresponding member of the first class (Sciences physiques et mathématiques) of the Institut National (February 6, 1804).

9. Member of the Gesellschaft zu Harlem (June 5, 1803).

10. Member of the Academy of Sciences of Wilna (August 10, 1805).

11. Foreign and full member of the Königliche Akademie der Wissenschaften zu München (April 5, 1808).

12. Honorary member of the Society of Physics and Medicine of Moscow (August 20, 1808).

13. Member of the Königliche Akademie der Wissenschaften zu Berlin (August 25, 1808).

14. Honorary member of the Wetterauer Gesellschaft für gesammte Naturkunde zu Hanau (November 30, 1808).

15. Member of the Academy of Sciences at Stockholm (July 4, 1810).

16. Member of the physische medizinische Gesellschaft zu Erlangen (February 20, 1811).

17. Foreign associate of the first class (Sciences physiques et mathématiques) of the Institut National (February 3, 1812).

18. Foreign honorary member of the naturforschende Gesellschaft zu Halle (December 5, 1812).

19. Foreign member of the Geological Society of London (June 16, 1815).

20. Corresponding member of the kaiserliche und königliche mährische schlesische Gesellschaft des Ackerbaues zu Brünn (December 14, 1815).

21. Foreign and ordinary assessor of the Jenaische mineralogische Gesellschaft (September 17, 1817).

22. First president of the Gesellschaft für Mineralogie zu Dresden (December, 1816).

23. Honorary member of the Wernerian Society of Edinburgh (January 12, 1808).