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THE CLASSIFICATION OF MINERALS: SOME REPRESENTATIVE MINERAL SYSTEMS FROM AGRICOLA TO WERNER

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This dissertation is gratefully dedicated

to my wife Carol

and to my sons Bryce, Richard, Jeffry

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THE CLASSIFICATION OF MINERALS: SOME REPRESENTATIVE MINERAL SYSTEMS FROM AGRICOLA TO WERNER

INTRODUCTION

A long-unresolved problem for mineral systematists was the casual, indefinite terminology that they had inherited. For example, "minerals" were defined by John Harris (1667?-1719) in his Lexicon technicum as "hard Bodies dug out of the Earth or Mines, (whence the Name) being in part of a Metalline, and in part of a Stony Substance, and sometimes with some Salt and Sulphur intermixed with the other."[1] Inexactly defined, the term "minerals" came to be inexactly applied as a synonym for the general term "native fossils." These were "sensible Bodies generated, and growing in, and of the Earth; whose constituent Parts are so simple, and homogeneous, that there is no apparent Distinction of Vessels, and Juices; between the Part, and the Whole."[2]

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[1]John Harris, "Minerals," Lexicon technicum, or an Universal English Dictionary of Arts and Sciences, Explaining Not Only the Terms of Art, but the Arts Themselves (London: Printed for Dan. Brown, Tim. Goodwin, John Walthoe, Tho. Newborough, John Nicholson, Tho. Benskin, Benj. Tooke, Dan. Midwinter, Tho. Leigh, and Francis Coggan, 1704).

[2]Ephraim Chambers, "Fossil Kingdom," Cyclopaedia, or an Universal Dictionary of Arts and Sciences. Containing the Definitions of the Terms and Accounts of the Things Signify'd Thereby, in the Several Arts, Both Liberal and Mechanical, and the Several Sciences, Human and Divine; the Figures, Kinds, Properties, Productions, Preparations, and Uses, of Things Natural and Artificial; the Rise, Progress,

Naturalists who studied minerals, in the general sense, were called "mineralists" or "mineralogists."[3] The study of minerals, mineralogy, was defined in the Encyclopédie in 1765 as "la partie de l'Histoire naturelle qui s'occupe de la connoissance des substances du regne minéral, c'est-à-dire des terres, des pierres, des sels, des substances inflammables, des pétrifications, en un mot, des corps inanimés & non pourvus d'organes sensibles qui se trouvent dans le sein de la terre & à sa surface."[4]

Other terms that are frequently encountered in the early literature of mineralogy are "fossil," "adventitious fossil," and "figured stone." The term "fossil," more commonly the Latin fossilium, was

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and State of Things Ecclesiastical, Civil, Military, and Commercial; with the Several Systems, Sects, Opinions, &c. among Philosophers, Divines, Mathematicians, Physicians, Antiquaries, Criticks, &c.; the Whole Intended as a Course of Antient and Modern Learning. Compiled from the Best Authors, Dictionaries, Journals, Memoirs, Transactions, Ephemerides, &c., in Several Languages (London: Printed for James and John Knapton, John Darby, Daniel Midwinter, Arthur Bettesworth, John Senex, Robert Gosling, John Pemberton, William and John Innys, John Osborn and Tho. Longman, Charles Rivington, John Hooke, Ranew Robinson, Francis Clay, Aaron Ward, Edward Symon, Daniel Browne, Andrew Johnston, and Thomas Osborn, 1728); Vol. I.

[3]Nathan Bailey, Dictionarium Britannicum, or a More Compleat Universal Etymological English Dictionary than Any Extant (London: Printed for T. Cox, 1730), unnumbered, defined a "Mineralist" as "one skilled in the Knowledge of Minerals" and a "Mineralogist" as "an Author who Treats on Minerals."

[4]Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une societé de gens de lettres (Paris: Chez Briasson, David l'aîné, Le Breton, Durand [Vols. 8-17 have Neufchastel: Chez Samuel Faulche & Compagnie], 1751-1765, X, 541: "the part of natural history that is occupied with knowledge of the substances of the mineral kingdom; that is to say, of the earths, stones, salts, inflammable substances, petrifications, in a word of the bodies inanimate and not provided with sensible organs that are found in the bosom of the earth and at its surface."

used to denote natural bodies that were "dug up"; this usage dates from classical antiquity.[5] In Greek the term corresponding to fossilium is ὀρυκτός;[6] the now-obsolete English words oryctognosy and oryctology derive from it.[7] "Adventitious fossils," also called "foreign fossils" or "extraneous fossils," were "the Exuviae of Sea and Land Animals; the Fossil-Shells, Bones, Teeth, &c. which are plentifully found in the Earth. . . ."[8] "Figured stones" or "formed stones" were "such bodies, which being either pure stone or spars, are found in the earth so formed, that their outward shape very nearly resembles to the external form of muscles, cockles and other shells, &c."[9] By the end of the eighteenth century the term "fossil" was still used in a general sense;[10] later, it assumed its modern, more restricted meaning.

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[5]Ethan Allen Andrews, Harper's Latin Dictionary: A New Latin Dictionary, Founded on the Translation of Freund's Latin-German Lexicon, Edited by E. A. Andrews, LL.D. (Revised, enlarged, and in great part rewritten by Charlton T. Lewis and Charles Short; New York: American Book Company, 1907), p. 774.

[6]Henry George Liddell and Robert Scott, A Greek-English Lexicon (9th ed., revised and augmented by Henry Stuart Jones and Roderick McKenzie; Oxford: At the Clarendon Press, [1953]), p. 1257.

[7]Oryctognosy is defined as "Mineralogy" and oryctology as "the science of things dug from the earth" in Noah Webster, Webster's New International Dictionary of the English Language (2d ed., unabridged; Springfield, Massachusetts: G. & C. Merriam Company, 1959), p. 1725.

[8]Harris, "Fossils," Lexicon technicum.

[9]Bailey, "Formed Stones," Dictionarium Britannicum.

[10]The third edition of the Encyclopaedia Britannica, VII (1797), 373, defined "Fossil" as follows: "Fossil, in natural history, denotes, in general, every thing dug out of the earth, whether they be natives thereof, as metals, stones, salts, earths, and other minerals; or extraneous, reposited in the bowels of the earth by some extraordinary means, as earthquakes, the deluge, &c."

In this paper the terms "mineral" and "native fossil" are used almost synonymously to convey the idea of a naturally occurring, homogeneous substance formed by inorganic processes. The terms "fossil" and "adventitious fossil" are used to convey approximately the idea of remains or evidences of organisms, preserved in the rocks of the earth's crust. "Native fossil" and "adventitious fossil" are used where they are relevant, in order to avoid using "mineral" and "fossil" anachronistically. "Native fossils" and "adventitious fossils" are collectively referred to as mineral substances. The term "mineralogy" is used to refer to the study of those substances regarded as belonging to the mineral kingdom; hence, it is used in a broad sense. By "mineral system" is meant the <u>product</u> of the <u>process</u> of mineral classification.

The process of mineral classification involves describing and naming mineral substances, but it is more than that. Mineral classification is an intellectual process whereby individual specimens, which are sensed, are idealized or generalized into abstract <u>kinds</u>; these kinds are then grouped, that is, set in relation to one another.[11] The product of classification is an orderly survey of some empirical information; it is a mineral system. This product, which is a combination of theoretical and empirical concepts into a coherent whole, may be expressed verbally, graphically, or in both ways, one complementing the other.

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[11]On classification in general see A. Broadfield, <u>The Philosophy of Classification</u> (London: Grafton & Co., 1946); and Classification Research Group, <u>The Sayers Memorial Volume: Essays in Librarianship in Memory of William Charles Berwick Sayers</u>, ed. D. J. Foskett and B. I. Palmer for the Classification Research Group (London: Library Association, 1961). Both of these works have been freely drawn upon for the ideas about classification expressed in this paragraph and the following two paragraphs.

There are basically two approaches to mineral classification. One is to postulate a few main classes of all the objects encompassed by the mineral kingdom and then subdivide these classes into less comprehensive groups. The other approach is that of placing individuals which possess a certain property into conceptual groups called species. In a similar way, the species are grouped into more generalized concepts, and so forth, for as many stages as may seem desirable, by a sort of inductive process.

The purpose of mineral classification is to organize one's thoughts about an unorganized mass of factual information and in so-doing to clarify the supposed relationships between individual minerals. A classification that is adequate to this task is not simply a catalog of facts or occurrences; it is a scheme in which facts are set <u>in relation</u> to one another. One use of such a classification is that properties not immediately sensible can be assumed for a member of a group because common features are indicated by the group name. An alphabetical array, common in the earlier history of mineralogy,[12] cannot set minerals in relation to one another without elaborate cross-references. Thus the usefulness of such an arrangement is less than some other possible arrangements. Another example of an inadequate classification is one in which minerals are grouped on the basis of use. For example, minerals that are used for personal adornment may be

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[12]According to Frank Dawson Adams, <u>The Birth and Development of the Geological Sciences</u> (Baltimore, Maryland: The Williams & Wilkins Company, 1938), p. 149, "in all the lapidaries which appeared prior to the sixteenth century the minerals, when any definite system of classification was adopted, were arranged and listed in alphabetical order.

classified as gems, but no general assertion can be made concerning the individuals of this group except that they are all gems. Thus, classifying certain minerals as gems does not clarify the relationships between the individuals. It is a grouping that is useless for achieving any theoretical insights.

This dissertation presents an analysis of early efforts to systematize the body of knowledge relating to minerals. These efforts have been obscured by the more impressive accomplishments of later mineralogists, but the work of the early systematists provided the foundation for later systematists. The systematic work of men such as John Woodward (1665-1728), Carl von Linné (1707-1778), and Johan Gottschalk Wallerius (1709-1785) is little-known today and only briefly mentioned in histories of the geological sciences. Franz von Kobell in Geschichte der Mineralogie (1864)[13] discussed systematic mineralogy during the century from 1650 to 1750 in twelve pages. Karl Alfred von Zittel in Geschichte der Geologie und Paläontologie (1899)[14] did not discuss the beginnings of systematic mineralogy. Archibald Geikie in The Founders of Geology (1905)[15] gave too much credit to later

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[13]Franz von Kobell, Geschichte der Mineralogie von 1650-1860 ("Geschichte der Wissenschaften in Deutschland, Neuere Zeit," Bd. 2; München: J. G. Cottaschen, 1864).

[14]Karl Alfred von Zittel, Geschichte der Geologie und Paläontologie bis Ende des 19. Jahrhunderts ("Geschichte der Wissenschaften in Deutschland, Neuere Zeit," Bd. 23; München und Leipzig: Druck und Verlag von R. Oldenbourg, 1899); also an abridged translation into English: Karl Alfred Von Zittel, History of Geology and Palaeontology to the End of the Nineteenth Century, trans. Maria M. Ogilvie-Gordon ("The Contemporary Science Series"; London: Walter Scott, 1901).

[15]Archibald Geikie, The Founders of Geology (2d ed.; London: Macmillan and Co., Limited, 1905).

mineralogists for the development of systematic mineralogy. E. H. M. Beekman in Geschiendenis der Systematische Mineralogie (ca. 1906)[16] presented epitomes of many schemes of mineral classification, but he did little to relate the schemes he tabulated. Hélène Metzger in La genèse de la science des cristaux (1918)[17] tried to demonstrate the necessity for divorcing the study of crystals from speculative philosophy and descriptive mineralogy before crystallography could emerge as an autonomous discipline; therefore, she had little to say about the early mineral systematists. Paul Heinrich von Groth in Entwicklungsgeschichte der mineralogischen Wissenschaften (1926)[18] was primarily interested in the crystallographers of the late eighteenth and the nineteenth centuries. Frank Dawson Adams in The Birth and Development of the Geological Sciences (1938)[19] presented a concise summary of the study of minerals in ancient and medieval times, but he ignored the early eighteenth century classifiers in his chapter on "The Birth of Modern Mineralogy."[20] All of these works lack sufficient depth to expose the nature of early efforts to classify minerals.

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[16] E. H. M. Beekman, Geschiedenis der Systematische Mineralogie ['s Gravenhage, 1906(?)].

[17] Hélène Metzger, La genèse de la science des cristaux (Paris: Félix Alcan, 1918).

[18] Paul Heinrich von Groth, Entwicklungsgeschichte der mineralogischen Wissenschaften (Berlin: Verlag von Julius Springer, 1926).

[19] Cited above, note 12.

[20] Adams, pp. 170-208.

CHAPTER I

THE HISTORICAL BACKGROUND OF MINERAL CLASSIFICATION

A wide range of mineral substances is mentioned and variously discussed in the literature of classical antiquity.[1] In the *Meteorologica*, Aristotle mentioned some two dozen mineral substances, including alum, amber, carbuncle, cinnabar, mill-stone, potter's clay, salt, stalactites, and the six classical metals--gold, silver, copper, tin, lead, and iron.[2] He explained that mineral substances were the result of interacting exhalations, one "vaporous" and one "smoky."[3] But Aristotle was not writing about mineral substances per se; they were only incidental to his topic. On the other hand, the fragmentary Περὶ λίθων by Theophrastus (c. 372-c. 288 B.C.) deals specifically

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[1]Brief surveys of the knowledge of mineral substances in antiquity are included in Frank Dawson Adams, *The Birth and Development of the Geological Sciences* (Baltimore, Maryland: The Williams & Wilkins Company, 1938), pp. 8-50 and 77-136; C. E. N. Bromehead, "Geology in Embryo (Up to 1600 A.D.)," *Proceedings of the Geologists' Association*, LVI (1945), 89-134; Nathaniel Fish Moore, *Ancient Mineralogy, or an Inquiry Respecting Mineral Substances Mentioned by the Ancients; with Occasional Remarks on the Uses to Which They Were Applied* (2d ed.; New York: Harper & Brothers, 1859); and George Sarton, *A History of Science: Ancient Science Through the Golden Age of Greece* (Cambridge, Massachusetts: Harvard University Press, 1952), pp. 558-61.

[2]See Aristotle, *The Works of Aristotle Translated into English*, ed. J. A. Smith and W. D. Ross (Oxford: At the Clarendon Press, 1908-1952), Vol. III.

[3]Aristotle *Meteorologica* iii. 6. 378^{a} 18-20.

with mineral substances. A brief philosophical-descriptive summary of contemporary knowledge of "stones," it describes or mentions some seventy mineral substances.[4]

In the first century A.D., Dioscorides (fl. c. 50 A.D.) in his herbal cataloged nearly a hundred mineral substances that were used as medicines,[5] and Pliny the Elder (23-79 A.D.) devoted five books of his Historia naturalis to minerals and related subjects, such as metals and mining.[6] Neither Dioscorides nor Pliny, however, approached the study of minerals with the same critical spirit as Theophrastus. Dioscorides, for example, in describing the virtues of the "aetites lithos" or eagle-stone said:

> Aetites lapis . . . is an holder in of ye Embrya when ye wombs are slippery, being tied about ye left arm; but in the time of deliverance, taking it from ye arm tie it about ye thigh, & she shall bring forth without pain: & it is a discloser of a thief, if any put it into ye bread that he offers him, for he that stole cannot be able to swallow down ye things chewed. . . .[7]

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[4]Theophrastus' Περὶ λίθων, frequently referred to as De lapidibus by modern writers, appears in a modern translation with a commentary in Earle R. Caley and John F. C. Richards, Theophrastus on Stones: Introduction, Greek Text, English Translation, and Commentary (Columbus, Ohio: The Ohio State University, 1956).

[5]Robert T. Gunther (ed.), The Greek Herbal of Dioscorides. Illustrated by a Byzantine, A.D. 512. Englished by John Goodyer, A.D. 1655. Edited and First Printed, A.D. 1933 (Oxford: Printed for John Johnson for the Author, at the University Press, 1934), pp. 623-60.

[6]C. Plinius Secundus Historia naturalis xxxiii-xxxvii. See C. Plinius Secundus, Pliny: Natural History. With an English Translation, trans. H. Rackham, W. H. S. Jones, and D. E. Eichholz ("The Loeb Classical Library"; Cambridge, Massachusetts: Harvard University Press, 1938-1963), Vols. IX and X. For discussions of Pliny's profound influence on later writers see Marshall Clagett, Greek Science in Antiquity (New York: Abelard-Schuman, Inc., 1955), pp. 108-12; and E. W. Gudger, "Pliny's Historia naturalis: The Most Popular Natural History Every Published," Isis, VI (1924), pp. [269]-81.

[7]Gunther, The Greek Herbal of Dioscorides, p. 656.

Pliny, similarly, reported the supposed properties of the aetite[8] and added a comparison of the four kinds of aetite, which came from Africa, Arabia, Cyprus, and Taphiusa (near the island of Leucas).[9] Theophrastus, on the other hand, was inclined to be skeptical of the powers ascribed to stones, he said that "some can be melted and others cannot, some can be burnt and others cannot. . . . Some have the power of attraction and others can test gold. . . . But the greatest and most wonderful power, <u>if this is true</u>, is that of stones which give birth to young."[10] In another passage he indicated his skepticism of a story that he had related by concluding: "But these statements depend entirely on their [i.e., the Egyptians,] writings."[11] In addition to critical acumen, Theophrastus' treatise exhibits a degree of systematization that is lacking in the treatises of both Dioscorides and Pliny. The latter organized their discussions in terms of extrinsic qualities of mineral substances--Dioscorides according to use and Pliny, for the most part, alphabetically. Theophrastus, however, set forth a general separation of "stones" on the basis of their appearance and behavior.

Except for the writings of Theophrastus, Dioscorides, and Pliny, the references to mineral substances in the literature of antiquity are

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[8] <u>Historia naturalis</u> xxxvi. 39: "Eagle stones, wrapped in the skins of animals that have been sacrificed, are worn as amulets by women or four-footed creatures during pregnancy so as to prevent a miscarriage. They must not be removed except at the moment of delivery: otherwise, there will be a prolapse of the uterus. On the other hand, if they were not removed during delivery no birth would take place." Quoted from Plinius Secundus, <u>Pliny: Natural History</u>, X, 121.

[9] <u>Ibid</u>., pp. 119 and 121.

[10] Caley and Richards, pp. 45-46. Italics are mine.

[11] <u>Ibid</u>., p. 50.

incidental to some other topic. Passing mention of minerals, as occurs in Aristotle's Meteorologica, is found in works devoted to history, architecture, materia medica, and geography in which there are descriptions of mines, ores, medicines, and building materials.[12] The study of mineral substances in antiquity did not develop into a formalized or systematic discipline.

Although comprehensive theoretical schemes were lacking, there was a substantial body of practical knowledge of minerals existing in Greek antiquity which was augmented in Roman antiquity and continued in epitomes such as Pliny's Historia naturalis. This knowledge passed to Islam during and after the decline of the Greco-Roman culture, where it was preserved in Arabic writings such as parts of the Kitāb al-Shifā' of Avicenna (980?-1037).[13] Little is known about the contributions of medieval Arabic, Christian, and Jewish writers. They did, however, preserve some of the ancient ideas.

In Europe during the period of Roman ascendancy and the early Middle Ages, the available knowledge concerning minerals was largely that appearing in the Historia naturalis of Pliny and the compendia of encyclopedists such as Isidore of Seville (died 636), Venerable Bede (died 735), and Hrbanus Maurus (776-856).[14] But such encyclopedias were not only the source of information about minerals, since some knowledge

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[12]See Moore, pp. 29, 30, 89, et passim.

[13]See Eric John Holmyard and D. C. Mandeville (eds. and trans.), Avicennae de congelatione et conglutinatione lapidum, Being Sections of the Kitāb al-Shifā'. The Latin and Arabic Texts, Edited with an English Translation of the Latter and with Critical Notes (Paris: Paul Geuthner, 1927).

[14]Adams, p. 138.

of minerals was accumulated in lapidaries. One medieval lapidary that is represented by more than 140 extant manuscripts was composed by Marbode, Bishop of Rennes (1035-1123).[15] This lapidary gave an account in verse of the medicinal and magical virtues of sixty common and precious stones.[16] Although awareness of minerals was continuous, there seem to have been few philosophers in medieval Europe who made original contributions to the study of minerals.[17]

The introduction of scientific knowledge into Europe occasioned by the translation into Latin of Arabic and other writings during the twelfth and thirteenth centuries likely brought only a small change in the status of European knowledge of mineral substances. The lapidary written by Marbode, before the main period of translations, and the

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[15]George Sarton, Introduction to the History of Science ("Carnegie Institution of Washington Publication," No. 376; Washington, D. C.: Carnegie Institution of Washington, 1927-1948), I, 764-65, said more than 140 manuscripts of Marbode's lapidary are known, including translations into seven vernacular languages.

[16]Marbode, Bishop of Rennes, Marbodi liber lapidvm sev de gemmis varietate lectionis et perpetva annotatione illvstratvs a Iohanne Beckmanno. Additis observătion bvs pictorii, alardi, cornarii. Svbiectis svb finem annotationibvs ad Aristotelis avscvltationes mirabiles et ad Antigoni Carystii historias mirabiles (Gottingae: Typis Ioann. Christian. Dieterich, 1799), pp. 8-87.

[17]Little is known about medieval European knowledge of mineral substances; however, some information can be found in Joan Evans and Mary S. Serjeantson, English Mediaeval Lapidaries ("Early English Text Society, Original Series," No. 190; London: The Early English Text Society, 1933); Karl Mieleitner, "Geschichte der Mineralogie im Altertum und im Mittelalter," Fortschritte der Mineralogie, Kristallographie und Petrographie, VII (1922), pp. 427-80; and Léopold Pannier, Les lapidaires français du Moyen Âge des XII^e^, XIII^e^, et XIV^e^ siècles. Réunis, classés et publiés, accompagnés de préfaces, de tables et d'un glossaire (Paris: École Pratique des Hautes Études, 1882). Sarton, Introduction, I, 764-65, distinguished three types of medieval European lapidary: (1) scientific, derived from Theophrastus and Dioscorides; (2) astrological, derived from Hellenistic Alexandrian writings; and (3) Christian, derived from Jewish writings on the precious stones of the high priests' breastplate and Apocalyptic allegories.

Speculum lapidum[18] written by Camillo Leonardi (fl. 1502), after the main period, differ little in quality or erudition. Leonardi included a greater number of mineral substances, but his treatment of them was traditional.

Near the end of the medieval period, knowledge of mineral substances was contained in a variety of works: lapidaries, alchemical treatises, handbooks of materia medica, and encyclopedias of natural history. A superficial knowledge of some minerals was widespread. Sarton, commenting upon the lapidary tradition in the fourteenth century in Europe, said: "The tradition of lapidaries . . . continued almost everywhere. . . . Interest in precious stones pervaded every country and every class of people; it was, like astrology, an integral part of mediaeval thought."[19] Judging from Marbode's and Leonardi's lapidaries, the encyclopedia of Bartholomaeus Anglicus (fl. 1220),[20] the Liber mineralium[21] of Albertus Magnus (1193?-1280), and the De le virtv de le herbe, & animali, & pietre preciose[22] attributed to Albertus

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[18]Camillo Leonardi, Speculum lapidum clarrissimi artium et medicine doctoris Camilli Leonardi Pisaurensis [Venetiis: Per Ioannem Baptistam Sessa, 1502].

[19]Sarton, Introduction, III, 214.

[20]Bartholomaeus Anglicus, Medieval Lore. An Epitome of the Science, Geography, Animal and Plant Folk-Lore and Myth of the Middle Age, Being Classified Gleanings from the Encyclopedia of Bartholomew Anglicus on the Properties of Things, ed. Robert Steele (London: Elliot Stock, 1893), pp. 30-38.

[21]Albertus Magnus, Liber mineralium [Oppenheym, 1518].

[22]Albertus Magnus, spurious and doubtful works, Alberto Magno de le virtv de le herbe, & animali, & pietre preciose, & di molte marauegliose cose del mondo (Vinegia, 1537).

Magnus, the knowledge of minerals that existed in medieval Europe was a mixture of observation, speculation, and tradition, lacking systematic organization.

The treatises of Georg Agricola (1494-1555) are often chosen to signalize the beginning of a science of mineralogy.[23] In De natura fossilium[24] and De re metallica,[25] Agricola approached the study of mineral substances in a naturalistic way. He rejected many of the myths that were associated with gems,[26] and his classification, inferred from his writings, exhibits a degree of generalization not found in Marbode's lapidary, Leonardi's Speculum lapidum, and other early handbooks.

Agricola regarded mineral substances as either composite or non-composite. The non-composite were either simple or mixed. There

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[23]Because of this, Agricola has been called the "Father of Mineralogy" by some writers. Adams, p. 183, held him in even higher esteem; he said that Agricola was "one of the most outstanding figures in the history of the geological sciences, not only of his own times but of all time."

[24]Georg Agricola, 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, siue de re metallica dialogus. Interpretatio germanica uocum rei metallicae, addito indice foecundissimo (Basileae: [Per Hieronymvm Frobenivm et Nic. Episcopivm], 1546). Hereafter cited as Agricola, De natura fossilium.

[25]Georg Agricola, Georgii Agricolae de re metallica libri XII. Qvibus officia, instrumenta, machinae, ac omnia deniq; ad metallicam spectantia, non modo luculentissimè describuntur, sed & per effigies, suis locis insertas, adiunctis latinis, germanicisq; appellationibus ita ob oculos ponuntur, ut clarius tradi non possint. Eivsdem, de animantibvs svbterraneis liber, ad autore recognitus. Cum indicibus diuersis, quicquid in opere tractatum est, pulchrè demonstrantibus (Basileae: [Apvd Hieron Frobenivm et Nicolavm Episcopivm], 1556).

[26]E.g., he said, De natura fossilium, pp. 180-81: "nam de uiribus quas magi Persarū tribuunt lapidibus & gemmis, nihil dicam. etenim ipsis & Arabibus, qui eos in hac opinionis uanitate leuitateq; sequūtur, fidem abrogare conuenit grauitati eorū, qui rerum naturas causasq; persequuntur."

were four kinds of simple substances: earth (terra), congealed juice (succus concretus), stone (lapis), and metal (metallum).[27] He defined earth as "corpus fossile simplex, quod potest manu subigi, cum fuerit aspersum humore: aut ex quo cum fuerit madefactū [sic], sit lutum."[28] Congealed juice was "corpus fossile siccum & subdurū, quod aquis aspersum aut non mollitur, sed liquescit: aut si mollitur, multum uel pinguitudine differt à terra, uel materia ex qua constat."[29] A stone was "corpus fossile siccum & durum, quod uel aqua longinquo tempore uix mollit, ignis uehemens redigit in puluerem: uel non mollit aqua, sed maximo ignis liquescit calore."[30] Finally, Agricola defined a metal as

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[27]Agricola, ibid., p. 185, described the classification of mineral substances as follows: "cum igitur corpus subterraneum expers animae duabus, ut dixi, formis finiatur: quarum unam eius quod effluit & expiratur nomine appellamus, alteram fossilis: corpus fossile est concretum ex partibus, aut sui similibus substantia, ut aurum purum, nam quaelibet eius pars est aurū: aut sui dissimilibus, ut gleba quae constat ex terra, lapide, metallo. etenim diuiditur in terram, lapidem, metallum. itaq; illud corpus fossile non compositum: hoc compositum nominamus. at non compositum rursus diuiditur in simplex & mistum. Simplicis autem quatuor sunt formae, terra scili cet, succus concretus, lapis, metallum: misti plures, ut paulo post dicam." Agricola's verbal description is represented graphically in Appendix I.

[28]Agricola, De natura fossilium, p. 185: "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." English translation from Mark Chance Bandy and Jean A. Bandy (trans.), De natura fossilium (Textbook of Mineralogy) ("The Geological Society of America Special Papers," No. 63; [New York:] The Geological Society of America, 1955), pp. 17-18.

[29]Agricola, De natura fossilium, p. 185: "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." English translation from Bandy and Bandy, p. 18.

[30]Agricola, De natura fossilium, p. 186: "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

"corpus fossile natura uel liquidū, uel durum quidem, sed quod ignis liquescit calore. uerum id ipsum refrigerato & extincto calore, rursus ad duriciam reuocatur, propriāq; formam. in quo sanè differt à lapide qui liquescit igni."[31] From these definitions it is evident that Agricola chose behavior in water and in fire as primary characteristics of division for a theoretical classification. The idea of using behavior in fire as a diagnostic index is found in rudimentary form in Theophrastus[32] and Avicenna.[33] Avicenna also mentioned behavior in water as a distinguishing mark.[34]

Agricola's grasp of the problems of classifying such diverse objects as mineral substances can be illustrated by his discussion of how simple earths might be treated:

> Ex differentiarū uero cōiunctione uariae terrarum oriuntur formae. . . . at certe uiri rerum naturas cōtemplantis est eas non modo numerare, sed etiam diligenter expendere, itaq; simplex terra cum, ut inde ordiar, primo sit uel macra, uel pinguis, mediocris'ue, tres eius efficiuntur differentiae. deinde cum quaelibet ex his tribus

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in only the very hottest fire." English translation from Bandy and Bandy, p. 18.

[31] Agricola, De natura fossilium, p. 186: "a natural mineral body which is either liquid or solid and will melt in a fire. The molten metal, on cooling, again becomes hard and returns to its original form. In this way it differs from a stone that melts in a fire." English translation from Bandy and Bandy, pp. 18-19.

[32] Theophrastus wrote: "Some of them [stones] melt and become fluid when subjected to fire, such as those which come from mines"; marble "burns up and lime is formed from it." Caley and Richards, p. 47.

[33] Avicenna wrote: "All malleable bodies are fusible . . . whereas most non-malleable substances cannot be fused . . . or even softened except with difficulty." Holmyard and Mandeville, p. 34.

[34] "Some [mineral bodies] have the nature of salt and are easily dissolved by moisture . . . while others are oily in nature and are not easily dissolved by moisture. . . ." Ibid.

sit uel rara, uel spissa: mediocris'ue, differentiarū numerus crescit, & nouem fiunt. macra enim est uel rara, uel spissa, mediocris'ue. similiter pinguis est uel rara, uel spissa, mediocris'ue. atq; etiam mediocris est uel rara, uel spissa, mediocris'ue. tum cum quaeuis harū possit esse uel mollis uel dura, mediocris'ue, maior sit numerus differentiarū. nam macra & rara, aut macra & spissa, aut macra et mediocris est uel mollis, uel dura, mediocris'ue. pari modo pinguis & rara, aut pinguis & spissa, aut pinguis atq; mediocris est uel mollis, uel dura, mediocris'ue. eadem ratione mediocris & rara, aut mediocris & spissa, aut mediocris in re utraq; est uel mollis, uel dura, mediocris'ue. quae omnes differentiae sunt septem & uiginti numero. mox, cum earum quaeq; esse possit uel leuis, uel aspera, mediocris'ue, plurimum differentiae numero augentur. . . . macro rara mollis, aut macra rara dura, aut macra rara mediocris, aut macra spissa mollis, aut macra spissa dura, . . . eodem modo pinguis rara mollis, aut pinguis rara dura, . . . atq; etiam mediocris rara mollis, . . . omnes autem in unum numerum cōgregatae fiunt una & octoginta. postea cum harum terrarum unicuiq; non unus color insideat, sed sit uel alba, uel nigra, uel lutea, uel rubra, uel uiridis, uel caerulea, uel cinerea, uel fusca, uel deniq; alterius coloris, maxima differentiarum multitudo colligitur, ut quisq; potest intelligere.[35]

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[35]Agricola, De natura fossilium, pp. 191-92: "Indeed, by conjoining of differences, various types of earths originate. . . . Certainly the contemplating of natural things by men is not only to enumerate them, but also to carefully consider them. Therefore, a simple earth, first, may be either lean, unctuous, or intermediate, thus three groups of those are produced. Next, any one of these three may be either loose, dense, or intermediate, thus the number of groups increase, and there are nine. Indeed, the lean one is either loose, dense, or intermediate. Similarly, the unctuous one is either loose, dense, or intermediate. And so also the intermediate one is either loose, dense, or intermediate. Next, any one of these can be either soft, hard, or intermediate, thus the number of groups may be greater. For, the lean and loose one, the lean and dense one, or the lean and intermediate one is either soft, hard, or intermediate. In the same way the unctuous and loose one, the unctuous and dense one, or the unctuous and also intermediate one is either soft, hard, or intermediate. For the same reason the intermediate and loose one, the intermediate and dense one, or the intermediate in both things is either soft, hard, or intermediate. Thus the number of all of the groups is twenty-seven. Thereupon, any one of them can be either smooth, harsh, or intermediate, thus they are augmented by a great number of groups. . . . [which may be] lean-loose-soft, lean-loose-hard, lean-loose-intermediate, lean-dense-soft, lean-dense-hard, . . . In the same way, unctuous-loose-soft, unctuous-loose-hard, . . . And also intermediate-loose-soft, . . . All assembled into one number, there are eighty-one. Besides, one color may not be fixed with any one of these earths, but may be either white, black, yellow, red, green, blue,

His lengthy, repetitious enumeration left no doubt in the reader's mind as to his meaning. After suggesting that mineral substances could be classified according to this variety of physical characteristics, he did not set forth any such scheme of classification. He simply described several varieties of earth, and he arranged his descriptions according to the purpose for which they were used. Thus, he spoke of earths used by farmers,[36] those used by potters and sculptors,[37] fullers,[38] painters,[39] and physicians.[40] He concluded with a discussion of earths that were named after their color or the place where they were found.[41]

Agricola arbitrarily postulated that certain mineral substances were related. He often did not give any explanation of why he said certain ones were related. For example, he began his discussion of stones that were found in animals by saying: "Lapides praeterea in animãtium corporibus nati, in gemmarum numero locoq; ducuntur: quod genus inuenitur in auibus, in piscibus, in conchis."[42] Another example is his discussion of some of the congealed juices: "Seqvitvr alter succus pinguis, naturali cognatione iunctus cum sulfure . . . Latini nominant bitumen. ex hoc constat non modo id quod à scriptorib. his nominibus appellat', sed etiam naphtha, cãphora, maltha, pissasphaltus,

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ash-color, tawny, or in short other colors, thus anyone can perceive a great number of groups are produced."

[36]Ibid., pp. 192-95. [37]Ibid., pp. 195-98.

[38]Ibid., p. 198. [39]Ibid., pp. 198-99.

[40]Ibid., p. 199. [41]Ibid., pp. 199-206.

[42]Ibid., pp. 306-07: "Stones that form in living bodies are placed among the gems. These stones are found in birds, fish and shellfish." English translation from Bandy and Bandy, p. 145.

gagates. . . ."[43] In a few instances, such as in the case of selenite and gypsum, his reason for relating minerals was based on supposed genetic likenesses: "Res gypso cognata lapis specularis est. nam & similiter interdū gignitur ex saxo calcario, sed cum pauca aqua permisto."[44] He did, however, make an effort to describe each mineral in respect to several physical characteristics, including color, taste, odor, transparency, luster, touch or feel, solubility in water, and friability. These properties, and a few others, he had considered in a general way in the first book of his treatise.

Agricola concluded his discussion of gems, a subgroup of stones, by indicating the relative value of each:

> quoniam uero margaritas magni precij esse dixi, res ipsa me monet, ut de excellentia praestantiaq; gemmarum nobilium dicam. igitur adamas maximi est precij. dein margaritae Indicae: tum smaragdus: mox opalus: postea carbūculus, quem sequitur iaspis, post quā laudatissima sapphirus, cui proxima cyanus, tertia asterios, quarta topazius. dein est chrysolithos, tū callais. mox amethystus. postea hyacinthus, quam sequitur prasius, achates, Beli oculus, & reliquae gemmae.[45]

But he did not indicate the value of any of them in terms of any monetary

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[43]Agricola, De natura fossilium, p. 229: "I shall now take up a second unctuous juice which is naturally related to sulphur. . . . The Latins have named it bitumen. Included under this name are not only the substances the older writers placed here but also naphtha, camphor, maltha, pittasphalt, jet. . . ." English translation from Bandy and Bandy, p. 61.

[44]Agricola, De natura fossilium, p. 256: "Selenite is related to gypsum. It forms from limestone in the same manner but has less admixed water." English translation from Bandy and Bandy, pp. 90-91.

[45]Agricola, De natura fossilium, pp. 307-08: "Since I have said that margaritas (pearls) command a high price it occurs to me that I should say something regarding the relative value of the precious gems. Diamond is the most valuable gem and is followed in turn by the Indian pearl, emerald, opal, ruby, jasper, lapis-lazuli, sapphire, asterios and chrysolite. Next comes chrysolithus, amethyst, hyacinthus, prase, agate, beli oculus and finally the other gens." English translation from Bandy and Bandy, p. 147.

units, nor did he indicate, for example, how many rubies of a given size were equivalent to a diamond of the same size. The best he did in this respect was to say: "uilis adamas minoris est precij quàm praestans carbunculus: & magna topazius pluris uenditur quàm paruus smaragdus: & achates, quae insignis rei imaginem exprimit, carius aestimatur, quàm deterior opalus."[46]

All stones that could be polished to a fine luster were called marble (<u>marmor</u>) by Agricola.[47] Included in this group were basalt (<u>basaltes</u>), porphyry (<u>porphyrites</u>), ophite (<u>ophites</u>), seyenite (<u>seyenites</u>), flint (<u>silex</u>), tufa (<u>tufus</u>), and others. After discussing these, he concluded his discussion of the four sub-groups of stones by describing what he called rocks (<u>saxa</u>). They were distinguished from other stones by having come from quarries. Rocks, he said, were used in buildings, sculpture, and for millstones. Agricola included three kinds of sands among the <u>saxa</u>: "fossicia quae ex arenarijs"; "fluuiatilis, quae reperitur ad amnes & riuos"; and "marina, quae in littore maris."[48]

Agricola completed his treatment of simple natural substances by briefly describing gold, silver, quicksilver, copper, <u>plumbum</u>, iron, and natural metal alloys.[49] The final book of <u>De natura fossilium</u> is

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[46]Agricola, <u>De natura fossilium</u>, p. 308: "A poor diamond will command a lower price than a fine ruby, a large chrysolite will sell for more than a small emerald and an agate that contains an exceptional image is more highly prized than an inferior opal." English translation from Bandy and Bandy, p. 147.

[47]Agricola, <u>De natura fossilium</u>, p. 309: "quae quia polita nitent, unde nomen ductum. . . ."

[48]<u>Ibid</u>., p. 320: "fossil, which is from sandpits"; "fluviatile, is found by streams and rivers"; and "marine, which is in the sea-shore."

[49]<u>Ibid</u>., pp. 330-46. Agricola identified three kinds of <u>plumbum</u>,

devoted to a discussion of those natural substances which Agricola called mixtures (<u>mista</u>) and composites (<u>cōpositas</u>).

Although he recognized six kinds of mixtures,[50] Agricola said that Nature produced others by various combinations of a stone, a metal, and congealed juices; however, he said, "ubi reperiant', ut nunc indicare nō possum, ita inueniri nō dubito."[51] Agricola's discussion of the composite mineral substances was brief and speculative. He was particularly interested in the possible combinations of simpler substances that could form a composite substance. He said:

> est aūt compositū gleba cōstans aut ex duob. simplicibus coagmentatis, uel trib. uel quatuor. aut ex duob. mistis, uel tribus, uel quatuor, uel quinq, , vel sex. aut ex uno simplici & uno misto, uel duob. pluribus'ue: aut ex duobus simplicib. et uno misto, uel duobus pluribus'ue: aut ex tribus simplicib. & uno misto, uel duob. pluribus'ue: aut ex quatuor simplicib. & uno misto, uel duobus pluribus'ue. tot in glebis existūt uarietates. quas operae preciū est considerare aliter enim multarū rerū uis & natura explicari nō potest. igitur si duo coponuntur simplicia, aut cū terra cōiungitur succus concretus, uel lapis, uel metallū: aut cū succo cōcreto connectitur uel terra, uel lapis, uel metallū. aut cū lapide copulatur uel terra, uel succus cōcretus, uel metallū, aut cū metallo iūgitur uel terra, uel succus concretus, uel lapis.[52]

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he said: "plumbum. cuius tria genera. unum cādidum [tin], alterum cinereum [bismuth], tertium nigrum [lead]." <u>Ibid</u>., p. 339.

[50]<u>Ibid</u>., p. 360: "primum constat ex lapide & succo concreto: alterum ex metallo & terra: tertium ex aequalibus lapidis & metalli partibus: quartum & quintum similiter constant ex lapide & metallo, sed alterum abundat metallo, alterum lapide: sextum ex lapide, metallo, succo cōcreto."

[51]<u>Ibid</u>., p. 372: "as I am not now able to show where they are found, so I do not doubt them to be discovered."

[52]<u>Ibid</u>.: "It [the composite kind] is either a uniformly composite substance; two, three, or four simple substances joined together; two, three, four, five, or six mixed substances; one simple and one, two, or more mixed substances; two simple and one, two, or more mixed; three simple and one, two, or more mixed; or four simple and one, two, or more mixed. So many varieties exist among the substances, that the work to

He then discussed composite substances consisting of two simple substances (i.e., two of the following four: earth, congealed juice, stone, and metal). He next mentioned composite substances composed of two mixed substances, and after giving a few examples of such mineral substances, he concluded that a great many combinations could be formed. Finally, he considered those composite substances that were formed of a combination of a simple substance and a mixed substance. Again, he discussed theoretically how many combinations could be produced, rather than discussing specific examples.[53]

Agricola's distribution of most mineral substances into one of the four groups, earths, congealed juices, stones, and metals, seems to parallel the arrangement inferred from the work of Theophrastus and Avicenna. There is no question that Agricola was acquainted with their work, because they are included in the one hundred authorities which he cited.[54] Besides demonstrating a familiarity with the literature of

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contemplate them is of value, otherwise the essence and nature of many things cannot be explained. Therefore, supposing that two simple substances are brought together, either congealed juice, stone, or metal is conjoined with earth; earth, stone or metal is connected with congealed juice; earth, congealed juice, or metal is joined together with stone; or earth, congealed juice, or stone is joined with metal."

[53]Ibid., pp. 372-80.

[54]Agricola said: "Scriptores, quorum inuentis usus sum. atq ex ipsis hi, qui nō extant, ab alijs ut rerum, de quibus scribunt, autores citantur." Ibid., p. [166]. He listed the following authorities who, he said, had written something about mineral substances: "Aelius Lampridius, Aelius Spartianus, Aeschylus, Aetius Amidenus, Albertus, Alexander Aphrodisiensis, Alexander Cornelius, Alexander qui scripsit res Lyciacas, D. Ambrosius, Antiphon, Apion Plistonices, Archelaus, Aristeas Proconesius, Aristophanes, Aristoteles, Asurabas, Auerroes, D. Augustinus, Aulus Gellius, Auicenna, Bocchus, C. Plinius Secundus senior, Cassiodorus, Columella, Cornelius Celsus, Cornelius

mineral substances, Agricola's treatise demonstrates that he had an awareness of some of the problems connected with classifying those substances. Still, he did not construct a mineral system. He described but did not generalize to any appreciable extent. Nevertheless, one can see that his discursive style was guided by a superficial application of philosophical concepts--there is an implied classification. But his theoretical framework was too comprehensive and too abstract to be of much use in arranging mineral substances into uniquely characterized groups. Agricola's forte was mineral description, not classification.[55] He codified much of the old knowledge, but seems to have developed no new insights. Perusal of contemporary books shows that soon after Agricola's works were published they were regarded as authoritative sources of information about mineral substances and mining matters. But the popular-style lapidaries and handbooks (or manuals) of mineral-lore continued to be published well into the seventeenth century.

Nepos, Cornelius Tacitus, Cresias, Diemachus, Democrit' qui scripsit De lapidibus, Demostratus, Diodorus Siculus, Dionysius Aser, Dioscorides, Empedocles Agrigentinus, Eratosthenes, Euripides, Fabius Pictor, Fl. Vopiscus, Galenus Pergamenus, Graecus ignot' qui scripsit De admirādis auditionibus, Hermogenes, Herodotus, Hesychius, D. Hieronymus, Hierocles, Hippocrates, Homerus, Horus, Iacchus, Ismenias, Iuba, M. Varro, Martialis, Megasthenes, Metrodorus, Mithridates, Mnesias, Mutianus, Nicanor, Nicias, Oribasius, Ouidius, Paulus Aegineta, Pausanias, Philemon, Philostratus, Philoxenus, Phocion grammaticus, Pindarus, Plutarchus, Posidonius, Pselus, Ptolomaeus, Pytheas, Quadrigarius, Satyrus, Seneca, Serapio, Sex. Pompeius Festus, Solinus, Sophocles, Sotacus, Stephanus, Strabo, Sudines, Suetonius, Theognides, Theophrastus, Theomenes, Theopompus, Timaeus, Valerius Maximus, Verrius, Virgilius, Vitruuius, Xenocrates, Xenophon, Zenothemis, and Zoroastres." Ibid.

[55]Adams, p. 195, said: "His system of classification, however, was not by any means Agricola's chief contribution to mineralogy. This lay rather in the description which he gives of many new minerals. . . ."

Among the many manuals of mineral-lore published during the sixteenth and seventeenth centuries are those written by Konrad Gesner (1516-1565),[56] Johan Kentman (1518-1574),[57] Andrea Cesalpino (1519-1603),[58] Ferrante Imperato (1550-1625),[59] Ulisse Aldrovandi (1522-1605?),[60] and Anselm de Boodt (c. 1550-1632).[61] The Gemmarvm et lapidvm historia of de Boodt is of particular interest as a seventeenth century manual that is more detailed, more extensive, more critical, and more systematic than

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[56]Konrad Gesner, Conradi Gesneri de rervm fossilivm, lapidvm et gemmarvm maximè, figuris & similitudinibus liber; non solum medicis, sed omnibus rerum naturae ac philologiae studiosis, vtilis & iucundus futurus (Tigvri: [Gesnervs], 1565).

[57]Johan Kentmann, Nomenclaturae rerum fossilium quae in Misnia praecipuè et in aliis quoque regionibus inueniuntur (Tigvri: Excudebat Jacobus Gesnerus, 1565).

[58]Andrea Cesalpino, De metallicis libri tres (Romae: Ex typographia Aloysij Zannetti, 1596).

[59]Ferrante Imperato, Dell'historia natvrale di Ferrante Imperato Napolitano, libri XXVIII. Nella qvale ordinatamente si tratta della diuersa condition di miniere, e pietre. Con alcune historie di piante, & animali; sin 'hora non date in luce (Napoli: Per Constantino Vitale, 1599).

[60]Ulisse Aldrovandi, Vlyssis Aldrovandi, patricii Bononiensis, mvsaevm metallicvm in libros IIII. distribvtvm Bartholomaevs Ambrosinvs in patrio Bonon., archigymnasio simpl., med. professor ordinarius, musei illustrissmi., senatus Bonon. et horti publici prefectus, labore et studio composuit, cum indice copiosissimo, Marcvs Antonivs Bernia proprijs impensis in lucem edidit ad serenissimvm Ranvtivm II Farnesivm Parmae Placentiae et C. Dvcem VI [Bononiae: Typis Io. Baptistae Ferronij, 1648].

[61]Anselm Boethius de Boodt, Anselmi Boetii de Boodt Brvgensis Belgae, Rvdolphi Secvndi Imperatoris Romanorvm personae medici, gemmarvm et lapidvm historia. Qua non solum ortus, natura, vis & precium, sed etiam modus quo ex iis, olea, salia, tincturae, essentiae, arcana & magisteria arte chymica confici possint, ostenditur. Opvs principibvs, medicis, chymicis, physicis, ac liberalioribus ingeniis vtilissimum. Cum variis figuris, indiceq; duplici & copioso (Hanoviae: Typis Wechelianis apud Claudium Marnium & heredes Ioannis Aubrii, 1609). Hereafter cited as de Boodt, Gemmarvm et lapidvm historia.

many earlier works. Moreover, it seems to have been well-known and highly regarded by subsequent authors, for five editions were issued within forty years and it is frequently cited by others.[62] Above all, it is an early example of a treatise on mineral substances that departs from an alphabetical arrangement in presenting descriptions of stones.

De Boodt, a physician at the court of Emperor Rudolph II, divided this work into two books. In book one he presented several general considerations relating to the properties of minerals. In book two, the major part of the treatise, he discussed about 130 kinds of mineral substances. For each substance, de Boodt attempted to record the various names under which it was known, physical properties, occurrences, imitations and the means of detecting imitations, uses (emphasizing reputed medicinal worth), and approximate cost.

De Boodt's critical, naturalistic spirit is apparent in his criticism of the belief in the curative virtues of various gems. Such attributions originate, he said, when people who lack sagacity impute a cure to a gemstone that was only accidentally associated with the sick person who became well. Adhering to the tenets of the iatro-chemists, de Boodt believed that any curative power of a stone lay within the

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[62] Latin editions were published in 1609, 1636, and 1647. French editions were published in 1644 and 1649 with the title _Le parfaict ioaillier, ov histoire des pierreries_. One could almost count Thomas Nicols, _A Lapidary, or the History of Pretious Stones, with Cautions for the Undeceiving of All Those That Deal with Pretious Stones_ (Cambridge, England: Printed by Thomas Buck, Printer to the Universitie, 1652), as an English edition because it followed de Boodt so closely. Nicols expressed his indebtedness to de Boodt in his preface, p. [_A 4 recto_], by saying that his own book was prepared in part by "acquainting _Anselmus Boetius_ with the _English_ tongue."

material of the stone acting in concert with the body, not in any supernatural virtue that it possessed.[63]

In discussing the various properties of gems and stones, de Boodt noted that the difference in hardness among minerals could be used as a crude diagnostic index. He distinguished three degrees of hardness and also included softness as a related but different property:

> Duri dicuntur qui neque digitis teri neque ferro scindi possunt. Qui enim possunt, hi molles, cum duriorb. comparati, dicuntur. Digitis teri possunt porus, pumex & armenus lapis: ferro scindi possunt fluores omnes qui etiamsi pulcherrimi sint, pro gemmis propterea habeti non debent. Duritiei tres statuo gradus, Primus cum chalibea solumodo lima lapis radi potest, qualis in Turchesia deprehenditur. Secundus cum non nisi Smiri lapide teri potest, qualis in Iaspide obseruatur. Tertius cum adamante tantum teri potest, qualis in adamante ipso & Topasio orientali seu chrysolitho veterum animadvertitur.[64]

He explained the observed variation in hardness as a result of a variation in the composition of stones:

> haec [terra, aqua, aer, sal] vt elementa ad materiam lapidum constituendam concurrunt; propter variam illorum commixtionem, tam varii gradus duritiei vel molliciei in gemmis & lapidibus sunt.[65]

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[63]De Boodt, <u>Gemmarvm et lapidvm historia</u>, pp. 42-45.

[64]<u>Ibid</u>., pp. 2-3: "They are called hard which neither can be rubbed away by the fingers, nor can be cut by iron. Indeed, those that can be, are called soft when compared with the harder. Tufa, pumice, and Armenian stone can be rubbed away by the fingers; all fluors can be cut by iron, which therefore, although they are most beautiful, should not be used for gems. I set up three degrees of hardness, the first when even a steel file can scratch the stone, such is discerned in turquoise. The second, when not able to be rubbed away except by Smyrna stone, such is observed in jasper. The third, when able to be rubbed away only by diamond, such is noted in the diamond itself and the oriental topaz or chrysolite of the ancients."

[65]<u>Ibid</u>., p. 27: "These [i.e., the chemical principles earth, water, air, and salt] come together as elements to constitute the material of stones; since there are various combinations of them, so there are various degrees of hardness or softness in gems and stones."

De Boodt rejected the customary explanation of transparency. He argued that it was not due to a predominance of water (i.e., the principle of humidity) in a body, but to the high degree of continuity among the constituent parts. On the other hand, he theorized that opacity resulted from discontinuity among the constituent parts of gems. He said:

> Existimo diaphanitatis causam esse propter terrae exactam, & in minimas particulas resolutionem, talemque earum vnionem vt corpus quod constituunt nullis poris aut atomorum terminis discretum, sed plane continuum sit. Continuitas enim sola omne corpus diaphanum facit. . . .[66]

The variation in heaviness was also explained by de Boodt on the basis of the mechanical arrangement of the constituent parts. He said that heaviness (grauitas) was simply an expression of the tendency of the constituent materials of a given gem or stone to move towards the center of the earth. That some gems were heavier than others was explained as a result of the constituent parts of the heavier gem being more compact, and consequently being less porous and air-filled. Thus, he explained both transparency and heaviness as a result of a high degree of contiguousness of the constituent parts of gems. The conclusion that transparent gems are heavier than opaque gems, which agreed with experience, was pointed out by de Boodt.[67]

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[66]*Ibid.*, p. 21: "I suppose the cause of diaphaneity to be on account of extraction of earth, and resolution of it into least particles, and such a union of them that the body which they constitute is not discrete with pores or the limits of atoms, but is entirely continuous. For continuity alone makes every body diaphanous. . . ."

[67]De Boodt wrote: "Grauitas quae nihil aliud est quam qualitas quaedam materiae insidens, qua mouere se ad centrum terrae conatur, lapidibus omnib. in est propter materiam terrestrem & aqueam ex quibus

Color was another extrinsic quality of mineral substances that de Boodt thought could serve to distinguish one mineral from another; however, since color was more variable than other properties, he thought it would be most useful as a diagnostic index for subspecies.[68]

De Boodt outlined two dichotomous divisions of all stones[69] and presented each scheme in a fold-out table. In each he used as characteristics of division some of the physical properties which he had discussed. The first scheme, which carried the title "Divisio lapidvm et gemmarvm," began with all stones (lapides alius). These were separated into large (magn') stones and small (paruus) stones. Each of these two groups was divided into stones that were rare (rarus) and stones that were common (frequens). The stones in each of these four groups were divided into hard (durus) stones and soft (mollis) stones. Three of the eight groups thus formed were not further divided. The remaining five groups were divided into attractive (pulcher) stones and unattractive (turpis) stones. After this fourth division, de Boodt did not attempt to divide each group on the basis of transparency (opacus-diaphanus), others on the basis of color (colore) and shape (figura), and some were not further divided.[70]

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constant. . . . Quod autem aliquae gemmae vel lapides aliis grauiores sint: id propter materiae terrestris & aqueae vel cōpositionem vel substantiam contingit. Si enim materia bene vnita ac coarctata fuerit, grauior erit lapis aut gemma, quàm si porosa fuerit multumque aeris aut aquae in se habeat. Ob id diaphanae opacis grauiores sunt, si ex eadem materia ac eiusdem magnitudinis fuerint. Nam materia ipsa plurimum ad gemmae grauitatem facit." Ibid., p. 28.

[68] Ibid., p. 24. Pp. 22-27 contain de Boodt's discussion of the nature and causes of mineral coloration.

[69] Ibid., pp. 2-3.

[70] Ibid.; see also the fold-out table, following p. 2.

De Boodt's second scheme was presented to emphasize his contention that classification was arbitrary, for de Boodt was well-aware that a classification was only a convenient mode of expressing relationships between things. He believed that the physical characters that he used as the basis of classification were only accidental, not essential, attributes of the mineral substances classified, but that they at least afforded a means for better understanding the essential nature of those substances.[71] Consequently, he said that his opinion as to the most convenient classification might well be different from someone else's opinion. Therefore, he invited those who did not approve of his classification to prepare another, using the same characteristics of division, but differently arranged.[72] Although de Boodt used many of the same characteristics of division in each classification scheme, the two are fundamentally different in that the first is a dichotomy of opposites, whereas the second is a privative dichotomy.[73]

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[71] Ibid., pp. 16-20. De Boodt specifically said that form, hardness, weight, color, opacity, and perspicuity were not essential attributes of mineral substances: "Causis, forma & loco generationis lapidum & gemmarum explicatis, nunc accidentia, ac formae extrinsecae explicandae sunt. His enim, nobis (qui essentias rerum intrinsecas prorsus ignoramus) in cognitionem veniunt. Inter accidentia numero formam accidentalem, duritiem, pondus, colorem, opacitatem & perspicuitatem." Ibid., p. 16.

[72] De Boodt wrote: "Hactenus differentias praecipuas, quae in lapidibus & gemmis depraehendi possunt ostendi: quarum vsus est, vt ex illis diuersae diuisionum species eruanttur, ac singuli lapides à se inuicem melius discerni possint. Cui itaque prior à me tradita diuisio displicet, is facile aliam ex praedictis capitib. concinnare poterit, cum multis diuisionibus suppeditent materiam: vt sequens diuisio demõstrabit, quae ex variis capitibus desumpta est, ac nonnullis fortassis magis quam prior placebit." Ibid., p. 7.

[73] The major elements of de Boodt's first scheme of classification are sketched in Figure 1; his second scheme is epitomized in Appendix II.

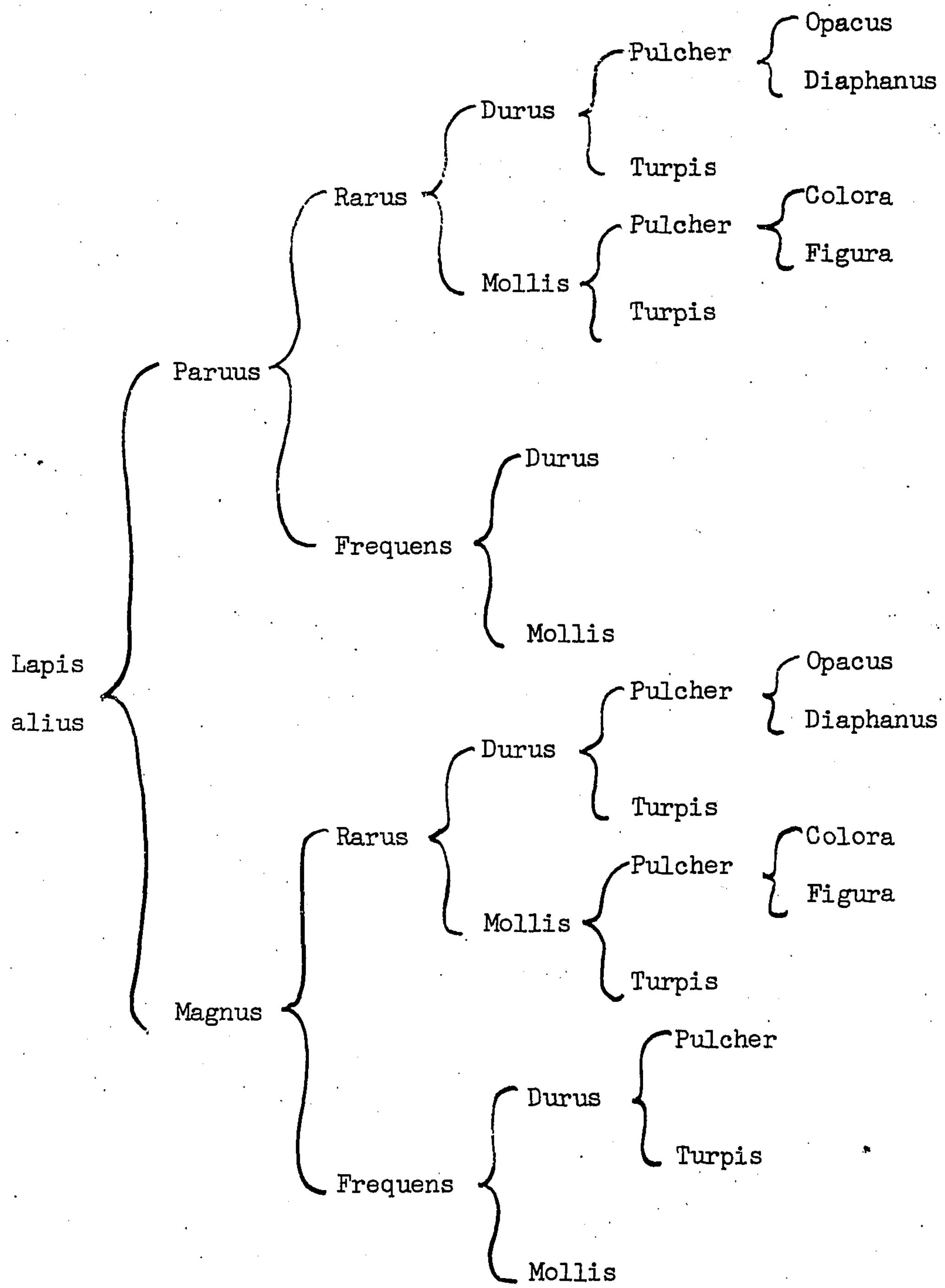

Fig. 1.--Major elements of one of Anselm de Boodt's schemes for classifying stones. Extracted from Gemmarvm et lapidvm historia, fold-out table following p. 2. Only the first five divisions of this scheme are shown, and all specific names have been omitted. See Appendix II for a synopsis of de Boodt's other scheme.

In his tabular sketches, de Boodt illustrated his theoretical classifications with examples of some of the gems or stones that would be contained in each ultimate group. For example, following the first scheme, the group characterized as large-common-hard-attractive stones was the group to which marble (marmor) was assigned; large-rare-hard-attractive-opaque stones included jasper (iaspis), coral (corallus), and agate (achates); and small-rare-hard-attractive-transparent-colored stones included gems such as beryl (berillus), ruby (rubinus), and emerald (smaragdus).[74] Following de Boodt's second scheme, the above-mentioned mineral substances are classified as follows: marble is an inanimate-non flammable-unfigured-opaque-unattractive stone; jasper and agate are inanimate-non flammable-unfigured-opaque-attractive-large stones; coral is animate-non volatile-terrestrial-plant produced stone; and beryl, ruby, and emerald are inanimate-non flammable-unfigured-transparent-complete-hard-colored stones.[75] With his dichotomous schemes de Boodt could accommodate any kind of stone.

In the second part of his treatise de Boodt, like Agricola, set forth descriptions of individual mineral substances in an order different from the order that he had described in his classification scheme. Since he departed from the usual alphabetical arrangement, de Boodt thought it necessary to justify his method. In his prefatory remarks he said:

> Inter omnes, beneuole Lector, qui de lapidibus ac gemmis scripserunt, ac ad manus meas peruenerunt, nulli hactenus peculiari

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[74]Ibid., fold-out table, following p. 2.

[75]Ibid., fold-out table, facing p. 7.

aliqua methodo vsi sunt. Nam alii secundum alphabeti ordimen, vt Plinius, Albertus Magnus & Ludouicus Dulcis, alii promiscue vt Franciscus Rueus ac Andreas Baccius de iis tractarunt. Solus quod sciam Gesnerus in classes vel à similitudine vel nominibus rerum sumptas, gemmas & lapides discreuit. Quia vero Gesneri methodus propter varias causas quas hic recensere longum esset, mihi non placebat; à rarioribus & carioribus tractationem incipere, mihi gemmis ipsis dignius esse magisque conuenire videbatur. Itaque à Diaphanis, vt ab Adamante omnium gemmarum preciosissima, diaphana, nulloque colore praedita, exordium sumpsi: Deinde ab ea ad diaphanas colore praeditas, & viliores gradatim progressus sum. Ita tamen, vt quae euisdem generis videbantur, licet dignitate multum inter se different, iisdem capitibus subiungerentur.[76]

Among the 130 substances dealt with individually were starstones,[77] corals,[78] snails,[79] sea urchins[80] and sea urchin spines,[81] shark teeth,[82] bones,[83] belemnites,[84] ammonites,[85] stalactites,[86]

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[76]Ibid., p. ††3 recto: "Among all those, kind reader, who have written about stones and gems, and also have reached my hand, none so far have used some special method. For some such as Pliny, Albertus Magnus and Lodovico Dolce have treated them according to alphabetical order, others such as François La Rue and Andrea Bacci have treated them without distinction. Gesner alone, of whom I know, has divided gems and stones into classes chosen either by likeness or by the names of things. However, because Gesner's method was not pleasing to me for various reasons which would be long to recount here, it seemed to me to be fitting and more appropriate to gems themselves to begin a treatment with the rarer and most costly. Therefore, I took the beginning from diamond because diamond is the most precious of all gems, transparent, and endowed with no color. Then, from it I progressed step by step to the transparent ones endowed with color, and then the cheaper ones. Nevertheless, those that appeared to be of the same kind, although they differ much among themselves in worth, were subordinated to the same heading."

[77]"De asteria vera seu stellari lapide," ibid., p. 152.

[78]"De corallis," ibid., pp. 153-61.

[79]"De umbilico marino," ibid., pp. 176-77.

[80]"De lapide ouum anguinum appellato," ibid., pp. 174-75.

[81]"De lapide Judaico," ibid., pp. 200-201.

[82]"De glossopetra eiusque loco natali, natura & facultatibus," ibid., pp. 170-71.

stalagmites,[87] and some prehistoric stone axes.[88] He also included an assortment of stones that were reputed to have a curious origin or magical properties; the toad-stone (bufonis lapis), for example, was said to come from the head of a toad,[89] and the aetite or eagle-stone was said to prevent miscarriages when applied to the left arm of a pregnant woman.[90] Many of the miraculous stones, in addition to their primary virtue, were supposed to be effective in counteracting poisons. Thus, the aetite was supposed to be effective against poisons administered in wine.[91] De Boodt usually presented the traditional account and opposing views in an impersonal way, in that way the reader could be the

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83"De ossifrago lapide," ibid., pp. 204-06.

84"De belemnite officinarum, lyncurio & dactilo ideo," ibid., pp. 235-37.

85"De cornu ammonis," ibid., pp. 215-16.

86"De stalactite seu stellatitio lapide," ibid., p. 207.

87"De stalagmite," ibid.

88"De ceraunia," ibid., pp. 237-40. Although it had been suggested that Cerauniae were iron implements turned to stone, de Boodt accepted the more generally held opinion that they were "thunder stones" resulting from lightning: "Quia autem omnes isti lapides, vel malleum vel cuneum vel securim vel vomerem vel similia instrumenta foramina habentia pro immittendo manubrio, forma simillima sunt: nonnulli non fulminis esse sagittas, sed ferrea instrumenta in lapides longo tempore mutata existimarunt. Illorum profecto opinionem probarem, nisi multi fide digni viri reclamarent, qui postquam à fulmine ictae domus aut arbores sunt, se tales lapides in ictus loco reperisse asserunt," Ibid., p. 238.

89Ibid., p. 152.

90Ibid., p. 187. See above, pp. 9-10, for reference to Dioscorides and Pliny on the properties of the eagle-stone.

91Ibid.: "Ad venena danda cum vino, dysenterias malignas aliosque alui malignos fluxus compescit."

judge of the correct explanation. Typical is his comment upon the alectorius, a stone that was found in the stomach of a cock:

> Num autem ibi generetur, . . . aut pabuli vice ab ipso inuentus deglutiatur incertum est.[92]

Agricola had accepted the traditional account:

> alectoriae ex gallis gallinacijs nomen duxerunt. etenim, quanquam raro, in eorum, atq; etiam castratorum, uentriculo & iecore gignuntur.[93]

These traditional beliefs did not dissappear from treatises on minerals for a long time after de Boodt wrote, but during the seventeenth century more and more authors looked skeptically upon the supernatural traditions.

In addition to the section on generalities (Book One) and the novel arrangement of the kinds of mineral substances, de Boodt included a discussion of the practical art of gem- and stone-cutting. Machines and methods that were used for cutting and polishing gems and stones are described and the text is illustrated with eight woodcuts of some of the apparatus discussed.[94] De Boodt went beyond Agricola in his treatment of the value of gems by adding tables for determining the value of diamonds, garnets, amethysts, and pearls.[95] The tables listed a variety of sizes and

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[92] Ibid., p. 171: "However, whether it is generated there . . . or food swallowed down is changed to that invention, is uncertain."

[93] Agricola, De natura fossilium, p. 307: "the alectoriae take their name from the poultry cock. For, although rare, they are produced in the belly and the liver of them, and also of capons."

[94] De Boodt, pp. 35-42.

[95] Ibid., pp. 66-67 (diamonds), 77-78 (garnets), 82 (amethysts), and 89-90 (pearls). The evaluation of many other stones was given in

qualities of each stone, and correlated them with the stone's value.

On the whole the content of de Boodt's treatise differs little from that of Agricola's De natura fossilium. De Boodt, however, was more explicit in expressing his ideas on classification in tabular form, but neither treatise can be said to present a thorough-going mineral system.

The explosion of technical literature dealing with mining and metallurgy that occurred during the sixteenth and seventeenth centuries provided another vehicle for mineralogical knowledge. The first such technical treatises known, the Bergbüchlein of Rülein von Kalbe (died 1523) and the anonymous Probier-büchlein, were published in Germany during the first quarter of the sixteenth century.[96] The first printed compilation of practical knowledge concerning the refining of metals was the De la pirotechnia published in 1540 by Vannuccio Biringucchi (1480-1539?).[97] Agricola's De re metallica[98] was published posthumously in

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more general terms. For example, see the discussion of the esteem and value of common topaz, p. 106.

[96]The Bergbüchlein was first published about 1505 and is the first known printed book dealing with mining. The Probierbüchlein was first published about 1520 and is the first known printed book dealing with refining of metals. See Bergwerk- und Probierbüchlein: A Translation from the German of the Bergbüchlein, a Sixteenth-century Book on Mining Geology, by Anneliese Grünhaldt Sisco; and of the Probierbüchlein, a Sixteenth-century work on Assaying, by Anneliese Grünhaldt Sisco and Cyril Stanley Smith. With Technical Annotations and Historical Notes ("The Seeley W. Mudd Series"; New York: The American Institute of Mining and Metallurgical Engineers, 1949).

[97]Vannuccio Biringucci, De la pirotechnia libri X. Dove ampiamente si tratta non solo di ogni sorte & diuersita di miniere, ma anchora quanto si ricerca intorno à la prattica di quelle cose di quel che si appartiene à l'arte de la fusione ouer gitto de metalli come d'ogni altra cosa simile à questa ([Venetia: Per Venturino Roffinello], 1540). See also Cyril Stanley Smith and Martha Teach Gnudi (eds. and

1556, Lazarus Ercker's (died 1593) treatise on ores and assaying appeared in 1574,[99] and Alvaro Alonso Barba (fl. 1640) published Arte de los metales[100] in 1640.[101] These works, although primarily concerned with

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trans.), The Pirotechnia of Vannoccio Biringuccio. Translated from the Italian with an Introduction and Notes ("The Seeley W. Mudd Series"; New York: The American Institute of Mining and Metallurgical Engineers, 1942).

[98]Cited above, note 25.

[99]See Anneliese Grünhaldt Sisco and Cyril Stanley Smith (trans.), Lazarus Ercker's Treatise on Ores and Assaying. Translated from the German Edition of 1580 (Chicago: The University of Chicago Press, [1951]).

[100]Alvaro Alonso Barba, Arte de los metales, en qve se enseña el verdadero beneficio de los de oro, y plata por açoque. El modo de fvndirlos todos, y como se han de refinar, y apartar unos de otros (Madrid: Imprenta del Reyno, 1640).

[101]Cyril Stanley Smith in the Introduction to The Pirotechnia of Vannoccio Biringuccio, p. xviii, said: "Although the seventeenth century was a period of great activity in physics and chemistry, and although metallurgical production was increasing rapidly at the time, the methods used were not much changed, and the demand for books on metals was satisfactorily met by reprints of the sixteenth-century authors, Birunguccio, Agricola and Ercker. Only one important original work appeared in the seventeenth century, El arte de los metales by Alvaro Alonzo Barba, which was published in Madrid in 1640." Examples of treatises that are heavily dependent upon one or more of the above four authors are: Christoph Entzelt, De re metallica, hoc est, de origine, varietate, & natura corporum metallicorum, lapidum, gemmarum, atq; aliarum, quae ex fodinis eruuntur, rerum, ad medicinae usum deseruientium, libri III (Franc[ofurti]: Apud Chr. Egenolphum, [1551]); Bernardo Pérez de Vargas, De re metalica, en el qval se tratan mvchos y diversos secretos del conocimiento de toda suerte de minerales, de como se deuen buscar ensayar y beneficiar, con otros secretos e industrias notables, assi para los que tratan los officios de oro, plata, cobre, estaño, plomo, azero, hierro, y otros metales, como para muchas personas curiosas (Madrid: En casa de Pierres Cosin, 1569); Joseph Duchesne, Ad Iacobi Avberti Vindonis de ortv et cavsis metallorvm contra chymicos explicationem. Iosephi Qvercetani Armeniaci d. medici breuis responsio. Eivsdem de exqvisita mineralium, animalium, & vegetabilium medicamentorum spagyrica praeparatione & vsu, perspicua tractatio (Lugduni: Apud Ioannem Lertotium, 1575); [Gabriel Plattes], A Discovery of Subterraneal Treasure, viz. of All Manner of Mines and Minerals, from the Gold to the Coal; with Plain Directions and Rules for the Finding of Them in All Kingdoms and Countries. And Also the Art of

metals and ores, invariably contained information about minerals, but they contributed little towards classification schemes or mineral systems.

In addition to general works, such as de Boodt's manual, and technical mining literature, mineral substances were discussed in treatises devoted to a thorough exposition of a certain substance. Such was Johan Philipp Büntingen's Sylva subterranea,[102] and Kaspar Bauhin's (1560-1624) De lapidis bezaar.[103] Bauhin, having examined the works of 165 authors,[104] wrote with a measure of authority concerning what was known about the bezoar stone.[105] The results of his extensive reading

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Melting, Refining, and Assaying of Them Is Plainly Declared So That Every Man That Is Indifferently Capacious May with Small Charge Presently Try the Value of Such Oares As Shall Be Found Either by Rule or by Accident. Also a Perfect Way to Try What Colour Any Berry, Leaf, Flower, Stalk, Root, Fruit, Seed, Bark, or Wood Will Give; with a Perfect Way to Make Colours that They Shall Not Stain, nor Fade Like Ordinary Colours (London: Printed for I. E. and are to be sold by Humphrey Moseley, 1653); Thomas Houghton, Rara avis in terris, or the Compleat Miner, in Two Books; the First Containing the Liberties, Laws and Customs of the Lead-Mines within the Wapentake of Wirksworth in Derbyshire in Fifty Nine Articles, Being All that Ever Was Made. The Second Teacheth the Art of Dialling and Levelling Grooves, a Thing Greatly Desired by All Miners, Being a Subject Never Written On Before by Any (London, 1681).

[102] Johann Philipp Büntingen, Sylva subterranea, oder vorttrefliche Nutzbarkeit des unterirdischen Waldes der Stein-kohlen, wie dieselben von Gott denen Menschen zu gut an denenjenigen Orthen, wo nicht viel Holtz wächset, aus Gnaden verliehen und mitgetheilet worden, auff hoher Patronen befehl und Curiosität entworffen und zum Druck befördert, von Johann Philipp Büntingen (Halle: Gedruckt von Christoph Salfelden, 1693).

[103] Kaspar Bauhin, Caspari Bavhini, Basil. d. eivsdemq. academ. anatom. et botanic. professor. ordin., de lapidis bezaar orient. et occident. Cervini item et Germanici ortv, natvra, differentijs, veroque vsu ex veterum & recentiorum placitis liber hactenus non editus (Basileae: Apud Conr. Waldkirch, 1613).

[104] Ibid., pp.)(5 verso-(:) recto.

[105] The term "bezoar stone" was applied to various concretions found in the alimentary organs of a variety of mammals.

were presented topically. He discussed the name "bezaar," the different kinds of bezoar stones, the similarity of bezoar stones to toadstones and asp stones, places where the stones were found, how they were generated, their sizes, their colors, their weights, and so forth. Whatever had been written about the bezoar stone was sought out by Bauhin, and his findings are reported in his book.

Another class of works which contain some of the mineral lore of the sixteenth and seventeenth centuries is the epitome of common and precious stones. One was Jean de La Taille's (1533?-1608?) Le blason des pierres precievses.[106] La Taille claimed to have consulted the best Greek and Latin authors, and then to have set down for each of the precious stones, their generation, names, colors, and virtues.[107] However, his description of what he said he did was better than the result of his labors, for he only briefly and unsystematically described eighteen stones.[108] His description of sapphire illustrates the caliber of his work:

> Le Saphyr, qui est de couleur azuree, & le plus agreable à l'oeil (apres l'Emeraude) reiouist totalement l'homme, & approche du Diamant en durté: Il proffitte (estant beu) aux melancoliques, & au coup, & morsure des Scorpions, & Serpens: Guerist mesmes vn anthrac, vulgairement dit clou ou charbon, (pourueu qu'il touche quelque temps à la chair, & qu'il soit grand.) Ayant des Estoiles Boquines ceste proprieté de rendre celuy qui le porte aymable: Il resiste au feu long temps, estant plus dur que l'Escarboucle: Toutesfois on le peult (estant de couleur debile, & ioint auec de

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[106] Jean de La Taille, Le blason des pierres precievses contenant levrs vertuz & proprietez (Paris: Pour Lucas Breyer, 1574).

[107] Ibid., p. 2 recto.

[108] Ruby, carbuncle, pearls, sapphire, topaz, opal, hyacinth, turquoise, agate, amethyst, heliotrope, crystal (quartz), chalcedony, jasper, coral, lodestone, amber, and selenite.

l'Or) fondre à petit feu, & en faire vn Diamant: Chose de bonne inuention, car il demeure pierre precieuse (sa couleur bleuë estant disparue) & la lyme ne peult mordre dessus, pourueu qu'il soit refroidy peu à peu.[109]

François La Rue (c. 1520-1585), a contemporary of La Taille, presented more information on some twenty-six stones in his epitome De gemmis aliqvot; his originality was limited to the particular way in which he arranged the information that he had gleaned from the thirty-five ancient and modern authors he cited as his sources.[110]

Another similar work was Le XII. pietre pretiose of Andrea Bacci (died 1600).[111] Bacci's only novel twist was the addition of a lengthy discussion of the unicorn.[112] A century after these books were

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[109] Ibid., p. 5 verso: "Sapphire, which is of azure color, and the most pleasing to the eye (after emerald) completely rejoices man, and approaches the diamond in hardness. It benefits (being blue) the melancholy, and the wound and bite of scorpions and serpents. It likewise heals an anthrax, commonly called a boil or carbuncle, (provided that it touches the flesh some time, and that it is large.) It has from the Boquines stars [the constellation Capricorn?] that quality of rendering amiable the one who carries it. It resists fire for a long time, is harder than carbuncle. Often, in a small fire, one is able to convert it (being of weak color, and united with gold), and make it a diamond. An ingenious thing because it remains a precious stone (its blue color is missing) and the file cannot eat into the surface, provided that it is cooled slowly."

[110] François La Rue, De gemmis aliqvot, iis praesertim qvarvm Diuus Ioannes Apostolus in sua Apocalypsi meminit, de aliis quoque, quarum vsus hoc aeui apud omnes percrebruit, libri duo, theologis non minus vtiles quàm philosophis, & omnino felicioribus ingeniis periucundi, e non vulgaribus vtriusque philosophiae adytis deprompti (Tigvri, 1566).

[111] Andrea Bacci, Le XII. pietre pretiose, le qvali per ordine di Dio nella santa legge, adornauano i vestimenti del sommo sacerdote. Aggivntevi il diamante, le margarite, e l'oro, poste da S. Giouanni nel'Apocalisse, in figura della celeste Gierusalemme. Con vn sommario dell'altre pietre pretiose. Discorso dell'alicorno, et delle sve singolarissime virtù, et della gran bestia detta alce da gli antichi (Roma: Appresso Giouanni Martinelli, 1587).

[112] This discussion was nearly two-thirds of the entire treatise. Ibid., pp. 44-130.

published, there was still a demand for such epitomes, as Samuel Chappuzeau's (1625-1701) History of Jewels[113] and others like it attest.

The technical handbooks and the epitomes were practical books; they devoted little space to discussions of the theoretical foundations upon which studies and knowledge of mineral substances were based. The authors of such treatises were not explicitly concerned with classification; it was incidental to their main interest, description. There were, however, some authors who were more concerned with the philosophical and theoretical aspects of the study of minerals. For example, Robert Boyle (1627-1691) in An Essay About the Origine & Virtues of Gems, explicitly stated his purpose to be philosophical:

> I propos'd this Discourse but as a Conjectural Hypothesis, wherein I attempted to derive the Origine of Gems and one of the main Causes, (I do not say, the only Cause) of their Qualities and Virtues, from Principles less remote, and more intelligible than those of the Peripateticks. . . .[114]

By means of closely reasoned arguments, he set out to convince the reader of the truth of his hypotheses. But Boyle was not proposing an explanation of the range of mineral substances, nor was he attempting to organize mineralogical knowledge into a system. Such systems, however, are often encountered in the printed catalogs of mineral collections.

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[113][Samuel Chappuzeau], The History of Jewels and of the Principal Riches of the East and West, Taken from the Relation of Divers of the Most Famous Travellers of Our Age, Attended with Fair Discoveries Conducing to the Knowledge of the Universe and Trade (London: Printed by T. N. for Hobart Kemp, 1671).

[114]Robert Boyle, An Essay About the Origine & Virtues of Gems. Wherein Are Propos'd and Historically Illustrated Some Conjectures about the Consistence of the Matter of Precious Stones, and the Subjects Wherein Their Chiefest Virtues Reside (London: Printed by William Godbid, and are to be sold by Moses Pitt, 1672), p. [A7 verso].

According to the modern author Maurice Daumas, collecting objects, both natural and man-made, became fashionable during the fifteenth century, and was a widespread pastime of the wealthier classes by the end of the sixteenth century.[115] The activity of collecting mineral specimens and establishing cabinets and museums, as the collections were called, focused attention on minerals and led to the preparation of catalogs and descriptions of the specimens. Both aided collectors with the task of identification.[116] Besides identification, collectors faced the problem of how to arrange their specimens in an appropriate and convenient way, that is, how were they to classify mineral substances. Solutions to this problem of classification appear in several printed catalogs of mineral collections.

Among the earliest-known mineral catalogs was the one prepared by Konrad Gesner of the collection of Johan Kentmann.[117] Gesner's catalog shows Kentmann's 1,614 specimens distributed into thirty groups. The groups containing the most examples are: earths (<u>terrae</u>), natural juices (<u>svcci natiui</u>), stones (<u>lapides</u>), stones from animals (<u>lapides ab animantibus</u>), and gems (<u>gemmae</u>). The other twenty-five groups contained only a few specimens, and many groups were restricted to one kind of

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[115] Maurice Daumas, <u>Les cabinets de physique au XVIII^{e} siècle</u> ("Les Conférences du Palais de la Découverte," [No. 2]; Paris: Université de Paris, 1951), p. [5].

[116] René Taton (ed.), <u>La science moderne (de 1450 a 1800)</u> ("Histoire générale des sciences," Tome II; Paris: Presses Universitaires de France, 1958), pp. 415-16.

[117] Konrad Gesner, <u>De omni rervm fossilivm genere, gemmis, lapidibvs, metallis, et hvivsmodi, libri aliqvot, pleriqve nvnc primvm editi</u> (Tiguri: Excudebat Iacobus Gesnerus, 1565).

substance. Thus, there was a group for gold and gold ores, one for lead (plvmbvm nigrum), and one for sands (arenae). Finally, there was a catch-all group which was called diversi alij.

The Mvsaevm metallicvm of Ulisse Aldrovandi was a generalized mineral system as well as a catalog.[118] Published at Bologna in 1648 by Aldrovandi's pupil Bartholomaeus Ambrosinus (1588-1657), the book gave the name and synonyms of each kind of stone, a description of its varieties, where it was found, and its uses (particularly medicinal). The treatise was divided into four books, each concerned with a major group of mineral substances: book one was metals; book two, earths; book three, congealed juices;[119] and book four, stones. This last book, which contained eighty-six of Aldrovandi's one hundred thirty-five chapters, included a variety of minerals,[120] fossils,[121] rocks,[122] and animal calculi.[123] Aldrovandi's discussion of glossopetra, a part of which follows, illustrates his straight-forward presentation of controversial material:

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[118]Cited above, note 60.

[119]In this category Aldrovandi included such things as coral (pp. 284-97), salt (pp. 298-320), sulphur (pp. 362-77), bitumen (pp. 377-88), and amber (pp. 403-18).

[120]E.g., pyrite (pp. 570-79), gypsum (pp. 673-77), talc (pp. 685-88), and amethyst (pp. 966-70).

[121]E.g., belemnites (pp. 618-23), star-stones (pp. 872-80), teeth of various kinds (pp. 721-23, 828, 830-31), and shells (pp. 832-47).

[122]E.g., schist (pp. 655-57), obsidian (pp. 709-10), and marble (pp. 746-79).

[123]E.g., bezoar (pp. 801-09) and toadstone (pp. 810-16).

Aliqui monimentis mandarunt Glossopetras esse naturae lapideae, sed dentes piscium armatorum, & testaceorum esse voluerunt, qui in terris, post vniuersalem inundationem, remanserunt: veluti multa Osteorum, & Chamarum tegumenta in montibus passim obseruantur. Haec opinio prorsus est explodenda; cum Glossopetrae sint lapides sui generis, & proprias habeant mineras; immo satis villes sunt, & diminuto pretio venduntur.[124]

In general, Aldrovandi's approach was to name and briefly describe mineral substances in qualitative terms. Since there were no generally accepted systematic procedures at that time, a variety of miscellaneous information accompanied the description of the physical characters of the specimen, and such topics as synonymy commanded a considerable portion of each description.[125]

During the seventeenth century the newly developing scientific societies encouraged the collection and study of mineral substances.[126] A catalog of the collection of natural objects of the Royal Society of London was published by Nehemiah Grew (1641-1712) in 1681.[127] Grew

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[124] Ibid., p. 601: "Some writings consign glossopetra to be natural stones, but want them to be the teeth of armed and testaceous fish, which remained on the earth after the universal inundation, just as many coverings of bones and cockles are observed here and there in the mountains. This opinion is utterly rejected since glossopetra are stones of their own kind and they [are associated with] characteristic minerals; moreover, they are quite common and they are sold for a small price."

[125] Aldrovandi began most of his descriptions with a section entitled "Synonima et etymvm," ibid., pp. 260, 299, 321, et passim.

[126] See Martha Ornstein, The Rôle of Scientific Societies in the Seventeenth Century (3d ed.; Chicago: The University of Chicago Press, 1938), pp. 112, 114-15, 169, 185-86, 192; also Charles E. Raven, English Naturalists from Neckam to Ray: A Study of the Making of the Modern World (Cambridge, England: At the University Press, 1947), pp. 317, 325-26.

[127] Nehemiah Grew, Musaeum Regalis Societatis, or a Catalogue & Description of the Natural and Artificial Rarities Belonging to the Royal Society and Preserved at Gresham Colledge. Whereunto Is

treated separately each kingdom--animal, plant, and mineral--, and he added a fourth part for "artificial matters." He divided the mineral kingdom into three major categories: stones, metals, and mineral principles. By the latter he meant "neither such imaginary ones as some have talked of: nor such as may possibly have a real existence, yet were never seen solitary or uncompounded: but those which come within the cognizance of sense. . . ."[128] More explicitly, he said they were salts, sulphurs, and earths.[129] Among the metals and their ores were included many specimens of "marchasite" and "pyrites."[130] Under stones, Grew listed petrified animal bodies, petrified plant bodies, corals and other marine productions, gems, regular stones, and irregular stones.[131] In all, he catalogued more than 900 specimens. Nevertheless, Grew's work was a descriptive list of minerals, not a mineral system.

Sixteenth and seventeenth century catalogs of collections of mineral substances reflect attempts to generalize mineralogical knowledge. If measured by twentieth century standards, the achievements of these classifiers seem elementary. But regarded in light of the traditional arrangements which their classifications were slowly setting aside, their accomplishments seem greater. Perhaps the greatest legacy from these naturalists was their emphasis on studying material substances

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Subjoyned the Comparative Anatomy of Stomachs and Guts (London: Printed by W. Rawlins, for the Author, 1681).

[128] Ibid., p. 338.

[129] Ibid.

[130] Ibid., pp. 336-38.

[131] Ibid., pp. 254-321.

after they were collected. The act of collecting became the means to an end, rather than an end in itself.

Once mineral substances began to be seriously studied, perplexing questions regarding their nature and origin could no longer be glossed-over. One of these questions was whether the so-called figured stones or adventitious fossils were of inorganic origin--sports of Nature--, or if they were originally of an organic nature and had subsequently turned to stone in some way.[132] Nehemiah Grew's opinion concerning this problem was expressed in his catalog of the Royal Society collections. Grew asked whether the "many subterraneal Bodies, which have the semblance of Animals, or Parts of them, . . ."[133] were ever exactly that. He replied: "Why not? Is there any thing repugnant in the matter?"[134] Other naturalists of his day could and did disagree with him, and averred that those "subterraneal Bodies" were never in any way connected with animals. Naturalists were only slowly convinced of the reasonableness of the idea that adventitious fossils were of an organic nature. It was a postulate and, therefore, could not be proved. The postulate was eventually accepted primarily on the basis of overwhelming circumstantial evidence. By the beginning of the eighteenth century, few were willing to defend the sport of Nature hypothesis for the origin of fossils.

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[132] Some information concerning the nature and resolution of this problem, often termed the fossil problem, is found in Marjorie Hope Nicolson, Mountain Gloom and Mountain Glory: The Development of the Aesthetics of the Infinite (Ithaca, New York: Cornell University Press, [1959]); and John C. Greene, The Death of Adam: Evolution and Its Impact on Western Thought (Ames, Iowa: The Iowa State University Press, [1959]).

[133] Grew, p. 253.

[134] Ibid.

At the end of the seventeenth century, the study of minerals was empirical and unsystematic. The mineral kingdom was regarded as comprehending anything dug up or found underground, and the knowledge of these "dug" objects was contained in a variety of treatises that were little more than descriptive enumerations of objects. But mineral substances were increasingly coming under scientific scrutiny, and questions as to their nature and origin were repeatedly raised and discussed in the flourishing scientific monographic and periodical literature.

CHAPTER II

MINERAL CLASSIFICATION ON THE BASIS OF PHYSICAL PROPERTIES

One of the problems occupying some naturalists during the early part of the eighteenth century concerned the nature of and distinctions between adventitious fossils and native fossils. To some it was apparent that the burgeoning knowledge of these mineral substances was no longer adequately accommodated by a simple enumeration of specimens. One of the more eloquent naturalists who helped to discriminate between native and adventitious fossils, and also one of the first to systematize them was John Woodward (1665-1728). Woodward, a London physician, clearly distinguished native from adventitious fossils in 1695 in his _Essay toward a Natural History of the Earth,_[1] which was a preliminary sketch of a larger work that was promised but never published. Believing in the organic nature of figured stones, Woodward tried to account for the observed inorganic composition of them. He said that those

> Bodies which consist of Stone, or Spar, Flint, and the like, and yet carry a resemblance of Cockles, Muscles, and other Shells, were originally formed in the Cavities of Shells of those kinds which they so resemble; these Shells having served as Matrices or _Moulds_ to them; the Sand, Sparry and Flinty Matter being then

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[1]John Woodward, _An Essay toward a Natural History of the Earth and Terrestrial Bodies, Especially Minerals, As Also of the Sea, Rivers, and Springs. With an Account of the Universal Deluge and of the Effects That It Had Upon the Earth_ (London: Printed for Ric. Wilkin, 1695).

> soft, or in a state of solution, and so, susceptible of any form, when it was thus introduced into these shelly-Moulds: and that it consolidated, or became hard afterwards.[2]

Those that were composed of metallic mineral substances, he said were alterations of the original shells.[3] Furthermore, he declared that many shells, teeth, and bones in his possession that were dug up, when "critically examined by very many Learned Men . . . skill'd in all parts of Natural History . . .," were not distinguishable from "the very <u>Exuviae</u> of Sea-fishes. . . ."[4]

Woodward tried to forestall critics who might object to his ideas on the ground that there was a lack of congruence between figured stones and modern organisms. To the objection that there were found "some Shells at Land, in Stone, and in Chalk, which cannot probably be match'd by any species of Shells now appearing upon our Shores,"[5] Woodward answered that even the strangest of the otherwise unknown fossil shells "have all the essential Notes and Characters of Sea-Shells, and shew as near a relation to some now extant upon the Shores. . . ."[6] Therefore, he said, "there were such Shell-fish <u>once</u> <u>in</u> <u>being</u>. . . ."[7] He also half-heartedly speculated that there could be innumerable undiscovered species in the vast uncharted oceanic wastes.[8] To explain the

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[2]<u>Ibid</u>., pp. 20-21.

[3]<u>Ibid</u>., p. 21.

[4]<u>Ibid</u>., pp. 23-24.

[5]<u>Ibid</u>., p. 25.

[6]<u>Ibid</u>.

[7]<u>Ibid</u>.

[8]<u>Ibid</u>., pp. 25-28.

converse of the foregoing, i.e., many modern sea-creatures, such as lobsters and crabs, were not represented among figured stones, Woodward asserted that it was erroneous to say they were never found. That they were seldom found, he admitted, but this he said was easily explained by his theory of the earth. According to his theory, at the time of the universal deluge the entire earth and its inhabitants were churned up into a fluid mass of rock particles, shells, vegetable and animal bodies, and water. In time the constituents settled out in layers according to relative specific gravities. The bodies that had a lower specific gravity, such as lobsters and crabs, would naturally settle out later than the denser bodies, and therefore could not be expected to be found associated with them.[9]

Woodward upheld the Baconian ideal of basing explanations upon empirical evidence. He said: "The World is at length convinc'd, that Observations are the only sure Grounds whereon to build a lasting and substantial Philosophy."[10] In refuting commonly held explanations for the observed occurrences of adventitious fossils he relied heavily upon sensory data, but he did not resolve the problem of adventitious fossils by studying the data--he postulated his way to a solution. In reviewing the reasons that were advanced "to perswade us that these Bodies [fossils] are mere Mineral Substances,"[11] he pointed out that the universal association of adventitious and native fossils in the earth did not necessarily

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[9] Ibid., pp. 28-33.

[10] Ibid., p. 1.

[11] Ibid., p. 15.

mean that they were both of inorganic origin. That conclusion depended upon the assumption that both were found in the place where they were formed. Woodward denied this assumption. Instead, he postulated that both native fossils and adventitious fossils had an independent "Being before ever they came thither [into the earth]: and were fully formed and finished before they were reposed in that manner."[12] His theory of the earth described the nature of that prior "Being." Convinced that the means proposed by previous authors "were not the true ones,"[13] Woodward set forth his conclusions as if they had been drawn from observations alone.

Having postulated that some fossils (in the broad sense) were ultimately of organic origin and others were of inorganic origin, Woodward had begun a dichotomous differentiation of the mineral kingdom. But within each of the two groups formed by this primary division there was a vast, diverse accumulation of substances to be organized. The organic derivatives could be further differentiated along the lines of botanical and zoological classification which had been developed during the sixteenth and seventeenth centuries,[14] but the inorganic derivatives were negatively characterized. How was <u>that which is not organic</u> to be differentiated? What was to be adopted as the <u>fundamentum divisionis</u> for dividing the native fossils? What principle of organization, what character or set of characters was to be the basis for establishing

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[12] <u>Ibid</u>., p. 20.

[13] <u>Ibid</u>., p. 45.

[14] See Erik Nordenskiöld, <u>The History of Biology: A Survey</u>, trans. Leonard Bucknall Eyre (New York: Tudor Publishing Co., 1949), pp. 190-202.

correspondences among minerals? Before asking such questions as these, one must assume that there are correspondences or relationships among minerals. If one assumes that there is only a chance relationship, it is fruitless to attempt anything more than a catalog.

John Woodward, in his Essay of 1695, denied any relationships among the various minerals. In Part Four of his Essay, in which he presented his views "Of the Origin and Formation of Metalls and Minerals,"[15] he said that writing intelligently about minerals was much more difficult than writing about plants or animals. The latter, he claimed, plainly exhibited their features and affinities.[16] In the mineral kingdom, however, there was "nothing regular, whatever some may have pretended: nothing constant or certain."[17] Woodward's faith in empiricism compelled him to be particularly careful and to constantly repeat observations in order to "truly and rightly . . . discern and distinguish Things. . . ."[18] But the concept of diagnosis--of distinguishing one from another--caries with it the implication of relationship, and also the assumption that there is something essential to the being of a particular mineral. Thus, Woodward had adopted a paradoxical set of assumptions. On the one hand he held that nothing about minerals was "regular," and on the other hand he held that they could be "distinguished," which implies that there is something regular about them.

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[15]Woodward, pp. 170-225.

[16]Ibid., p. 171.

[17]Ibid.

[18]Ibid.

Attaining discrimination within the framework of the assumption that nothing was constant, presented Woodward with an almost insurmountable task, since he had no basis for recognizing likenesses and differences. He said: "Colour, or outward Appearance, is not at all to be trusted. . . . Nor may we with much better Security rely upon Figure, or external Form."[19] Similarly, the mode of occurrence of minerals was not a reliable distinguishing property: "Sometimes we find them [minerals] in the perpendicular Intervalls [i.e., veins]: sometimes in the Bodies of the Strata, being interspers'd amongst the Matter whereof they consist: and sometimes in both. . . ."[20] Then too, there was no single material common to a mineral: "We shall meet with the same Metall or Mineral embodied in Stone, or lodged in Cole, that elsewhere we found in Marle, in Clay, or in Chalk."[21] Also mineral and metal associations were variable; copper and iron were found together, copper and gold, silver and lead, tin and lead, and sometimes all were found mixed in one lump. To further complicate the problem of the relationships of the minerals and metals, Woodward noted: "Nor do Metalls only sort and herd

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[19] Ibid., p. 172. He explained that "a common Marcasite or Pyrites shall have the Colour of Gold most exactly: and shine with all the Brightness of it, and yet upon tryal, after all, yield nothing of worth, but Vitriol, and a little Sulphur. . . . 'Tis usual to meet with the very same Metall or Mineral, naturally shot into quite different Figures: as 'tis to find quite different kinds of them all of the same Figure. And a Body, that has the shape and appearance of a Diamond, may prove, upon Examination, to be nothing but Crystal, or Selenitis: nay perhaps only common Salt, or Alum, naturally crystallized and shot into that Form." Ibid.

[20] Ibid., p. 173.

[21] Ibid., p. 174.

with Metalls in the Earth: and Minerals with Minerals: but both indifferently and in common together."[22]

Woodward held that in order to resolve the confusion of immediately sensible properties, which were encountered at every turn, one should discriminate minerals, hence classify, on the basis of their composition: "The only standing Test, and discriminative Characteristick of any Metall or Mineral must be sought for in the constituent Matter of it."[23] But he did not attempt such a classification. Instead, he dismissed mineralogical knowledge as "confused and obscure,"[24] and passed on to the question of "the Origin and Production of these Metallick and Mineral Bodies."[25] The problem of mineral classification was not pressing upon Woodward in 1695. It was more important for him to support his theory of the earth by demonstrating that just as "Stone, Marble, Earth, and the rest, owe their present Frame and Order to the Deluge: so likewise do Metalls and Minerals. . . ."[26]

Woodward confronted the problem of the classification of minerals and dismissed it as of little interest. He recognized, however, that the apparent chaos of the phenomena required some kind of explanation; so he explained the <u>apparent</u> chaos as a result of <u>actual</u> chaos. That is, minerals and fossils exhibit a chaotic array of properties

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[22] <u>Ibid</u>.

[23] <u>Ibid</u>., pp. 174-75.

[24] <u>Ibid</u>., p. 176.

[25] <u>Ibid</u>., p. 179.

[26] <u>Ibid</u>.

because they were formed in a chaotic manner. In other words he adopted the expedient solution that things are what they seem to be. Thus, he sought order by the denial of order, which was no explanation at all. In his search for order in the mineral kingdom, Woodward had failed to find a general organizing principle to relate individual minerals in a conceptual scheme. Although he did suggest that the composition of mineral bodies might be the organizing principle for minerals, he did not propose a mineral system in his Essay. In treatises written later, Woodward resolved the problems of classifying minerals, not by ignoring them, but by modifying his postulates. Since he did not know the essential characters of minerals, he chose from among the known characters, rather than deny order and relation.

In the years following the publication of the Essay, Woodward continued to lecture on physic in Gresham College and to participate in the activities of the Royal Society. He also maintained an active interest in collecting and studying fossils and minerals, which had first attracted his attention during his student days. Some of his manuscripts show that he worked on an expanded version of his natural history of the earth, but it was never printed and the manuscripts have since been destroyed.[27] A second edition of the Essay was published in 1702, and a Latin translation prepared by J. J. Scheuchzer was published in 1704.[28]

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[27]John Ward, The Lives of the Professors of Gresham College; to Which Is Prefixed the Life of the Fovnder, Sir Thomas Gresham. With an Appendix Consisting of Orations, Lectvres, and Letters Written by the Professors, with Other Papers Serving to Illustrate the Lives (London: Printed by John Moore for the Avthor, 1740), pp. 298-300.

[28]John Woodward, Specimen geographiae physicae quo agitur de terra et corporibus terrestribus, speciatim mineralibus, nec non mari,

That same year, John Harris published in his Lexicon technicum an abbreviated mineral system[29] that he said was "extracted out of a Natural History of these Bodies, composed by Dr. Woodward, and founded wholly upon Experiments and Observations made upon them."[30] This is the first printed record of Woodward's classificatory scheme. In view of his opinion in 1695, one suspects that the scheme was developed after that date.

In 1712 Elias Camerarius (1672-1734), Professor of Physic at Tubingen, published a critique of Woodward's Essay. In the face of earlier criticisms, Woodward had remained silent, but in 1714 he replied to Camerarius in a work titled Naturalis historia telluris illustrata & aucta.[31] On the whole, the treatise is an extension and

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fluminibus, & fontibus. Accedit diluvii universalis effectuúmque ejus in terra descriptio, trans. J. J. Scheuchzer (Tiguri: Typis Davidis Gessneri, 1704).

[29]See Appendix III for a synopsis of the scheme that Harris presented.

[30]John Harris, "Fossils," Lexicon technicum, or an Universal English Dictionary of Arts and Sciences, Explaining Not Only the Terms of Art, but the Arts Themselves (London: Printed for Dan. Brown, Tim. Goodwin, John Walthoe, Tho. Newborough, John Nicholson, Tho. Benskin, Benj. Tooke, Dan. Midwinter, Tho. Leigh, and Francis Coggan, 1704).

[31]John Woodward, Johannis Woodwardi, med. in Coll. Greshamensi prof. &c., naturalis historia telluris illustrata & aucta. Una cum ejusdem defensione; praesertim contra nuperas objectiones D. El. Camerarii, med. prof. Tubingensis. Ad illustrissimum & nobilissimum virum Thomam Pembrochiae comitem, &c. Accedit methodica, & ad ipsam naturae normam instituta, fossilium in classes distributio (Londini: Typis J. M. Impensis R. Wilkin, 1714). Hereafter cited as Woodward, Naturalis historia telluris. Woodward said he did not answer previous criticisms because: "Homo sum Ingenij neque ad Vindicias suscipiendas, nec quidem ad Controversias de Rebus quibusvis ineundas proclivis." However, Camerarius had embodied in his work virtually all of the earlier objections to his Essay and had added some new ones. So, he said, in answering Camerarius he refuted the others as well. Ibid., pp. ii-iii.

elaboration of his 1695 Essay. But Woodward exhibited a more knowledgeable approach to classification. He complained that Camerarius did not understand the basic principles of classification: "Res Naturales in medium promiscuè effundat, & inter se Naturâ diversissimas, nullâque Affinitate conjunctas, in eundem Ordinem & Seriem redactas exhibeat. . . . Testas, Corpora in Testis formata, & Lapides, nativaque Fossilia, quae se mutuò nullo Naturae nexu attingunt, quasi Res ejusdem omnino Classis, simul exhibuit."[32] He also had a clear understanding of the importance of nomenclature as shown by his criticism of Camerarius's nomenclature:

> Isti Rerum Confusioni addi possent monstrosa illa, quae recenset, Nomina, à cerebrosis hominibus excogitata, & imposita; qualia sunt, Ombria, Brontia, Gryphites, Hysterolithos, Bucardites, Balanoides, & alia; Quae quidem Nomina nec quidquam per se docent, neque ad Rerum, quibus imposita sunt, Constitutionem, aut Proprietates intelligendas, quidquam conferunt. Physici certè est Res, haud ita vulgò notas, describendo declarare: non Nominum, nullam omnino vel harum vel aliarum quarumvis Rerum Naturam, aut veram Idéam Lectorum animis repraesentantium, Caligine tectas, obscuriores reddere.[33]

From these remarks, it is evident that Woodward, in 1714 at least,

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[32] Ibid., p. 55: "He pours out natural things indiscriminately for the public, and he exhibits collected into the same order and series, those of the most different nature and joined together by no affinity. . . . He has exhibited together shells, bodies formed in shells, stones, and native fossils, which do not relate to each other by any mutual connection of Nature, just as things of all the same class."

[33] Ibid., pp. 55-56: "To that confusion of things can be added those strange names which he recounts, contrived and imposed by harebrained men. Such are: Ombria, Brontia, Gryphites, Hysterolithos, Bucardites, Balanoides, and others. Which names, indeed, teach nothing by themselves, nor convey anything towards understanding the constitution or properties of the things upon which they are imposed. Certainly, it is for the natural philosopher by describing, to explain things not so commonly noted, but not to render them more obscure, concealed by a fog of names, not altogether presenting to the mind of the reader either these or any other natural things or true notions."

comprehended the inter-dependent nature of nomenclature and classification. From his Essay it is not clear whether or not he understood this in 1695.

Annexed to the rebuttal of Camerarius was a sketch of Woodward's scheme for classifying native fossils; it is titled Methodica, et ad ipsam naturae normam instituta fossilium in classes distributio.[34] The method presented is virtually the same as that given by Harris in 1704, but this was the first time Woodward had published it. The Methodica, which was addressed to Sir Isaac Newton (1642-1727), was prepared by Woodward in order to facilitate the study of minerals: "Faciliori etenim certiorique Naturalium Rerum Cognitioni multum conducit recta singularum Ordinatio, &, secundum naturales earum Proprietates, mutuamque inter se Convenientiam, in proprias suas Classes Dispositio."[35] He remarked that animals and plants had been reduced to a method in recent years by the labor of very many learned men, but that the mineral kingdom had been neglected: "Fossilia vero, quanticunque Pretij & Momenti ea sint, pene neglecta fuerunt, & soli Fossorum, merorumque Artificum Curae & Culturae relicta."[36] Woodward said this

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[34]John Woodward, Methodica, et ad ipsam naturae normam instituta fossilium in classes distributio. Ad illustrem virum D. Isaacum Newtonum, Eq. Aur. et Soc. Reg. praesidem in Naturalis historia telluris, separately paged.

[35]Woodward, Methodica, p. [iv]: "For indeed, a right arrangement of separate things and disposition into their proper classes, according to the natural properties of them and mutual agreement among themselves, is of much use for an easier and more certain knowledge of natural things."

[36]Ibid.: "Truly, minerals, however great the value and importance of them, have been almost neglected and left solely to the care and cultivation of miners and mere artisans."

was unfortunate but he believed it was to be expected because animals and plants were better known at the outset than were minerals. Furthermore, re-asserting his earlier view, he said that the characters which distinguish and differentiate plants and animals were easily discerned, but diagnostic mineral indices were more abstruse: "Mineralia vero sunt altioris & longe difficilioris Indaginis."[37]

Woodward supported the assertion of the complex nature of minerals, and hence the study of minerals, by citing the heterogeneity of mineral occurrences, the multiplicity of mineral associations, and the external variation in different samples of the same kind of mineral. From the latter and the observation that many minerals have extraneous matter included in them, Woodward concluded that the internal constitution of minerals must be highly variable.[38] In 1695 he had said that "constituent Matter" was the only useful "discriminative Characteristic" for mineral substances,[39] but in 1714 he wrote that "constituent Matter" was not constant, and therefore, not the proper basis of classification. He concluded, however, that the problem of classifying minerals was solvable, and he set forth as a solution his scheme of classification, which was based upon physical properties. One can infer that Woodward,

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[37] Ibid.: "Truly, minerals are of a more lofty and by far more difficult inquiry."

[38] Ibid., pp. [iv-v]. He said: "Hujus autem Rei non nisi unum vel alterum Indicium hic proferam, cum de Eâ alibi fusiùs olim disseruerim. Ut enim ejusdem Mineralis exterior Figura, & Facies nativa, ita etiam Constitutio ejus interior, pro variâ illâ quae sibi in primâ suâ Formatione contigit extraneae Materiae Mixturâ, sint longè diversae oportet. Neque minor est Diversitas in Mineralium Situ, & Loco, atque in Materiâ terrestri, cui commissa in Tellure recondita inveniuntur."

[39] Woodward, Essay (1695), pp. 174-75.

who had earlier decided physical properties were inconstant, hence not essential and of little use for classification, had come to the conclusion that physical properties were not wholly accidental and in some way were a reflection of the essential nature of minerals. Thus, Woodward based his classification upon external or physical marks.

In his efforts to determine the essential nature of fossils and minerals, Woodward adhered to what he thought was an empirical approach. He began by making observations upon natural objects. From these observations alone, so he thought, he deduced the original state of all mineral substances: "It hath been prov'd from Observations, made on the present Condition of them, that they have been once all in a State of Solution and Disorder."[40] But disorder was an anathema to him and his eighteenth century contemporaries. In an attempt to extricate himself from the impasse of seemingly having proved disorder, Woodward set about to methodically investigate the various physical and chemical properties of each mineral substance. In addition to the immediately sensible properties--color, feel, taste, and small--, he determined the hardness and specific gravity of each mineral. He finished with an analysis of each mineral: "Igni demum, & Analysi, Chymiae ope factae, singula Mineralia subjeci, observaturus an Halitum ederent, an

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[40] John Woodward, "Letter II. To Sir John Hoskyns Baronet," Letters Relating to the Method of Fossils in Fossils of All Kinds Digested into a Method Suitable to Their Mutual Relation and Affinity; with the Names by Which They Were Known to the Antients, and Those by Which They Are at This Day Known; and Notes Conducing to the Setting Forth the Natural History and the Main Uses of Some of the Most Considerable of Them. As Also Several Papers Tending to the Further Advancement of the Knowledge of Minerals, of the Ores of Metalls, and of All Other Subterraneous Productions (London: Printed for William Innys, 1728), p. 21. Hereafter cited as Woodward, "Letter II."

vero Fumum, aut Flammam: an Oleum praeberent, aut Salem: an in Carbonem abirent, vel in Calcem: an denique in Vitrum funderentur, vel in istiusmodi Massam quae Metallurgis Regulus dici solet."[41]

By these investigations he hoped to educe the nature of the constituent parts of minerals, which were not immediately sensible.[42] His studies led him to conclude that the constituent parts were both variable and difficult to determine. His investigations uncovered disorder, but his faith in the simple, orderly nature of things compelled him to find order in a world of phenomena that he had shown to be chaotic. Woodward could not accept chaos in answer to the question that he asked of Nature. When he wrote, "There being no single Character steady, or to be rely'd upon, I am oblig'd to make Use of one or other of them, as I see most fit, and conducing to my Purpose,"[43] he admitted failure in his attempt to discover essential characters of minerals. He also affirmed his belief that minerals were governed by orderly principles, and lacking an ordering principle that one must resort to an arbitrary selection of properties in order to establish classificatory groups.

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[41]Woodward, Methodica, p. [v]: "At length I subjected the minerals one at a time to fire and to analysis, made by strong chemicals, to observe whether they would give out an halitus, a true vapor, or a flame; whether they would furnish an oil or salt; whether they would change into a coal or into a calx; finally, whether they would melt into a glass or into a mass of that kind which is accustomed to be called a regulus by metallurgists."

[42]Ibid.: "Earum in his Corporibus Partium, quae se Sensibus non statim exhibent, Naturam investigare, plerosque Examinis & Probationis Modos proposui."

[43]Woodward, "Letter II," p. 22.

Woodward recognized six major classes of native fossils:[44] earths (terrae), stones (lapides), salts (salia), bitumens (bitumina), minerals (mineralia), and metals (metalla). Each group was characterized by the possession or non-possession of a few physical and chemical properties. For example, earths were opaque, without taste, friable, soluble in water, and non-flammable;[45] stones were tasteless, hard, non-ductile, and insoluble.[46] Earths were divided into those that were unctuous, such as "Fullers Earth" and "Tobacco-Pipe-Clay," and those that were dry and rough, as "Tripely" and "Umbre."[47]

Class Two, Stones, was by far the most subdivided class. The first division was on the basis of size. Thus, one group comprized stones that were found in great masses such as "Rag-Stone," marble and granite. The other group comprized stones that were found in smaller masses. This group was divided into those that were harder than marble and those that were not as hard as marble. Each of these was divided into groups on the basis of a miscellaneous assortment of physical properties such as shape, texture, transparency, and color.[48]

Woodward's remaining four classes were only briefly treated and were almost undivided. His characterization of the members of each

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[44]See Appendix IV for a synopsis of Woodward's classification scheme.

[45]Woodward, Methodica, p. 1: "Corpora opaca, insipida, friabilia: in Aquâ solubilia: Flammam non concipientia."

[46]Ibid., p. 2: "Corpora insipida, dura: non ductilia: nec in Aquâ solubilia."

[47]Ibid., pp. 1-2.

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

of those classes was similarly brief. Salts were friable, somewhat pellucid, pungent to the taste, soluble in water, and formed angular figures when their solutions were evaporated.[49] Bitumens were readily flammable, yielded oil, and were insoluble.[50] Minerals were bodies that, being heavy, lustrous and fusible, shared some properties with metals, but they were not ductile as were metals.[51] The sixth class comprized ores of the traditional six metals: gold, silver, copper, iron, tin, and lead.[52]

Woodward adopted physical properties of minerals as the primary basis for establishing groups, although he also utilized some chemical properties in defining his groups. Thus, he attempted to base his classification on intrinsic properties of minerals that could easily be observed or determined. In this he departed from many of his predecessors. Agricola, for example, defined an earth as "corpus fossile simplex, quod potest manu subigi, cum fuerit aspersum humore: aut ex quo cum fuerit madefactū, sit lutum,"[53] whereas Woodward defined an

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[49]Ibid., p. 7: "Corpora friabilia, aliquatenus pellucida, Linguam pungentia, Aquâ solubilia, eá autem evaporatâ, denuo coalescentia, & in Figuras angulares se formantia."

[50]Ibid., p. 8: "Corpora Flammam facilè concipientia, & Oleum praebentia, Aquâ non solubilia."

[51]Ibid.: "Corpora Metallis affinia, quibusdam scilicet Metallorum Proprietatibus praedita, Pondere saltem, & Splendore."

[52]Ibid., p. 9: "Corpora ponderosa, splendentia, dura, fusilia, & ductilia. Aurum. Aregntum. Cuprum. Ferrum. Stannum. Plumbum."

[53]Georg Agricola, 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, siue de re metallica dialogus. Interpretatio germanica uocum rei metallicae, addito indice foecundissimo (Basileae: [Per Hieronymvm Frobenivm et

earth as "Corpora opaca, insipida, friabilia: in Aquâ solubilia: Flammam non concipientia."[54] Woodward's departure from the patterns set by his predecessors is also evident in the overall execution of his work. He, unlike Agricola, de Boodt, Aldrovandi, and others, combined the theoretical-classificatory and the practical-descriptive aspects of the study of minerals into a coherent whole; his was a mineral system. In Agricola's and de Boodt's treatises the theoretical discussion of classification and the descriptions of minerals were separate, and in Aldrovandi's there was no general discussion of classification. Furthermore, Aldrovandi did not adopt any reasoned plan of organization for his descriptions of minerals,[55] and Agricola and de Boodt used an organization different from the classificatory framework that they sketched

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Nic. Episcopivm], 1546), p. 185: "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." English translation from Mark Chance Bandy and Jean A. Bandy (trans.), De natura fossilium (Textbook of Mineralogy) ("The Geological Society of America Special Papers," No. 63; [New York:] The Geological Society of America, 1955), pp. 17-18.

[54]Woodward, Methodica, p. 1: "bodies [that are] opaque, tasteless, friable, soluble in water, not able to catch fire."

[55]For example, the substances that he included in the group called succus concretus were described in this random order: "De coralio," "De sale," "De nitro," "De alvmine," "De chalcantho," "De chrysocolla," "De caervleo," "De armenio," "De aervgine et ferrvgine," "De auripigmento," "De sandaracha," "De svlphvre," "De bitvmine," "De naphtha," "De pissasphalto," "De mvmia," "De svccino," "De gagate," "De caphvra," and "De ambra." Ulisse Aldrovandi, Vlyssis Aldrovandi, patricii Bononiensis, mvsaevm metallicvm in libros IIII. distribvtvm Bartholomaevs Ambrosinvs in patrio Bonon., archigymnasio simpl., med. professor ordinarius, musei illustrissmi., senatus Bonon. et horti publici prefectus, labore et studio composuit, cum indice copiosissimo, Marcvs Antonivs Bernia proprijs impensis in lucem edidit ad serenissimvm Ranvtivm II Farnesivm Parmae Placentiae et C. Dvcem VI [Bononiae: Typis Io. Baptistae Ferronij, 1648], pp. 284-434.

in their theoretical discussions.[56] Woodward let his theoretical classification guide his arrangement of specific minerals. On the whole, Woodward's mineral system, although deficient in many respects, did provide a generalized description of the mineral kingdom. During the eighteenth century Woodward's system was used as a model by several naturalists.

For many months before he died, Woodward experienced general ill health, but continued to work on several manuscripts. John Ward in Lives of the Professors of Gresham College described his ceaseless activity and final illness in this way:

> Dr. Woodward declined in his health a considerable time before he died, and tho he had all along continued to prepare materials for his large work, relating to the natural history of the earth; yet it never was finished, but only some collections, said to have been detached from it, were printed at different times, as inlargements upon particular topics of his Essay. He was confined first to his house, and afterwards to his bed, many months before his death. During this time he not only drew up instructions for the disposal of his books and other collections, but also compleated and sent to the press his Method of fossils in English, and lived to see the whole of it printed, except the last sheet.[57]

The Method of fossils that Ward mentioned was an emended translation of the Methodica of 1714. Besides notes and considerably expanded explanations, Woodward annexed several letters and miscellaneous writings on matters related to geology and mineralogy.[58]

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[56]For example, Agricola discussed the distinctive physical features of mineral substances, but arranged his descriptions on the basis of other features, such as use; see above pp. 14-18. De Boodt presented two theoretical schemes based on physical properties, but he arranged his descriptions according to the value of the gems and stones, see above pp. 31-32.

[57]Ward, p. 293.

[58]Woodward, Fossils of All Kinds, cited above, note 40.

Completed in two volumes in 1729, Woodward's posthumously published Attempt at a Natural History of the Fossils of England[59] was a methodical catalog of his collections. The classification scheme underlying this catalog was the same as that outlined by Woodward in 1714. In this catalog, Woodward's conviction that there was some order behind the apparent chaos of nature was firmly stated. He said that nature was steady and constant in all her productions,[60] including the formation of all bodies:

> This happens, 1°. from the Constancy of the Proceedure of the Agents that are instrumental to the Formation of those Bodies: And, 2°. from the Unalterableness of the Corpuscles, which serve for the constituting and composing of those Bodies.
>
> All Gold, when equally pure, and freed from extraneous Matter, is absolutely alike in Colour, Consistence, specific Gravity, and all other respects; the Corpuscles which constitute that Body being perfectly uniform and homogeneous.
>
> The same holds in Silver, Iron, and all other Metals: as likewise in all the simple Minerals, particularly Talc, and Crystal; which are found incorporated with all the several kinds of Metals, much more frequently than any other Bodies besides in all the whole mineral Kingdom.[61]

He also reaffirmed his faith in the efficacy of the empirical approach: "The true and only proper End of Collections, of Observations, and Natural History" is that from them one can build "a Structure of Philosophy . . . that might turn to the Benefit and Advantage of the World."[62]

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[59] John Woodward, An Attempt towards a Natural History of the Fossils of England; in a Catalogue of the English Fossils in the Collection of J. Woodward, M.D. Containing a Description and Historical Account of Each; with Observations and Experiments, Made in Order to Discover, As well the Origin and Nature of Them, As Their Medicinal, Mechanical, and Other Uses (2 vols.; London: Printed for F. Fayram, J. Senex, and J. Osborn and T. Longman, [1728]-1729).

[60] Compare with his earlier view, above pp. 51-54.

[61] Ibid., I, 186.

[62] Ibid., p. xiv.

By the time of his death, then, Woodward unreservedly proclaimed that the principle of order was applicable to the mineral kingdom. The esoteric principles which determined that order were left for his successors to elucidate.

Woodward's ideas were widely circulated during the early part of the eighteenth century.[63] He had set forth a mineral system that was based for the most part upon readily determinable properties; he omitted myths and magical properties in favor of straightforward physical description. He lacked unequivocal terminology and standards of measurement for the properties that he used, and therefore it was difficult for others to implement his classification; however, Woodward's basic scheme was copied and adapted by several naturalists. One was the Swiss Johann Jacob Scheuchzer (1672-1733).

Scheuchzer is often remembered for the descriptions and illustrations that he published of what he thought to be the remains of one of the sinners whose misdeeds were responsible for the biblical deluge.[64] Somewhat overzealous in 1726 when he described that skeleton, which he named Homo diluvii testis,[65] Scheuchzer deserves to be

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[63]This is shown by the translations of his works into French, Latin, and Italian, and reviews in the Philosophical Transactions of the Royal Society of London, the Journal des Sçavans, and the Acta Eruditorum.

[64]For example, Bernhard Kummel, History of the Earth: An Introduction to Historical Geology (San Francisco: W. H. Freeman and Company, [1961]), p. 4, said: "Another Diluvialist that is still remembered was a Swiss, Johann Scheuchzer (1672-1733), an enthusiastic follower of Woodward. Scheuchzer published descriptions and illustrations of what he thought to be 'the bony skeleton of one of those infamous men whose sins brought upon the world the dire misfortune of the deluge.' This fossil, which he named Homo diluvii testis, was later shown to be nothing but the skeleton of a salamander."

[65]I.e.: Man, witness to the Deluge.

remembered for his taxonomic work with plant and animal fossils.[66] Born in Zürich, Scheuchzer received a doctorate from the University of Utrecht in 1694, then studied mathematics at the university in Altdorf for two years. In 1696 he returned to Zürich and was appointed junior town physician. He remained in Zürich the rest of his life, practicing medicine, teaching mathematics, and studying natural science.[67]

In 1718 Scheuchzer published Meteorologia et oryctographia Helvetica.[68] The book was divided into three approximately equal parts. The first was concerned with the meteorological phenomena of Switzerland, the second with the minerals, and the last with the fossils of Switzerland.[69] In the mineralogical part, Scheuchzer presented a mineral system constructed upon the Woodwardian theoretical framework[70] and illustrated

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[66]"Scheuchzer (Jean-Jacques)," Nouvelle biographie générale, depuis les temps les plus reculés jusqu'a nos jours. Avec les renseignements bibliographiques et l'indication des sources a consulter, ed. Jean Chrétien Ferdinand Hoefer, XLIII (1864), cols. 509-10.

[67]Ibid., cols. 509-11; also William Augustus Brevoort Coolidge, "Scheuchzer, Johann Jakob (1672-1733)," The Encyclopaedia Britannica, 11th ed., XXIV (1911), 322.

[68]Johann Jacob Scheuchzer, Meteorologia et oryctographia Helvetica, oder Beschreibung der Lufft-Geschichten/Steinen/Metallen/und anderen Mineralien des Schweitzerlands/absonderlich auch der Uberbleibselen der Sündfluth ("Natur Geschichten des Schweitzerlands," Vol. 6; Zürich: In der Bodmerischen Truckerey, 1718). This volume was reprinted in 1746 and again in 1753.

[69]The first part, "Vorstellung der Lufft-Geschichten des Schweitzerlands," ibid., pp. 1-98, deals with meteorological phenomena; the second part, "Von denen Mineralien des Schweitzerlandes," ibid., pp. 98-202, deals with minerals; and the third part, "Von denen im Schweitzerland befindtlichen Uberbleibselen der Sündfluth," ibid., pp. 203-336, deals with fossils.

[70]Scheuchzer acknowledged his dependence upon Woodward by

by Scheuchzer's Swiss mineral specimens. Scheuchzer's major groups were: _Erden_, _Steinen_, _Saltze_, _Erdpech_ (bitumens), _Metallen verwandte Cörper_ (i.e., minerals), and _Metallen_.

Scheuchzer's purpose was to provide a descriptive catalog of the minerals of Switzerland.[71] Since he was less interested in pursuing classification than was Woodward, Scheuchzer did not subdivide his major groups (except for the _Steinen_). After describing the characteristics of each class, he enumerated individual types, and under each type he cataloged his specimens, listing them by the canton in which they were found. For each specimen he gave the place from which it came, the museum number that he had assigned to it, and anything that was peculiar to the specimen itself. Typical of his approach was his treatment of the class _Saltze_, which he described as follows:

> Nun/nachdeme die Steine verhandelt/folgen die _Salia_, Saltze/ unter welchem allgemeinen Namen wir verstehen brüchige/mehr oder minder durchscheinende/die Zungen stechende/oder gesaltzene Cörper/ welche sich in dem Wasser lassen auflösen/und nach dessen Abrauchung sich wiederum in Crystallen von gewisser Figur samlen. Ich wil mich nicht aufhalten bey einer _methodi_schen Eintheilung der Saltzen/und Vorstellung der besonderen _Figur_/welche einem jeden Saltz zustehet/ und je ein Saltz von dem anderen unterscheidet/noch weiniger wil aufsteigen zu jener _Philosophi_schen Betrachtung der Sauren und _Alcali_schen Saltzen/oder nachgrüblen/wie diese oder jene würfflcihte-

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sketching his scheme: "Woodvvard. . . . Theilet alle _Fossilia_ ein in VI. Haupt-Classen: Die I. begreifft die Erden/_Terras_. Die II. die Stein/_Lapides_. Die III. die Salze/_Salia_. Die IV. Schweffel oder Erdpech/_Bitumina & Sulphura_. Die V. allerhand denen Metallen verwandte _Miner_lien/oder Erze/_Metallis affinia Mineralia_. Die VI. die Metall/ _Metalla_ selbs. Diesen allen werden angehenket diejenigen _Fossilia_, welche eigentlich zu dem Thier-und Kräuter Reich gehören/und heut zu Tag unter die Uberbleibselen der Sündflut mit recht gerechnet werden." _Ibid_., p. 98.

[71] _Ibid_., pp. 98 and 202.

> sechs-achteckichte Figur herauskomme/sondern kurz und begriffenlich anzeigen/was wir in unseren Landen vor Gattungen Saltz haben.[72]

The class was subdivided into five kinds of salts: common salt (Gemeines Saltz), saltpeter or niter (Salpeter), alum (Alaun), Vitriol (Vitriol), and borax (Borris).[73] Each kind was characterized in a few words; concerning vitriol he said:

> Diese Art Saltzes ist schon gemeiner. Alle Saurwasser haben in sich ein Vitriolum Martis: alle Pyritae oder Schweffelkiess beherbergen gleichfals ein Vitriol, ja es werden diejenigen Pyritae, so man Vitrioli parentes nennet/von dem Kind das sie im Busen tragen/ich wil sagen/von dem Vitriol offt so zerfressen/dass sie von selbs zerfallen.[74]

Scheuchzer listed eight specimens of vitriol. He recorded his specimen from the canton of Zürich this way:

> Mus. n. 1565. Vitriolum ex vena Horgensi. Vitriol aus einem Schweffelkiess/und Steinkohlen/welche gegraben werden zu Horgen am Zürich-See.[75]

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[72]Ibid., p. 175: "Now, after discussing stones, follow the salts, under which general name we comprehend brittle, more or less transparent, pungent to the tongue, or saline bodies, which can dissolve in water and following their evaporation always form into crystals of definite shape. I, myself, will not dwell on a methodical division of the salts and presentation of the particular figure which belongs to every salt and always distinguishes one salt from the others, still less will I ascend to that philosophical view of the acid and alcali salts, or ponder how this or that cubical, hexagonal, or octagonal figure came about. On the contrary, I will briefly and comprehensibly report what we have of the genus salts in our lands."

[73]Ibid., pp. 175-79.

[74]Ibid., p. 178: "This kind of salt is still more common. All mineral water has an iron vitriol. All pyrites likewise harbor a vitriol; indeed, it [vitriol] comes from pyrites, thus we speak of parent of vitriol from the child that it carries in its bosom. I will say [that it is] often so eaten away by the vitriol that it disintegrates of itself."

[75]Ibid.: "Museum number 1565. Vitriolum ex vena Horgensi. A vitriol from a [specimen of] pyrite and coal, which was dug at Horgen on the Lake of Zurich."

Scheuchzer divided the class Steinen into fourteen subclasses, then he enumerated the specific kinds of minerals assigned to each subclass, again by canton. Scheuchzer's fourteen subdivisions closely paralleled divisions from various levels of subordination in Woodward's classification. His first subdivision, for example, was "Grössere in lager abgetheilte Steine/von grober/dicker/rauher Materi/deren Theile vester oder lucker Zusamenhalten,"[76] which corresponds to Woodward's membrum 1, caput 1, classis 2.[77] Another example of the close parallel to Woodward's scheme is Scheuchzer's twelfth division: "Kleine halb durchsichtige Steine/welche härter sind als Marmor/und ihre Farben nach verschiedener Situation gegen dem Liecht und Aug anderen."[78] This corresponds to Woodward's sectio 1, articulus 2, membrum 2, caput 2, classis 2.[79] All of these subdivisions were treated as if they were of the same level of subordination, and no systematic arrangement was used to show how, or if, the subgroups were related to one another.

Within the theoretical framework of Woodward's scheme of classification, Scheuchzer emphasized grouping individual specimens on the basis of a set of shared characters. He used classification as a

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[76] Ibid., p. 108: "Larger stones separated into layers of coarser, thicker, rougher matter, whose parts cohere more tightly or loosely."

[77] Woodward, Methodica, pp. 2, 3: "Lapides; qui mole majore reperiuntur, in strata; compositionis laxioris, ad tactum scabri." Compare the synopsis of Woodward's classification, Appendix IV, with the synopsis of Scheuchzer's classification, Appendix V.

[78] Scheuchzer, p. 163: "Small, semi-transparent stones, which are harder than marble, and their colors change according to the different position toward the light and eye."

[79] Woodward, Methodica, pp. 2, 3, 5, 6: "Lapides; qui mole sunt minore; marmore duriores; semi-pellucidi; versicolores, prout vario situ luci objiciuntur."

convenience for organizing his knowledge of Swiss minerals and, therefore, did not have a carefully constructed scheme of mineral classification. A more carefully constructed scheme, also based upon the physical properties of minerals, was the one set forth by John Hill (1716?-1775) in 1748.

Hill, a London apothecary and dilettante litterateur, was described by a biographer as "a versatile man of unscrupulous character, with considerable abilities, great perseverance, and unlimited impudence."[80] In 1746 he published the Greek text and the first English version, freely translated, of Theophrastus's Περὶ λίθων. Two years later he published A History of Fossils, which was the first volume of a projected three that would be a complete natural history of all parts of the world.[81]

The History of Fossils was a highly structured scheme, claimed by Hill to have been erected upon an empirical foundation: "It is the bodies themselves . . . . which can alone give us a true knowledge of their

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[80]George Fisher Russell Barker, "Hill, John, M. D.," The Dictionary of National Biography, 2d reprinting, IX (1937-1938), 849.

[81]John Hill, A General Natural History, or New and Accurate Descriptions of the Animals, Vegetables, and Minerals of the Different Parts of the World; with Their Virtues and Uses, As Far As Hitherto Certainly Known, in Medicine and Mechanics. Illustrated by a General Review of the Knowledge of the Ancients, and the Discoveries and Improvements of Later Ages in These Studies. Including the History of the Materia Medica, Pictoria, and Tinctoria of the Present and Earlier Ages. As Also Observations on the Neglected Properties of Many Valuable Substances Known at Present; and Attempts to Discover the Lost Medicines, &c. of Former Ages, in a Series of Critical Enquiries into the Materia Medica of the Ancient Greeks. With a Great Number of Figures Elegantly Engraved, Vol. I: A History of Fossils (London: Printed for Thomas Osborne, 1748).

nature; the great step . . . was the examining these severally, and searching into their different properties and qualities as well as figures."[82] In his classification scheme, Hill began with all fossils, which he differentiated into three groups: 1. those "naturally and essentially simple, and unmetallick," 2. those "Naturally and essentially Compound, and unmetallick," and 3. those that were "Metallick."[83] The first and second groups each comprised three subgroups: 1. fossils that were "Not inflammable, nor soluble in water," 2. those that were "Soluble in water, not inflammable," and 3. those that were "Inflammable, not soluble in water."[84] The "Metallick" fossils were not divided at this stage, but they were characterized as "Hard, and remarkably heavy."[85] These seven general groups were divided into a total of fourteen subgroups that Hill called "Series." The series contained a total of twenty-seven "Classes," which contained sixty-six "Orders," and they in turn contained one hundred thirty-nine "Genera."[86]

Hill justified his work by saying that although many books had been written on minerals, "something was still greatly wanting toward attaining a true knowledge of them. . . ."[87] He said that "if we take the works of the several Authors on it [i.e., mineralogy], together, we find them miserably ignorant of the true nature of the bodies they

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[82] Ibid., p. a recto.

[83] Ibid., fold-out "Table of Fossils."

[84] Ibid. [85] Ibid.

[86] Ibid. See Appendix IX for a synopsis of Hill's classification scheme.

[87] Ibid., p. [A2 recto.]

treat of, and usually taking upon trust from one another accounts, which when trac'd up to their original, will often be found to have sprung from error or credulity."[88] He implied that the "egregious errors" made by "the very greatest of the Authors of late ages" could have been avoided if "the Criterions of the different Fossils by which alone they could be brought to the test . . ." had been established--"till there are characters invariable and distinctive known of each of these Classes of bodies, all must be still confusion."[89]

Hill proposed resolving the confusion by means of proceeding empirically:

> After it is found how little assistance can be had from books in order to a true knowledge of Fossils, recourse is naturally to be had to the bodies themselves. And here a strict examination will make it appear, that true and distinctive characters are wanting in books only, not in nature; and that a variety of experiments on the substances themselves, with the assistances of acid menstruums, that stronger menstruum fire, and the help of the Microscope, will shew real and innate properties and qualities in these bodies, which are invariably found in all those of the same class, and never in those of any others; and which therefore give us true characters, by which we shall always be able to know the Fossils of the same class as such, and to distinguish them from all others.[90]

Thus, he advocated an approach that necessitated the prior assumption of the existence of a knowable natural order. Moreover, one had to assume some theoretical structure before one could select the most important empirically determinable, natural characters. Without such an assumption one could not proceed to generalize, for all characters would be equally important, and no one could be subordinated to another.

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[88] _Ibid_.

[89] _Ibid_., p. [A2 _verso_.]

[90] _Ibid_.

Nevertheless, Hill developed a classification scheme that he thought was a natural classification discovered by means of an empirical-deductive approach to the phenomena of inorganic Nature. To him, his groups were not theoretical schemes that had been invented as a convenient way to organize a certain amount of empirical information.

The method by which he arrived at the "true knowledge" of the nature of minerals was described by Hill to be an "examining" and "searching into" the "different properties and qualities as well as figures" of all the mineral bodies.[91] "This," he said, "naturally led to the knowledge of their mutual alliances one with another, and they were easily, according to their several more general characters, arrang'd into the several Series nature had ordain'd of them."[92] This deductive procedure was then extended:

> The different subjects of these Series more minutely examin'd, were afterwards found to have their several secondary alliances in distinct sets, which were owing to characters the same in all of the same set, and those of each set wholly different from those of all the others; and the dividing the several series into these sets gave the different Classes of Fossils. Among these new divided sets, there appear'd also on a farther view certain general and distinctive characters, separating them into several Orders, as the more general characters, had before divided the whole Fossile world into series; and under these on the ultimate research were found certain regular subdistinctions; and the arrangement of the whole order of bodies into their several alliances according to these, gave the last distinction of Fossils into Genera, under which the farther differences were no more than those of species from species.[93]

The truth of his scheme seemed obvious to Hill, because "a general table made from the characters of these [groups], became a

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[91] Ibid., p. a recto.

[92] Ibid.

[93] Ibid.

scheme into which all the known Fossils, were easily reducible. . . ."[94] But, he noted, there were many more classes and genera in his scheme, than "had before appear'd in the writings of those who had left several different Genera undistinguish'd from one another."[95] Since "every Genus must have its denotative expression," necessarily "names must be wholly wanting for many of them. . . ."[96] Therefore, he concluded that it was necessary to use many new words, which he regarded as "undesirable, though unavoidable."[97]

Because many of his groups were designated by combinations or sets of characters, and there could not be "in any language words ready form'd, expressive of such combinations of characters in the different bodies of the same Genus,"[98] Hill proposed a sort of abbreviated notation in which elements of the Greek language were compounded into single words. His aim was to express the entire set of characters for any given group in one word. The result was words such as "phlogidiaugia,"[99] "leptodecarhombe,"[100] and "thraustomichthes."[101] He hoped "the

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[94] Ibid., pp. a recto et verso.

[95] Ibid., p. a verso.

[96] Ibid.

[97] Ibid.

[98] Ibid.

[99] The class phlogidiaugia consisted of "Transparent inflammable bodies." Ibid., p. 399.

[100] The genus leptodecarhombe was characterized as follows: "Selenitae consisting of ten planes, each so nearly equal to that opposite to it, as very much to approach to a decahedral parallellopiped, tho' never truly or regularly so: Two of the planes in this, which may properly enough be call'd the top and bottom in this Genus, are

generality of Readers" would pardon the use of his new words,[102] but they were not adopted.

Although he championed empiricism and sought innate and unalterable qualities as the basis of his classification, Hill in practice was guided by a vague classifying instinct that enabled him to construct a scheme that had some close resemblances to both Agricola's and Woodward's schemes. For example, Hill first divided all "Fossils" into those that were simple, those that were compound, and those that were metallic.[103] Agricola had suggested dividing mineral substances into those that were composite and those that were non-composite.[104] The parallel is obvious. Hill's second differentiation, of the simple and the compound fossils, was made on the basis of solubility in water and flammability. Both of these properties were important group properties that Woodward used in defining four of his six major groups.[105]

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ever broader and flatter than the rest; and these, tho' not regularly equal, usually very nearly answer one another, as do also the other eight in two sets of fours. There are four shorter planes meeting in somewhat acute angles, two and two from the ends, or two shorter edges of the two flat and broad Rhomboidal planes before describ'd; and four longer meeting in more obtuse angles, from the sides or longer edges of the same Romboidal planes. As the broader and flatter planes, or top and bottom in this Genus, are not regularly equal to each other, so neither are the eight narrower to their opposites, but there are usually differences in their angles and in the breadth of them." Ibid., p. 120.

[101]"The genus thraustomichthes was characterized as follows: "Loams compos'd of Sand, and a less viscid Clay, and of a friable texture." Ibid., p. 424.

[102]Ibid., p. a verso.

[103]Ibid., see the fold-out "Table of Fossils."

[104]Agricola, p. 185

[105]Woodward, Methodica, pp. 1, 2, 7, 8. Woodward's class five

Hill seems to have been preoccupied with recognizing minerals. He concluded his preface with this remark on the use of his work: "For the more readily distinguishing the native Fossils, there is subjoin'd a general Table of the method alone, by which an unknown Fossil may be trac'd from its more general alliances to its particular Genus, and on turning to the descriptions of the several species of that, it will not then remain long unknown."[106] An important use, then, for his work was to assist in naming specimens. As diagnostic properties, Hill particularly relied on the immediately sensible characters: texture, shape, hardness, heaviness, general appearance, friability, and color (although he realized the limitations of this last property). He also described the appearance of specimens through the microscope, their reaction with acid, and their behavior in fire. After detailing the determinable properties, he discussed the places where the mineral was found and for what it was used.[107] Since these descriptions were not linked to particular specimens or the holdings of a certain museum, as were Woodward's and Scheuchzer's works, Hill accomplished a more general descriptive treatment of minerals than they did.

Hill adopted the same view of extraneous fossils as had Woodward, and therefore excluded them from the main portion of his treatise. He said, since they were "bodies of the animal or vegetable kingdoms accidentally bury'd in the earth," they "belong properly to the

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(Mineralia) and class six (Metalla) were not defined in terms of either solubility or flammability. Ibid., pp. 8, 9.

[106]Hill, p. [a2 verso.]

[107]Ibid., pp. 2, 3, 4, et passim.

histories of plants and animals. . . ," and "are much more properly to be enquir'd into when we come to describe the bodies at large to which they belong."[108] Nevertheless, he appended seventeen pages of text and seven plates[109] dealing with "animal and vegetable substances bury'd in the earth"[110] so that "nothing relating to the study of Fossils may be omitted. . . ."[111]

Hill's scheme was an impressive compilation of contemporary knowledge of mineral substances, arranged in a more or less ~~tr~~aditional way. He was primarily interested in identifying and classifying minerals on the basis of external or physical characters; nevertheless, he included a few chemical tests in his descriptions.

Another impressive compilation of mineral knowledge was published in 1755 by Antoine Joseph Dezallier d'Argenville (1680-1765). After briefly surveying the literature dealing with mineral substances,[112] Dezallier d'Argenville presented a précis of his mineral system then launched into a detailed discussion of his scheme. Dezallier d'Argenville recognized three classes of minerals: earths (<u>terres</u>), stones (<u>pierres</u>), and all others (<u>qui contient les sels, les soufres, les métaux</u>

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[108] <u>Ibid</u>., p. [a2 <u>verso</u>.]

[109] The text covered pp. 638-54; Plates 6-12 were devoted to illustrating fossil forms.

[110] <u>Ibid</u>., p. 638.

[111] <u>Ibid</u>., p. [a2 <u>verso</u>.]

[112] [Antoine Joseph Dezallier d'Argenville], <u>L'Histoire naturelle eclaircie dans une de ses parties principales, l'oryctologie, qui traite des terres, des pierres, des métaux, des minéraux, et autres fossiles. Ouvrage dans lequel on trouve une nouvelle méthode Latine & Françoise de les diviser, & une notice critique des principaux ouvrages qui ont paru sur ces matières</u> (Paris: Chez De Bure l'Aîné, 1755), pp. [1]-36.

et les mineraux).[113] These groups were differentiated primarily on the basis of physical properties. Thus, the four subdivisions of the second class, pierres, were: "pierres très-dures," "pierres tendres et calcaires," "pierres écailleuses," and "les pierres sablonneuses, poreuses, tartareuses, spongieuses."[114]

Dezallier d'Argenville claimed that his system was a new method of dividing fossils "suivant leurs qualités naturelles & apparentes . . . ."[115] In reality it followed the tenets set forth by several of his predecessors, as can be seen by comparing his scheme, Appendix X, with the schemes of Agricola, de Boodt, Woodward, and Scheuchzer, previously discussed. Dezallier d'Argenville defended his choice of physical characters in preference to chemical characters, which were used by a number of his contemporaries,[116] saying: "Persuadés que la méthode la plus simple est toujours la meilleure, lorsqu'elle n'est point opposée aux principes généraux, nous ne suivrons point celle des Chymistes. . . ."[117] He thought the chemical methods had too many

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[113]Ibid., pp. 39, 41, 65. See Appendix X for a synopsis of Dezallier d'Argenville's classification scheme.

[114]Ibid., pp. 41, 56, 58, 59: "very hard stones," "soft and calcareous stones," "scaly (or squamous) stones," and "sandy, porous, tartareous, and spongy stones."

[115]Ibid., p. xi: "following their natural and apparent qualities. . . ."

[116]See below, Chapter IV.

[117]Ibid.: "Persuaded that the most simple method is always the best, when it is not contrary to the general principles, we will not follow those of the chemists. . . ."

faults: "Toutes ces contrariétés nous ont déterminés à chercher une nouvelle méthode pour parvenir au même but; nous la croyons très-suffisante pour bien distinguer la nature des Fossiles sans en confondre les genres ni les espèces, & sans employer tout l'attirail d'un fourneau:"[118]

Less apprehensive of adopting some of the newer ideas was Johann Heinrich Gottlob von Justi (died 1771), who published a brief sketch of the mineral kindgom in 1757. Justi's last of six major divisions of inorganic productions, stones and earths (Steinen und Erden), was divided into precious stones (Edelgesteinen), semi-precious stones (Halbedelgesteinen), fire-resistant stones and earths (Feuerbeständigen Steinen und Erden), calcareous stones and earths (Kalkartigen Steinen und Erden), and fusible stones and earths (glassachtigen, oder schmelzbaren Steinen und Erden).[119] This subdivision shows a mixture of differentiae: value, such as in precious stones; physical properties, as in the fire-resistant stones and earths; and composition (a chemical property), as in the calcareous stones and earths.

The same year that Justi published his sketch, the first (and only) volume of an elaborate work purported to be a synthesis of the chemical and physical modes of arrangement was published by Emanuel

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[118] Ibid.: "All of these difficulties have caused us to seek a new method in order to attain the same goal; we believe it quite sufficient to easily distinguish the nature of fossils without confusing the genera or the species, and without employing all the apparatus of a furnace."

[119] Johann Heinrich Gottlob von Justi, Grundriss des gesamten Mineralreiches worinnen alle Fossilien in einem, ihren wesentlichen Beschaffenheiten gemässen, Zusammenhange vorgestellet und beschrieben werden (Göttingen: Im Verlag der Wittwe Vandenhöck, 1757), pp. 193-232.

Mendes da Costa (1717-1791). He optimistically described his scheme in the preface:

> My system is simple, natural, and easy to be understood; the agreement between Fossils [minerals] in their structure, texture, or appearance, is first noticed; afterwards their disagreements are considered, as they come to be examined by simple experiments, with fire, steel, and acids.[120]

He did not, however, achieve his ideal in the execution of his work. In his attempt to overlook nothing of value and include everything pertinent to the subject, Mendes da Costa ended up with a work that was for the most part a criticism of earlier authors. That he did not understand the nature of classification and system-making is clear from his lack of generalization, sparing use of hypothesis, and violation of the rules of classification. He explicitly unfolded his lack of acumen in the preface:

> In the course of the work I have been very cautious not to indulge a speculative fancy in forming hypotheses or systems, the bodies being simply described, according to the appearances which they exhibit to the senses.[121]

Principally sympathetic with Woodward's approach of systematization on the basis of exterior qualities, Mendes da Costa, nevertheless, did include some chemical information and based several minor groups upon behavior towards acids. Thus, the least important diagnostic feature in his scheme was a chemical property. For example, he distinguished three kinds of red boles on the basis of behavior with acid. The first kind was not acted upon by acids, the second kind was acted upon by acids,

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[120] Emanuel Mendes da Costa, A Natural History of Fossils (London: Printed for L. Davis and C. Reymers, 1757), p. vi.

[121] Ibid., p. iv.

and the third kind was "imperfectly described in regard to the effects acids have on them."[122] A similar role was accorded to acid reaction for other groups of his scheme. That he was more inclined to accept physical properties as more constant is shown by his preference for color over acid reaction as a diagnostic index for the boles,[123] even though it was well-known that color was highly variable.

Mendes da Costa's scheme is incomplete, cumbersome, and lacks originality.

Still another advocate of classification based upon external marks was Jacques Christophe Valmont de Bomare (1731-1807), who in 1762 published _Mineralogie, ou nouvelle exposition du regne minéral_.[124] He, however, as had Justi, Mendes da Costa, and others, found it convenient to use some of the chemical characters of minerals in his mineral system.

Valmont de Bomare described his _Mineralogie_ as "un cours d'étude minéralogique; une maniere aisée de reconnoître & de se familiariser avec les diverses substances de ce régne; un abrégé des démonstrations de notre Cabinet; une introduction à la connoissance des entrailles de la terre; en un mot ce qu'on appelle dans les écoles les prologomenes de

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[122] _Ibid._, pp. 9-22.

[123] Thus, the boles were grouped according to color (white boles, ashcoloured boles, red boles, yellow boles, brown boles, and green boles), then subdivided according to acid reaction. _Ibid._, pp. [1], 8, 9, _et passim_.

[124] Jacques Christophe Valmont de Bomare, _Mineralogie, ou nouvelle exposition du regne minéral. Ouvrage dans lequel on a tâché de ranger dans l'ordre le plus naturel les individus de ce regne, & où l'on expose leurs propriétés & usages méchaniques. Avec un dictionnaire nomenclateur et des tables synoptiques_ (2 vols.; Paris: Chez Vincent, 1762).

la science."[125] He began his "prolegomena" to mineralogy with definitions, so as to delimit his subject. First, he defined natural history: "La science qui s'occupe de l'énumération & de la description des différens corps que renferment les minéraux, les végétaux & les animaux."[126] The natural historian's task was "de regarder, de recueillir & de ranger tous les corps qui existent dans la nature; de pouvoir dire de quelle maniere ils sont faits, soit au dedans, soit au dehors, & à quel régne, classe, ordre, espece & variété ils appartiennent."[127] That part of natural history called mineralogy, which was Valmont de Bomare's subject, comprehended "l'énumération & la description des eaux, des fossiles, des minéraux, des demi-métaux, des métaux, & de toutes les substances qui se trouvent à la surface, ou dans l'intérieur de notre globe."[128] Valmont de Bomare called the enumeration and description of minerals the systematic part of his mineralogical treatise. In addition, he had inserted notes and observations. The notes were to help clarify obscure points,

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[125] Ibid., I, ix: "a course of mineralogical study; an easy way to explore and familiarize oneself with the diverse substances of this kingdom; a résumé of the exhibitions of our cabinet; an introduction to the knowledge of the bowels of the earth; in a word, that which in the schools they call the prolegomena of the science."

[126] Ibid., p. [1]: "The science which handles the enumeration and description of the different bodies that comprise the minerals, the plants, and the animals."

[127] Ibid.: "to look at, to collect, and to arrange all the bodies which exist in nature; to be able to say in what way they are made, either inside, or outside, and to what kingdom, class, order, species and variety they belong."

[128] Ibid., pp. [1]-2: "the enumeration and description of the waters, fossils, minerals, semi-metals, metals, and of all the substances which are found at the surface or in the interior of our globe."

and the observations were the catch-all for a variety of miscellaneous information: "Nous avons donné le nom d'observations aux découvertes ou conjectures que l'on a formées sur certains corps du régne minéral, aux travaux qu'on leur a fait subir, à leurs usages, à leurs propriétés, aux ressources que nous en avons tirées."[129]

Valmont de Bomare distributed all the bodies of the mineral kingdom into 352 species comprised in 61 genera and 10 classes.[130] He characterized the classes as follows:

> La premiere classe, qui traite des eaux (Aquae,) ne renferme que celles que la nature nous fournit, & qui sont, ou fluides ou concrétes, ou froides ou chaudes, ou simples ou composées.
>
> La deuxieme des terres (Terrae,) dont les particules ne sont pas liées, & qui peuvent être délayées & divisées par l'eau.
>
> La troisieme, des sables (Arenae;) substances qui appartiennent autant aux terres qu'aux pierres, & qui sont plus ou moins composées, & dures.
>
> La quatrieme, des pierres (Lapides;) corps solides & durs, dont les particules étroitement liées les unes aux autres, ne sont point malléables, & ne peuvent être, ni divisées, ni délayées par l'eau ou par l'huile, mais se briser en plusieurs morceaux sous le marteau, & qui ont assez de fixité dans le feu.
>
> La cinquieme, des sels (Salia;) corps minéraux, solides, inflexibles, friables & transparens, dont les plus petites parties ont plusieurs côtés taillés à facettes, & leurs extrémités taillées en angles ou en pointes, qui ont la propriété de se dissoudre dans l'eau, & de produire de la saveur; de se crystalliser, d'entrer en fusion au feu, ou de s'y volatiliser, &c.
>
> La sixieme, des pyrites (Pyrites,) qui sont, ou sulfureuses & vitrioliques, ou arsenicales, ou métalliques.
>
> La septieme, des demi-métaux (Semi-metalla;) corps non ductiles, ni malléables, mais fusibles, & ayant d'ailleurs toutes les propriétés des métaux.

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[129] Ibid., p. vij: "We have given the name observations to the discoveries or conjectures that people have framed about certain bodies of the mineral kingdom, to the works that people have submitted them to, to their uses, to their properties, to the resources that we have drawn on for them."

[130] See Appendix XIII for a synopsis of Valmont de Bomare's classification scheme.

La huitieme, des métaux (<u>Metalla</u>,) dont les propriétés générales sont d'entrer en fusion au feu, d'y prendre une surface convexe, d'avoir de l'éclat, d'être des corps ductiles & malléables, & les plus pesans se la nature.

La neuvieme, les substances inflammables (<u>Inflammabilia</u>;) tels sont les bitumes & les soufres qui s'unissent aux huiles & qui s'enflamment dans le feu.

Enfin la dixieme classe, qui est composée de fossiles étrangers à la terre, (<u>Heteromorpha</u>;) telles sont les différentes especes de végétaux, de coquilles & autres animaux changés en pierre. On y comprend aussi les calculs (<u>Calculi</u>,) & les pierres figurées (<u>Figurata</u>,) que l'on appelle Jeux de la nature, & qui ne sont que des especes de concrétions, qu'on trouve accidentellement formées dans des endroits où on ne les soupçonnoit pas.[131]

This last class, however, he said was only "un appendice au systêm minéral contient les pétrifications, les pierres figurées & les calculs."[132]

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[131] <u>Ibid</u>., pp. 2-4: "The first class, which treats of the waters, only comprises those that nature furnishes us, and which are, either fluid or solid, either cold or hot, either simple or compound. The second, earths, whose particles are not bound [together], and which can be diluted and divided by water. The third, sands; substances which belong as much to the earths as to the stones, and which are more or less composite, and hard. The fourth, stones; solid and hard bodies, whose particles [are] tightly bound to one another, are not malleable, and can be neither divided nor diluted by water or by oil, but break into several pieces under the hammer, and which have tolerable stability in fire. The fifth, salts; solid, inflexible, friable and transparent mineral bodies, whose smallest parts have several sides shaped into faces, and their extremities shaped into angles or points, which have the property of dissolving in water, and producing a taste; of crystallizing, of melting in fire, or of becoming volatilized there, etc. The sixth, pyrites, which are either sulphurous and vitriolic, or arsenical, or metallic. The seventh, semi-metals; bodies [which are] not ductile, nor malleable, but fusible, and have moreover all the properties of the metals. The eighth, metals, whose general properties are melting in fire, assuming a convex surface there, having luster, being ductile and malleable bodies, and the heaviest in nature. The ninth, inflammable substances; such are the bitumens, and sulphurs which unite with oils and ignite in fire. Finally the tenth class, which is composed of fossils extraneous to the earth; such are the different kinds of plants, shells and other animals changed into stone. One also includes here the calculi and the figured stones that they call sports of nature, and which are only some kinds of concretions that one accidentally finds formed in some places where one does not suspect them."

[132] <u>Ibid</u>., p. 2: "an appendix to the mineral system, [which] contains petrifactions, figured stones and calculi."

The greatest difficulty that had to be overcome in the execution of his _Mineralogie_, said Valmont de Bomare, was the chaos of nomenclature. Partly as a result of this difficulty and partly because each science had its own idiom,[133] he included a "Lexicon alphabétique de minéralogie"[134] in which he defined 288 "termes d'Histoire naturelle, de Physique & de Chymie . . . qui paroissent être moins généralement entendus."[135]

Valmont de Bomare's emphasis on physical characters as principles of division is seen in several groups. For example, argillaceous earths (_terres argilleuses_) are divided into those that are grainy (_en poussiere_)[136] and those that are unctuous (_grasses_)[137] calcareous stones (_pierres calcaires_) are divided into those that are opaque and uncrystallized (_opaques & non crystallisées_)[138] and those that are crystallized and transparent (_crystallisées & transparentes_);[139] and rocks (_roches_) are divided into those that are coarse (_grossiere_),[140] massive (_en masse_),[141] and brightly colored (_couleurs vives_).[142] He

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[133]_Ibid._, pp. vij-viij. [134]_Ibid._, II, 331-59.

[135]_Ibid._, p. 331: "terms of natural history, physics and chemistry . . . which appear to be less generally understood."

[136]_Ibid._, I, 45-52.

[137]_Ibid._, pp. 52-66.

[138]_Ibid._, pp. 148-61.

[139]_Ibid._, pp. 161-76.

[140]_Ibid._, pp. 266-68.

[141]_Ibid._, pp. 268-77.

[142]_Ibid._, pp. 277-87.

used chemical characters of minerals for some divisions, such as his class salts (<u>sels</u>), which was subdivided into nine genera on the basis of kind of salt;[143] also, the class pyrites was subdivided compositionally into sulphurous pyrite (<u>pyrite sulfureuse</u>)[144] and arsenical marcasite (<u>marcassite d'arsenic</u>).[145] Metals were treated in the cutomary way, being arranged according to kind of metal; however, Valmont de Bomare made a distinction between true metals (<u>métaux</u>) and what he called semi-metals (<u>demi-métaux</u>). The former included only the classical six metals--lead, tin, iron, copper, silver, and gold--;[146] the latter included arsenic, cobalt, bismuth, zinc, antimony, and mercury.[147]

On the whole, Valmont de Bomare's originality consisted of putting into convenient form the well-known work of his predecessors, upon whom he relied heavily for his information.[148] Besides a convenient form, his work has the additional merit of showing an understanding of the nature and purposes of classification schemes, and his lexicon underlined the need for a uniform nomenclature in mineral description.

Woodward's influence on the classification of minerals persisted well into the eighteenth century. It is apparent in the

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[143] <u>Ibid</u>., pp. 287-352.

[144] <u>Ibid</u>., II, 4-14.

[145] <u>Ibid</u>., pp. 14-19.

[146] <u>Ibid</u>., pp. 93-245.

[147] <u>Ibid</u>., pp. 20-92.

[148] Throughout his work Valmont de Bomare cited the sources that he used. He cited Pliny, Agricola, Scheuchzer, Woodward, Dioscorides, and others several times. Most frequently cited were the works of contemporaries, such as Johan Gottschalk Wallerius, Carl von Linné, Johann Lucus Woltersdorf, and Johann Friedrich Henkel, whose works will be discussed in Chapters III and IV.

mineral systems of Scheuchzer, Hill, Valmont de Bomare, and others, who based their classifications primarily upon the easily determinable physical characters of minerals. But classifying minerals from the point of view of their physical properties was only one approach to the study of minerals.

CHAPTER III

MINERAL CLASSIFICATION ON THE BASIS OF PHYSICAL AND CHEMICAL PROPERTIES

Mineralogy was greatly influenced by the developments that took place in chemical theory and practice during the late seventeenth and early eighteenth centuries. Of particular importance to mineralogy was the development of material theories of matter, which emphasized the importance of physical and chemical properties of matter, and concomitantly, the development of analytic chemistry as an investigative tool.[1] As a result of these developments in chemistry, some naturalists approached the study of minerals from a chemical point of view.

Among the first to be concerned with minerals from a chemical point of view, rather than a purely pharmaceutical or metallurgical point of view, was the German alchemist and mystic Johann Joachim Becher (1635-1682). In 1667 he published _Physicae subterraneae_ which contained classifications of all substances--animals and plants as well as minerals. A fundamental part of these classifications was Becher's idea that the

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[1]See Henry M. Leicester, _The Historical Background of Chemistry_ (New York: John Wiley & Sons, Inc., [1956]), pp. 110-37; Marie Boas, "The Establishment of the Mechanical Philosophy," _Osiris_, X (1952), [412]-541; and Andrew Gerardus Maria van Melsen, _From Atomos to Atom: The History of the Concept Atom_, trans. Henry J. Koren ("Duquesne Studies, Philosophical Series," No. 1; Pittsburgh, Pennsylvania: Duquesne University Press, 1952), pp. 81-128.

proximate constituents of all bodies were reducible to three earthy principles and water. These principles, which received various denominations from Becher, may be referred to as the vitreous earth, the combustible earth, and the fluid earth.[2]

The triad of earthy principles illustrates Becher's assumption that trinities of natural things were particularly significant. In all his classifications he set forth tripartite arrangements. Thus, he considered the mineral kingdom to be composed of three groups (_simplicia_, _composita_, and _decomposita_[3]), and each of those to be composed of three subgroups.[4] It is evident from the following passage that triads held a metaphysical significance for Becher:

> Sciendum . . . totum hoc universum in aliquo _esse_ consistere, istud _esse_, est aliquid, & hoc _aliquid_ vel est increatum, vel creatum. Increatus est solus _Deus_, in quo Trinitas est, quam alibi in nostris scriptis Theologicis exposuimus; quicquid vero praeter vel extra Deum est, ab eo creatum est: & hoc _creatum_ est rursus _trinum_, _vel spirituale_, _vel corporale_, _vel medium ex his_. In _spiritualibus_ creatis rursus est Trinitas; sunt enim Spiritus _boni_, _mali_, _& at quidam volunt_, _indifferentes_. In _creatis Intermediis_, quae nec _puri spiritus nec pura corpora_ sunt, rursus _trinitatem_ invenies; _animarum_, _potentiarum_, _& qualitatum occultarum_ juxta quorundam

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[2]Becher used the terms _terra prima_, _lapis fusilis_, _terra lapidea_, and _terra vitrescibili_ synonymously to refer to what is above called vitreous earth. Similarly, _terra secunda_ and _terra pinguis_ correspond to combustible earth, and _terra tertia_ and _terra fluida_ correspond to the fluid (or mercurial) earth. Regardless of the denomination, these three principles were meant to represent nearly the same thing as the Paracelsian principles salt, sulphur, and mercury. Johann Joachim Becher, _Joh. Joachimi Beccheri, D. Spirensis Germani, Sacr. Caes. Majest. Consil. & Med. Elect. Bav., physica subterranea profundam subterraneorum genesin, e principiis hucusque ignotis, ostendens_, ed. Georg Ernst Stahl (editio novissima; Lipsiae: Ex Officina Weidmanniana, 1738), pp. 61, 66, 76, _et passim_.

[3]_Ibid_., pp. 233, 273, _et passim_.

[4]See Figure 2, following.

- Simplicia (sive principia)
  - Terra prima
  - Terra secunda
  - Terra tertia
- Composita
  - Terrae
    - Arenae
    - Limi
    - Hortensis
  - Lapides
  - Metalla
    - Minus perfecta (sive mineralia)
    - Perfecta (sive metalla)
- Decomposita
  - Terrea
    - Sicca
      - Pinguia
      - Macra
    - Liquida
      - Oleosa
      - Aquea
  - Lapidea
    - Pinquia
    - Macra
    - Mineralia
    - Salina
    - Aquea
  - Metallica
    - Sicca
      - Pinguia
      - Media
      - Macra
    - Liquida

Fig. 2.--Synopsis of Becher's classification of mineral substances[5]

[5]This synthetic list of the major elements of Becher's classification scheme was extracted from the more extensive discussion in ibid., pp. 231-67.

> opinionem: In creatis corporeis quoque Trinitas est, sunt enim aliqua summe simplicia, ut elementa; alia nonnihil mixta ut Planetae, meteora; alia magis mixta ut corpora. Et haec rursus sunt triplicia, vel animalia, vel vegetabilia, vel mineralia, de quibus noster sermo. In his quoque non occultatur Trinitas, pars enim eorum Terra, pars lapis, pars metallum est.[6]

Earlier Georg Agricola had suggested a differentiation of mineral substances that resulted in triads, but he, unlike Becher, did not hint that there was a metaphysical significance in such an arrangement.

An idea that is a prominent part of later-published schemes of classification, and is traceable to Becher, is the threefold division of substances into those that vitrify, those that calcine, and those that are unaffected by fire. Becher observed that different sands (i.e., arenae, one of the three subdivisions of earths [terrae]) varied in their behavior towards fire. He said: "Aliqua [arenae] in igne in vitrum, alia in calcem mutatur, alia immutabilis persistit. . . ."[7] He

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[6]Ibid., p. 232: "One knows . . . the whole of this universe to consist of some being, that being, is something, and this something is either uncreated, or created. God alone is uncreated, in Whom is the Trinity, which we have explained elsewhere in our theological writings. Indeed, anything that is beyond or outside God, was created by Him. And this creation is again threefold, either spiritual, corporeal, or midway between these. In spiritual creations again there is a trinity, for spiritual things are good, bad, and as they say, indifferent. In the intermediate creations, which are neither of pure spirit, nor of pure substance, again one finds a trinity: of animae, of potentiae, and of qualitates occultae according to the opinion of certain people. In corporeal creations, also, there is a trinity; for some are extremely simple, as elements; others are mixed, as planets and meteors; still others are more mixed, as sensible bodies. And these again are triple, either animal, vegetable, or mineral, of which I speak of the latter one. In these also a trinity is unconcealed, for a part of them is earth, a part is stone, and a part is metal."

[7]Ibid., p. 235: "Some [sands] are changed in fire into a glass; others are changed into a calx; still others, unchangeable, remain constant. . . ." Although these effects of fire on minerals was well-known in antiquity and the Middle Ages, Becher may well have originated the idea of classifying minerals according to this threefold difference.

expressed the same idea in regard to stones (lapides): "Alii enim lapides fluunt, alii non fluunt; sed in calcem vivam, forti igne, rediguntur: alii nec fluunt, nec in calcem rediguntur, sed in igne etiam fortissimo incolumes persistunt."[8] But for distinguishing among the stones Becher valued physical properties more than chemical properties: "Lapides vario modo distingui possunt; physica tamen eorum differentia omnium optima censetur."[9] His discussion of ways in which the composita lapides could be classified by means of physical properties paralleled Anselm de Boodt's discussion, which he cited as a major source.[10] Thus, Becher, as had de Boodt, included hardness, color, transparency, shape, heaviness, etc., as diagnostic physical properties of minerals.[11] Since it was based upon both physical and chemical principles, Becher's classification can be called a mixed classification.

A younger contemporary of Becher was the Swedish chemist Urban Hiärne (1641-1724). Hiärne, who studied medicine at Uppsala, became interested in chemistry during a continental tour that lasted from 1669 to 1674. In 1674 he returned to Sweden and settled in Stockholm where he practiced medicine and discharged various governmental assignments

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[8] Ibid., p. 61: "For some stones flow, others do not flow; but are reduced by a strong fire into quicklime: still others neither flow, nor are reduced into a calx, but remain unimpaired in even the strongest fire."

[9] Ibid., p. 237: "Stones can be distinguished in various ways; however, their physical difference is regarded the best of all."

[10] Ibid., p. 238.

[11] Ibid., pp. 238-52.

for more than forty-five years. In 1675 Hiärne was named to an administrative post with the Board of Mines; in 1683 he headed the newly-founded, government-sponsored Laboratorium chymicum; and in 1696 he was appointed first physician to the King of Sweden.[12]

In 1683, when the Laboratorium chymicum was established, chemistry was still largely in the service of medicine and mining. Since the government expected the laboratory to serve primarily practical ends, Hiärne worked on practical problems. In particular, he sought ways to improve the exploitation of mineral resources, and he directed the preparation of mineral-derived medicines, especially tinctures.[13] Although successful in these practical endeavors, he "wanted to fathom the secrets of nature, to dissect things in order to study their artful composition."[14] To this end he applied the methods of analytical chemistry in the study of mineral substances.

The results of Hiärne's studies of mineral substances are contained in Een kort Anledning till åtskillige Malm- och Bergarter, Mineraliers Wäxters, och Jordeslags, sampt flere sällsamme Tings effter-söpriande och angifwande, published in Stockholm in 1694.[15] The classification that was embodied in this work shows elements of a traditional

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[12]See Sten Lindroth, "Urban Hiärne (1641-1724)," Swedish Men of Science, 1650-1950, ed. Sten Lindroth (Stockholm: The Swedish Institute/Almqvist & Wiksell, 1952), pp. 42-49; "Hjaerne (Urbain)," Nouvelle biographie générale, XXIV (1858), cols. 812-14; and Sten Lindroth, "Urban Hiärne och Laboratorium chymicum," Lychnos (1946-1947), pp. [51]-116.

[13]Lindroth, Swedish Men of Science, p. 46. [14]Ibid.

[15]Citation from British Museum General Catalogue of Printed Books (London: The Trustees of the British Museum, 1931--), CIII, col. 529.

sort. Hiärne recognized six kinds of mineral substances: earths, stones, metals, semi-metals, salts, and sulphurs. Some of these classes were subdivided; stones, for example, were divided into stones from mountains, common stones, common useful stones, figured stones, stones formed in animals, and precious stones.[16] Superficially, such an arrangement seems to offer little of note; however, subsequent naturalists regarded Hiärne's work as an important precursor to their own.[17] In a brief biography of Hiärne, Sten Lindroth suggested that Hiärne's main contribution to science was in providing an impetus to the study of analytical chemistry in Sweden.[18] He concluded his evaluation of

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[16]E. H. M. Beekman, Geschiedenis der Systematische Mineralogie ['s Gravenhage, 1906(?)], p. 19.

[17]Magnus von Bromell (1679-1731), another Swedish physician-chemist, said: "Muss vor allen andern mit verdienten Lob, der verstorbene Landes-Hauptmann and Archiater, Herr Vrban Hierne, gerechnet werden, als welcher durch seine kurtze Anleitung zur Aufsuchung und Angebung allerhand Malm- und Berg-Arten den Weg gleichsam dazu gebähnet, und dabey einem angenehmen Unterricht ertheilet hat, wie, dergleichen unterirrdische Schätze bey uns sollen aufgesuchet und erkannt werden." Magnus von Bromell, Mineralogia et lithograpica Svecana, das ist Abhandlung derer in dem Königreich Schweden befindlichen Mineralien und Steinen. Ehemahls in Schwedischer Sprache abgefasst nunmehro aber ihrer besondern Merckwürdigkeit halben ins Teutsche übersetzt, mit einem Vorbericht von dem vor kurtzer Zeit in Schweden entblössten Gold-Ertz begleitet, und mit darzu dienlichen Kupfern ans Licht gestellt von Mikrandern (Stockholm und Leipzig: bey Gottfried Kiesewetter, 1740), p.)(5 recto. Axel Fredrik Cronstedt (1722-1765) said: "Hiarne and Bromell were, as far as I know, the first who founded any mineral system upon chemical principles. However, they were only the projectors of this manner of proceeding. . . ." Axel Fredrik Cronstedt, An Essay towards a System of Mineralogy, by Axel Fredric Cronstedt. Translated from the Original Swedish, with Notes, by Gustav von Engestrom. To Which Is Added a Treatise on the Pocket-Laboratory, Containing an Easy Method, Used by the Author, for Trying Mineral Bodies, Written by the Translator. The Whole Revised and Corrected, with Some Additional Notes, by Emanuel Mendes da Costa (London: Printed for Edward and Charles Dilly, 1770), p. viii.

[18]Lindroth, Swedish Men of Science, pp. 48-49.

Hiärne's work by saying that "he raised the curtain on Swedish chemistry . . . ."[19]

Mixed principles of classification, physical and chemical, are embodied in the scheme of Magnus von Bromell, a countryman of Hiärne's. Bromell, whose professional employment was as a physician, published his mineral system in 1730 in a work titled Mineralogia, eller Inledning til nödig kundskap at igenkiänna och uppfinna Allahanda Berg-Arter, Mineralier, Metaller samt Fossilier, Och huru de måge til sin rätta nytta anwändas.[20] A second edition was published in 1739 and a German translation was published in 1740.[21]

Designed as a handbook to help the naturalist recognize and identify mineral substances, especially those found in Sweden, Bromell's Mineralogia is a mineral system that reflects some of the concepts of mineral relationships seen in Becher's and Hiärne's works. In his preface Bromell said that his book would have a threefold usefulness:

> Ich bin inzwischen versichert, dass der geneigte Leser einen dreyfachen Nutzen von diesem kleinen Tractat werde erwarten können. Indem er erstlich daraus lernen kan, die vornehmsten Mineralien zu unterscheiden und zu erkennen; nebst denen eigentlichen Nahmen derer Berg-Arten und Malmen, wie auch derselben Beschaffenheit, Gebrauch und Nutzen. Zweytens welcher gestalt dergleichen nützliche fossilien hier bey uns sollen erfunden und ausgesuchet werden, und endlich drittens welche Metalle und Mineralien, hier in diesem

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[19] Ibid., p. 49.

[20] Citation from Gerhard Regnéll, "On the Position of Palaeontology and Historical Geology in Sweden before 1800," Arkiv för Mineralogi och Geologi, I (1949), 25.

[21] British Museum General Catalogue of Printed Books, XXVI, col. 101. The German edition of 1740, cited above, was used in this study.

> Reiche bereits erfunden, und welche noch sollen aufgesucht werden.[22]

Bromell subdivided minerals into earths, salts, sulphur and sulphurous rocks, stones, minerals and semi-metals, and ores and metals.[23] These major divisions parallel those of Hiärne, Woodward, and others, and are a frequently encountered arrangement in early eighteenth century mineral classifications. Bromell's subdivision of the class earths into medicaments, earths used by painters and dyers, earths used for cleaning and polishing, earths used in ceramics, fertilizers, earthy ores, and fuels,[24] resembles Agricola's arrangement of earths on the basis of what they were used for. Three of the subdivisions of the class stones are fire-resistant stones, stones that calcine, and stones that fuse and vitrify. Bromell said:

> Findet men unzehlich viele verschiedene [Stein-]Arten, welche in Ansehung ihrer unterschiedenen Gestalt, Farbe, Nutzen, Werth und Beschaffenheit auf mancherley Art pflegen unterschieden zu werden, sie können aber am besten eingetheilet werden, in solche, welche entweder in einem gewöhnlichen Feuer der Feuers Hitze wiederstehen, und daher feuerbeständige genannt werden, oder auch im Feuer zu Fluss und Glass fliessen, oder auch durch die Feuer-flammen zu Kalck und Pulver gebrannt werden.[25]

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[22]Bromell, pp.)(5 verso-[)(6 recto]: "Meanwhile, I am convinced that the kind reader can expect a threefold benefit from this small treatise. In that, first, he can learn therefrom to distinguish and to recognize the principal minerals; in addition, he can learn the proper names of the rocks and ores, also their nature, habit and use. Second, what kind of such useful fossils should be found and located here by us, and finally, third, which metals and minerals have been found here in this kingdom already, and which should still be sought out."

[23]See Appendix VI.

[24]*Ibid.*, pp. [1]-10; see also Appendix VI.

[25]*Ibid.*, pp. 23-24: "One finds innumerable different kinds [of stones], which in consequence of their variable shape, color, uses, value and nature, are differentiated in various ways. They can, however, be

These groups of stones were modeled after the threefold distinction made among earths and stones by Becher on the basis of behavior in fire. Becher's discussion, however, was speculative, whereas Bromell thought his grouping was a natural arrangement, following the order ordained by Nature. Bromell said: "Wann man zu diesen [i.e., the above-mentioned three groups] die so genannte Figur-Steine, petrificata und allerhand Steine von Thüren leget, so hat man vermuthlich die bishero bekannte Stein-Sorten in ihre rechte und natürlichen Ordnung gebracht."[26] Although he seems to have regarded his scheme as mirroring the natural order which he thought existed among inorganic bodies, Bromell demonstrated by his emphasis upon describing the properties of minerals that he was less interested in their natural order than he was in the orderly description of their natural characters.

Although some naturalists, such as Bromell, were more interested in descriptive mineralogy than in theoretical mineralogy, there were those who were aware of the deficiencies of the conceptual framework supporting descriptions of minerals and sought to provide a more adequate theoretical foundation. In 1730, the same year that Bromell first published his Mineralogia, René de Réaumur (1683-1757) chided naturalists for neglecting the theoretical aspects of mineralogy. He said that for too long a time naturalists had studied the various substances of the

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best arranged into such that, in an ordinary fire, resist the fire's heat (and from that are called fire-resistant), melt to flux and glass in the fire, or are burned to calx and powder by means of the flames."

[26]Ibid., p. 24: "When one places with these the so-called figured stones, petrifactions, and diverse stones of animals, he has likely brought the hitherto known kinds of stones into their correct and natural order."

earth without characterizing the various principal kinds of mineral things.[27] Using earths (terres) as an example, he said: "Il seroit utile à Histoire naturelle, à la Physique & aux Arts, de distribuer les différentes terres en classes, ou en genres premiers, en genres seconds & en especes."[28] He suggested that primary divisions be based upon physical properties such as hardness and ductility, and secondary divisions be based upon chemical properties such as effects of fire and of acids upon the substances.[29] Réaumur's plea for systematization of mineral substances in general and earths in particular was rephrased and amplified in the Histoire of the Academie Royale des Sciences for 1730:

> On sent assez ce qu'on peut attendre des recherches qui se feront sur toutes ces qualités de terres, si exposées à tout le monde pour la plûpart, & si peu observées. Leurs combinaisons feront naître une distribution générale des terres en classes, genres & especes, pareille à celle qui a paru si nécessaire en Botanique, & dont on s'occupe depuis si longtemps. Ces sortes d'ordres, ou d'ordonnances, si l'on veut, ne sont, à la vérité, que des productions de l'esprit humain: mais ils nous aident à embrasser mieux tout ce que la nature ne nous a donné que péle-mêle & en confusion; quelquefois même ils donnent lieu de découvrir des causes générales, & de prévoir avec vrai-semblance des faits particuliers.[30]

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[27] René Antoine Ferchault de Réaumur, "De la nature de la terre en general, et du caractere des differentes especes de terres," Memoires de mathematique et de physique, tirés des registres de l'Académie Royale des Sciences. De l'année M.DCCXXX in Histoire de l'Academie Royale des Sciences. Avec les mémoires de mathématique & de physique (1732), p. 243.

[28] Ibid., p. 278: "It would be useful to natural history, to physics and to the arts, to arrange the various earths in classes, or primary kinds, secondary kinds, and species."

[29] Ibid., pp. 245-46.

[30] Anonymous, "Sur la nature de la terre en général, et sur ses caracteres," Histoire de l'Academie Royale des Sciences. Annee M.DCCXXX (1732), pp. 31-32: "People know enough that they ought to look for investigations which could be made on all those qualities of earths, so

A general system for the mineral kingdom, however, was not immediately forthcoming.

Réaumur called for a compromise between the convenience of a classification based on external properties, which were known to be greatly variable, and one based upon chemical behavior, which had the advantage, in his opinion, of being based upon less variable properties of minerals. In 1735 Carl von Linné (1707-1778) in his Systema naturae[31] set forth an epitome of a carefully reasoned classification of the mineral kingdom, based upon both physical and chemical properties of mineral substances.

Posterity has come to regard Linné as the fountainhead of systematic botany,[32] but he also contributed to understanding the animal and mineral kingdoms through his summation and systematization of the works of his predecessors. In the Systema naturae Linné propounded an

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exposed to everyone for the most part, and so little noticed. Their combinations could produce a general distribution of the earths into classes, genera and species, parallel to those which have proven so necessary in botany, and which have been employed for such a long time. These kinds of categories, or arrangements, if one wishes, are truly only products of the human intellect: but they help us to grasp better all that Nature has given us only jumbled and in confusion; sometimes the same give rise to discovering some general causes, and to forecasting with probability some specific facts."

[31]Carl von Linné, Caroli Linnaei, Sveci, doctoris medicinae, systema naturae, sive regna tria naturae systematice proposita per classes, ordines, genera, & species (Lugduni Batavorum: Apud Theodorum Haak, 1735). The following edition was used: Carl von Linné, Carolus Linnaeus systema naturae 1735; Facsimile of the First Edition. With an Introduction and a First English Translation of the "Observationes" by Dr. M. S. J. Engel-Ledeboer and Dr. H. Engel ("Dutch Classics on History of Science," No. 8; Nieuwkoop, Holland: B. de Braaf, 1964); hereafter cited as Linné, Systema naturae Translation.

[32]E.g., see "Linnaeus, Carolus (Carl Von Linné) (1707-1778)," Encyclopaedia Britannica, 1962 ed., XIV, 173.

all-inclusive systematization of natural productions. By means of a careful application of rules of classification to minerals, plants, and animals, he had devised a scheme of classification that reduced Nature's infinite variety to a generalized conceptual scheme.

Extending to inorganic Nature a system of classification designed for plants, Linné organized mineral substances into species, genera, orders, and classes. His classification was presented in the traditional form of a logical-deductive scheme, but, he indicated, it was firmly based upon the study of individual specimens. In his prefatory observations Linné postulated God, Creation, and a generative mechanism, and said: "Individua sic progenita, in prima & tenerrima aetate, omni prorsus notitia carent, ac omnia sensuum externorum ope ediscere coguntur."[33] Since the external senses apprehended natural objects,[34] he asked: "quamobrem Creator hominem, ejusmodi sensibus & intellectu praeditum, in globum terraqueum locaverit, ubi nihil in sensus incurrebat praeter Naturalia, tam admirando & stupendo mechanismo constructa?"[35] He answered his own question by saying: "Anne ob aliam

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[33]Linné, "Observationes in regna III. naturae," <u>Systema naturae</u>, observation 5: "Individuals thus procreated, lack in their prime and tender age absolutely all knowledge, and are forced to learn everything by means of their external senses." English translation from Linné, <u>Systema naturae Translation</u>, p. 18.

[34]Linné, "Observationes in regna III. naturae," <u>Systema naturae</u>, observation 8: "Naturalia magis sub sensus cadunt quam reliqua omnia, sensibusque nostris ubivis obvia sunt."

[35]Linné, "Observationes in regna III. naturae," <u>Systema naturae</u>, observation 8: "why the Creator put man, who is thus provided with senses and intellect, on the earth globe, where nothing met his senses but natural objects, constructed by means of such an admirable and amazing mechanism." English translation from Linné, <u>Systema naturae Translation</u>, p. 18.

causam, quam ut Observator Artificem ex opere pulcherrimo admiraretur & collaudaret."[36] Linné said that natural science was necessary to man in order for him to have knowledge of natural objects, from which everything useful originated; but to proceed to knowledge, one must know things in themselves:

> Primus est gradus sapientiae res ipsas nosse; quae notitia consistit in vera idaea objectorum; objecta distinguuntur & noscuntur ex methodica illorum divisione & convenienti denominatione; adeoque Divisio & Denominatio fundamentum nostrae Scientiae erit.[37]

Thus, he justified his own work of naming and classifying, which he thought to be fundamental to natural science and a major occupation of a naturalist.

The Systema naturae exhibits the mineral kingdom (regnum lapideum) divided into three classes, rocks (petrae), minerals (minerae), and fossils (fossilia); each class is divided into three orders.[38] The first class, petrae, is characterized as including all simple stones, called gangue (Bergarter) by metallurgists, and consists only of similar particles.[39] The second class, minerae, consists of composite stones or

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[36]Linné, "Observationes in regna III. naturae," Systema naturae, observation 8: "Surely for no other reason than that the observer of the wonderful work might admire and praise its Maker." English translation from Linné, Systema naturae Translation, p. 18.

[37]Linné, "Observationes in regna III. naturae," Systema naturae, observation 10: "The first step in wisdom is to know the things themselves; this notion consists in having a true idea of the objects; objects are distinguished and known by classifying them methodically and giving them appropriate names. Therefore, classification and name-giving will be the foundation of our science." English translation from Linné, Systema naturae Translation, p. 18.

[38]See Appendix VII for a synopsis of Linné's mineral classification.

[39]Linné, "Caroli Linnaei regnum lapideum," Systema naturae:

ores (Malmarter); they are petrae impregnated by foreigh particles.[40] The third class, fossilia, are stony aggregates, called Grusarter in Sweden, and consists of a mixture of particles derived from petrae, minerae, or both.[41]

Based upon behavior in fire, Linné's subdivisions of petrae are modeled after the classifications of his predecessors Hiärne and Bromell. The order apyri contains substances that are unchanged by, or are resistant to fire.[42] The order calcarii contains substances that are calcinable (i.e., are reduced to a powder when heated).[43] The order vitrescentes contains those substances that melt into a glass.[44] Included under apyri are three kinds of asbestos, muscovite mica, and four kinds of talc. Among calcarii are several kinds of marble, calcite (islandic spar), and four species of schist. The order vitrescentes includes sandstone, flint, jasper, agate, and quartz.

Each of Linné's orders are divided into a few genera; thus, the three orders of the class petrae had a total of eleven genera. For each

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"PETRAE sunt Lapides SIMPLICES, qui Metallurgis dicuntur Bergarter. constant particulis tantummodo similaribus."

[40]Ibid.: "MINERAE sunt Lapides COMPOSITI qvi Metallurgis Svecis dicuntur Malmarter constant Petrâ particulis peregrinis impraegnatâ."

[41]Ibid.: "FOSSILIA sunt Lapides AGGREGATI, qvi à Svecis dicuntur Grusarter. constant particulis petrosis vel mineralicis mixtis."

[42]Ibid.: "APYRI in igne docimastico vix destrictibiles."

[43]Ibid." "CALCARII igne docimastico usti & Aquâ rigati, in farinam reducuntur."

[44]Ibid." "VITRESCENTES igne docimastico usti in vitrum liquescunt."

genus Linné specified the diagnostic generic characteristic. For the genus spatum of the order calcarii the rhombohedral shape of the fragments of a broken specimen was characteristic; for the genus amiantus of the order apyri, parallelism of the constituent fibers was the generic characteristic. The terms genus and species were not used by Linné in the previously commonly-used relative sense that each group is called a genus of the one or ones subordinated to it, and a species of the one to which it is subordinated. To him a species was a concept that had a one-to-one correspondence with natural objects; it was a group of individuals which possessed common attributes. A genus was a group consisting of related species. Linné emphasized his narrower usage of the terms genus and species by specifying generic and specific characters for each group.

The subdivision of the class minerae into the orders salia, sulphura, and mercurialia was not based upon a single test as was the division of the class petrae. Salia or salts are characterized as soluble in water and having a taste; sulphura or sulphurs are characterized as fuming in fire and having an odor; and mercurialia or mercuries are characterized as becoming melted and purified in fire.[45] Though all salts were supposed to be soluble in water, many insoluble gemstones, which were considered by Linné as belonging to the genus nitrum because they had the shape characteristic of nitre, and hence the composition of

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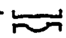
[45] Ibid.: "1. SALIA in aqua solubilia & sapida sunt. simpliciter composita saepe occurrunt." "2. SULPHURA in Igne fumantia & odorata sunt. Decomposita saepe occurrunt." "3. MERCURIALIA igne fusa, depurata & nitida evadunt. Supradecomposita communiter occurrunt. Igne fusa dicuntur Metalla."

nitre, were included in the order *salia*.[46] Because these transparent, precious gems distinctly differed from one another only by color, Linné assigned all of them to the same species (*qvartzosum*) and distinguished them as varieties. Thus, topaz was *Nitrum qvartzosum luteum*, ruby was *Nitrum qvartzosum rubrum*, amethyst was *Nitrum qvartzosum purpureum*, emerald was *Nitrum qvartzosum viride*, and so forth.[47]

The genera of the order *sulphura* are characterized by the odor and color of the fumes given off when a specimen is burned. In addition, members of the genus *pyrites*, when heated, were said to give off salty tasting acidic fumes and those of the genus *arsenicum* to give off sweet tasting alkaline fumes.[48]

The order *mercurialia* contains the common metallic ores, and although the specified generic characters are based upon the external properties of the specimen and the derived metal, the groups are delineated on the basis of metallic constituent. To six of the ten genera, Linné added a chemical test as a distinctive character. He described the test by using symbols; for example, the test for the genus *cuprum* is shown as follows: ∇F  ♂ . Although the meaning is veiled by his notation, the symbols seem to mean that any member of the genus *cuprum* when dissolved in aqua fortis (∇F) forms a precipitate () when

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[46]Linné, "Observationes in regnum lapideum," *Systema naturae*, observation 7: "*Nitrum Qvartzi* nostrum, seu Crystallum, Qvartzum [i.e., of the order *Vitrescentes*] esse docent proprietates omnes, exceptâ duritie & figurâ; *figuram* obtinet ipsissimam verissimamque Nitri; sine dubio itaque Nitro aquae primordiali lapidum admisto adscribenda sit . . . ."

[47]Linné, "Caroli Linnaei regnum lapideum," *Systema naturae*.

[48]*Ibid*.

iron (♂) is placed in the solution. Finally, Linné added that members of the genus stibium tinged glass yellowish brown; of the genus stannum, white; plumbum, yellow; and ferrum, black.[49]

Whereas Linné in general tried to use variations in the same quality or set of qualities for characterizing all the subgroups of any given suprageneric group,[50] when he formulated species he used any convenient character. For example, of the twelve subdivisions of the genus ferrum, three are characterized on the basis of their composition,[51] two on the basis of luster,[52] two on geometrical (crystal) shape,[53] one on fracture,[54] one on its magnetic property,[55] and three on structure.[56]

Linné's third class, fossilia, is divided into earths (terrae), which consist of pulverized particles,[57] concretions (concreta), which are consolidated particles of earth,[58] and petrifactions (petrificata),

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[49] Ibid.

[50] E.g., the genera of the order salia were characterized by their behavior in fire, their geometrical shape, and by their essential chemical nature (acid or alkaline); similarly, the orders of the class petrae were characterized by their behavior to fire.

[51] Ferrum sulphure non adulteratum, Ferrum sulphure arsenico impraegnatum, and Ferrum sulphure pyrite impraegnatum.

[52] Ferrum petrae vitrescentis, pauperrimum and Ferrum petrae vitrescentis, dives.

[53] Ferrum nudum octaëdron and Ferrum tessulatum, fere nudum.

[54] Ferrum fracturis nitidum.

[55] Ferrum ferrum & mundi polos respiciens.

[56] Ferrum ollaris è centro radiati Zincci, extus puculati, Ferrum amianti angulosi rigidi, and Ferrum amianti rigidi, extus puculati.

[57] Linné, "Caroli Linnaei regnum lapideum," Systema naturae: "TERRAE particulis pulverulentis constant."

[58] Ibid.: "CONCRETA particulis terrestribus coalita sunt."

which display a likeness of plant or animal impressions.[59] Here again, the distinctive character or the genera of each order is based upon the same quality. The six genera of the order terrae are characterized by describing a particularly important feature of the constituent particles. For example, the genus argilla consists of slippery, firmly cohering particles;[60] humus, of torn apart (destroyed) plants or animals;[61] and arena, of pulverized stones.[62]

The genera of the order concreta are distinguished by the place of origin of the members of the various genera. Thus, generation in the element fire is characteristic of the genus pumex,[63] generation in the element air for stalactites,[64] generation in water for tophus,[65] generation in earth for saxum,[66] generation within natural stones for aetites,[67] generation whithin plants for tartarus,[68] and generation within animals for calculus.[69] By using such abstruse characteristics, Linné violated

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[59] Ibid.: "PETRIFICATA simulacrum Vegetabilis vel Animalis impressum ostendunt."

[60] Ibid.: "Particulis lubricis, tenaciter cohaerentibus."

[61] Ibid.: "Vegetabili vel animali destructo."

[62] Ibid.: "Lapidis cujuscunque pulvere."

[63] Ibid.: "Generatus In elemento Igneo."

[64] Ibid.: "In elemento Aëreo."

[65] Ibid.: "In elemento Aqvco."

[66] Ibid.: "In elemento Terreo."

[67] Ibid.: "Intra naturale Lapideum."

[68] Ibid.: "Intra natur. Vegetabile."

[69] Ibid.: "Intra naturale Animale."

his practice of basing groups on qualities that could be empirically determined from the specimens alone. The order _concreta_ is a catch-all group, and as such has no common properties. Since Linné's rules of classification necessitated a common element, he postulated unspecific places of generation as the common factor.

Seven of the eight generic divisions of Linné's final order, _petrificata_, are determined by his classification of the organic realms. Into these seven genera Linné placed those stones that possessed an apparent affinity either to plants or animals. Thus, the genus _phytolithus_ contains the petrified plants, _entomolithus_ the petrified insects, _zoolithus_ the petrified quadrupeds, and so forth. One genus is reserved for all plant-like stones, and six, which correspond to the six classes of animals, are reserved for animal-like stones.[70] The eighth genus, _graptolithus_, contains those petrifactions that simulated pictures or drawings,[71] the dendrites, for example. Linné had reduced all organism-like petrifactions to seven genera--he said no more were possible[72]-- and he criticized contemporaries who, failing to generalize, formed as many genera of petrifactions as there were species: "_Petrificata_ plurium Auctorum recentiorum deliciae & Sirenes, ad tot genera quot species sunt, redacta fuere, eodem prorsus modo quo Hortulani suas

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[70]In his "Regnum animale" Linné recognizes six classes: _Quadrupedia_, _aves_, _amphibia_, _pisces_, _insecta_, and _vermes_. The corresponding genera of petrificata are: _zoolithus_, _ornitholithus_, _amphibiolithus_, _ichthyolithus_, _entomolithus_, and _helmintholithus_.

[71]_Ibid_.: "Petrificatum picturâ assimilans."

[72]Linné, "Observationes in regnum lapideum," _Systema naturae_, observation 11: "Ad septem tamen genera reduci possunt omnia Petrificata, nec plura possibilia sunt. . . ."

plantas disponunt, qui tot species Tuliparum, Hyacinthorum, Anemonum &c. quot sunt horum variationes, fingunt."[73]

The morphological affinity to plants or animals exhibited by the petrifactions served to link the mineral kingdom to the plant and animal kingdoms in Linné's generalized system of Nature. A more explicit conceptual unity among the three kingdoms was provided by Linné by his postulating, as did other eighteenth century naturalists, that all terrestrial bodies possessed the powers of growth and generation. In his "Observations in regna III. naturae" he said: "Lapides crescunt. Vegetabilia crescunt & vivunt. Animalia crescunt, vivunt & sentiunt."[74] No one could doubt that plants and animals possessed the powers of growth and generation, but that minerals possessed these powers, although a commonly held opinion,[75] was not so obvious. Moreover, with plants and animals the structures that served to promote growth and generation were visible, but in minerals there were no visible structures for carrying out those functions. Still, minerals were thought to grow by intussusception and therefore were analogous to plants and animals, which served as archetypes for defining growth.[76] Lacking a mechanical

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[73]Ibid.: "Petrifactions, the delight and temptation of several modern authors, had been referred to as many genera as there were species, in exactly the same way in which the plants are arranged by horticulturists, who form as many species of tulips, hyacinths, anemones etc., as there are varieties." English translation from Linné, Systema naturae Translation, p. 21.

[74]Linné, "Observationes in regna III. naturae," Systema naturae, observation 15: "Stones grow. Plants grow and live. Animals grow, live and feel."

[75]Frank Dawson Adams, The Birth and Development of the Geological Sciences (Baltimore, Md.: The Williams & Wilkins Company, 1938), p. 95.

[76]Ibid., pp. 94-95.

explanation of mineral growth, some naturalists, impressed by their studies of natural and artificial crystals and crystallization, postulated a principle of crystallization as Nature's mechanism.[77] Although Linné postulated mineral growth, he was preoccupied with determinable characters, not speculations upon processes of growth.

Linné postulated-away the lack of generative and nutritive structures in minerals. For organic natural things he had extrapolated from the present number of individuals in each species to a single parent;[78] similarly he postulated that all stones (lapides) originated from a few simple things (primogenitas terras) that were compounded by external actions. He said:

> Primogenitas Terras tantummodo Glaream & Argillam nominamus, e quibus, Elementorum ope, totum Regnum Lapideum existimamus esse productum. Hinc reliqui Lapides temporis, a Creatione praeterlapsi, progenies sunt.[79]

In this way Linné could explain the lack of any internal structures. Although he spoke in terms of organic growth, he described the formation of minerals in mechanical terms. He said sand (glarea) and clay (argilla),

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[77] See John Garrett Burke, "The Establishment and Early Development of the Science of Crystallography" (unpublished Ph.D. dissertation, Department of History, Stanford University, 1961), pp. 42-76.

[78] Linné, "Observationes in regna III. naturae," Systema naturae, observation 3: "Si hanc individuorum multiplicationem in unaquaque specie retrograde numeremus, modo quo multiplicavimus prorsus simili, series tandem in unico parente desinet, seu parens illo ex unico Hermaphrodito (uti communiter in Plantis) seu e duplici, Mare scilicet & Femina (ut in Animalibus plerisque) constet."

[79] Linné, "Observationes in regnum lapideum," Systema naturae, observation 1: "We call only sand and clay primary earths, from which, by the work of the elements, we regard the whole mineral kingdom to be produced. From them, in the time slipped away since Creation, the remaining stones are progeny."

the first-formed mineral substances, were the raw materials for all of the other objects of the mineral kingdom. Simple stones (petrae) and aggregate stones (fossilia) were formed by the apposition of sand or clay particles by means of the elements. If simple or aggregate stones were then impregnated with a mineral principle, such as the saline principle, the result was a composite stone (i.e., one of the class minerae). Thus he concluded, that there was no generation from a seed in the mineral kingdom. Nor, he said, was there vascular circulation.[80]

Linné further explained the interrelationships among the various kinds of mineral substances by saying: "Petram omnem, vix ullâ exceptâ, e Terris originem ducere extra controversiam est. e. gr. ex Humo vegetabili palustri Schistus, e Glarea Cos, ex Argilla Marmor."[81] He continued in the next observation: "Petra cum fuerit impraegnata materiâ aliquâ, respectu ad Simplices, peregrinâ, Minera dicitur. Petra vel Minera comminuta Terra nominatur; sed non vice versâ. Terra mixta si concrescat Concretum dicitur."[82] Thus, he postulated that both rocks (petrae), which were simple substances, and concretions (concreta), which

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[80] Ibid., observation 2, embodied these ideas: "Generatio Lapidum Simplicium & Aggregatorum per appositionem particularum externam fit; & si hi principio aliquo Minerali, forte salino, in humore quodam soluto, impraegnantur, Compositi dicuntur. Hinc generatio in Regno Lapideo nulla ex ovo. Hinc nulla humorum per vasa circulatio, ut in reliquis Naturae Regnis."

[81] Ibid., observation 3: "It is beyond question that all rocks, excepting scarcely any, originate from earths. For example, from boggy vegetable humus schist, from sand sandstone, from clay marble."

[82] Ibid., observation 4: "Rock is called mineral when it has been impregnated by some material foreign in respect to the simple constituents. Crushed rock or mineral is named earth; but not vice versa. Mixed earth is called concretion if it congeals."

were complex aggregates, are formed from earths (terrae). But he did not set forth any reasons for the different products, nor did he provide an explanation of the mechanisms by which rocks or concretions were derived from earths. These postulated connections among the material entities of the mineral kingdom achieved a natural, material unity that complemented the artificial, conceptual unity that Linné had provided for his classificatory groups.

Methodical classification and appropriate naming were said by Linné to be the foundation of natural science, because it was by these that objects were distinguished and known.[83] Consequently, Linné endeavored to provide in the Systema naturae a suitable descriptive nomenclature for minerals. Since his denominations were based upon physical and chemical properties of minerals and were often not related to the commonly used names of the substances, it was necessary for him to include synonyms in order for his work to be understood and used. In addition to the specific name assigned to each kind of stone, Linné listed the common Latin name and the Swedish name of each.[84] This necessary synonymy weakened the effect of his proposed revision of nomenclature. Naturalists were understandably hesitant to forsake the familiar terms in favor of the more cumbersome, but more expressive names proposed by Linné. For example, Linné suggested that Judaicus lapis be renamed Helmintholithus echini articuli spiniferi and that

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[83] Linné, "Observationes in regna III. naturae," Systema naturae, observation 10.

[84] Linné, "Caroli Linnaei regnum lapideum," Systema naturae. Linné designated these names as: "Differentiae specificae Auctoris," "Synonyma," and "Nom. Svecica."

Cinnabaris nativa be replaced by Hydrargyrum rubro-tinctorium.[85] Linné's terminology was consistent with the mixed bases of his classification, which they reflected, but although his classification was widely used, most of his mineral names were not accepted.

Linné supplied a system for the mineral kingdom that distributed individual specimens into species, genera, orders, and classes. His arrangements were not proved by experience, nor could they be; they were intuited from slim empirical data. By means of a reasoned classification, Linné sought to explain what intuition told him were the natural relationships existing among mineral bodies. His assumption of some sort of a progenitorial unity created by an omnipotent and omniscient being[86] made it necessary for all mineral bodies to be related in some way. There was not, however, any necessity to attach a greater taxonomic value to any one character. Linné attempted to distinguish the least variable characters, which he postulated as essential, then he constructed his classification upon them. He discarded color, medicinal use, and taste as of little importance, and he adopted chemical behavior as one of the more fixed characters.

Linné, of course, was influenced in his choice of characters of classification by his predecessors. The ideas of Woodward, Bromell,

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[85] Ibid. In Linné's classification Judaicus lapis is a species of the genus Helmintholithus, order Petrificata, class Fossilia; Cinnabaris nativa is a species of the genus Hydrargyrum, order Mercurialia, class Minerae.

[86] Linné, "Observationes in regna III. naturae," Systema naturae, observation 4: "cum unitas in omni specie ordinem ducit, necesse est, ut unitatem illam progeneratricem, Enti cuidam Omnipotenti & Omniscio attribuamus, Deo nempe, cujus opus Creatio audit."

and others are evident in each class, several orders, and some genera. But Linné's system differs fundamentally from those of his forerunners; his is a reasoned, logically subdivided scheme, not a descriptive summary of minerals grouped according to generally accepted notions of how they should be arranged.

A younger contemporary of Linné and, like him, a professor at Uppsala was Johan Gottschalk Wallerius. Following in the footsteps of Bromell and Linné, Wallerius prepared a systematic treatment of the materials of the mineral kingdom based upon a mixture of physical and chemical characters. His book, entitled Mineralogia, eller Mineral-Riket,[87] was described by Nils Zenzén as "a summary of the whole mineralogical knowledge of the time."[88] Born in 1709, Wallerius studied at Uppsala, taught medicine at Lund, then returned to Uppsala in 1735 as a lecturer in medicine. As a member of the medical faculty, Wallerius taught physiology and anatomy, but he was also interested in chemistry and mineralogy. In pursuit of these interests he set up his own chemical laboratory, where he carried out experiments and lectured on chemistry, assaying, and mineralogy.[89] In 1750 Wallerius was appointed to a newly created professorship of chemistry at Uppsala, and he served in that capacity until 1767 when failing health necessitated his retirement.

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[87] E.g., Johan Gottschalk Wallerius, J. H. N. Mineralogia, eller Mineral-Riket (Stockholm: Uplagd på Lars Salvii egen kostnad, 1747).

[88] Nils Zenzén, "Johan Gottschalk Wallerius (1709-1785); Axel Fredrik Cronstedt (1722-1765)," Swedish Men of Science, 1650-1950, ed. Sten Lindroth (Stockholm: The Swedish Institute/Almqvist & Wiksell, 1952), p. 103.

[89] Ibid., pp. 93-94.

He spent his remaining eighteen years in the country where he continued his natural historical studies and writing.[90]

First published in Swedish, Wallerius's Mineralogia was soon translated into German,[91] French,[92] and Russian.[93] Between 1772 and 1775 Wallerius issued a revised and expanded edition of his mineralogy, this time in Latin.[94] In the foreword he said that his book could serve as a practical determinative text and also as a review of the extent and cultivation of the field of mineralogy.[95] He briefly recounted in chronological order the mineralogical accomplishments of some of his

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[90]Ibid., p. 95. See also James Riddick Partington, A History of Chemistry (London: Macmillan & Co., Ltd., 1961--), III, 169-72; and Nils Zenzén, "Johan Gottschalk Wallerius' Självbiografi," Lychnos (1953), pp. 235-59.

[91]The first German edition was published in 1750; a second edition was published in 1763. See Christian Gottlob Kayser, Vollständiges Bücher-Lexicon enthaltend alle von 1750 bis zu Ende des Jahres 1832 in Deutschland und in den angrenzenden Ländern gedrückten Bücher (Leipzig: Verlag von Ludwig Schumann, 1834-1836), VI, 144; Georges Cuvier, "Wallérius (Jean Gottschalk)," Biographie universelle, ancienne et moderne, ou histoire, par ordre alphabétique, de la vie publique et privée de tous les hommes qui se sont fait remarquer par leurs écrits, leurs actions, leurs vertus et leurs crimes (Paris: Chez Michaud, 1811-1828), L, 127-29; and British Museum General Catalogue of Printed Books, CCLII, cols. 290-91.

[92]The first French edition was published in 1753; it was reissued with a new title page in 1759. Ibid., col. 290.

[93]According to Zenzén, Swedish Men of Science, p. 95.

[94]The Latin edition was corrected and published as a second edition in 1778. British Museum General Catalogue of Printed Books, CCLII, col. 291.

[95]Wallerius, p.)(2 recto: "Andamålet är; endels, at de aldeles okunnige må kunna deraf lära känna och skilja Jord, Stenar och Malmer, det ena slaget ifrån det andra, samt i kårthet få veta hvad vid dem är, at observera; endels, at kårteligen föreställa, huru mycket i desse saker kan redan vara kunnigt."

Swedish predecessors,[96] then mentioned a few who had written more specialized works.[97] He dispatched all other writers on mineralogy in a sentence: "Alla desse [i.e., the Swedish naturalists that he mentioned], och än flere utländske, hafva banat en god och jämn väg til detta Mineralogiska arbetet."[98]

True to his age, Wallerius claimed to have approached mineralogy empirically. He said that he made use of tests in fire and water, correcting here and there his predecessors' work and in places going beyond them.[99] He particularly acknowledged the helpfulness of the work of Daniel Tilas, and set forth his wish that his own work would encourage others to seek out mineralogical knowledge so that in time the area would be even better illuminated.[100] He pointed out that many should engage in the work because "ens mans flit och ålder är icke tilräckelig at <u>examinera</u> alla Mineraliska kroppar, ej eller stå de på et ställe at finna."[101]

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[96] He included Sigfrid Aron Forsius (died 1637), Urban Hiärne, Magnus von Bromell, Emanuel Swedenborg (1688-1772), Carl von Linné, Daniel Tilas (1712-1772), and Eberhard Rosen (1706-1773). <u>Ibid</u>., pp.)(2 <u>recto</u>-)(3 <u>verso</u>.

[97] E.g., Eric Odelstierna (1661-1704) who wrote on quicksilver and Kilian Stobaeus (1690-1742) who wrote on figured stones and petrifactions. <u>Ibid</u>., pp.)(3 <u>verso</u>-)(4 <u>recto</u>.

[98] <u>Ibid</u>., p.)(4 <u>recto</u>: "All these [i.e., the Swedish naturalists that he mentioned], and many more foreigners, have prepared a good and smooth way for this mineralogical work."

[99] <u>Ibid</u>., "Dessutom, har jag ock <u>communicerat</u> de <u>Mineralogiska</u> begrep jag ägt, med dem, som äga mycken förfarenhet i Bärgssaker."

[100] <u>Ibid</u>.

[101] <u>Ibid</u>., p.)(4 <u>verso</u>: "One man's diligence and lifetime is not sufficient to examine all mineral bodies, nor do they exist to be found in one place."

He cautioned that there was much yet unknown, and that his work was by no means the ultimate study of mineralogy:

> At alla Arter af Jord, Sten, Malmer och Stenhårdningar, här skulle finnas upräknade, må väl ingen tro, fast jag användt all möda, at sammanleta [sic] dem; än mindre, at alla Variationer och ändringar skulle finnas här nämde. Annu är mycket härutinnan obekant, som framtiden lärer väl frambringa i dagsljuset.[102]

That his scheme of subdivision was mixed, using both chemical and physical characters to determine subdivisions, was recognized by Wallerius and defended on the basis of greatest usefulness of the classification. He implied that usefulness, rather than logical rigor was the more important determining factor in establishing a mineral classification, for a purely descriptive treatment or a purely logical classification do not serve man's needs.[103] An important step was his specific exclusion of descriptive material relating to mineral uses, which he said could be found in many other books:

> De bekantaste nyttigheter i hushollningen, Medecin, Bärgsväsendet, af de upräknade Mineralier, äro, at undvika mycken vidlöftighet, förbigångne, emedan de kunna läsas och finnas i de förr nämde Svenske böcker.[104]

As to terminology, he said that he tried to follow a middle course, using clear and simple terms, some derived from mining terms,

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[102] Ibid.: "That all kinds of earth, stone, mineral and concretions, should be found enumerated here, no one may well believe, although I applied all pains to bring them together; even less, that all variations and alterations should be found named here. As yet, much in this respect is unknown that the future no doubt is likely to bring forth into daylight."

[103] Ibid., p.)(4 verso.

[104] Ibid., pp.)(4 verso-a5 recto: "The known usefulness in housekeeping, medicine [and] mining, of the enumerated minerals, is, to avoid much prolixity, left out, because they can be read and found in the above mentioned Swedish books."

but in all cases he sought unambiguous terms.[105] The usefulness and clarity of his work was considerably enhanced by Wallerius's inclusion of Latin equivalents for the Swedish designations of his divisions.

Wallerius clearly and admittedly relied heavily upon the systematic work of his predecessors, particularly Linné. Following the pattern set by Linné, Wallerius used four levels of subordination; thus, he distributed minerals into species, genera, orders, and classes.[106] Wallerius grouped all the productions of the mineral kingdom into four classes (_flocken_). The first class, _Jordarter_, contains mineral bodies that consist of loose parts that are insoluble in oil and water, but are softened by them. Furthermore, Wallerius held that the _Jordarter_ were composed of the same kind of elementary materials that were the constituents of members of the second class, which he called _Stenarter_ (i.e., stones).[107] _Stenarter_ are described as densely compacted fine particles that can not be dissolved by oil or water, nor softened by them. When melted and then allowed to solidify, _Stenarter_ are said to display a hollow or concave surface.[108] _Malmarter_, the third class, are

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[105] _Ibid._, p. a5 _recto_.

[106] See Appendix VIII for a synopsis of Wallerius' classification scheme.

[107] _Ibid._, pp. 3-4: "Jordarter äro _mineraliska_ kroppar, som bestå af löst eller icke sammanhängande delar, hvilka hvarken i ollja eller vatten uplösas; men väl upmjukas kunna, af hvilka ock stenarna fit grund-ämne hafva."

[108] _Ibid._, p. 4: "Stenarter äro faste och til sina delar hårdt samman satte kroppar, hvilka ock intet inneholla något som i vatten eller ollja kan uplösas; kunna ej eller af dem upmjukas. När desse smältas, så stelna de med en ingröpt eller _concav_ och vidlådande _Superficies_, och är då den smälte _massan_ lättare, än den rå stenen."

earths or stones that contain either salt, sulphur, or metal (either semi-metal or metal "properly so-called"). They can be dissolved either in water or oil, and they solidify with a convex surface after having been melted. The final characteristic feature of the class is the heaviness of each member; all are heavier than stone or earth.[109] The fourth class, Stenhårdningar, which includes all fossils, is composed of disrupted and reconsolidated earths, stones, or minerals, and of objects that are produced in an unusual place or generated by a caprice of Nature.[110]

The parallels between Wallerius's and Linné's treatment of the mineral kingdom are evident at many points, but particularly in Wallerius's Class II, Stenarter, is there a close relationship to Linné's Class I, petrae. Wallerius characterized the members of the class Stenarter, which he postulated were "hårda och til sina delar hårdt sammanhängande kroppar,"[111] in the following way:

> 1) Kunna de ej lätteligen med fingren rifvas eller med knif skäras, och endel icke ens med Stålfil rifvas.
> 2) Äro de allesamman sköra och bräckeliga, och kunna hvarken hamras eller sträckas.
> 3) Så litet som de i vatten mjukna, så litet kunna de ock der uplösas.

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[109] Ibid.: "Malmarter äro jordarter eller Stenarter hvilka inneholla antingen Salt, Svafvel, half eller hel metall, det är, något som antingen i vatten eller ollja kan uplösas, eller som efter smältning stelnar med en convex Superficies, och är tyngre än sten eller jord."

[110] Ibid." "Stenhårdningar kallas de mineralier, jord- sten- eller malm-arter, som efter förstöring och sammanblandning, åter äro samman vuxne; eller som på ovanliga ställen, eller i ovanligt lynne frambringas."

[111] Ibid., p. 38: "hard and also its parts hard coherent bodies."

4) Kan icke eller i Olja någon sten blifva hvarken hårdare eller mjukare.[112]

Four orders (afdelningar) of stones were distinguished by Wallerius. The order Kalkarter comprises those genera (slägter) that when burned, fall into dust (i.e., they calcined); also, they do not strike fire with steel.[113] The order Glasarter is composed of stones that melt when subjected to fire. They are usually hard, therefore, strike fire with steel. They do not react with acids.[114] The order Eldhärdningar are those stones that withstand strong heating without changing; they are usually brittle, do not strike fire with steel, and most of them do not effervesce with acids.[115] From the descriptions of the group characteristics and a comparison of the species included in each group by Linné and by Wallerius, one can see that Wallerius's order Kalkarter is equivalent to Linné's order calcarii, that the order Glasarter is equivalent to the order vitrescentes, and that Eldhärdningar is equivalent to

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[112] Ibid.: "1) They can not be scratched easily with fingers or be cut with a knife, and none [can] be scratched with a steel file. 2) They are all brittle and fragile, and can neither be hammered nor stretched. 3) As some soften in water, so some can also be dissolved there. 4) Nor in oil can any stone become either harder or softer."

[113] Ibid., p. 39: "Kalckarter kallas de stenar, som i elden brände falla sönder til stoft, hvilket åter på åtskilligt sätt blandadt med vatten eller annat, antager en ny hårdnad; äro ock så löse, at de emot stål slagne gifva ingen eld ifrån fig."

[114] Ibid., p. 66: "Glasarter kallas de stenar, hvilka i elden smälta och gå til glas; äro ock merendels så hårde, at de emot stål slagne gifva eld; åtminstone äga de endera af desse egenskaper; men ingen af dem gäser med Skedvatten, eller någon annan skarp Spiritus."

[115] Ibid., pp. 128-29: "Eldhärdningar kallas de stenar, som uthärda svår eld, utan at gå i glas eller kalk; äro merendels så löse och sköre, at de ej gifva någon eld emot Stål; gäsa ock icke med Skedvatten eller någon annan sur Spiritus, några undantagande."

apyri. Wallerius's fourth order of stones, Hällebärgsarter, for which there is no equivalent order in Linné's class petrae, are common stones. Today one would designate them rocks. Wallerius defined them in this way: "Hällebärgsarter äro de stenar, hvilka af de förre och beskrefne Stenarter sammansatte äro, och af hvilka i gemen alla bärg och fjäll beståå, hvarifrån, sedermera, de på marken liggande löse stenar, som gemenligen kallas antigen Grâstenar eller klapur, äro genom hvarjehanda tilfällen lösrefne och kringspridde."[116]

Wallerius divided each of his four classes into four orders; the resulting sixteen orders contained sixty-seven genera into which four hundred seventy-nine species of minerals were distributed. Linné had recognized fifty genera which contained one hundred sixty species and two hundred forty-two varieties. Linné's descriptions of his classificatory groups were concise, often limited to one main characteristic. Wallerius, on the other hand, attempted to record all of the variety of physical and chemical properties that could be utilized in the identification of a given mineral. In general, chemical properties were used to distinguish orders, and distinction of species was based upon external characters. The characteristics of genera were a combination of both physical and chemical properties.

Wallerius tabulated the distinctive characteristics of each genus, just as he had carefully listed the characteristics of each class

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[116] Ibid., p. 147: "Hällebärgsarter are stones, which are composed of the former and described Stenarter, and of which in general every hill and mountain consists, from which, then, those stones lying on the ground loose, that commonly are called either graystones or rubblestones, are torn off through various occasions and spread around."

and order. For example, the genus Kalksten contained individuals with the following characters:

> 1) Particlarne i kalkstenar äro små, och kan ej synnerligen märkas någon viss figur, annat än såsom gnistror och små fjäll.
> 2) Då desse stenar brytas och slås sönder, falla de i ovissa stycken och kanter.
> 3) Är väl all kalksten hård, men dock med jern eller fil lätteligen rifvas; tager ock icke gerna an politure; hyser ock icke rena eller vackra färgor.
> 4) I Luften förvittrar han af sig sjelk sönder, och förfaller under bar himmel; den ena arten mer och den andra mindre; dock, ju finare art desto snarare förfaller den.
> 5) I elden bränd och calcinerad, drar sedan stark vätska til sig; hettas deraf, och förfaller af sig sjelf i luften til stoft; äfven i elden calcinerad, gifver med Salmiaks Spiritus en urinös lukt.
> 6) Med skedvatten och andra skarpa Spiritus gäser han starkt, fast än han är rå och obränd.
> 7) Des gravitas specifica är til vatten som 2,810::100 [sic] eller 2,81::100.[117]

At the generic and specific levels, Wallerius included a synoptic synonymy. For Kalksten, he said: "CALCAREUS. Marmor fusaneum. Dioscor. Marmor rude. Linn. Saxum Calcareum. Agric."[118] The first term, "CALCAREUS," indicated the Latin equivalent of the Swedish generic designation (i.e., Kalksten); the other terms were synonyms inferred by Wallerius from the works of various authors, in this case of Dioscorides,

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[117]Ibid., pp. 39-40: "1) Particles in calcareous stones [i.e., limestone] are small, and any definite figure can not particularly be observed, other than by way of sparkles and small scales. 2) When these stones are broken and smashed up, they fall into indefinite pieces and edges. 3) All carcareous stones are quite hard, but nevertheless are easily scratched with iron or a file; [they] also do not easily take a polish; also do not contain pure or pretty colors. 4) In air it crumbles away, broken of itself, and decays beneath bare sky; one kind more and another less; however, the finer kind decays so much sooner. 5) Burnt and calcined in fires, then [it] draws liquid to itself strongly; being heated thereby, and decays of itself in air to dust; also calcined in fires, gives with Salmiaks Spiritus a smell of urine. 6) With aqua fortis and other strong spirits it effervesces strongly, even though it is raw and unburned. 7) Its specific gravity is to water as 2,810::100[0] or 2,81::100."

[118]Ibid., p. 39.

Linné, and Agricola. Similarly, he gave Latin equivalents and previously used designations for the species that he listed. However, in presenting synonyms, cast into his classificatory framework, Wallerius imposed his order upon the work of his predecessors. He imposed an order that was not present in their work.

The concise descriptions of species used by Wallerius were intended to help in properly identifying, hence categorizing, a specimen. The species Tät Kalksten, for example, was described as "en så tät och jämn kalksten, at des particlar med blåtta ögonen ej kunna skönjas än mindre ifrån hvarandra skiljas; bryter sig ofta i concava och convexa stycker, och kan då ej annars än antigen med eldstål, eller fil, eller Skedvatten skiljas ifrån en grof flinta."[119] Found occurring in many colors, the species was subdivided into varieties on the basis of color. Thus, there was hvit tät kalksten, grå tät kalksten, mörkgrå tät kalksten, brun tät kalksten, röd tät kalksten, grön tät kalksten, svart tät kalksten, and ådrig och randig tät kalksten.[120] Superfluous information was included, but it was relegated to appended annotations.

Although Wallerius's work was not an innovation, it was at least a departure from previous works. He incorporated logical rigor such as exemplified in Linné's work, and he also utilized general chemical

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[119] Ibid., p. 40: "a very dense and smooth calcareous stone [i.e., limestone], that its particles can not be discerned even less be separated from one another with a naked eye; [they] often break into concave and convex pieces, and then can not be distinguished from a rude flint even with fire-steel, file, or aqua fortis."

[120] Ibid., pp. 40-41: white dense-limestone, gray dense-limestone, dark gray dense-limestone, brown dense-limestone, red dense-limestone, green dense-limestone, black dense-limestone, and veined and ribbed dense-limestone.

principles to guide his divisions into orders.[121] Having had experience in mining matters, Wallerius had an eye for what properties or information would be useful in the identification of minerals. Throughout his work recurs the idea that a classification should serve as an instrument for determination. He thought that his system could be used as a determinative scheme in order to discriminate and name unknown minerals without description and without previous practical knowledge of mineral substances, he hoped a student would be able to identify minerals by using his Mineralogia. Consistent with this goal, Wallerius supplied concise, abstract descriptions and a more precisely-used terminology. He was still thinking in qualitative terms, however; chemical tests, color, hardness, and other observable properties were described inexactly and qualitatively.

On the whole, Wallerius's scheme represented a refinement of the work of earlier writers. His work was a welcome addition to the growing literature of systematic mineralogy because of his careful attention to definition and concise description, but there were drawbacks to his mineral system. Wallerius's terminology was often vague and he did not break away from the traditional view that all inorganic terrestrial productions--minerals, rocks, fossils--should have a niche in a mineral system. It was reserved to Axel Fredrik Cronstedt, a countryman of Wallerius, to more narrowly circumscribe the mineralogist's purview.

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[121]Except for the subdivision into orders of the fourth class, Stenhårdningar.

CHAPTER IV

MINERAL CLASSIFICATION ON THE BASIS OF CHEMICAL PROPERTIES

The mid-eighteenth century trend toward formulating mineral systems in terms of chemical principles, rather than external characters, is reflected in the Encyclopédie of Denis Diderot (1713-1784):

> Mais se seroit en vain qu'on se flatteroit que le coup d'oeil extérieur pût donner des connoissances suffisantes en Minérologie; l'on n'auroit que des notions très-imparfaites des corps, si on n'en jugeoit que par leur aspect & par leurs surfaces . . . ce sont les analyses & les expériences de la Chimie que seules peuvent guider dans ce labyrinthe. . . .[1]

> L'Histoire naturelle des minéraux comprend encore l'énumeration de leurs usages & de leurs propriétés; mais leur définition exacte ne peut se faire que par le moyen de la Chimie.[2]

The reason for Diderot's emphasis on chemistry is best explained in his words: "L'histoire naturelle doit avoir pour object l'utilité de la société, il faut avoir une connoissance des qualités internes des

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[1]"Minérologie," Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, par une société de gens de lettres (Paris: Chez Briasson, David l'aîné, Le Breton, Durand [Vols. 8-17 have Neufchastel: Chez Samuel Faulche & Compagnie], 1751-1765), X, 542: "But it will be in vain that one will hope that the exterior appearance can give sufficient knowledge in mineralogy; one would only have some very imperfect notions of the bodies, if one judged them only by their look and their surfaces . . . it is analyses and chemical tests which alone can guide in this labyrinth. . . ."

[2]"Histoire naturelle," Encyclopédie, VIII, 228: "The natural history of the minerals includes moreover the enumeration of their uses and their properties; but their exact definition can only be made by means of chemistry."

substances minérales, pour savoir les usages auxquels ils peuvent être employés; & ce n'est que la Chimie qui puisse procurer cette connoissance."[3]

Although emphasizing the value of chemistry in mineralogy, Diderot did not completely reject the value of using external characters for identification, but he thought that the study of them was unfruitful because "il est constant que le coup d'oeil extérieur ne suffit point pour nous faire connoître les corps du regne minéral . . . ."[4] He concluded that "il est très-difficile de trouver un ordre méthodique qui présent les <u>minéraux</u> sous ces différens points de vûe à la fois; il y a même peu d'espérance que l'on puisse jamais concilier ces deux choses. Cependant, il ne paroît point que l'on soit en droit pour cela de rejetter tout ordre systématique, ou toute méthode. . . ."[5] He knew, however, that it was fruitless to search for a natural order, since all systems in natural history are arbitrary, and he demonstrated this philosophical sophistication in regard to the formation of systems in the article "Histoire naturelle":

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[3]"Minéraux," <u>Encyclopédie</u>, X, 544: "natural history ought to have the benefit of society for [its] aim, it is necessary to have a knowledge of the inward qualities of mineral substances, in order to know the uses to which it can be employed; and it is only chemistry which is able to procure this knowledge."

[4]<u>Ibid</u>.: "it is an established fact that the exterior appearance does not suffice for us to know the bodies of the mineral kingdom. . . ."

[5]<u>Ibid</u>.: "it is very difficult to find a methodical order which presents <u>minerals</u> under these different points of view all at once; there is little hope that one can ever reconcile these two things. However, it does not appear that one in fact is to reject on account of that systematic order, or all method. . . ."

> Le chef-d'oeuvre de l'esprit humain est de combiner les faits connus, d'en tirer des conséquences justes, & d'imaginer un système confome aux faits. Ce système paroît être le système de la nature, parce qu'il renferme toutes les connoissances que nous avons de la nature; mais un fait important nouvellement découvert change les combinaisons, annulle les conséquences, détruit le système précédent, & donne de nouvelles idées pour un nouveau système, dont la solidité dépend encore du nombre ou de l'importance des faits qui en sont la base.[6]

Some of the ideas expressed by Diderot were gleaned from works such as those of Hiärne, Bromell, Linné, and Wallerius, who had presented mineral systems based upon a mixture of physical and chemical principles. There were others during the first half of the eighteenth century, however, who approached the study of minerals in a more exclusively chemical way. Among these were the chemists Johann Friedrich Henkel (1679-1744), Johann Heinrich Pott (1692-1777), Johann Lucas Woltersdorf (1721-1772), and Axel Fredrik Cronstedt.

Henkel, a physician and director of mines in Freiberg, had an extensive practical knowledge of mineralogy. He shared with many of his contemporaries an interest in analyzing mineral waters, but is particularly well-known for his Pyritologia[7] and for his chemical studies

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[6]"Histoire naturelle," Encyclopédie, VIII, 229: "The principal work of the human mind is to combine known facts, to extract from them some sound consequences, and to imagine a system conformable to the facts. This system appears to be the system of nature, because it includes all the knowledge that we have of nature; but an important newly discovered fact changes the combinations, annuls the consequences, destroys the preceding system, and gives new ideas for a new system, whose soundness depends once more on the number or importance of the facts which are the basis of it."

[7]Johann Friedrich Henkel, Pyritologia Oder Kiess-Historie, Als des vornehmsten Minerals, Nach dessen Nahmen, Arten, Lagerstätten, Ursprung . . . (Leipzig, 1725). Citation from James Riddick Partington, A History of Chemistry (London: Macmillan & Co. Ltd., 1961--), II, 706. The work appeared in English in 1757 under the title Pyritologia, or a History of the Pyrites, the Principal Body in the Mineral Kingdom (London: Printed for A. Millar and A. Linde, 1757).

of various metallic ores. Henkel rejected innate physical properties as a basis for a primary division of minerals. Instead, he related minerals on the basis of their composition and refractoriness. His Idea generalis de lapidum origine, published a year before Linné's Systema naturae, discussed a theory of the origin of stones. From observations and experiments, Henkel thought one could reduce the explanation of the generation of stones to five operations: congelatio, coalescentia, germinatio, crystallisatio, and petrificatio.[8] In discussing the empirical basis of his theory, he said that stones could be divided into four groups depending on their behavior in fire. The groups consisted of these stones that were unchanged by fire (permanentes), hardened by fire (indurescentes), calcined by fire (pulverabiles), and fused by fire (fusiles).[9] Furthermore, he thought that testing with fire and water had proved that the essential substances (essentia hypostatica) of stones were clay (marga), chalk (cretacea), and metals (metallica). Some stones, he noted, were composed of an equal mixture of marga and cretacea; the examples of the latter that he gave were transparent gemstones such as ruby, sapphire, topaz, emerald, and diamond. He suggested that a variety of materials in smaller

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[8]Johann Friedrich Henkel, Joh. Friderici Henkelii, S. Regiae Poloniar. Majestatis et Electoris Saxioniae, Collegii Metallici Consiliarii, idea generalis de lapidum origine per observationes experimenta & consectaria succincte adumbrata (Dresdae & Lipsiae: In Officina Libraria Hekeliana, 1734), pp. 74-75: solidification, coalescence, germination, crystallization, and petrification.

[9]Ibid., pp. 54-56. See also Partington, II, 706-09; and E. H. M. Beekman, Geschiedenis der Systematische Mineralogie ['s Gravenhage, 1906(?)], pp. 33-34, for brief discussions of Henkel's work.

quantities, such as salt (<u>salina</u>) and sulphur (<u>sulphurea</u>), gave rise to the perceptible differences among stones.[10]

Henkel's mineralogical writings were published posthumously in 1747 by J. E. Stephanus in a work titled <u>Mineralogia redivivvs</u>.[11] The classification of terrestrial productions implied in this work can be represented as follows:[12]

- Water
  - Superterrestrial
  - Subterranean
- Earth juices
  - Dry
  - Fluid
- Salts
  - Acid
  - Alkaline
  - Neutral
- Earths
  - Refractory
  - Fusible
- Stones
  - Calcareous
  - Siliceous
  - Calc-siliceous
  - Argillaceous
- Metals

Though not entirely based on chemical principles, this classification is representative of the growing tendency among many authors to base their arrangements on similarities in behavior of the specimens when subjected to laboratory tests.

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[10]Henkel, <u>Idea generalis</u>, pp. 59-66.

[11]Johann Friedrich Henkel, <u>Henckelivs in mineralogia redivivvs, Das ist: Henckliśscher aufrichtig und gründlicher Unterricht von der Mineralogie oder Wissenschaft von Wassern, Erdsäfften, Saltzen, Erden, Steinen und Ertzten, Nebst angefügtem Unterricht von der Chymia Metallurgica . . .</u>, ed. J. E. Stephanus (Dressden [<u>sic</u>], 1747). Citation from Partington, II, 707.

[12]According to Beekman, p. 34.

Johann Pott, a noted chemist and convinced empiricist, at the behest of the King of Prussia, reportedly performed over thirty thousand laboratory tests in his search for the secret of Meissen porcelain.[13] His Chymische Untersuchungen, which resulted in part from his studies of porcelain clays, did not attempt a complete systematic description of the mineral kingdom, as it excluded metallic ores, fossils, and salts; but it did discuss earths and stones. Pott made an important break with tradition by regarding earths and stones as of the same type of materials, their apparent differences being entirely explained by the infinitely variable and indistinct property of hardness. Pott distributed the substances usually classed as earths and stones into four groups on the basis of their behavior in fire. He called the groups alkaline earths (terra alcalina, also calcaria), gypseous earths (terra gypsea), argillaceous earths (terra argillacea), and siliceous earths (terra vitrescibilis strictius sumta),[14] a subdivision that soon became a standard grouping among his successors.[15]

Unimpressed with the behavior of minerals toward "Chymischen Menstrua," Pott placed most weight on tests of a specimen's behavior

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[13]Partington, II, 718.

[14]Johann Heinrich Pott, Chymische Untersuchungen welche fürnehmlich von der Lithogeognosia oder Erkäntniss und Bearbeitung der gemeinen einfacheren Steine und Erden ingleichen von Feuer und Licht handeln (2d ed.; Berlin: bey Christian Friderich Voss, 1757), p. 3. The first edition, under the same title, was published in Potsdam in 1746. The second edition included the two supplements that were published in 1751 and 1754.

[15]E.g., Axel Fredrik Cronstedt, Johann Heinrich Gottlob von Justi (died 1771), and Giovanni Antonio Scopoli (1723-1788). Wallerius adopted this arrangement in part in the second edition of his Mineralogia published from 1772 to 1775.

when subjected to varying degrees of heat.[16] That he noted the results in terms of a compositional difference, rather than simply in terms of the physical effects of heat, as had Henkel before him, signifies that Pott had a more generalized conception of mineral substances. Whereas Henkel spoke of a class of materials that were fused by fire (fusiles), Pott postulated a compositional unity for such fusible materials, and identified that unity by classing such materials under the head gypseous earths (terra gypsea).

Having broken away from classifying earths and stones on the basis of apparently important external characters, Pott had provided a new mode of framing certain classificatory groups. According to his chemical point of view, groups should be established on the basis of compositional principles. Although not a totally new idea, since salts and most metallic ores had been separated according to their more obvious chemical differences by many naturalists, it was an innovation to arrange the traditionally termed earths and stones in this way.

Johann Woltersdorf, critical of current schemes of classification, set out to frame a mineral system that would embrace the whole mineral kingdom. Woltersdorf's scheme retained the distinction of earths and stones, but the subgroups of earths, stones, and salts were defined in chemical terms. Woltersdorf, however, lacked precision in his description of the group characters. Typical was his description of the class stones: "'Steine bestehen aus fest aneinander hängenden erdigen

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[16] Ibid., p. 2: "Das Feuer ist hierinn der beste analysta . . . ."

Theilen. Werden durch's Wasser nicht erweichet.'"[17] That stones were erdigen Theilen was his theoretical bias, not an empirically determinable character. Such a definition is useless for purposes of identification, one of Woltersdorf's primary objectives. His definition of the orders of stones was better; for example, he defined the class Glasartige as those stones that "'lassen sich von sauern Salzen . . . night auflösen, aber im Feuer am leichtesten au einem klaren Glase schmelzen; schlagen Feuer.'"[18] He employed a variety of physical properties to distinguish genera, but his genera were the traditional groups. The genus Edelstein, for example, was characterized this way: "'Hat gemeiniglich eine prissmatisch eckige, an Enden zugespitzte Gestalt, ist durchsichtig, lässt sich nicht feilen.'"[19] The genus Sandstein included specimens with no definite shape that were composed of fragments of quartz,[20] and Bimstein were pumiceous stones with a fibrous texture that floated on water.[21]

Axel Fredrik Cronstedt is today best-remembered for his

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[17]Franz von Kobell, Geschichte der Mineralogie von 1650-1860 ("Geschichte der Wissenschaften in Deutschland, Neuere Zeit," Bd. 2; München: J. G. Cottaschen, 1864), p. 64: "Stones consist of tightly adhering parts of earth. They do not become softened by means of water."

[18]Ibid.: "can not be dissolved by acids . . . , but in fire melts with ease to a clear glass; strikes fire."

[19]Ibid." "Commonly has a prismatic hexangular, pointed-at-the-ends shape, is transparent, cannot be polished."

[20]Ibid., p. 65: "'Hat keine bestimmte Gestalt, ist aus den Trümmern des Quartzes zusammengesetzt.'"

[21]Ibid.: "'Hat keine bestimmte Gestalt, ein faseriges Gewebe, ist voller Löcher, schwimmt auf dem Wasser.'"

discovery and naming of the metal nickel;[22] his contemporary fame, however, rested more upon his reputation as a mineralogist, which he gained in large part from the book Försök til Mineralogie published in 1758.[23] Cronstedt was born at Ströppsta in the province of Södermanland in Sweden in 1722. His parents were of a noble lineage and ample circumstances, which afforded young Cronstedt easy access to an education. In 1738 he went to the University of Uppsala; while there he studied chemistry and mineralogy under Wallerius. Rejecting a career as a military engineer, which his father had intended for him, Cronstedt in 1742 sought and obtained a position as an auditor at the Board of Mines. Independently he continued studying mining practice, metallurgy, and chemistry. In 1748 Cronstedt was appointed assistant inspector of mines

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[22]John Gilbert Dean, "Nickel," Encyclopaedia Britannica, 1962 ed., XVI, 423; "Chemistry," ibid., V, 367.

[23]Axel Fredrik Cronstedt, Försök til Mineralogie, eller Mineral-rikets upställning (Stockholm, 1758). Citation from British Museum General Catalogue of Printed Books (London: The Trustees of the British Museum, 1931--), XLV, col. 421. Concerning the reputation of Cronstedt's book, Gustav von Engeström (1738-1813) said in the translator's preface to Axel Fredrik Cronstedt, An Essay towards a System of Mineralogy, by Axel Fredric Cronstedt. Translated from the Original Swedish, with Notes, by Gustav von Engestrom. To Which Is Added a Treatise on the Pocket-Laboratory, Containing an Easy Method, Used by the Author, for Trying Mineral Bodies, Written by the Translator. The Whole Revised and Corrected, with Some Additional Notes, by Emanuel Mendes da Costa (London: Printed for Edward and Charles Dilly, 1770), pp. ii-iii: "The universal applause, and the favourable reception it met with in Sweden, made it soon known in Norway and Denmark. In the year 1760 it was translated into German, and was equally approved in Germany; nor, indeed, has it been unknown to the learned in England." William Whewell, History of the Inductive Sciences, from the Earliest to the Present Times (London: John W. Parker, 1837), III, 230, said: "Cronstedt's own Essay towards a System of Mineralogy, published in Swedish in 1758, had perhaps more influence than any other, upon succeeding systems."

in a silver-copper-iron mining district northwest of Stockholm in southern Sweden. As assistant inspector, Cronstedt undertook numerous journeys and mine inspection tours which broadened his already extensive knowledge of Sweden's mining industry. He also had access to a well-provided chemical laboratory, in which he carried out investigations that led ultimately to his discovery of the metal nickel. His descriptions of nickel were published in the journal of the Academy of Science in Stockholm in 1751 and 1754. During a leave of absence because of ill-health in 1757, Cronstedt drafted the manuscript for his Försök til Mineralogie, which was published anonymously the following year. That same year he was promoted to inspector of mines, but his interest in mineralogy and chemistry soon began to flag. For the remaining few years of his life his attention was directed towards the practical and economic applications of botany. In 1765, after a brief illness, Cronstedt died at the age of forty-two.[24]

Cronstedt's Essay is an attempt to present a mineral system based on chemical theory and practice. In his preface Cronstedt credited Hiärne and Bromell with initiating the use of chemical principles in classifying minerals, and he said that their work served as models for the systems of Linné and Wallerius.[25] Cronstedt saw a departure from this mixed approach in the work of Pott and Woltersdorf:

> Mr. Pott, a chemist by profession, and consequently inclined rather to believe the effects of his experiments, than the external

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[24]Nils Zenzén, "Johan Gottschalk Wallerius (1709-1785); Axel Fredrik Cronstedt (1722-1765)," Swedish Men of Science, 1650-1950, ed. Sten Lindroth (Stockholm: The Swedish Institute/Almqvist & Wiksell, 1952), pp. 97-102.

[25]Cronstedt, Essay, pp. viii-ix.

> appearances alone, proceeded farther than was customary before his time, in the assaying of stones by fire, and afterwards published his acquired knowledge by the title of Lithogeognesia. . . . Mr. Woltersdorff, a disciple of Mr. Pott, then begun immediately to form an entire mineral system, founded upon chemical experiments; but his master did not approve of it, still insisting that materials were yet wanting for the purpose; and that every mineral body ought first to be examined and tried with the same care that he had tried and examined the most simple of them; to wit, the Earths and Stones.[26]

In his own work, Cronstedt attempted to extend the chemical-empirical approach of Pott and Woltersdorf to all minerals.

The Essay began with a definition of what the mineral kingdom was:

> The Mineral Kingdom contains all those bodies which have been formed under the surface of our earth, whether at the first creation, or any other time since that period; and which are still daily produced from their original or primary principles, being destitute of seed, life, or any circulation of fluids.[27]

Cronstedt apologized for the nebulosity of this definition in a footnote:

> The limits between the three acknowledged kingdoms of Nature are almost impossible to be ascertained; whence arises the difficulty of giving any true definition of them: and indeed it may be questioned, whether any such definition can take place, when we become so far advanced in knowledge, as to see clearly the dependence and connexion of all natural bodies into one regular Chain or System.[28]

In his definition and accompanying explication, Cronstedt postulated three essential conditions of mineralness (i.e., of being a mineral). First, minerals are subterranean productions. He did not stipulate that all mineral bodies were formed at one time; on the contrary, he said that

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[26] Ibid., p. ix.

[27] Ibid., p. [1].

[28] Ibid., p. [1, note].

minerals could be in process of forming at the present time. Second, mineral bodies are produced from primary or original matter, as opposed to the derived matter that composes plants and animals. Third, minerals lack all attributes of life. He explained that minerals were "deprived of those wonderful and incomprehensible qualities of life and vegetation, the properties of the animal and vegetable kingdoms."[29]

A major defect of the foregoing theory was the lack of any explanation of the origin or generation of stones. Cronstedt postulated that minerals were not like plants or animals and could not, therefore, arise as they did. But this is a negative assertion; it only says how minerals are not formed, not how they are formed. Having made the assertion, Cronstedt tried to support it by suppositions as to how minerals might form. He suggested that a mechanical process of precipitation might account for the generation of stalactites and native or virgin metals:

> The water carried along with it the invisible particles of lime, copper, or silver, and deposits them upon other subjects, either by means of an attractive power in these, or by some alteration in itself, occasioned by its motion.[30]

He set forth a few other ideas, then, attempting to forestall his critics, he suggested that such considerations were not appropriate to his work: "To enumerate the many different ways of generation, which we have any reason to suspect, does not properly belong to this work; besides, it

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[29] Ibid., p. 2.

[30] Ibid., p. 4.

would carry me too far from my subject, and might also surpass my capacity to explain."[31]

In defining minerals, Cronstedt set forth postulates that significantly deviated from the traditional discussions about the inorganic _growth_ of minerals. For example, a decade before the _Essay_ was published, Wallerius defined minerals in this paradoxical way:

> Mineralier, som ock kallas _underjordiska_ _kroppar_, _Fossilia_, _Mineralia_, åro de kroppar, som växa utan lif, och utan någon i rör och ådror innesluten synlig saft. Finnas mäst i jordenes sköt, dock understundom ock annorstädes.[32]

In effect, he said minerals are bodies that grow, but they do not grow; they occur in the earth, but they occur elsewhere. He operated for the most part from the unstated premise that everyone knew what a mineral was anyhow. Cronstedt tried to define what was included as minerals in his system, but his definition was of little help in understanding the essence of _mineralness_. Having failed to explicitly define a mineral, Cronstedt launched into the detailed account of minerals.

In the _Essay_ four classes of mineral bodies were recognized: earths, inflammables, salts, and metals. Cronstedt defined earths as "those mineral bodies, not ductile, for the most part not dissoluble in water or oils, and that preserve their constitution in a strong heat," and he arranged them "according to their constituent parts, as far as

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[31] _Ibid_., p. 5.

[32] Johann Gottschalk Wallerius, _J. H. N. Mineralogia, eller Mineral-Riket_ (Stockholm: Uplagd på Lars Salvii egen kostnad, 1747), p. [1]: "Minerals, which are also called _underjordiska kroppar_, _Fossilia_, [and] _Mineralia_, are those bodies that grow without living, and without some visible juice enclosed in tubes and veins. Most are found in the earth's bosom, yet at times also in other places."

hitherto discovered," into nine orders.[33] By the term earths, Cronstedt did not simply mean to imply the usual friable materials that were called earths; rather, he meant <u>all minerals</u> that met the physical and chemical specifications which he set up. Thus, those minerals more generally called stones and grouped apart from earths were included in Cronstedt's first class.

In merging minerals traditionally classified as earths or stones, Cronstedt was re-echoing the claim of Johann Pott that the old classification was unjustified. Faithful to empiricism, Cronstedt contended that chemical tests had shown earths and stones to "consist of the same principles" and "are by turns converted from one into the other, insomuch that an earth may in length of time become as hard as a stone, and *vice versa*. . . ,"[34] thereby justifying their inclusion under the same class.

Concerning the ultimate constituents of all earths, Cronstedt repeated the view of Henkel: "We have strong reasons to believe that the calcareous and argillaceous earths are the two principal ones, of which all the rest are compounded, although this cannot yet be perfectly proved to a demonstration."[35] Because the state of the chemical art was not sufficiently advanced to confirm (or deny) his theory, however, Cronstedt found it necessary to recognize nine kinds of earth, each of which was designated as an order of the class earths.[36] For each of these

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[33]Cronstedt, *Essay*, p. 9.

[34]*Ibid*., p. xiii.

[35]*Ibid*., pp. xvii-xviii.

[36]See Appendix XII for a synopsis of Cronstedt's classification scheme.

orders, Cronstedt enumerated several group characters. Although briefer than several descriptions, the characterization of the fifth order, micaceous earths, is typical of his use of chemical and physical properties:

> 1. Their texture and composition consist of thin flexible particles, divisible into plates or leaves, having a shining surface.
> 2. These leaves, or scales, exposed to the fire, lose their flexibility, and become brittle, and then separate into thinner leaves: but in a quick and strong fire, they curl or crumple, which is a mark of fusion; though it is very difficult to reduce them into a pure glass by themselves, or without addition.
> 3. They melt pretty easily with borax, the microcosmic salt, and the alcaline salt; and may, by means of the blow-pipe, be brought to a clear glass, with the two former salts. The martial [iron-containing] mica is, however, more fusible than the uncoloured ones.[37]

From his descriptions of the group characters of the several orders of earths, it is evident that Cronstedt emphasized a chemical-experimental approach to the study of minerals, but he did not completely deny the usefulness of external properties. Therefore, in addition to a variety of docimastic tests, he included relative hardness, transparency, luster, texture, flexibility, brittleness, and heaviness among the diagnostic characters for one or more orders.

Cronstedt defined his second class, salts, as "those mineral bodies . . . which can be dissolved in water, and give it a taste; and which have the power, at least when they are mixed with one another, to form new bodies of a solid and angular shape, when the water in which they are dissolved is diminished to a less quantity than is required to keep them in solution; which quality is called Cristallisation."[38]

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[37] Ibid., p. 104.

[38] Ibid., pp. 126-27.

However, he had no intention of admitting into a mineral system all the substances known to chemists that would satisfy the above conditions: "No other salts ought to be considered and ranked in a mineral system, but those which are found natural in the earth; and for this reason a great number of salts will be in vain looked for here, viz. all such as are either natural or prepared by art in the other two kingdoms of nature, and from substances belonging to them."[39] He directed those who were interested in more information on salts to chemistry books: "The perfect knowledge of these bodies must be had from chemical books and practical chemistry, being almost the chief subject of that science."[40]

The salts are divided into two orders: acid salts (<u>salia acida</u>) and alcaline salts (<u>salia alcalina</u>). Acid salts have a sour taste, are corrosive (i.e., have "a power of dissolving a great number of bodies"),[41] are attracted to and united with alcaline salts and earths, change "blue juices of vegetables into red,"[42] separate alcali from fat when united in soap, and are volatile and subtile.[43] This last character, Cronstedt said, prevented their being known in the pure state. Cronstedt identified two pure acid salts: vitriolic acid (i.e., sulphuric acid) and acid of sea-salt (i.e., muriatic acid). He did not explain why these were considered as salts when they did not form "bodies of a solid and

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[39] <u>Ibid</u>., p. 127, note.

[40] <u>Ibid</u>., p. 149.

[41] <u>Ibid</u>., p. 127.

[42] <u>Ibid</u>., p. 128.

[43] <u>Ibid</u>., pp. 127-28.

angular shape"[44] as required of salts by his definition; he only referred the reader to "chemical books" in order to "learn why the acids are considered as salts."[45]

Although the pure acid salts are not found in Nature, many natural mixtures of them with earths, alcaline salts, and metals produce a variety of mineral bodies. For example, vitriolic acid mixed with metals produces the "vitriols." When mixed with iron it produces green vitriol; mixed with copper it produces blue vitriol; and mixed with zinc, white vitriol.[46] Mixed with calcareous earth, vitriolic acid forms gypsum,[47] and acid of sea-salt forms _sal ammoniacum fixum_.[48] Vitriolic acid mixed with alcaline salt forms glauber's salt,[49] and acid of sea-salt mixed with alcaline salt forms rock salt.[50]

The alcaline salts, Cronstedt's second order of the class salts, were "known by their action on the above-mentioned acids [i.e., vitriolic acid and acid of sea-salt], when they are joined together, whereby a fermentation arises, and a precipitation ensues of such bodies as either of them had before kept in dissolution. . . ."[51] The salts resulting

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[44] _Ibid_., p. 126.

[45] _Ibid_., p. 149.

[46] _Ibid_., pp. 130-32.

[47] _Ibid_., p. 133

[48] _Ibid_., p. 138.

[49] _Ibid_., pp. 135-37.

[50] _Ibid_., p. 139.

[51] _Ibid_., p. 141.

from the combinations with the acids, he said, were called neutral salts. Cronstedt identified three principal alcaline salts: alcali of the sea (sal soda),[52] borax,[53] and volatile alkali (i.e., ammonia).[54] He drew particular attention to borax because its properties were not consistent with his definitions or chemical theory. He called borax "a peculiar alcaline salt" and suggested that it was either an "unknown alkali, united with an earth" or "an alcaline salt." He said, although many experiments had been made "in order to discover its origin and constituent parts," it was still known only by its observed qualities. Perhaps the most curious quality, curious because it was anomalous, was the behavior in fire.[55] Cronstedt described its behavior in fire this way:

> It swells and froths in the fire, as long as any humidity remains in it, but melts afterwards very easily to a transparent glass, which, as it has no attraction to the phlogiston, keeps itself in the form of a pearl on the charcoal, when melted with the blow-pipe.[56]

But of particular interest was that borax, unlike other vitrifiable minerals, after melting to a glass, could then be dissolved in water.

Class three, mineral inflammable substances of <u>phlogista mineralia</u>, comprehends "all those subterraneous bodies that are dissoluble in oils, but not in water, which they repel; catch flame in the fire; and are electrical."[57] Included in this group are several substances

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[52]<u>Ibid</u>., pp. 142-43.

[53]<u>Ibid</u>., pp. 145-46.

[54]<u>Ibid</u>., p. 147.

[55]<u>Ibid</u>., p. 145.

[56]<u>Ibid</u>.

[57]<u>Ibid</u>., p. 150.

that chemists thought were nearly pure phlogiston (i.e., the principle of inflammability). To simplify classifying these minerals, Cronstedt ignored the small quantity of earthy substances, which all phlogista left behind when burned, and considered them to be pure mineral phlogista. He included varieties of "amber grise," amber, and "rock-oil" in this group.[58] Sulphur is an example of phlogiston mixed with other material. It is "Mineral Phlogiston, or Bitumen, united with the vitriolic acid."[59] But phlogiston, said Cronstedt, exists in most mineral bodies to some extent; and, therefore, under this category he enumerated only those kinds in which it is considered to be a principal constituent.[60] As a result, the group includes a variety of substances described as "sulphur that has dissolved, or is saturated with metals . . . ."[61]

Cronstedt's final class, metals, is characterized as "those mineral bodies which, with respect to their volume, are the heaviest of all hitherto-known bodies; they are not only malleable, but they may also be decompounded, and in a melting heat be brought again to their former state, by the addition of the phlogiston they had lost in their decomposition."[62] Wallerius included as a distinctive property of metals the convex surface assumed by them when melted; Cronstedt, however,

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[58] _Ibid._, pp. 150-54.

[59] _Ibid._, p. 154.

[60] _Ibid._, p. 162.

[61] _Ibid._, p. 155.

[62] _Ibid._, pp. 163-64.

denied the value of this characteristic of fused metals, and held that it was common to many substances. He said:

> That the convex surface metals take after being melted, is a quality not particularly belonging to them, because every thing that is perfectly fluid in the fire, and has no attraction to the vessel in which it is kept, or to any added matter, takes the same figure; as we find the borax, sal fusibile microcosmicum, and others do, when melted upon a piece of charcoal.[63]

From this he concluded that one should not "invent such definitions as shall include several species at once. . . ."[64] But Cronstedt was guilty of ignoring his own advice in several places in his mineral system.

Cronstedt adopted the generally accepted division of metallic bodies into metals and semi-metals, thus violating his operating rule of subdividing in terms of chemical properties. He said in a footnote that "metals have commonly been considered more with regard to their malleability than to their fixity in the fire . . .";[65] the result being to call metals those that were malleable, and to call semi-metals those that were brittle. He pointed out that zinc, however, occupied a middle-ground between the two groups. Cronstedt would have preferred the division of the class into perfect and imperfect metals. The former[66] being incapable of destruction by fire alone; the latter[67] losing the coherency of their particles in a calcining heat. But, he pointed out, the division into perfect and imperfect metals was not wholly satisfactory

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[63] Ibid., pp. 9, note-10, note.

[64] Ibid., p. 10, note.

[65] Ibid., p. 164, note.

[66] Gold, silver, and platina del pinto.

[67] Tin, lead, copper, iron, quicksilver, bismuth, zinc, antimony, arsenic, cobalt, and nickel.

either. Quicksilver was not destroyed in the fire but simply had its particles separated. Thus, it occupied a middle-ground between the two groups established on the basis of chemical behavior. Cronstedt gave no reason for adopting the traditional mode of division instead of the chemical mode, which he thought was superior.

For each of the fourteen metals that he discussed, Cronstedt listed the physical and chemical characters and qualities of the pure metal (i.e., the metallic calx plus phlogiston). He noted physical properties such as color, specific gravity compared to water, ductility, hardness, malleability, sonorousness, texture, and fusibility. He treated the chemical properties of the metals more extensively, and included descriptions of their reactions with air, water, fire, and a variety of "menstrua." He indicated how easily the metals were calcined, their attraction to other metals, and various methods of compounding and decompounding the metal. Copper, for example was described in part as follows:

> It dissolves in all the acids; viz. the acids of vitriol, sea-salt, nitre, and the vegetable; and likewise in all alcaline solutions. That it becomes rusty, and tarnishes in the air (a consequence of a former solution), depends very much on some vitriolic acid which is left in the copper in the refining of it. This metal is easier dissolved when in form of a calx than in a metallic state, especially by the acids of vitriol and sea-salt, and the vegetable acid.[68]

Color was an important part of Cronstedt's descriptions. He noted that "the calx of copper being dissolved by acids becomes green, and by alcalies blue," and that copper is "easily calcined in the fire into a blackish blue substance, which, when rubbed to a fine powder, is

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[68] _Ibid._, p. 189.

red. . . ."[69] Some metals impart color to a flame; copper colors a flame green,[70] zinc burns "with a flame of a changeable colour, between blue and yellow, . . ,"[71] and cobalt and arsenic when they are melted together produce a blue flame.[72] Several, when melted with glass, tinge it a characteristic color: copper produces "a transparent green or sea-green colour";[73] cobalt calx "gives to glasses a blue colour, inclining a little to violet";[74] iron gives "a blackish brown colour to the glass";[75] and nickel calx "tinges glass of a transparent reddish brown, or jacinth colour."[76]

In addition to the above references to color, the first item in the description of each metal was its color. Table I, below, summarizes his descriptions. From the table one can see that Cronstedt's terminology for colors and shades of a color is inexact. A corresponding inexactitude pervades many of the descriptions of physical properties, although this was by no means a defect unique to his work. Another property, besides color, that Cronstedt consistently recorded for the metals was the intensity of heat necessary to fuse or volatilize the metal. His descriptions are recorded in Table 2. Although a vague notion

[69] _Ibid._, p. 188.

[70] _Ibid._, p. 189.

[71] _Ibid._, p. 214.

[72] _Ibid._, p. 231.

[73] _Ibid._, p. 189.

[74] _Ibid._, p. 230.

[75] _Ibid._, p. 195.

[76] _Ibid._, p. 237.

TABLE I

CRONSTEDT'S DESCRIPTION OF THE COLOR OF THE METALS

Gold	"It is of a yellow shining colour."
Silver	"Of a white shining colour."
Platina del Pinto	"It is of a white colour."
Tin	"Of a white colour, which verges more to the blue than that of silver."
Lead	"Of a blueish white colour when fresh broke, but soon dulls or sullies in the air."
Copper	"Of a red colour."
Iron	"Of a blackish blue shining colour."
Quicksilver	"Its colour is white and shining, a little darker than that of silver."
Bismuth	"Of a whitish yellow colour."
Zink	"Is colour comes nearest to that of lead, but it does not so easily tarnish."
Antimony	"Of a white colour almost like silver."
Arsenic	"Nearly of the same colour as lead . . . and changes sooner its shining colour in the air, first to yellow, and afterwards to black."
Cobalt	"Of a whitish grey colour, nearly as fine tempered steel."
Nickel	"It is of a white colour, which however inclines somewhat to red."[77]

[77]*Ibid*., pp. 164, 169, 178, 180, 183, 188, 195, 207, 210, 214, 220, 224, 230, and 236.

TABLE II

CRONSTEDT'S DESCRIPTION OF THE FUSIBILITY OF THE METALS

Gold	"It requires a strong heat before it melts, nearly as much, or a little more than copper."
Silver	"It melts easier than copper."
Platina del Pinto	"It is so refractory in the fire, that there is no degree of heat yet found by which it can be brought into fusion by itself, the burning-glass excepted, which has not yet been tried."
Tin	"It is the most fusible of all metals."
Lead	"It melts in the fire before it is made red-hot, almost as easily as the tin."
Copper	"It requires a strong degree of heat before it melts, yet it is a lesser degree than for iron."
Iron	[No description.]
Quicksilver	"It is volatile in the fire."
Bismuth	"It is very fusible. . . ."
Zink	"It melts in the fire before it has acquired a glowing heat. . . ."
Antimony	"In the fire it is volatile. . . ."
Arsenic	"Is very volatile in the fire. . . ."
Cobalt	"It is fixt in the fire. . . ."
Nickel	"It requires . . . a red heat before it can be brought into fusion, and melts a little sooner, or almost as soon as copper or gold, consequently sooner than iron."[78]

[78]Ibid., pp. 166, 170, 178, 180, 184, 189, 207, 210, 214, 220, 224, 230, and 238. Modern determinations of melting points enable one to rank these metals according to difficulty of melting in the following order: platinum, iron, cobalt, nickel, copper, gold, silver, antimony, zinc, lead, bismuth, and tin. Mercury is not included because it is fluid at ordinary temperatures, and arsenic is not included because it sublimates when heated.

of the fusibility of each metal can be had from these comparative descriptions, they lack standardization and are, therefore, meaningful only to an experienced technician.[79]

After these lengthy preliminaries, Cronstedt described the forms in which each metal and semi-metal are found in nature. Gold, silver, platina del pinto, copper, quicksilver, bismuth, antimony, and arsenic were said to be found in the native state. Three of these--coper, bismuth, and arsenic--are found as the metal calx; so, also, are tin, lead, iron, zinc, cobalt, and nickel. Cronstedt defined his usage of the term calx in this way: "I have used the term calx, in describing the metals; by which word is understood the same as the chemists call a crocus, or terra metallorum phlogisto privata."[80] All of the metals, except platina del pinto, were found "dissolved or mineralised." By "mineralised" he meant that the metal was so intimately "entangled in other bodies"[81] that it did not exhibit its usual metallic properties. Examples of "mineralised" metals are galena, which is lead mineralized with "sulphurated silver,"[82] marcasite, which is iron "perfectly saturated with sulphur,"[83] and blue vitriol, which is copper "dissolved by the vitriolic acid."[84] Most of the "mineralised" substances mentioned were some mixture of a metal and sulphur with minor amounts of other metals or earths.

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[79] Ibid., p. xiv.

[80] Ibid., p. 182.

[81] Ibid., p. 168.

[82] Ibid., p. 186.

[83] Ibid., p. 202.

[84] Ibid., p. 195.

Having described the earths, salts, mineral phlogista, and metals, Cronstedt had covered all of those bodies that he had initially admitted into the mineral kingdom. His system was complete. Throughout he had emphasized a chemical-experimental approach to minerals. He held that the laboratory was "the compleat tribunal where all disputes [in mineralogy] . . . can be accurately decided"; there, all kinds of apparatus "may be employed as means to obtain the knowledge of these intricate and unknown bodies [i.e., minerals]."[85] He implied that the empirical method was the only method of obtaining any knowledge of the mineral kingdom. Although he has a strong empiricist bias, his classificatory categories are not all defined in purely experiental terms. Cronstedt's commitment to the phlogiston theory is reflected in his classification. One of his groups is labeled "Calcareous Earth mixed with phlogiston alone."[86] Both "Calcareous Earth" and "phlogiston" are theoretical terms, not observational terms. In the class metals, the groups that are identified as being in the form of a calx and the groups that were "mineralised" are defined in theoretical terms. "Calx of lead," for example, does not have the observable properties that lead has; it is a theory that connects the two denominations.

Cronstedt understood the artificial nature of his mineral system; he did not imply that his system was a representation of the plan of creation. He believed that for minerals, chemical properties are more significant than physical characteristics, more significant

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[85]*Ibid.*, p. x.

[86]*Ibid.*, pp. 28-29.

in the sense that on the basis of chemical properties the minerals could be organized into a more adequate system. Therefore, he elaborated his system upon the postulational-definitional foundation of chemistry. Having accepted chemical doctrine as a foundation, Cronstedt could explain the phenomena of chemistry and the phenomena of mineralogy from one conceptual scheme, rather than two. In order to perform this conjunction, however, he had to restrict the compass of the mineral kingdom, for its traditional purview included too many disparate phenomena. Cronstedt accomplished this limitation of purview by excising those objects that he thought were compounded from simpler substances. Thus, mineral aggregates are excluded from his mineral system.

The distinction between minerals and mineral aggregates is not explicitly formulated in the Essay. Cronstedt, however, listed "Lusi Naturae,"[87] "stones that are found in animals and fishes,"[88] sands, saxa, and petrifactions[89] as mineral aggregates and "unnecessary and superfluous"[90] in a mineral system. He justified the exclusion of sand on the ground that "in reality [it] is nothing else than very small stones" and to include it in a mineral system "would be a multiplicatio entium praeter necessitatem. . . ."[91] Moreover, he said the saxa had to be excluded from any system because they are essentially only indurated sand. Furthermore, the petrifactions are excluded because they

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[87] Such as the aetite, ibid., p. xviii.

[88] Ibid., p. xix.

[89] Ibid., pp. xiv-xv.

[90] Ibid., p. xix.

[91] Ibid., p. xiv.

> consist of such principles as ought to be described in their proper places, without regard to their figure; for which reason they cannot be enumerated a second time. The principal reason for collecting them, is to acquire a knowledge of such bodies of the animal and vegetable kingdoms, as are not usually found in their natural state, and in this respect they belong properly to the studies of the Botanists and Zoologists.[92]

In order to gain tolerance, if not acceptance, of his definition of what is comprehended in the mineral kingdom, Cronstedt said: "If some objects are thrown out from mineral collections on account they do not belong to them, other collections will be augmented. . . ."[93]

Mineral aggregates, however, are not completely ignored by Cronstedt in his Essay. He appended a short classification of "Saxa and Fossils commonly called Petrefactions" because "these bodies, especially the latter, occupy so considerable a place in most mineral collections, and the former must necessarily be taken notice of by the miners in the observations they make in the subterranean geography. . . ."[94] He did not claim to have placed them in a natural order, but only a convenient order: "I . . . have tried to put them in such an order as may answer that purpose, for which miners and mineralists pay any regard to them."[95]

Cronstedt recognized two kinds of saxa, or rocks. The first kind, compound saxa, are described as those "stones whose particles, consisting of different substances, are so exactly fitted and joined together, that no empty space, or even cement, can be perceived between

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[92]Ibid., pp. xiv-xv.

[93]Ibid., pp. xix-xx.

[94]Ibid., p. 242.

[95]Ibid.

them; which seems to indicate, that some, if not all, of these substances have been soft at the instant of their union."[96] These rocks are entirely composed of identifiable grains of minerals.[97] Included in this group are ophites,[98] varieties of veined marble,[99] norrka,[100] whetstone,[101] porphyry,[102] trapp,[103] gronsten,[104] and granite.[105]

The second kind of saxa, conglutinated stones, are those "whose particles have been united by some cementitious substance, which, however, is seldom perceivable, and which often has not been sufficient to fill every space between the particles: In this case the particles seem

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[96]Ibid., pp. 242-43.

[97]Holocrystalline in modern parlance.

[98]Ibid., p. 243.

[99]Ibid.

[100]Ibid., pp. 244-45. This was described as a stone composed of mica, quartz, and distinct garnets.

[101]Ibid., pp. 245-46. This included a variety of what modern geologists would term sandstones, shales, and slates. Cronstedt defined them as "Saxum compositum micâ, quartzo, et forsan argillâ martiali in nonnullis speciebus." Ibid., p. 245.

[102]Ibid., pp. 247-48. In terms of modern theory the inclusion of porphyry with holocrystalline rocks is anomalous. Cronstedt's definition of porphyry, however, was entirely compatible with such an association. He defined a porphyry as: "Saxum compositum jaspide et feltspato, interdum micâ et basalte." Ibid., p. 247.

[103]Ibid., pp. 248-50. This was a dark colored rock that "sometimes constitutes or forms whole mountains. . . ." Ibid., p. 248.

[104]Ibid., p. 251. Gronsten was "hornblende, interspersed with mica . . . of a dark green colour. . . ."

[105]Ibid., pp. 251-52. The granites were described as "saxum compositum feltspato, micâ et quartzo, quibus accidentaliter interdum hornblende, steatites, granatus et basaltes immixti sunt." Ibid., p. 251.

to have been hard, worn off, and in loose, single, unfigured pieces, before they were united.[106] Included in this group are five kinds of breccia: "limestone cemented by lime," "kernels of jasper cemented by a jaspry substance," "siliceous pebbles, cemented by a jaspry substance," "quartzose kernels combined with an unknown cement," and "kernels of several different kinds of stones."[107] Also included are a variety of "conglutinated stones of granules or sands of different kinds,"[108] and "stones and ores cemented together."[109]

That Cronstedt's descriptions are highly qualitative is emphasized in an explanatory note about the breccias: "Any certain bigness for the kernels or lumps in such compounds, before they deserve the name of Breccia, cannot be determined, because that depends on a comparison, which every one is at liberty to imagine."[110] But he did realize that there are advantages in standardized descriptions of materials. For example, he thought that it might be possible to deduce from observations some general rules concerning what kinds of rocks contained ores and what kinds were barren. But to accomplish this on a global scale, however, it would be necessary to have a universally understood nomenclature. He said: "It may be concluded, how necessary it is to communicate all such observations [upon the occurrence of ores] which . . . ought to be made over the whole globe, and to agree on fixing

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[106] Ibid., p. 243.

[107] Ibid., pp. 252-54.

[108] Ibid., p. 255.

[109] Ibid., p. 257.

[110] Ibid., p. 255, note.

certain names on the Saxa, in order to avoid too great a prolixity in their descriptions."[111] In order to provide a basis for a uniform nomenclature, Cronstedt gave "specific names to those Saxa which are found in this northern country [Sweden], and which Saxa I know. . . ."[112]

The second kind of inorganic substance that Cronstedt included in the appendix to his Essay are the petrifactions, or as he preferred to call them, the mineral-changes (Mineralia-Larvata). They are "mineral bodies in the form of animals or vegetables, and for this reason no others belong to this order, than such as have been really changed from the subjects of the other two kingdoms of nature."[113]

Fossils, or petrifactions, were ordinarily organized according to their form, along the lines of zoological and botanical classifications. But here, also, Cronstedt departed from the traditional approach, and he attempted an arrangement based upon the composition of the bodies. He had five major groups. Four of these are determined by the type of material into which the plants and animals had been changed; the fifth group is for those bodies in process of changing. This last group comprizes molds, turf, and humus. The other groups correspond to the four major divisions of Cronstedt's mineral classification. Thus, there are petrifications which have been changed into earths, salts,[114] mineral inflammable substances, and metals.[115] A representation of his scheme for petrifactions is shown below in Figure 3.

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[111] Ibid., p. 259. [112] Ibid. [113] Ibid., p. 260.

[114] "Penetrated by mineral salts." Ibid., p. 263.

[115] Ibid., pp. 260-67.

- Earthy changes
  - Calcareous changes
    - Loose or friable
    - Indurated
  - Siliceous changes
  - Argillaceous changes
    - Loose and friable
    - Indurated
- Saline changes
  - By the vitriol of iron
    - Animals
    - Vegetables
- Phlogistic changes
  - By pit-coals
  - By rock oil
  - By marcasite and pyrites
- Metallic changes
  - By silver
    - Native
    - Mineralised
  - By copper
    - In form of calx
    - Mineralised
  - By iron
    - In form of calx
    - Mineralised
- Extraneous bodies decomposing
  - Animal mould
  - Vegetable mould

Fig. 3.--Synthetic list of the major divisions of the classification scheme for petrifactions set forth by A. F. Cronstedt.[116]

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[116]Extracted from <u>ibid</u>., pp. xxxiv-xxv and 260-67.

Seemingly as an afterthought, Cronstedt added a third order to his appendix, which he called natural slags. "Slags," he said, "according to our opinion, . . . cannot be produced but by means of fire," but are found in many places "where no subterraneous fire is now known." They are "not properly to be called natural, since they have marks of violence," but neither are they artificial, "according to the universally received meaning of this word." The ubiquity of slags prompted Cronstedt to "enumerate some of them, according to their external marks."[117]

Cronstedt briefly described five slags: "Iceland agat,"[118] Rhenish millstone,[119] pumice-stone, pearl slag,[120] and slag-sand or ashes.[121] He concluded this section and his Essay with the observation that the attainment of knowledge and understanding in the mineral realm was slow and groping, because of the complexity of the problems faced and the limitations to what one man could accomplish in a lifetime.[122]

Cronstedt said, "We should be employed in observing the phoenomena and drawing conclusions from them, instead of only searching for

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[117] Ibid., p. 268.

[118] "It is black, solid, and of a glassy texture; but in thin pieces, it is greenish and semi-transparent like glass bottles. . . ." Ibid., p. 269.

[119] "Is blackish grey, porous, and perfectly resembles a sort of slag produced by mount Vesuvius." Ibid.

[120] "Is compounded of white and greenish glass particles, which seem to have been conglutinated while yet soft, or in fusion." Ibid., p. 270.

[121] "This is thrown forth of the volcanos in form of larger or smaller grains." Ibid.

the principles of those effects. . . ."[123] The means to be used in such a phenomenological approach to the mineral kingdom was chemical experimentation. Because of his chemical bias, Cronstedt paid little attention to the external characters of minerals; to him they were helpful for describing some aspects of mineral substances, but they were not the essential characters. For him, the essence of a mineral is embodied in the description of its composition. Knowing that a chemical basis for mineral classification was the best, he criticized those who adhered to classification based on external characters: They "are so possessed with the _figuromania_, and _so addicted to the surface of things_, that they are shocked at the boldness of calling a _Marble_ a _Limestone_, and _of placing the Porphyry amongst the Saxa_."[124] His allusions were well-chosen; Cronstedt knew that chemically, marble was indistinguishable from limestone,[115] and that porphyry was an indurated aggregate of mineral particles.

The basic features of Cronstedt's chemical mineral system were only slowly accepted by mineralogists, even though his _Essay_ appeared in several translations and editions during the ensuing years.[126] That Cronstedt's work did not have much immediate impact upon mineralogy is attested to by Valmont de Bomare's _Minéralogie_ in which Cronstedt's

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[123] _Ibid_., p. xi.

[124] _Ibid_., p. xxi.

[125] _Ibid_., p. 14, note.

[126] German translations were published in 1760 and 1770; an English translation in 1770, second edition in 1772; a French translation in 1771; a second Swedish edition in 1773; an Italian translation in 1775; and a Russian translation in 1776.

Essay is ignored. Not only is the Essay ignored, but Cronstedt's discovery of nickel is also ignored. Valmont de Bomare's careful attention to synonymy and the previous literature of mineralogy precludes his ignorance of Cronstedt's work.[127] Another index to the slow acceptance of Cronstedt's work is the continued popularity of the Mineralogia of Wallerius. A revised and expanded edition of this work, which was subsequently translated into German, was published from 1772 to 1775.[128]

Two features of Cronstedt's Essay hindered the acceptance of his system of classification. First, his scheme is not as convenient as others. He did not cast his descriptions of minerals into the procrustean bed of the customary classificatory divisions--class, order, genus, species. He was less interested in logical consistency than in cataloging all the observable properties of minerals, and a highly formalized classificatory framework was not suitable to this purpose. Cronstedt also violated the rule of classification that groups should be mutually exclusive. For example, a mineral that was composed of sulphur and copper was provided a place both in class three (mineral inflammables)[129] and also in class four (metals).[130] The second defect

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[127]In the second edition in 1774 Valmont de Bomare added nickel to his discussion of metals. Jacques Christophe Valmont de Bomare, Minéralogie, ou nouvelle exposition du regne minéral. Ouvrage dans lequel on a tâché de ranger dans l'ordre le plus naturel les substances de ce règne, & où l'on expose leurs propriétés & usages mécaniques, &c. Avec un lexicon ou vocabulaire, des tables synoptiques, & un dictionnaire minéralogico-géographique (2d ed.; Paris: Chez Vincent, 1774), II, 94-96.

[128]See British Museum General Catalogue of Printed Books, CCLII, cols. 290-91, for a list of several of the translations and editions of this work.

[129]"Sulphur with copper, grey or vitreous copper ore." Cronstedt, p. 158.

[130]"Cuprum sulphure mineralisatum. Grey copper ore." Ibid., p. 192.

in Cronstedt's mineral system is that it is incomplete by mid-eighteenth century standards. Cronstedt re-defined what kinds of objects were appropriate to mineralogy.[131] In so-doing he fragmented the traditional mineral realm, which included all inorganic bodies, and arbitrarily excluded certain bodies. He postulated that petrifactions could not be separately placed in a system merely because they retained part of their original form; moreover, he postulated that saxa are mixtures of different mineralogically simple substances (minerals) and, therefore, are not admissible into a mineral system.

Cronstedt's chemically based system of mineralogy eliminated many of the former class boundaries and gave rise to the possibility of recognizing new associations and resemblances, but it was too radical a departure for many. Wallerius's more traditional, more logically rigorous, mixed system was still an accepted authority. By rejecting those things that were composites of simple materials, Cronstedt arrived at a notion of "mineral" that was more compatible with the conceptual scheme of chemistry than were earlier notions of "mineral." This was significant to him because he was committed to the belief that chemical means

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[131]From several statements in his Essay, it is clear that Cronstedt regarded minerals as bodies that were simple, naturally occurring, and not visibly mixed. His working definition of mineral is illustrated by his remarks upon the order siliceous earths: "The mineral bodies that are comprehended in this order, are, indeed, somewhat different from one another. This difference, however, on first sight may be discerned; but . . . while we are no farther advanced in the art of decompounding these hard bodies, and as long as no one has thought it worth the trouble and expense to use those means which are already discovered for this purpose; I mean the burning-glass or concave mirror; and to continue such experiments which Mr. Pott has ingeniously begun, as a basis for his Lithogeognosia. . . . there is no other way left, than to consider these bodies as simple substances (how much soever compounded they may be). . . ." Ibid., pp. 47-48.

were the proper way in which to study inorganic Nature. But there were many naturalists who were unwilling to reject external characters in favor of chemical characters in the study of minerals. To them, Cronstedt's restriction of the term "mineral" was unwarranted.

CHAPTER V

TRANSITION TO THE ERA OF MODERN MINERAL CLASSIFICATION

Indices of the increased interest in minerals manifested during the third quarter of the eighteenth century are provided by the multitude of popular-style summaries,[1] bibliographies,[2] scholarly books and papers,[3] and dictionaries[4] dealing with mineral substances that were

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[1]Exemplary and typical is [Bernard Nicolas Bertrand], Élémens d'oryctologie, ou distribution méthodique des fossiles. Par M. B. C. P. de la C. de P., Membre de plusieurs académies (Neuchatel: De l'Imprimerie de la Société Typographique, 1773). This small book was designed to serve those who desired "un plan d'arrangement pour un cabinet de fossiles." (Ibid., p. A2 recto.) It included a justification of mineralogy, a brief explanation of the theoretical grounds of the subject, a survey of mineralogical literature, and a systematic enumeration and description of minerals.

[2]An indication of the tempo of publication in mineralogy can be gained from an examination of the bibliographies of Laurentius Theodorus Gronovius, Bibliotheca regni animalis atque lapidei, seu recensio auctorum et librorum, qui de regno animali & lapideo methodice, physice, medice, chymice, philologice, vel theologice tractant, in usum naturalis historiae studiosorum (Lugduni Batavorum: Sumptibus Auctoris, 1760), Julius Bernhard von Rohr, Julius Bernhards von Rohr, Merseb. Domherrn und Land-Cammerraths, Physikalische Bibliothek, worinnen die vornehmsten Schriften, die zur Naturlehre gehören, angezeiget werden, mit vielen Zusätzen und Verbesserungen herausgegeben von Abraham Gotthelf Kästner (2d ed.; Leipzig: bey Johann Wendlern, 1754), pp. 354-427; or Jean Baptiste Louis de Romé de L'Isle, Essai de cristallographie, ou description des figures géométriques, propres à différens corps du regne minéral, connus vulgairement sous le nom de cristaux. Avec figures et développemens (Paris: Chez Didot jeune; Knapen & Delaguette, 1772), pp. xvij-xxviij.

[3]The above-cited bibliographies list many of these books and papers.

[4]For example, the one appended to Jacques Christophe Valmont

published during the period. At the same time there was a tendency on the part of naturalists to confine their investigations to a more narrowly circumscribed area. This specialization is seen in Johann Jakob Ferber's (1743-1790) Beyträge zu der Mineral-Geschichte von Böhmen,[5] which is a discussion of the minerals found in a small geographical area, and Balthazar Georges Sage's (1740-1824) Élémens de minéralogie docimastique,[6] which is a discussion of chemical testing of minerals. Another example, described below, is the work with mineral crystals of Jean Baptiste Louis de Romé de L'Isle (1736-1790).

Romé de L'Isle directed his attention to "les formes régulieres & constantes que prennent naturellement certains corps que nous désignons par le nom de CRISTAUX."[7] He said he encountered considerable difficulty in his studies, in part because few people had paid any attention to these regularly formed bodies. He noted that in descriptions of species, mineralogists ordinarily neglect single crystals, preferring to describe

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de Bomare, Mineralogie, ou nouvelle exposition du regne minéral. Ouvrage dans lequel on a tâché de ranger dans l'ordre le plus naturel les individus de ce regne, & où l'on expose leurs propriétés & usages méchaniques. Avec un dictionnaire nomenclateur et des tables synoptiques (Paris: Chez Vincent, 1762), II, 331-59; Élie Bertrand, Dictionnaire universel des fossiles propres, et des fossiles accidentels (Avignon: Chez Louis Chambeau, 1763); and Pierre Joseph Buc'hoz, Dictionnaire minéralogique et hydrologique de la France (4 vols.; Paris: Chez J. P. Costard, 1772-1776).

[5]Johann Jakob Ferber, Beyträge zu der Mineral-Geschichte von Böhmen (Berlin: Bey Christian Friedrich Himburg, 1774).

[6]Balthazar Georges Sage, Élémens de minéralogie docimastique (2 vols., 2d ed.; Paris: De l'Imprimerie Royale, 1777).

[7]Romé de L'Isle, p. x: "the regular and constant forms when naturally assumed by certain bodies that we designate by the name crystals."

groups of crystals. But, he said, "j'ose le dire, on a trop négligé les Cristaux solitaires, qui presque toujours sont & [sic] plus réguliers & plus complets que les Cristaux en grouppes."[8] The regularity that Romé de L'Isle saw in the crystals of chemically diverse substances suggested to him a hidden affinity:

> Je veux dire seulement que ces figures, malgré leurs variétés sans nombre, se trouvant être les mêmes, ou à peu-près les mêmes, dans diverses substances salines, pierreuses, métalliques, semblent indiquer dans ces substances une affinité cachée, que nous parviendrons peut-être à découvrir un jour.[9]

Premising his work on the assumed essential importance of crystal form, Romé de L'Isle sought "les rapports qui peuvent exister entre les Cristaux salins, pierreux & métalliques."[10] His method was to list together all the crystals that had an analogous form, that is, he classified crystals. However, in his classification, crystal form is used as a diagnostic feature only at the specific level; his higher orders are based upon chemical and physical properties.[11] His primary grouping of crystals into four classes is based upon chemical behavior; he described these classes as follows:

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[8]Ibid., p. xj: "I venture to say, they have too often neglected solitary crystals, which nearly always are more regular and more complete than crystals in groups."

[9]Ibid., pp. 9-10: "I only wish to say that these figures, in spite of their variety without number, are found to be the same, or nearly the same, in diverse saline, stoney, [and] metallic substances, seems to indicate a hidden affinity in these substances, that perhaps we shall succeed in discovering one day."

[10]Ibid., p. 24, note: "the correspondences which must exist among the saline, stoney, and metallic crystals."

[11]See Appendix XIV for a synopsis of Romé de L'Isle's classification scheme.

1°. Les Cristaux salins, dont le principal caractère est d'être solubles dans l'eau.
2°. Les Cristaux pierreux, souvent transparens, ne fumants point dans le feu.
3°. Les Cristaux pyriteux, ou sulfureux & arsénicaux, qui rendent une fumée désagréable, lorsqu'on les expose au feu.
4°. Les Cristaux métalliques, qui se fondent dans le feu.[12]

Subdivision of the four classes is based upon both chemical and physical properties, but the subdivisions are not characterized by any general crystal form. Thus, cristaux spathiques, a subdivision of class two, is characterized as containing those crystals which are "pour l'ordinaire, moins transparens que les Cristaux quartzeux; leur peu de dureté fait qu'on les égratigne facilement. Ils sont de nature calcaire, attaquables aux acides, & ne font point feu, quand on les frappe avec le briquet: leurs parties constituantes paroissent être rhomboïdales."[13] It is in characterizing species that Romé de L'Isle employs crystal form.[14]

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[12]Ibid., p. 7: "1°. The saline crystals, whose principal character is being soluble in water. 2°. The stoney crystals, often transparent, do not emit smoke in fire. 3°. The pyritic or sulphurous and arsenical crystals, which emit a disagreeable smoke when one exposes them to fire. 4°. The metallic crystals, which are founded [i.e., melted] in fire."

[13]Ibid., p. 112: "ordinarily less transparent than the quartzose crystals; their little hardness lets one scratch them easily. They are of a calcareous nature, may be attacked by acids, and make no fire when one strikes them with steel: their constituent parts appear to be rhomboidal."

[14]For example, Romé de L'Isle designated the fifteen species of the group cristaux spathiques as follows: "Espece I, Le Spath Cubique ou Rhomboïdal, ne doublant point les objets"; "Espece II, Le Spath Rhomboïdal, doublant les objets, connu vulgairement sous le nom de Cristal d'Islande"; "Espece III, Le Spath Cubique ou Rhomboïdal, cristallisé en grouppes"; "Espece IV, Le Spath Calcaire polygone"; "Espece V, Le Spath Calcaire prismatique, hexaëdre, tronqué aux deux bouts"; "Espece VI, Le Spath Calcaire prismatique, hexaëdre, dont les côtés sont inégaux, terminé par deux pyramides triangulaires tronquées

At the outset, Romé de L'Isle made it clear that he was not attempting to explain the mechanism of crystallization; he was describing shapes and finding "de nouveaux rapports entre les différens Cristaux que nous connoissions, & quelques autres qui n'avoient point encore été décrits."[15] He said, however, that from several lines of reasoning he had concluded that "l'attraction & les exhalaisons souterraines, ou le concours de l'air & de l'eau, modifié par le chaud & le froid, sont les principaux agens de toute Cristallisation, & que ce méchanisme doit être le même soit qu'il s'agisse des sels ou de toute autre substance connue du regne minéral."[16] More important to Romé de L'Isle than such speculations was his faith that he had demonstrated the necessity for assuming the fundamental nature of crystal form, for as he said, "c'est

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& opposées"; "Espece VII, Le Spath Calcaire prismatique, hexaëdre, terminé par deux pyramides triangulaires obtuses, placées en sens contraire"; "Espece VIII, Le Spath Calcaire prismatique, hexaëdre, terminé par deux pyramides hexaëdres, dont les plans répondent aux angles du prisme"; "Espece IX, Le Spath Calcaire prismatique, hexaëdre, comprimé, terminé par deux sommets dièdres placés en sens contraire"; "Espece X, Le Spath Calcaire prismatique, quadrangulaire, terminé par deux sommets dièdres, placés en sens contraire"; "Espece XI, Le Spath Calcaire pyramidal, hexaëdre, composé de deux pyramides inégales jointes base à base, ou d'un prisme qui se termine insensiblement en pyramide"; "Espece XII, Le Spath Calcaire pyramidal, hexaëdre, formé par deux pyramides hexaëdres, égales, engagées par leurs bases en sens contraire"; "Espece XIII, Le Spath Calcaire pyramidal, dodécaëdre, formé par deux pyramides pentagones tronquées, jointes base à base"; "Espece XIV, Le Spath Calcaire pyramidal, trièdre"; "Espece XV, Le Spath Calcaire pyramidal, subhexaëdre, terminé par un plan triangulaire." Ibid., pp. 113-35.

[15] Ibid., p. 8: "new correspondences among the different crystals that we know, and some others which have not yet been described."

[16] Ibid., p. 31: "the attraction and the subterranean exhalations, or the meeting of air and water, modified by heat and cold, are the principal agents of all crystallization, and that this mechanism ought to be the same whether it is a question of the salts or of any other known substance of the mineral kingdom."

un axiome reçu, que la nature ne fait rien au hazard."[17]

Romé de L'Isle's work, a large part of which was the accurate description of crystals, resulted in the demonstration that there was a constant geometrical relationship between the varieties of crystalline forms that a substance might exhibit.[18] Once it was shown that the external form of mineral crystals varied within definite limits, form could be used as a diagnostic property in mineral descriptions. Thus, Romé de L'Isle's specialized interest resulted in providing a quantitative descriptive parameter for minerals.

In 1770 quantitative concepts were generally lacking in mineralogy. Mineral description and classification was pursued largely by qualitative means. There were no arbitrary, universally used standards by which qualitative differences of minerals could be measured. Moreover, definitions of the various qualities of minerals were not precise. It was to the clarification of the definitional basis and to the standardization of the parameters of mineral description that Abraham Gottlob Werner (1749-1817) addressed his book Von den äusserlichen Kennzeichen der Fossilien.[19]

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[17] Ibid., p. 10: "it is a recognized axiom, that nature does nothing at random."

[18] Romé de L'Isle is generally recognized as the discoverer of the principle of the constancy of interfacial angles, which was one of the fundamental bases for the development of crystallography in the late eighteenth century. However, John Garrett Burke, "The Establishment and Early Development of the Science of Crystallography" (unpublished Ph.D. dissertation, Department of History, Stanford University, 1961), pp. 88-91, presents convincing evidence to indicate that the honor should be shared with his student Arnould Carangeot (1742-1806), who invented the contact goniometer.

[19] Abraham Gottlob Werner, Von den äusserlichen Kennzeichen der Fossilien, (Leipzig: bey Siegfried Lebrecht Crusius, 1774).

In his book, Werner dealt with the art of describing minerals. Preoccupied with the importance of rapid identification, he strove to systematize with precision the superficial qualities of minerals.[20] He said:

> Hieraus ergiebt sich nun, dass die empirischen Kennzeichen[21] völlig unvollkommen sind; dass die physikalischen Kennzeichen[22] ebenfalls unvollkommen und noch dazu unbequem aufzusuchen sind; dass ferner die innern oder chymischen Kennzeichen[23] zwar ziemlich vollständig, und zuverlässig, doch aber etwas unbestimmt, und die aller unbequemsten zur Aufsuchung sind, weil es blos ein geschickter Chymiker thun kann, nächstdem auch andre Körper und viele Anstalten dazu erfordert werden, und überdieses ein jedes Individuum, das man ganz allein nach ihnen kennen will, zerleget werden muss, wozu aber ein grosser Theil derselben nicht bestimmt ist und viele auch zu klein sind; endlich aber, dass die äussern Kennzeichen[24]

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[20]E.g., color (<u>die Farbe</u>), external form (<u>die äussere Gestalt</u>), luster (<u>der Glanz</u>), fracture (<u>der Bruch</u>), transparency (<u>die Durchsichtigkeit</u>), streak (<u>der Strich</u>), hardness (<u>die Härte</u>), flexibility (<u>die Biegsamkeit</u>), adhesion to the tongue (<u>das Anhängen an der Zunge</u>), timbre (<u>der Klang</u>), unctuosity (<u>das Anfühlen</u>), coldness (<u>die Kälte</u>), heaviness (<u>die Schwere</u>), smell (<u>der Geruch</u>), and taste (<u>der Geschmack</u>). <u>Ibid</u>., erste Tafel, following p. 86.

[21]Werner defined <u>die empirischen Kennzeichen</u> as those "welche man zu der Beurtheilung eines Fossils von dem Orte, wo es bricht, und von denen Fossilien mit denen es bricht hernimmt; als welches sich zuweilen auf eine Eigenschaft desselben gründet. Ich habe letztern den Namen der empirischen gegeben, weil sie hauptsächlich von denenjenigen, welche die Kenntniss der Fossilien blos empirisch treiben, gebraucht werden." <u>Ibid</u>., p. 33.

[22]Werner defined <u>die physikalischen Kennzeichen</u> as those "welche von besondern physikalischen Eigenschaften der Fossilien hergenommen werden, die man aus dem Verhalten der Fossilien gegen andre Körper, so man dazu bringt, bemerket." <u>Ibid</u>.

[23]Werner defined <u>die innern oder chymischen Kennzeichen</u> as those "welche wir bey den Fossilien aus der Zerlegung ihrer Mischung nehmen . . . . Sie durch chymische Hülfsmittel und Versuche gefunden werden." <u>Ibid</u>.

[24]Werner defined <u>die äussern Kennzeichen</u> as those "welche wir bloss durch unsere Sinne an der Zusammensetzung, oder dem Aggregat der Fossilien, welches man auch das Aeussere derselben nennt, aufsuchen:

> völlig vollständig, zuverlässig unterscheidend, am bekanntesten, am leichtesten zu bestimmen und am bequemsten aufzusuchen sind; undalso vorzüglich und eigentlich in die Mineralogie gehören.[25]

In the course of his work, Werner introduced new terms for some of the characters he discussed, and he more exactly defined some of the older terms.[26] To eliminate vagueness, he tried to propose reproducible quantitative standards that could be universally understood by mineralogists.[27] The problem that he attempted to resolve was the long recognized deficiency of the language of descriptive mineralogy.[28] Although

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Sie werden auch sinnliche Kennzeichen genennt, weil wir zu ihrer Aufsuchung nur allein unsere Sinne nöthig haben." Ibid., pp. 32-33.

[25]Ibid., pp. 43-44: "From the foregoing considerations, it follows that empirical characters are entirely imperfect and that physical characters are also imperfect and moreover inconvenient to determine. Internal or chemical characters are almost complete and reliable, yet somewhat inconclusive and the most inconvenient of all to discover because an able chemist is required. Moreover, reagents and special equipment are necessary, and each specimen which we want to identify through these characters must be analyzed, though many of them are unfit or too small for such analysis. External characters are thoroughly complete, reliably discriminative, best known, easiest to recognize, and most convenient to determine; consequently they should be preferred to the others and should belong specifically to oryctognosy." English translation from Albert V. Carozzi (trans.), On the External Characters of Minerals (Urbana, Illinois: University of Illinois Press, 1962), p. 5.

[26]Alexander Meier Ospovat, "Abraham Gottlob Werner and His Influence on Mineralogy and Geology" (unpublished Ph.D. dissertation, Graduate College, University of Oklahoma, 1960), pp. 134-36.

[27]Ibid., pp. 137-38.

[28]Cronstedt, p. xi, had complained of "all the vague expressions" found in the mineralogical works of his predecessors, and Élie Bertrand, p. [v], said "Je ne crois pas qu'il y ait en particulier une science dans laquelle un Nomenclateur exact soit plus nécessaire que dans l'Oryctologie, ou la description des fossiles." He went on to explain the lack of a satisfactory nomenclature by saying: "Comme il y a souvent peu d'accord dans les idées sur la nature & l'origine des corps fossiles, de-là vient encore une étonnante diversité dans leurs dénominations. Ici

his solutions were not immediately or universally accepted by mineralogists,[29] his work presaged the development of a systematic mineralogy based upon measurement.

Werner was not concerned with setting forth a mineral system in Von den äusserlichen Kennzeichen der Fossilien;[30] however, he did say that he considered a chemical approach to mineral classification to be the best:

> Meine Meynung ist: Die Fossilien müssen bis auf ihre Gattungen herunter nach ihrer Mischung eingetheilet werden. Denn ein Mineralsystem hat keinen andern Zweck, als die natürliche Folge oder Reihe der verschiedenen Fossilien zu bestimmen, und je genauer dieses darinnen geschiehet, je vollkomner wird das Mineralsystem seyn: Nun liegt aber die wesentliche Verschiedenheit der Fossilien in ihrer Mischung, so wie sie bey den Thieren und Pflanzen in ihrer Zusammensetzung liegt, und erstreckt sich bis auf ihre Gattungen herunter: Es müssen also auch die Fossilien bis auf ihre Gattungen herunter, nach dem Grunde ihrer wesentlichen Vershiedenheit, d. i. nach ihrer Mischung, geordnet werden.[31]

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il est arrivé comme dans la Botanique, chacun aspirant peut-être à la gloire d'être chef de secte, ou du moins au privilège d'être cité, a baptisé les choses, selon son hypothèse ou sa méthode distributive, souvent même selon son caprice." Ibid., p. viij.

[29]For example, Torbern Olof Bergman, Manuel du minéralogiste, ou sciagraphie du règne minéral, distribué d'après l'analyse chimique, trans. and annotated by Jean André Mongez (Paris: Chez Cuchet, 1784), p. xxxiv, said: "Le systêm de Werner est totalement fondé sur les caractères apparens aux cinq sens; mais il est si compliqué, qu'il ne peut être d'aucun usage: souvent en multipliant les caractères, bien loin de répandre la clarté, on augmente l'obscurité que l'on cherche à dissiper. Cet Auteur, par exemple, compte pour caractères distinctifs, la couleur, dont il donne cinquante-quatre variétés; la fracture, qui lui en fournit vingt-une, &c. &c."

[30]On p. 31 he wrote" "Da aber die äusserlichen Kennzeichen der Fossilien der eigentliche Gegenstand dieser kleinen Abhandlung sind, so will ich hier weiter nichts von denselben [i.e., mineral classification] erwähnen. . . ."

[31]Ibid., p. 20: "My opinion is: minerals should be classified and the species separated on the basis of their composition, for a

Nevertheless, from other works it is clear that Werner adopted a mixed system instead of a purely chemical system of classification.

Werner's classification of minerals was outlined in <u>Bergmännisches Journal</u> in 1789.[32] A comparison of this précis with Cronstedt's system reveals a striking correspondence. Werner, following Cronstedt, excluded from his mineral system all seemingly non-homogeneous objects traditionally assigned to the mineral kingdom. Thus, adventitious fossils, mineral aggregates, calculi, and so forth, were not a part of his scheme. He also followed Cronstedt (and others before him) by using a four-fold subdivision of minerals into classes: earths and stones (<u>Erd- und Steinarten</u>), salts (<u>Salzarten</u>), inflammable substances (<u>Brennliche Wesen</u>), and metals (<u>Metallarten</u>).[33] Cronstedt divided minerals into earths, salts, mineral inflammables, and metals.[34]

Werner's first class, earths and stones, is divided into five subgroups: flinty kinds (<u>Kieselarten</u>), clayey kinds (<u>Thonarten</u>), talcky

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mineral system has no other purpose than to determine the natural order or classification of the different minerals. The more accurately this is accomplished, the more perfect the mineral system will be. Now, the essential difference between minerals lies in their composition (as it lies in the mode of association found in animals and plants) and extends to their species; therefore, the minerals, including their species, should also be classified on the basis of their essential differences, i.e., according to their composition." English translation from Carozzi, p. xxvi.

[32][Abraham Gottlob Werner,] "Mineralsystem des Herrn Inspektor Werners mit dessen Erlaubnis herausgegeben von C. A. S. Hoffmann," <u>Bergmännisches Journal</u>, I (1789), 369-98. See Appendix XV for a synopsis of Werner's 1789 classification scheme.

[33]<u>Ibid</u>., pp. 373, 379, 380.

[34]See above pp. 137-58 for a discussion of Cronstedt's classification scheme. A synopsis of his classification is contained in Appendix XII.

kinds (Talkarten), calcareous kinds (Kalkarten), and heavy kinds (Schwerarten).[35] The first three and the last of these subgroups are determined on the basis of general physical resemblances of the included mineral species. The subgroup "calcareous kinds" is determined on the basis of the assumed chemical composition of the included species.

Werner's second class, salts, following a chemical principle of division, is divided into vitriolic salts (Vitriolische Salze), nitrous salts (Salpetersaure Salze), muriatic salts (Kochsalzsaure Salze), and alkaline salts (Alkalische Salze).[36] Cronstedt divided salts into three groups on the basis of composition: alkaline salts, muriatic salts, and vitriolic salts.

Werner's third class, inflammable substances, includes such materials as naptha (Naphta), native sulphur (Natüralicher-Schwefel), amber (Bernstein), petroleum (Erdöl), asphalt (Erdpech), and coal (Steinkohle).[37] A similar array of combustible substances is included in Cronstedt's third major group.

The metals comprise the fourth major group in both Werner's and Cronstedt's classification schemes. Werner, however, abandoned the common practice of dividing the metals into the so-called perfect metals and the semi-metals. He simply listed in one sequence the seventeen metals that he recognized.[38]

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[35] Ibid., pp. 373-79.

[36] Ibid., p. 379.

[37] Ibid., pp. 379-80.

[38] Besides the fourteen metals included by Cronstedt, Werner's scheme contains three metals that were not recognized by Cronstedt: Molybdän, Braunstein, Scheel. Ibid., p. 386.

Between 1789 and 1815 Werner's list of mineral species grew from 181 to 317 species, but his basic approach to classifying them was unchanged.[39] Although he extolled the merits of a strictly chemical system of mineral classification, his own classification was based upon a mixture of both physical and chemical characteristics. Furthermore, his scheme, although kept abreast of current discoveries, closely followed the schema of his predecessors.

Both Romé de L'Isle and Werner are transitional figures in the history of mineralogy. For the most part their mineralogical works are cast in traditional molds, but Romé de L'Isle's systematization of exterior form contained in the Essai de cristallographie and Werner's systematization of exterior qualities contained in Von den äusserlichen Kennzeichen der Fossilien are innovations. Nevertheless, it is easy to overestimate their contributions to the development of modern systematic mineralogy, a distinctive feature of which is the quantitative approach to the study of minerals.

In the more than two centuries intervening between Georg Agricola's De natura fossilium (1546) and Abraham Gottlob Werner's Von den äusserlichen Kennzeichen der Fossilien (1774) the study of minerals evolved from a highly practical pursuit into a theoretical-descriptive scientific activity. The changing character of this study, which came to be called

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[39]In 1815 Werner prepared an outline of his classification of minerals which was published posthumously in Abraham Gottlob Werner, Abraham Gottlob Werner's letztes Mineral-System. Aus dessen Nachlasse auf oberbergamtliche Anordnung herausgegeben und mit Erläuterungen versehen (Freyberg und Wien: bey Craz und Gerlach und bey Carl Gerold, 1817). Appendix XVI contains a synopsis of this classification scheme.

mineralogy during the eighteenth century, has been traced in this dissertation by an analysis of some mineral classification schemes promulgated during the period.

The best efforts of sixteenth and seventeenth century naturalists to organize the rapidly accumulating knowledge of mineral substances and to incorporate this knowledge into some scheme of classification are represented by the works of Agricola and Anselm de Boodt. Agricola's naturalistic, physical approach to the study of mineral substances became a model for subsequent writers. Although he did not construct a mineral system in which both classification and description were intertwined, his definitional-postulational basis for studying minerals and his manifold mineral descriptions helped to codify much of the old knowledge and point to new approaches in studying the objects of the mineral kingdom.

De Boodt's <u>Gemmarvm et lapidvm historia</u>, published a little more than half a century after Agricola's <u>De natura fossilium</u>, is more detailed, more extensive, more critical, and more systematic than Agricola's book. De Boodt illustrated his theoretical discussions of mineral classification with specific examples of how minerals could be arranged, which Agricola did not. Neither Agricola's nor de Boodt's treatise, however, is a thorough-going mineral system, because their mineral descriptions are separate from their theoretical discussions of mineral classification. Although both assumed minerals to be related on the basis of superficial physical resemblances, Agricola arranged his mineral descriptions according to use and de Boodt in his list arranged minerals according to their value.

Traditional beliefs about the virtues of stones and the arrangement of mineral descriptions according to some extrinsic quality did not disappear from treatises on minerals for a long time after Agricola and de Boodt published their works. Nevertheless, as time went on, more and more authors looked skeptically upon the supernatural traditions and recognized the advantages of arranging their descriptions according to some principle that depended only upon the intrinsic qualities of the mineral specimens themselves.

Some of the mineral lore of the sixteenth and seventeenth centuries was carried in a variety of practical books for the miner, the jeweler, or the interested layman. These books, however, are brief and unsystematic. They are primarily devoted to description, and therefore the theoretical aspects of mineralogy are slighted. In addition to these practical books, several catalogs of private mineral collections were published during the sixteenth and seventeenth centuries. An early example of such catalogs is the one prepared by Konrad Gesner of the collection of Johann Kentmann. Another is the Mvsaevm metallicvm of Ulisse Aldrovandi. Although they are perhaps better considered descriptive lists of specific minerals than mineral systems, these catalogs, because of their emphasis upon arranging mineral specimens, were probably an important factor in directing the attention of naturalists to the problems of mineral classification.

There is no doubt that by the end of the seventeenth century there existed a large body of knowledge concerning minerals that had been accumulated during the preceding few centuries. This knowledge, however, was poorly systematized.

During the eighteenth century there were varied and numerous attempts to construct comprehensive, rationally conceived mineral systems in which the classification and the description of minerals were conjoined. In these systems, relationships among minerals were postulated on the basis of physical similarities, similar chemical behavior, or similarities of a combination of both physical and chemical properties.

Among the first to prepare a comprehensive, carefully reasoned mineral system was John Woodward. Woodward distributed native fossils into six classes: earths, stones, salts, bitumens, minerals, and metals. Each class was characterized by the possession or non-possession of a few (mostly physical) properties, such as transparency, taste, friability, hardness, ductility, and solubility in water. Woodward consciously tried to base his classification on the intrinsic properties of minerals that could be readily observed or determined. This was an important departure from many of his predecessors, such as Agricola and de Boodt, who admitted extrinsic properties of minerals on an equal basis with the intrinsic properties in their classifications. Woodward also departed from the practice of separating the theoretical and descriptive aspects of the study of minerals. He let his theoretical classification guide his arrangement of specific minerals and thereby combined the theoretical-classificatory and the practical-descriptive aspects of the study of minerals into a coherent whole; his scheme was a mineral system. Deficient in detail, Woodward's mineral system did provide a generalized description of the mineral kingdom that was widely used as a model during the eighteenth century, just as Agricola's work was widely copied during the sixteenth and seventeenth centuries.

Woodward's scheme rested on the assumption that the ideal classification, the natural classification which supposedly summed up the total degree of similarity among the various minerals, was most nearly achieved by using physical or external characters as the diagnostic indices of classification. He omitted myths and magical properties in favor of straightforward physical description, but he lacked unequivocal terminology and standards of measurement for the properties that he used. Because of that, it was difficult for others to implement his classification; nevertheless, Woodward's basic scheme was copied and adapted by several naturalists, including Johann Jacob Scheuchzer, John Hill, Antoine Joseph Dezallier d'Argenville, Johann Heinrich von Justi, and Jacques Christophe Valmont de Bomare.

Within the theoretical framework of Woodward's classification, Scheuchzer emphasized grouping individual specimens on the basis of a set of shared characters. Hill was preoccupied with recognition of minerals, and therefore he emphasized an empirical approach to the study of minerals. His treatise, however, was little more than a compilation of contemporary knowledge of mineral substances arranged more or less like Woodward's arrangement. Dezallier d'Argenville and von Justi added little that was original, and Valmont de Bomare's originality consisted of putting into convenient form the well-known work of his predecessors.

Classifying minerals from the point of view of their physical properties is only one approach to the study of minerals. As chemistry became increasingly associated with the study of minerals during the eighteenth century, many authors incorporated chemical theory into the framework of their mineral systems. Mixed principles of classification, physical and chemical, are embodied in the schemes of Magnus von Bromell, Carl von Linné, and Johan Gottschalk Wallerius.

Bromell, who seems to have regarded his scheme as mirroring the natural order which he thought existed among inorganic bodies, was more interested in descriptive mineralogy than in the conceptual framework supporting descriptions of minerals. Therefore, he paid little attention to carefully constructing a reasoned classification; instead, he adopted groups that were compatible with his main objective, the orderly description of the natural characters of minerals.

Linné, on the other hand, set forth in his Systema naturae an epitome of a carefully reasoned classification of the mineral kingdom. He organized mineral substances into species on the basis of what he considered to be their least variable characters. These characters he postulated as essential to those minerals, and hence the only acceptable basis for classification. Linné's intuitively determined species are grouped under genera, orders, and classes which he admitted are artificial. Thus, Linné sought to explain what intuition told him were the natural relationships existing among mineral bodies by means of a reasoned, logically subdivided scheme, not, as many of his predecessors had done, by presenting a descriptive summary of minerals grouped according to generally accepted notions of how minerals should be arranged.

Wallerius relied heavily on the systematic work of Linné. Parallels are evident at many points in the two systems; however, Linné's hallmark, brevity, is missing from Wallerius's system. Wallerius's treatise is concise, but it is also detailed. He tried to record all of the variety of physical and chemical properties that could be utilized in the identification of a given mineral and also to include, in notes, a great deal of unnecessary information. A dominant theme in his work is that classification should serve as an instrument for determination. He thought that his treatise could be used as a determinative scheme in order to discriminate and name unknown minerals without previous practical knowledge of mineral substances, an ideal later upheld by Werner. On the whole, Wallerius's work is a refinement of the work of earlier writers.

The growing tendency among many authors during the eighteenth century to base their arrangements on similarities in behavior of mineral specimens when subjected to laboratory tests can be seen in the work of Johann Heinrich Pott, who divided the traditionally termed earths and stones into compositional groups on the basis of their reaction to heat. His system was incomplete, however, since he concerned himself only with the earths and stones. Perhaps the first to set forth a complete, almost exclusively chemical system of mineralogy was Axel Fredrik Cronstedt. His system was almost entirely based on the assumed chemical constituents of minerals, and throughout his treatise he emphasized a chemical-experimental approach to the study of minerals.

Because of his chemical bias, Cronstedt paid little attention to the external characters of minerals. For him, the essence of a mineral was embodied in the description of its composition. Therefore, composition was more significant to him than physical properties, insofar as constructing a mineral system was concerned. Although he held the view that the chemical characters of minerals are the best basis for classifying minerals, he recognized that his system was only artificial and not a representation of the plan of creation.

Having accepted chemical doctrine as the foundation for explaining the phenomena of mineralogy, Cronstedt found that the traditional limits of the mineral kingdom included too many disparate phenomena to be adequately accommodated in a single system. Because of this he limited the scope of mineralogy by excluding those objects that he thought were compounded from simpler substances. Thus, he did not include fossils, rocks, natural slags, etc., in his mineral system.

Cronstedt's work did not have much immediate impact upon mineralogy. In the long run, the chemical approach to the problem of classifying minerals, which he championed, proved highly fruitful, particularly through Werner's teaching.

Throughout the eighteenth century some classifiers attempted all-inclusive systematizations of mineralogical knowledge based upon various preconceived notions of the nature of minerals, but during the third quarter of the century some classifiers directed their attention to a more limited part of the mineral kingdom. Thus, for example, still very much within the traditional theoretical framework, Romé de L'Isle studied and systematically arranged mineral crystals, and Werner attempted to standardize the characters by which Minerals could be recognized and described.

Although none of the many schemes proposed by mineral systematists during the sixteenth, seventeenth, and eighteenth centuries was generally accepted, each scheme contributed to the codification, extention, and transmission of the accumulated knowledge of mineral substances.

In consequence, the prominent position as the systematizer of mineralogical knowledge frequently accorded to Werner must be reviewed in light of the influential pioneer work of a host of naturalists whose ideas were adopted in large part by Werner. These ideas, through the teaching of Werner, presumably had much influence in shaping mineral systems during the last quarter of the eighteenth century and the first quarter of the nineteenth century. Since Werner was heavily indebted to his predecessors for his mineralogical views, his mineral system did not constitute a sharp break with the past. At the same time one must not underestimate Werner's contribution toward reforming the descriptive language of mineralogy. In the final analysis, however, his systematic work should be regarded as the end of the prolegomena to the era of modern mineralogy, rather than the beginning of that era.

APPENDICES

SYNOPSES OF SOME REPRESENTATIVE MINERAL SYSTEMS FROM AGRICOLA TO WERNER

APPENDIX I

SYNOPSIS OF THE CLASSIFICATION SCHEME OF

GEORG AGRICOLA, 1546*

- corpus subterraneum expers animae
  - quod effluit & expiratur
  - fossilis
    - concretum ex partibus sui similibus substantia (non-compositum)
      - simplex
        - terra
        - succus concretus
        - lapis
        - metallum
      - mistam
    - concretum ex partibus sui dissimilibus substantia (compositum)

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*This synthetic list of the major elements of Agricola's classification scheme was extracted from the discussion in Georg Agricola, *De ortu & causis subterraneorum lib. V. De natura eorum quae effluunt ex terra lib. IIII. De natura fossilium lib. X. De ueteribus*

APPENDIX I

SYNOPSIS OF THE CLASSIFICATION SCHEME OF

GEORG AGRICOLA, 1546

- subterranean substance without life
  - which flows and is exhaled
  - fossil
    - formed from particles of a substance like itself (non-composite)
      - simple
        - earth
        - congealed juice
        - stone
        - metal
      - mixed
    - formed from particles of a substance unlike itself (composite)

& nouis metallis lib. II. Bermannus, siue de re metallica dialogus. Interpretatio germanica uocum rei metallicae, addito indice foecundissimo (Basileae: [Per Hieronymvm Frobenivm et Nic. Episcopivm,] 1546), p. 185.

APPENDIX II

SYNOPSIS OF A CLASSIFICATION SCHEME OF

ANSELM BOETHIUS DE BOODT, 1609*

- Animatis
  - Volatilibus
  - Non volatilibus
    - Aquatilibus
      - Piscibus
      - Insectis
    - Terrestribus
      - Plantis
      - Animalibus
        - Homine
        - Bruto
          - Quadrupede
          - Insecto

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*This synthetic list of the major elements of one of de Boodt's classification schemes was extracted from the more detailed enumeration in Anselm Boethius de Boodt, <u>Anselmi Boetii de Boodt Brvgensis Belgae, Rvdolphi Secvndi Imperatoris Romanorvm personae medici, gemmarvm et lapidvm historia. Qua non solum ortus, natura, vis & precium, sed etiam modus quo ex iis, olea, salia, tincturae, essentiae, arcana & magisteria arte chymica confici possint, ostenditur. Opvs principibus, medicis,</u>

APPENDIX II

SYNOPSIS OF A CLASSIFICATION SCHEME OF

ANSELM BOETHIUS DE BOODT, 1609

Animate

    Volatile

    Non volatile

        Aquatic

            From fish

            From insects

        Terrestrial

            From plants

            From animals

                Man

                Beasts

                    Quadrupeds

                    Insects

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chymicis, physicis, ac liberalioribus ingeniis vtilissimum. Cum variis figuris, indiceq, duplici & copioso (Hanoviae: Typis Wechelianis apud Claudium Marnium & heredes Ioannis Aubrii, 1609), table facing p. 7. In this scheme, de Boodt began with all stones that came from things (lapides ex rebus) and first divided them into those obtained from animate things (animatis) and those obtained from inanimate things (inanimatis).

- Inanimatis
  - Ardentibus
  - Non ardentibus
    - Certam figuram
      - Mathematicam
        - Rotundam
        - Aliam
          - Angularem
          - Aliam
            - Hemisphaericam
            - Aliam
      - Alicuius rei
        - Animatae
          - Totae
            - Sensitiuae
            - Vegetabilis
          - Partis
            - Sensitiuae
            - Vegetabilis
        - Inanimatae
          - Naturalis
          - Artificialis
    - Nullam certam figuram
      - Diaphani
        - Integre
          - Duri

- Inanimate
  - Flammable
  - Non flammable
    - With a certain figure
      - Mathematical
        - Round
        - Other
          - Angular
          - Other
            - Half spherical
            - Other
      - Of some thing
        - Animate
          - Whole
            - Sentient
            - Vegetative
          - Part
            - Sentient
            - Vegetative
        - Inanimate
          - Natural
          - Artificial
    - With no certain figure
      - Transparent
        - Complete
          - Hard

Colore aliquo

Rubro

Flauo

Aureo

Viridi

Ceruleo

Purpureo

Nullo colore

Molles

Parui

Magni

Non integre

Secundum partes

Secundum totum

Opaci

Pulchri

Parui

Magni

Turpes

With some color

Red

Yellow

Golden

Green

Blue

Purple

With no color

Soft

Small

Large

Incomplete

According to the part

According to the whole

Opaque

Attractive

Small

Large

Unattractive

APPENDIX III

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHN WOODWARD
AS GIVEN IN THE LEXICON TECHNICUM, 1704*

Class 1. Earths

Class 2. Stones

Section 1. Those that are found in larger masses

Section 2. Stones found in lesser masses

Article 1. Those that do not exceed marble in hardness

§ . 1. Those that are of an indeterminate figure and texture

§ . 2. Those that are of an indeterminate figure, but of a regular texture

§ . 3. Those that are commonly of determinate figures

Article 2. Stones found in lesser masses, that do exceed marble in hardness

§ . 1. Those that are opake

Subdivision 1. Of one colour

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*This synthetic list of the major elements of Woodward's classification scheme was extracted from the more detailed enumeration in John Harris, "Fossils," *Lexicon technicum, or an Universal English Dictionary of Arts and Sciences, Explaining Not Only the Terms of Art, but the Arts Themselves* (London: Printed for Dan. Brown, Tim. Goodwin, John Walthoe, Tho. Newborough, John Nicholson, Tho. Benskin, Benj. Tooke, Dan. Midwinter, Tho. Leigh, and Francis Coggan, 1704). This was an attempt to organize only native fossils, not all *fossilia*.

<u>Subdivision 2</u>. Of different colours mixt in the same body

<u>§. 2</u>. Semi-pellucid stones

<u>Subdivision 1</u>. With colours changeable, according to the different position of the stone to the light

<u>Subdivision 2</u>. With colours permanent

<u>§. 3</u>. Stones diaphanous, with colours

<u>Subdivision 1</u>. Yellow, or partaking of it

<u>Subdivision 2</u>. Red, or partaking of it

<u>Subdivision 3</u>. Blue, or partaking of it

<u>Subdivision 4</u>. Green, or partaking of it

<u>§. 4</u>. Stones diaphanous, and without colours

<u>Class 3</u>. Salts

<u>Class 4</u>. Bitumina

<u>Section 1</u>. Liquid

<u>Section 2</u>. Solid

<u>Class 5</u>. Metallick minerals

<u>Class 6</u>. Metals

APPENDIX IV

SYNOPSIS OF THE CLASSIFICATION SCHEME OF

JOHN WOODWARD, 1714*

Classis 1. Terrae

Caput 1. Ad tactum laeves, & quasi sebaceae

Membrum 1. Quae, si linguae admoveantur, illi adhaerent

Membrum 2. Quae linguae non adhaerent

Caput 2. Ad tactum siccae, & scabrae

Classis 2. Lapides

Caput 1. Qui mole majore reperiuntur, in strata dispositi

Membrum 1. Compositionis laxioris, ad tactum scabri

Membrum 2. Compositionis spissioris, ad tactum laeves, quique attritu aliquatenus politi fiunt

Membrum 3. Constitutionis adeo durae, & compactae, ut ad nitorem poliri possint

Caput 2. Qui mole sunt minore

Membrum 1. Marmore non duriores

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*This synthetic list of the major elements of Woodward's classification scheme was extracted from the more detailed enumeration in John Woodward, Methodica, et ad ipsam naturae normam instituta fossilium in classes distributio. Ad illustrem virum D. Isaacum Newtonum, Eq. Aur. et Soc. Reg. praesidem in Johannis Woodwardi, med. in Coll. Greshamensi prof. &c., naturalis historia telluris illustrata & aucta. Una cum ejusdem defensione; praesertim contra nuperas objectiones D. El.

APPENDIX IV

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHN WOODWARD, 1714

Class 1. Earths

Chapter 1. Smooth and just as grease to the touch

Member 1. Which, if applied to the tongue, adheres to it

Member 2. Which does not adhere to the tongue

Chapter 2. Dry and rough to the touch

Class 2. Stones

Chapter 1. Which are found in larger masses, arranged into strata

Member 1. Of a looser composition, rough to touch

Member 2. Of a composition more dense, smooth to the touch, and that worn away to a certain degree become polished

Member 3. Of a constitution so hard and compact that they can be polished to brilliance

Chapter 2. Which are in smaller masses

Member 1. Not harder than marble

Camerarii, med. prof. Tubingensis. Ad illustrissimum & nobilissimum virum Thomam Pembrochiae comitem, &c. Accedit methodica, & ad ipsam naturae normam instituta, fossilium in classes distributio (Londini: Typis J. M. Impensis R. Wilkin, 1714). This scheme is somewhat more extensive and more definite than the one published in the Lexicon technicum (cf., Appendix III).

<u>Articulus 1</u>. Tam figurae, quam constitutionis, incertae, & indeterminatae

<u>Articulus 2</u>. Figurae extus variae, & incertae: texturae vero internae, determinatae, & regularis

<u>Sectio 1</u>. Compositi è fibris parallelis, quae in horum plerisque flexiles sunt, & vi elasticâ praeditae

<u>Sectio 2</u>. Compositi è laminis praesertim planis & parallelis, quae flexiles sunt, & vi elasticâ praeditae

<u>Sectio 3</u>. Qui, interpositione laminarum, è materiâ ad fluores dictos potissimum accedente constantium, dividuntur in talos, seu partes angulares, pentagonas sc. hexagonas, aut alius cujusvis figurae angularis

<u>Sectio 4</u>. Fistulosi, ex tubulis, eadem etiam materiâ constantibus compositi

<u>Sectio 5</u>. Compositi è crustis, alterâ alteri superinductis

<u>Subdivisio 1</u>. Arctè cohaerentibus, nullâ intus cavitate

<u>Subdivisio 2</u>. Intus cavi, cum materiâ quadam inclusâ, crustae non adhaerenti, sed mobili

<u>§§§1</u>. Solidâ, & lapideâ

<u>§§§2</u>. Laxâ

<u>§§§3</u>. Liquidâ.

<u>Articulus 3</u>. Figurae, & constitutionis, certae, regularis, & determinatae

<u>Membrum 2</u>. Lapides, mole minore, marmore duriores

<u>Articulus 1</u>. Opaci

<u>Sectio 1</u>. Plerumque unicolores

<u>Sectio 2</u>. Variorum in eodem corpore colorum

<u>Articulus 2</u>. Semi-pellucidi

Article 1. Both of a figure and a constitution uncertain and indeterminate

Article 2. Of a various and uncertain external figure: but of an internal texture determinate and regular

Section 1. Composed of parallel fibers, which in most of them are flexible and furnished with elastic strength

Section 2. Composed chiefly of plane and parallel plates, which are flexible and furnished with elastic strength

Section 3. Which, by the interposition of plates of a firm material chiefly approaching that called spar, are divided into tali, or angular parts, namely pentagons, hexagons, or any other angular figure.

Section 4. Fistulous, composed of tubes also of the same firm material

Section 5. Composed of crusts, one covering the other

Subdivision 1. Closely cohering, no cavity inside

Subdivision 2. Hollow inside, with a certain material included, not adhering to the crust, but movable

§§§1. Solid and stony

§§§2. Loose

§§§3. Liquid

Article 3. Figure and constitution certain, regular and determinate

Member 2. Stones, in smaller masses, harder than marble

Article 1. Opaque

Section 1. Chiefly of one color

Section 2. Of various colors in the same body

Article 2. Semi-transparent

<u>Sectio 1</u>. Versicolores, prout vario situ luci objiciuntur

<u>Sectio 2</u>. Coloribus in subjecto permanentibus

<u>Articulus 3</u>. Pellucidi

<u>Sectio 1</u>. Colorati

<u>Sectio 2</u>. Coloris expertes

<u>Classis 3</u>. Salia

<u>Classis 4</u>. Bitumina

<u>Caput 1</u>. Liquida

<u>Caput 2</u>. Solida

<u>Classis 5</u>. Mineralia

<u>Caput 1</u>. Fluida

<u>Caput 2</u>. Solida, igne fusilia, sed non ductilia

<u>Classis 6</u>. Metalla

Section 1. Of changeable colors, according to the changeable position held before the light

Section 2. Permanent colors in the subject

Article 3. Transparent

Section 1. Colored

Section 2. Without color

Class 3. Salts

Class 4. Bitumens

Chapter 1. Liquid

Chapter 2. Solid

Class 5. Minerals

Chapter 1. Fluid

Chapter 2. Solid, fusible in fire, but not ductile

Class 6. Metals

APPENDIX V

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHANN JACOB SCHEUCHZER, 1718*

Erden

Fette und Magere Erden (terrae pinques & macrae)

Mon-Milch (lacte lunae)

Steinen

I. Grössere in lager abgetheilte Steine/von grober/dicker/rauher Materi/ deren Theile vester oder lucker zusamenhalten

A. Grosse Steine und Felsen (saxa)

B. Labezzstein (lapis ollaris)

C. Sandstein und Sand (saxum arenarium, arena)

D. Toff- oder Tugstein (tofus, tophus)

E. Mühlstein (molaris lapis)

F. Kalkstein (calcarium saxum)

G. Gips (gypsum)

II. Steine von einer dichteren Art/welche sich um etwas lassen glatt machen/und polieren

A. Wetz- oder Schleiff-Stein (cos)

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*This synthetic list of the major elements of Scheuchzer's classification scheme was extracted from the more extensive discussion in Johann Jacob Scheuchzer, Meteorologia et oryctographia Helvetica, oder Beschreibung der Lufft-Geschichten/Steinen/Metallen/und anderen

APPENDIX V

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHANN JACOB SCHEUCHZER, 1718

Earths

Unctuous and dry earths

Lacte lunae

Stones

I. Larger stones separated into layers of coarser, thicker, rougher matter, whose parts cohere more tightly or loosely

A. Large stones and rocks

B. Pot-stone (steatite)

C. Sandstone and sand

D. Tufa

E. Millstone

F. Limestone

G. Gypsum

II. Stones of a more dense sort, which can make something smoother and polished

A. Whetstone or grindstone

Mineralien des Schweitzerlands/absonderlich auch der Uberbleibselen der Sündfluth ("Natur-Geschichten des Schweitzerlands," Vol. 6; Zürich: In der Bodmerischen Truckerey, 1718), pp. 99-202. Shown in parentheses are the Latin terms that Scheuchzer designated as the equivalents of his German denominations.

III. Harte und sehr dichte Steine/welche sich schön glatt polieren lassen

A. Marmel (marmor)

B. Alabaster (alabastrita)

IV. Kleinere Steine/welche gemeinlich nicht härter sind als der Marmor/von unordentlicher/ungewisser Gestalt

A. Kieselstein (silex)

V. Kleine Steine/welche aus langen gleichlauffenden oder parallel ligenden Zäseren bestehen

A. Federweiss (amianthus)

VI. Kleine Steine/welche bestehen aus ebenen/dünnen/biegsamen/ elastischen/meistens parallel ligenden Blättlein

A. Talk (talcum)

B. Glimmer (mica)

VII. Steine/welche aus Blättlein bestehen/und aber auch in ganzen Stucken eine gewisse würfflichte/oder fünf-sechseckichte Figur vorstellen

A. Fraueneis (selenites, specularis)

B. (Androdamas)

C. Spath (spatum)

VIII. Köhrichte Steine/welche aus lauter kleinen Köhrlein bestehen

IX. Steine/welche aus vielen übereinander ligenden Schalen oder Kinden bestehen

X. Steine/welche eine gewisse Gestalt vorbilden

A. Tropfstein (stalactites)

B. Luchstein (belemnites)

C. Beinwell-Wallstein (osteocolla)

XI. Kleine dunkle Steine/welche härter sind als Marmor

A. Nierenstein (nephriticus)

III. Rough and very dense stones, which can be smoothly polished nicely

A. Marble

B. Alabaster

IV. Smaller stones, which commonly are not harder than marble, of more irregular, more indeterminate shape

A. Flint

V. Small stones, which consist of long parallel-lying fibers

A. Amianthus

VI. Small stones, which consist of flat, thin, flexible, elastic, for the most part parallel-lying small plates

A. Talc

B. Mica

VII. Stones, which consist of small plates, and in whole pieces exhibit a certain cubical or pent-hex-angular figure

A. Selenite

B. Androdamas

C. Spar

VIII. Rubble stones, which consist of nothing but small rubble

IX. Stones, which consist of many shells or layers lying one upon another

X. Stones, which represent a certain shape

A. Dripstone (stalactites)

B. Belemnites

C. Osteocolla

XI. Small dark stones, which are harder than marble

A. Kidney stone

XII. Kleine halb durchsichtige Steine/welche härter sind als Marmor/ und ihre Farben nach verschiedener Situation gegen dem Liecht und Aug anderen

XIII. Kleine halb durchsichtige Steine/welche härter sind als Marmor/und beständig gleiche Farben haben

A. Achat (Achates)

XIV. Kleine durchsichtige Steine/welche härter sind als der Marmor/ ohnfärbig/oder von allerhand Farben

A. Granat (granatus)

B. Amethist (amethystus)

C. Carfunkle (carbunculus)

D. Crystall (crystallus)

E. Diamant (adamas)

Saltze (salia)

I. Gemeines Saltz (sal commune)

II. Salpeter (nitrum)

III. Alet/alaun (alumen)

IV. Vitriol (vitriolum)

V. Borris (borax)

Erdpech (bitumina)

I. Schweffel (sulphur)

II. Steinkohle (lithanthrax, carbo fossilis)

III. Erdpech (bitumen)

Denen Metallen verwandte Cörper (mineralia, metallis affinia)

I. Schweffelkiess (pyrites)

II. Spiessglas (antimonium)

III. Quecksilber (argentum vivum)

IV. Berggrün (chrysocolla)

XII. Small, semi-transparent stones, which are harder than marble, and their colors change according to the different position toward the light and eye

XIII. Small, semi-transparent stones, which are harder than marble and have unchanging colors

A. Agate

XIV. Small transparent stones, which are harder than marble, colorless or of diverse colors

A. Garnet

B. Amethyst

C. Carbuncle

D. Rock crystal

E. Diamond

Salts

I. Common salt

II. Saltpeter

III. Alum

IV. Vitriol

V. Borax

Bitumens

I. Sulphur

II. Coal

III. Bitumen (asphalt)

Metal-related bodies (minerals)

I. Pyrites

II. Antimony (stibnite)

III. Quicksilver

IV. Chrysacolla

V. Blende/Glimmer (mica)

Metalle (metalla)

I. Gold (aurum)

II. Silber (argentum)

III. Kupfer (aes)

IV. Eisen (ferrum), Stahel (chalybs)

V. Zinn (stannum seu plumbum candidum)

VI. Bley (plumbum)

V. Blende

Metals

I. Gold

II. Silver

III. Copper

IV. Iron, steel

V. Tin

VI. Lead

APPENDIX VI

SYNOPSIS OF THE CLASSIFICATION SCHEME OF

MAGNUS VON BROMELL, 1730*

Erstes Capitel. Von allerhand fetten und trockenen Erd-Arten

§. 1. Von denen, welche zur Medicin dienen

§. 2. Von denen, welche von Künstlern und sonsten gebraucht werden

§. 3. Tripel

§. 4. Weisser Porcellain-Thon

§. 5. Marga, oder Mergel

§. 6. Gur Metallicum

§. 7. Torff

Zweytes Capitel. Von allerhand Saltz-Arten

§. 1. Vom Saltz

§. 2. Vom Salpeter

§. 3. Vom Alaum

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*Bromell first published his mineral system in Swedish as Mineralogia, eller Inledning til nödig kundskap at igenkiänna och uppfinna Allahanda Berg-Arter, Mineralier, Metaller samt Fossilier, Och huru de mage til sin rätta nytta anwändas (Stockholm, 1730). This synthetic list of the major elements of Bromell's classification scheme was extracted from the contemporary German translation: Magnus von Bromell, Mineralogia et lithograpica Svecana, das ist Abhandlung derer in dem Königreich Schweden befindlichen Mineralien und Steinen. Ehemahls in Schwedischer Sprache abgefasst nunmehro aber ihrer besondern Merckwürdigkeit halben ins

APPENDIX VI

SYNOPSIS OF THE CLASSIFICATION SCHEME OF MAGNUS VON BROMELL, 1730

First Chapter. Of diverse unctuous and dry kinds of earth

§. 1. Of those which serve medicine

§. 2. Of those which are used by artists and others

§. 3. Tripoli

§. 4. White porcellain clay

§. 5. Marble

§. 6. Clayey ores

§. 7. Peat

Second Chapter. Of diverse kinds of salt

§. 1. Of salt

§. 2. Of saltpeter

§. 3. Of alum

Teutsche übersetzt, mit einem Vorbericht von dem vor kurtzer Zeit in Schweden entblössten Gold-Ertz begleitet, und mit darzu dienlichen Kupfern ans Licht gestellt von Mikrandern (Stockholm und Leipzig: bey Gottfried Kiesewetter, 1740). According to Gerhard Regnéll, "On the Position of Palaeontology and Historical Geology in Sweden before 1800," Arkiv för Mineralogi och Geologi, I (1949), 25, the eighth chapter of this translation ("Achtes Capitel. Von allerhand petrificatis, oder in Stein verwandelten See- und Erd-Gewächsen," pp. 56-94) is a summary of some of Bromell's earlier publications that are concerned with petrifications, and this chapter was added to the Mineralogia by the editor of the translation.

§. 2. Of arenaceous stone, or sandstone

§. 3. Of pebblestones

§. 4. Of garnets

§. 5. Of flints

§. 6. Of white quartz

§. 7. Of rock crystal

§. 8. Of the flowing crystals [fluorite], or emerald-colored topaz-colored, and amethyst-colored fluxes

Seventh Chapter. Of diverse stones which have some strange and unusual figures

§. 1. Of Ölandish and Gotlandish figured stones in marble

§. 2. Aetite and geodes, or eagle- and rattle-stone

§. 3. Osteocolla, or broken bone

§. 4. Of the so-called thunderstones

§. 5. Of violet stone

Eighth Chapter. Of diverse petrifactions, or those animals, sea-plants, and land-plants changed into stone

§. 1. From the vegetable kindgom

§. 2. From the animal kindgom

Ninth Chapter. Of those stones which grow and are generated in diverse animals

§. 1. Of the so-called serpent-stone and above-mentioned eagle-stone

§. 2. Of stones produced in horses, sheep, rams, swine, and other animals

§. 3. Of stones produced in birds and poultry

§. 4. Of northern bezoar, that is, crab-stones

§. 5. Of foreign and especially native Swedish and Finnish pearls

3. Vom Kupffergrün, oder Chrysocolla. Item von figurirten Kupfferhaltigen Schiefer. Item Kupfferhaltigen Sand-Stein

4. Von dem so genannten Schwedischen harten und weichen Kupffer-Ertz

§. 4. Vom Zinn-Malm

§. 5. Vom Bley-Malm

§. 6. Vom Eisen-Malm

3. Of verdigris, or chrysocolla, also cupriferous shale, also cupriferous sandstone

4. Of the hard, smooth, so-called Swedish copper ore

<u>§. 4</u>. Of tin ore

<u>§. 5</u>. Of lead ore

<u>§. 6</u>. Of iron ore

APPENDIX VII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF CARL VON LINNÉ, 1735*

Classis I. Petrae

Ordo 1. Apryi

Genus 1. Asbestus

Genus 2. Amiantus

Genus 3. Ollaris

Genus 4. Talcum

Genus 5. Mica

Ordo 2. Calcarii

Genus 1. Schistus

Genus 2. Spatum

Genus 3. Marmor

Ordo 3. Vitrescentes

Genus 1. Cos

Genus 2. Silex

Genus 3. Qvartzum

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*This synthetic list of the major elements of Linné's classification scheme was extracted from his sketch of the mineral kingdom in Carl von Linné, Caroli Linnaei, Sveci, doctoris medicinae, systema naturae, sive regna tria naturae systematice proposita per classes, ordines, genera, & species (Lugduni Batavorum: Apud Theodorum Haak, 1735). The following

APPENDIX VII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF CARL VON LINNÉ, 1735

<u>Class I</u>. Rocks

- <u>Order 1</u>. Refractory
  - <u>Genus 1</u>. Asbestus
  - <u>Genus 2</u>. Amiantus
  - <u>Genus 3</u>. Pot-stone (steatite)
  - <u>Genus 4</u>. Talc
  - <u>Genus 5</u>. Mica
- <u>Order 2</u>. Calcareous
  - <u>Genus 1</u>. Schist
  - <u>Genus 2</u>. Spar
  - <u>Genus 3</u>. Marble
- <u>Order 3</u>. Glassy
  - <u>Genus 1</u>. Sandstone
  - <u>Genus 2</u>. Flint
  - <u>Genus 3</u>. Quartz

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edition was used: Carl von Linné, *Carolus Linnaeus, systema naturae 1735; Facsimile of the First Edition. With an Introduction and a First English Translation of the "Observationes" by Dr. M. S. J. Engel-Ledeboer and Dr. H. Engel* ("Dutch Classics on History of Science," No. 8; Nieuwkoop, Holland: B. de Graaf, 1964).

Classis II. Minerae

Ordo 1. Salia

Genus 1. Nitrum

Genus 2. Muria

Genus 3. Alumen

Genus 4. Vitriolum

Ordo 2. Sulphura

Genus 1. Electrum

Genus 2. Bitumen

Genus 3. Pyrites

Genus 4. Arsenicum

Ordo 3. Mercurialia

Genus 1. Hydrargyrum

Genus 2. Stibium

Genus 3. Zincum

Genus 4. Vismutum

Genus 5. Stannum

Genus 6. Plumbum

Genus 7. Ferrum

Genus 8. Cuprum

Genus 9. Argentum

Genus 10. Aurum

Classis III. Fossilia

Ordo 1. Terrae

Genus 1. Glarea

Genus 2. Argilla

Class II. Minerals

Order 1. Salts

Genus 1. Saltpeter

Genus 2. Muria

Genus 3. Alum

Genus 4. Vitriol

Order 2. Sulphurs

Genus 1. Amber

Genus 2. Bitumen

Genus 3. Pyrite

Genus 4. Arsenic

Order 3. Mercurials

Genus 1. Mercury

Genus 2. Antimony

Genus 3. Zinc

Genus 4. Bismuth

Genus 5. Tin

Genus 6. Lead

Genus 7. Iron

Genus 8. Copper

Genus 9. Silver

Genus 10. Gold

Class III. Fossils

Order 1. Earths

Genus 1. Gravel

Genus 2. Clay

<u>Genus 3.</u> Humus

<u>Genus 4.</u> Arena

<u>Genus 5.</u> Ochra

<u>Genus 6.</u> Marga

<u>Ordo 2.</u> Concreta

<u>Genus 1.</u> Pumex

<u>Genus 2.</u> Stalactites

<u>Genus 3.</u> Tophus

<u>Genus 4.</u> Saxum

<u>Genus 5.</u> Aetites

<u>Genus 6.</u> Tartarus

<u>Genus 7.</u> Calculus

<u>Ordo 3.</u> Petrificata

<u>Genus 1.</u> Graptolithus

<u>Genus 2.</u> Phytolithus

<u>Genus 3.</u> Helmintholithus

<u>Genus 4.</u> Entomolithus

<u>Genus 5.</u> Ichthyolithus

<u>Genus 6.</u> Amphibiolithus

<u>Genus 7.</u> Ornitholithus

<u>Genus 8.</u> Zoolithus

Genus 3. Soil

Genus 4. Sand

Genus 5. Ocher

Genus 6. Marl

Order 2. Concretions

Genus 1. Pumice

Genus 2. Dripstone, stalactites

Genus 3. Tufa

Genus 4. Rock

Genus 5. Aetite or eagle-stone

Genus 6. Tartar

Genus 7. Calculus

Order 3. Petrifactions

Genus 1. Pictures of stone

Genus 2. Plants of stone

Genus 3. Worms of stone

Genus 4. Insects of stone

Genus 5. Fish of stone

Genus 6. Amphibians of stone

Genus 7. Birds of stone

Genus 8. Quadrupeds of stone

APPENDIX VIII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHAN GOTTSCHALK WALLERIUS, 1747*

Första flocken. Jordarter (terrae)

Afdelningen 1. Mullarter (terrae macrae)

Slägte 1. Mylla (humus)

Slägte 2. Krita, bränjord (creta, terra calcarea)

Afdelningen 2. Lerarter, täte jordarter (terrae pingves)

Slägte 1. Lera (argilla)

Slägte 2. Mergel (marga)

Afdelningen 3. Malmblandade jordarter (terrae minerales)

Slägte 1. Saltblandade jordarter (terrae salinae)

Slägte 2. Svafvelblandade jordarter (terrae sulphureae)

Slägte 3. Metallblandade jordarter (terrae metallicae, ochrae)

Afdelningen 4. Sandarter (Arenae)

Slägte 1. Mojord, mo (arena pulverulenta, glarea)

Slägte 2. Sand, stensand (arena)

Slägte 3. Malm-sand (arena metallica)

Slägte 4. Djur-sand (arena animalis)

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*This synthetic list of the major elements of Wallerius's classification scheme was extracted from the more extensive discussion in Johan Gottschalk Wallerius, J. H. N. Mineralogia, eller Mineral-Riket

APPENDIX VIII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHAN GOTTSCHALK WALLERIUS, 1747

First class. Kinds of earth

Order 1. Dry earths

Genus 1. Soil

Genus 2. Chalk, calcareous earth

Order 2. Argillaceous or unctuous kind

Genus 1. Clay

Genus 2. Marl

Order 3. Mineralized kinds of earth

Genus 1. Saline earths

Genus 2. Sulphurous earths

Genus 3. Metallic earths

Order 4. Kinds of sand

Genus 1. Gravel

Genus 2. Sand

Genus 3. Ore sand

Genus 4. Animal sand

(Stockholm: Uplagd på Lars Salvii egen kostnad, 1747). Shown in parentheses are the Latin terms that Wallerius designated as the equivalents of his Swedish denominations.

<u>Andra flocken</u>. Stenarter (lapides)

<u>Afdelningen 1</u>. Kalkarter (lapides calcarei)

<u>Slägte 1</u>. Kalksten (calcareous)

<u>Slägte 2</u>. Marmor (marmor)

<u>Slägte 3</u>. Gips (gypsum)

<u>Slägte 4</u>. Spat (spatum, selenites)

<u>Afdelningen 2</u>. Glasarter (lapides vitrescentes)

<u>Slägte 1</u>. Skifver (fissilis)

<u>Slägte 2</u>. Sandsten (cos)

<u>Slägte 3</u>. Kiselsten, agat (silex, acathes)

<u>Slägte 4</u>. Haelleflinta, Iaspis (Petrosilex, Jaspis)

<u>Slägte 5</u>. Quartz, kisel (qvartzum, silex)

<u>Slägte 6</u>. Crystaller, äkta stenar (crystalli, gemmae)

<u>Afdelningen 3</u>. Eldhardingar, hornater (lapides apyri)

<u>Slägte 1</u>. Skimmer (mica)

<u>Slägte 2</u>. Talk (talcum)

<u>Slägte 3</u>. Telgsten (ollaris)

<u>Slägte 4</u>. Hornbärg (corneus)

<u>Slägte 5</u>. Amiant (amiantus, asbestus)

<u>Slägte 6</u>. Asbest (asbestus, amiantus)

<u>Afdelningen 4</u>. Hällebärgs arter, gråbärgen (saxa)

<u>Slägte 1</u>. Enfälls hällebärg (saxum simplex)

<u>Slägte 2</u>. Gråbärg (saxum mixtum)

<u>Slägte 3</u>. Mörk gråsten, kneis (saxum griseum)

<u>Slägte 4</u>. Gyttrad hällesten (saxum concretum)

<u>Second class</u>. Kinds of stones

<u>Order 1</u>. Calcareous kind

<u>Genus 1</u>. Limestone

<u>Genus 2</u>. Marble

<u>Genus 3</u>. Gypsum

<u>Genus 4</u>. Spar

<u>Order 2</u>. Glassy kind

<u>Genus 1</u>. Slate

<u>Genus 2</u>. Sandstone

<u>Genus 3</u>. Flint, agate

<u>Genus 4</u>. Jasper

<u>Genus 5</u>. Quartz

<u>Genus 6</u>. Crystals, gems

<u>Order 3</u>. Refractory

<u>Genus 1</u>. Mica

<u>Genus 2</u>. Talc

<u>Genus 3</u>. Pot-stone (steatite)

<u>Genus 4</u>. Hornstone

<u>Genus 5</u>. Amiantus

<u>Genus 6</u>. Asbestus

<u>Order 4</u>. Kinds of rocks

<u>Genus 1</u>. Simple rocks

<u>Genus 2</u>. Mixed rocks (granite)

<u>Genus 3</u>. Greystone

<u>Genus 4</u>. Conglomerated rocks

<u>Tredie flocken</u>. Malmarter (minerae)

<u>Afdelningen 1</u>. Saltarter (salia)

<u>Slägte 1</u>. Viktril (vitriolum)

<u>Slägte 2</u>. Alun (alumen)

<u>Slägte 3</u>. Saltpeter (nitrum)

<u>Slägte 4</u>. Koksalt (muria, sal commune)

<u>Slägte 5</u>. Alkaliskt-salt (sal alkali)

<u>Slägte 6</u>. Surt salt (sal acidum)

<u>Slägte 7</u>. Medel-salt (sal neutrum)

<u>Slägte 8</u>. Salmiak (sal ammoniacum)

<u>Slägte 9</u>. Boras (borax)

<u>Afdelningen 2</u>. Svafvelarter (sulphura)

<u>Slägte 1</u>. Bärgfetma (bitumen)

<u>Slägte 2</u>. Bärnsten, raf (succinum)

<u>Slägte 3</u>. Ambra (ambra)

<u>Slägte 4</u>. Svafvel (sulphur)

<u>Afdelningen 3</u>. Halfmetaller (semimetalla)

<u>Slägte 1</u>. Qvicksilfver (hydrargyrum, mercurius)

<u>Slägte 2</u>. Arsenik (arsenicum)

<u>Slägte 3</u>. Kobolt (cobaltum)

<u>Slägte 4</u>. Spitsglas (antimonium, stibium)

<u>Slägte 5</u>. Vissmut, askbly (vismutum)

<u>Slägte 6</u>. Zink, spiauter (zincum)

<u>Afdelningen 4</u>. Metaller (metalla)

<u>Slägte 1</u>. Järn (ferrum, mars)

<u>Slägte 2</u>. Koppar (cuprum, aes, venus)

Third class. Kinds of ore (minerals)

Order 1. Kinds of salt

Genus 1. Vitriol

Genus 2. Alum

Genus 3. Saltpeter

Genus 4. Common salt

Genus 5. Alcali salt

Genus 6. Acid salt

Genus 7. Neutral salt

Genus 8. Sal ammoniac

Genus 9. Borax

Order 2. Kinds of sulphur

Genus 1. Bitumen

Genus 2. Amber

Genus 3. Ambergris

Genus 4. Sulphur

Order 3. Semi-metals

Genus 1. Quicksilver

Genus 2. Arsenic

Genus 3. Cobalt

Genus 4. Antimony

Genus 5. Bismuth

Genus 6. Zinc

Order 4. Metals

Genus 1. Iron

Genus 2. Copper

Slägte 3. Bly (plumbum, plumbum nigrum, saturnus)

Slägte 4. Tenn (stannum, plumbum album, jupiter)

Slägte 5. Silfver (argentum, luna)

Slägte 6. Gull (aurum, sol)

Fjerde flocken. Stenhårdningar (concreta)

Afdelningen 1. Stengyttringar (pori indurata)

Slägte 1. Stengyttringar i eld (pori ignei)

Slägte 2. Stengyttringar i vatten (pori aqvei)

Afdelningen 2. Stenvandlingar (petrificata)

Slägte 1. Stenvandlade växter (petrificata vegetabilia)

Slägte 2. Coralla, stenväxter (coralla, lithophyta)

Slägte 3. Stenvandlade djur (petrificata animalia, zoolithi)

Slägte 4. Conchylier (petrificata animalia testacea, conchylia fossilia)

Afdelningen 3. Stengyckel (figurata, lapides heteromorphi, lusus naturae)

Slägte 1. Målade stenar (lithomorphi, lapides picti, lapides engraphi)

Slägte 2. Bildstenar (lithoglyphi)

Slägte 3. Formlike stenar (lithotomi, lapides incisi)

Afdelningen 4. Stenafvel (calculi)

Slägte 1. Växters stenar (calculi vegetabilium)

Slägte 2. Djur stenar (calculi animalium)

<u>Genus 3</u>. Lead

<u>Genus 4</u>. Tin

<u>Genus 5</u>. Silver

<u>Genus 6</u>. Gold

<u>Fourth class</u>. Concretions

<u>Order 1</u>. Concreted stones (indurated tufa)

<u>Genus 1</u>. Stones concreted in fire

<u>Genus 2</u>. Stones concreted in water

<u>Order 2</u>. Petrifactions

<u>Genus 1</u>. Petrified plants

<u>Genus 2</u>. Corals

<u>Genus 3</u>. Petrified animals

<u>Genus 4</u>. Shellfish

<u>Order 3</u>. Stony sports

<u>Genus 1</u>. Painted stones

<u>Genus 2</u>. Figured stones

<u>Genus 3</u>. Formed stones

<u>Order 4</u>. Calculi

<u>Genus 1</u>. Plant stones

<u>Genus 2</u>. Animal stones

APPENDIX IX

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHN HILL, 1748*

Part 1. Fossils naturally and essentially simple, and unmetallick

Book 1. Not inflammable, nor soluble in water

Series 1. Of no regular structure, or determinate figure

Class 1. Constituting strata, or shapeless masses

Order 1. Of a smooth surface, and firmer texture

Order 2. Of a rough, dusty surface, and a looser texture

Series 2. Of a regular structure, but no determinate figure

Class 1. Of a foliaceous or flaky structure, flexile and elastick (Talc)

Order 1. Compos'd of plates of great Extent; each making singly the whole surface of the mass

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*This synthetic list of the major elements of Hill's classification scheme was extracted from the "Table of Fossils" in John Hill, A General Natural History, or New and Accurate Descriptions of the Animals, Vegetables, and Minerals of the Different Parts of the World; with Their Virtues and Uses, As Far As Hitherto Certainly Known in Medicine and Mechanics. Illustrated by a General Review of the Knowledge of the Ancients, and the Discoveries and Improvements of Later Ages in These Studies. Including the History of the Materia Medica, Pictoria, and Tinctoria of the Present and Earlier Ages. As Also Observations on the Neglected Properties of Many Valuable Substances Known at Present; and Attempts to Discover the Lost Medicines, &c. of Former Ages, in a Series of Critical Enquiries into the Materia Medica of the Ancient Greeks. With a Great Number of Figures Elegantly Engraved, Vol. I: A History of Fossils (London: Printed for Thomas Osborne, 1748).

<u>Order 2</u>. Compos'd of small plates in form of spangles, laid in different directions in the mass

<u>Class 2</u>. Of a fibrose or thready structure (Fibraria)

<u>Order 1</u>. Compos'd of filaments, arrang'd perpendicularly in the mass, not flexile nor elastic, and readily calcining in the fire

<u>Order 2</u>. Compos'd of filaments, arrang'd horizontally in the mass, flexile and elastic, and not calcining readily in the fire

<u>Class 3</u>. Of a granulose texture (Gypsum)

<u>Order 1</u>. Of a firm, compact texture, and considerably hard

<u>Order 2</u>. Of a lax, loose texture, soft and crumbly

<u>Series 3</u>. Of a regular structure, and determinate figure

<u>Class 1</u>. Compos'd of slender filaments arrang'd into plates, and those forming complex masses, which are flexile but not elastick, easily calcinable, but not soluble in acids (Selenites)

<u>Order 1</u>. Compos'd of horizontal plates, and approaching to a rhomboidal form

<u>Order 2</u>. Compos'd of horizontal plates, and of a columnar and angular form

<u>Order 3</u>. Of a striated appearance

<u>Order 4</u>. Flat, but of no determinately angular figure.

<u>Order 5</u>. Form'd of plates perpendicularly arrang'd

<u>Order 6</u>. Form'd of congeries of plates or fibres, rang'd in form of a Star

<u>Order 7</u>. Of a complex, and indeterminate figure

<u>Class 2</u>. Of angular figures, very bright, giving fire with steel, and not soluble in acids, nor readily calcining (Crystal)

<u>Order 1</u>. Compos'd of an hexangular column, terminated at each end by an hexangular pyramid

Order 2. Compos'd of two pyramids join'd base to base without a column

Order 3. Compos'd of an angular column, terminated at one end by a pyramid, and at the other growing to some solid body

Class 3. Of angular and indeterminate figures, of a crystalline appearance, not giving fire with steel, soluble in acids, and readily calcining (Spar)

Order 1. Compos'd of an angular column terminated at each end by an angular pyramid

Order 2. Compos'd of two pyramids, joined base to base without any intermediate column

Order 3. Compos'd of angular columns, terminated at the summit by a pyramid, but adhering by their base to some solid body

Order 4. Compos'd of single pyramids, affix'd to some solid body by their bases without any column

Order 5. Of a parallellopiped figure

Order 6. Of an irregular figure, but compos'd of rhomboidal concretions

Order 7. Of an impure texture, and in form of crusts or thin plates

Order 8. Of an earthy texture, forming plates or incrustations

Order 9. Form'd into long conical bodies hanging from the roofs of caverns

Order 10. Form'd into small round figures of a crustated structure

Book 2. Soluble in water, not inflammable

Series 1. Of an Acrid Taste

Class 1. Not inflammable, soluble in water, and concreting again into regular Crystals (Simple salt)

Order 1. Found native and pure

Order 2. Found in the state of ores, their particles being blended in Earths or Stones

Order 3. Found suspended in waters, and in a liquid form

Book 3. Inflammable, not soluble in water

Series 1. In a solid form

Class 1. Of a purer texture, and in some degree pellucid (Phlogidiaugium)

Order 1. Of a lax texture, soft and friable

Order 2. Of a finer texture, and considerable hard

Class 2. Of a coarser texture, and not pellucid (Phlogiscierium)

Order 1. Found loose, and in detach'd masses

Order 2. Constituting whole strata

Series 2. In a liquid form

Class 1. Thinner fluids (Gelaeopsilum)

Class 2. Thicker fluids (Gelaeopachium)

Part 2. Fossils naturally and essentially Compound, and unmetallick

Book 1. Not inflammable, nor soluble in water

Series 1. Of no regular structure, or determinate figure, and Forming whole strata

Class 1. Compos'd of argillaceous or marley matter, blended with other particles, and never found pure (Compound Earth)

Order 1. Compos'd of Sand, and a viscid clay

Order 2. Compos'd of argillaceous or marly particles, with animal and vegetable remains

Class 2. Composing beds of great extent, hard and dry, not soluble in water, nor oil, nor at all ductile (Stone)

Order 1. Coarse, harsh, of a lax texture, and visible gritt, lodg'd in a cementitious matter

Order 2. Moderately fine, and even in texture, and of no visible grit or grain

Order 3. Of a fine substance, elegant structure and great brightness, compos'd of Granules, sometimes more, sometimes less distinct, but never lodg'd in any cementitious matter

Series 2. Form'd in detach'd masses, of a regular structure, and determinate figure

Class 1. Form'd by simple concretions, and divided by thin partitions into various parcels (Septaria, or waxen vein)

Order 1. Constituting large masses, of a plain simple structure, and divided by thick septa

Order 2. Constituting smaller masses, of a crustated structure, and divided by thin septa

Class 2. Form'd by repeated Incrustations of earthy and ferrugineous matter (Siderochitum, or crustated ferrugineous body)

Order 1. Those which contain regular and solid Nuclei

Order 2. Those which contain soft or fluid matter instead of Nuclei

Series 3. Form'd in detach'd masses, of no determinate figure, or regular structure, and compos'd of Crystal or Spar debas'd by earth

Class 1. Found in large detach'd masses without crusts, compos'd of variously debas'd crystalline matter (Scrupi)

Order 1. Those of a more rude, and irregular structure in the mass

Order 2. Those of a more equal and regular construction

Class 2. Of a slightly debas'd crystalline matter, of great beauty and brightness, and a moderate degree of transparence usually and found in small masses (Semipellucid Gemms)

Order 1. Of but few variegations, and frequently of one plain simple colour, tho' sometimes vein'd

Order 2. Remarkable for their Zones, veins and variegations

Class 3. Of a considerably debased crystalline matter, covered with an opake crust, and of great beauty and brightness, tho' but a slight degree of transparence (Lithidium)

Order 1. Compos'd of crystalline matter, debas'd by only one kind of earth

Order 2. Compos'd of crystalline matter, debas'd by various earths

Class 4. Found in small disunited particles making together a sort of loose powder (Conissalae)

Order 1. Seeming original concretions

Order 2. Seeming fragments of larger masses

Series 4. Of a fine pellucid substance not foul'd by earth

Class 1. Extreamly hard, pellucid, and of the greatest lustre and beauty of all Fossils (Pellucid Gemm)

Order 1. Of invariable colours

Order 2. Of changeable colours

Book 2. Soluble in water, not inflammable

Series 1. Containing Metals, and nauseous acrid tastes

Class 1. Not inflammable, but fusible by fire, soluble in water, and concreting again into regular figures (Metalick Salt)

Order 1. Found naturally in a solid form

Order 2. Naturally in a liquid form

Book 3. Inflammable, not soluble in water

Series 1. Forming whole strata

Class 1. Not found in loose masses (Marcasita)

Order 1. Of an obscurely foliaceous structure

Series 2. Form'd in detach'd masses

Class 2. Forming detach'd masses of no determinately angular figure (Pyrites)

<u>Order 1</u>. Of a plain and simple internal structure

<u>Order 2</u>. Of a regularly striated, internal structure

<u>Class 3</u>. Forming detach'd masses of determinately angular figures (Phlogonium)

<u>Order 1</u>. Of six plains

<u>Order 2</u>. Of eight plains

<u>Order 3</u>. Of twelve plains

<u>Part 3</u>. Metallick Fossils

<u>Series 1</u>. Fusible by fire

<u>Class 1</u>. Imperfectly metallick (Asphurelatum)

<u>Order 1</u>. Fusible by fire, and not malleable in their purest state

<u>Class 2</u>. Perfectly metallick (Metallum)

<u>Order 1</u>. Fusible by fire, and malleable when pure

APPENDIX X

SYNOPSIS OF THE CLASSIFICATION SCHEME OF ANTOINE JOSEPH DEZALLIER D'ARGENVILLE, 1755*

Fossiles naturels a la terre

- Premiére classe. Les terres
  - Premier article. Les terres
  - Second article. Les bols
- Seconde classe. Lithologie, ou les pierres
  - Premier genre. Pierres très-dures
    - Première espèce. Pierres cristallines
      - Premier article. Pierres diaphanes, ou transparentes
      - Second article. Pierres demi-transparentes
    - Seconde espece. Pierres opaques
      - Premier article. Pierres fines qui reçoivent le poli
      - Second article. Pierres d'un grain plus gros, ou d'une nature grasse, qui ne peut se polir
    - Troisième espece. Les cailloux
      - Premier article. Les cailloux cristallisés

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*This synthetic list of the major elements of Dezallier d'Argenville's classification scheme was extracted from the more detailed enumeration in [Antoine Joseph Dezallier d'Argenville,] L'Histoire naturelle eclaircie dans une de ses parties principales, l'oryctologie, qui

APPENDIX X

SYNOPSIS OF THE CLASSIFICATION SCHEME OF ANTOINE JOSEPH DEZALLIER D'ARGENVILLE, 1755

Fossils native to the earth

First class. Earths

First article. Earths

Second article. Boles

Second class. Stones

First genus. Very hard stones

First species. Crystalline stones

First article. Diaphanous or transparent stones

Second article. Semi-transparent stones

Second species. Opaque stones

First article. Fine [grain] stones that take a polish

Second article. Stones of a larger grain, or of an unctuous nature, that cannot be polished

Third species. Flintstones

First article. Crystallized flintstones

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traite des terres, des pierres, des métaux, des minéraux, et autres fossiles. Ouvrage dans lequel on trouve une nouvelle méthode Latine & Françoise de les diviser, & une notice critique des principaux ouvrages qui ont paru sur ces matières (Paris: Chez De Bure l'Aîné, 1755) pp. 39-94.

<u>Second article</u>. Les cailloux transparens

<u>Troisième article</u>. Les cailloux opaques

<u>Première espèce</u>. Cailloux qui peuvent se polir

<u>Seconde espèce</u>. Cailloux peu propres à être polis

<u>Quatrième article</u>. Cailloux communs

<u>Première espèce</u>. Cailloux qui frottés l'un contre l'autre, jettent du feu

<u>Seconde espèce</u>. Cailloux qui, quoique frottés l'un contre l'autre, ne font point de feu

<u>Second genre</u>. Pierres tendres et calcaires

<u>Première espèce</u>. Pierres qui ont les pores peu serrés & le grain gros, très-faciles à tailler

<u>Seconde espèce</u>. Pierres qui ont les pores plus serrés, le grain plus fin, & qui sont plus difficiles à tailler

<u>Troisième genre</u>. Pierres écailleuses

<u>Premiere espèce</u>. Les transparentes

<u>Seconde espèce</u>. Pierres opaques

<u>Quatrième genre</u>. Les pierres sablonneuses, poreuses, tartareuses, spongieuses

<u>Troisième classe</u>. Qui contient les sels, les soufres, les métaux et les mineraux

<u>Premier genre</u>. Les sels

<u>Second genre</u>. Les soufres

<u>Troisième genre</u>. Les metaux et les mineraux

<u>Première espèce</u>. Les metaux

<u>Seconde espèce</u>. Demi-metaux

<u>Troisième espèce</u>. Pierres martiales, ou ferrugineuses

<u>Quatrième espèce</u>. Pierres pyriteuses

<u>Second article</u>. Transparent flintstones

<u>Third article</u>. Opaque flintstones

<u>First species</u>. Flintstones that can be polished

<u>Second species</u>. Flintstones little suited to be polished

<u>Fourth article</u>. Common flintstones

<u>First species</u>. Flintstones, that rubbed against one another, emit fire

<u>Second species</u>. Flintstones that, although rubbed against one another, make no fire

<u>Second genus</u>. Soft and calcareous stones

<u>First species</u>. Stones that have pores little closed and large grain, very easy to fashion

<u>Second species</u>. Stones that have the pores more closed, finer grain, and are more difficult to fashion

<u>Third genus</u>. Scaly (or squamous) stones

<u>First species</u>. Transparent

<u>Second species</u>. Opaque stones

<u>Fourth genus</u>. Sandy, porous, tartareous, and spongy stones

<u>Third class</u>. Which contains salts, sulphurs, metals, and minerals

<u>First genus</u>. Salts

<u>Second genus</u>. Sulphurs

<u>Third genus</u>. Metals and minerals

<u>First species</u>. Metals

<u>Second species</u>. Semi-metals

<u>Third species</u>. Ironstones or ferruginous stones

<u>Fourth species</u>. Pyritic stones

<u>Cinquième espèce</u>. Pierres quartzeuses

<u>Sixième espèce</u>. Pierres spatheuses

<u>Septième espèce</u>. Pierres que jettent les volcans

<u>Les fossiles étrangers a la terre</u>

<u>Premiére classe</u>. Contenant les parties des animaux

<u>Premier article</u>. Les vraies parties des animaux

<u>Second article</u>. Les parties d'animaux imprimées sur la pierre

<u>Seconde classe</u>. Contenant les parties des végétaux

<u>Premier article</u>. Les vraies parties des végétaux

<u>Second article</u>. Les mêmes parties des végétaux imprimées sur la pierre

<u>Troisième classe</u>. Contenant les pierres poreuses que la mer a produites, qui ont été amenées par le déluge dans les entrailles de la terre, & qui lui sont étrangères

<u>Quatrième classe</u>. Contenant les pierres étrangères aux animaux & aux végétaux, & qui s'y engendrent journellement

<u>Fifth species</u>. Quartzose stones

<u>Sixth species</u>. Sparry stones

<u>Seventh species</u>. Stones that volcanos throw out

<u>Fossils extraneous to the earth</u>

<u>First class</u>. Containing parts of animals

<u>First article</u>. Genuine parts of animals

<u>Second article</u>. Parts of animals impressed on stone

<u>Second class</u>. Containing the parts of plants

<u>First article</u>. Genuine parts of plants

<u>Second article</u>. The same parts of plants impressed on stone

<u>Third class</u>. Containing porous stones that the sea has produced, which were introduced by the deluge into the bowels of the earth, and are extraneous to it

<u>Fourth class</u>. Containing the extraneous stones of animals and plants, and which daily are produced there

APPENDIX XI

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHANN HEINRICH GOTTLOB VON JUSTI, 1757*

<u>Erste Abtheilung</u>. Von denen Metallen

- <u>Erstes Hauptstück</u>. Von dem Golde
- <u>Zweytes Hauptstück</u>. Von Silber und dessen Erzten
- <u>Drittes Hauptstück</u>. Von Kupfer und dessen Erzten
- <u>Viertes Hauptstück</u>. Von Eisenerzten
- <u>Fünftes Hauptstück</u>. Von Zinnerzten
- <u>Sechstes Hauptstück</u>. Von den Bleyerzten

<u>Zweyte Abtheilung</u>. Von denen Halbmetallen

- <u>Siebentes Hauptstück</u>. Von dem Quecksilber und dessen Erzten
- <u>Achtes Hauptstück</u>. Von Spiessglass und dessen Erzten
- <u>Neuntes Hauptstück</u>. Von dem Wissmuth und dessen Erzten
- <u>Zehntes Hauptstück</u>. Von Zink und dessen Erzten
- <u>Eilftes Hauptstück</u>. Von Arsenik und dessen Minern
  - <u>Erster Abschnitt</u>. Von den eigentlichen Minern des Arseniks
  - <u>Zweyter Abschnitt</u>. Von denen Kobalden

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*This synthetic list of the major elements of Justi's classification scheme was extracted from the more extensive discussion in Johann Heinrich Gottlob von Justi, <u>Grundriss des gesamten Mineralreiches worinnen</u>

APPENDIX XI

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JOHANN HEINRICH GOTTLOB VON JUSTI, 1757

First division. Of the metals

First chapter. Of gold

Second chapter. Of silver and its ores

Third chapter. Of copper and its ores

Fourth chapter. Of iron ores

Fifth chapter. Of tin ores

Sixth chapter. Of lead ores

Second division. Of the semi-metals

Seventh chapter. Of quicksilver and its ores

Eighth chapter. Of antimony and its ores

Ninth chapter. Of bismuth and its ores

Tenth chapter. Of zinc and its ores

Eleventh chapter. Of arsenic and its minerals

First section. Of the true minerals of arsenic

Second section. Those of cobalt

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alle Fossilien in einem, ihren wesentlichen Beschaffenheiten gemässen, Zusammenhange vorgestellet und beschrieben werden (Göttingen: Im Verlag der Wittwe Vandenhöck, 1757).

<u>Third division</u>. Of minerals of combustible substances

<u>Twelfth chapter</u>. Of the fluid combustible substances and those solid combustible minerals from the same

<u>Thirteenth chapter</u>. Of coal and other combustible minerals mixed with stones and earths

<u>Fourteenth chapter</u>. Of sulphur and its minerals

<u>First section</u>. Of naturally occurring sulphur and the true sulphur minerals

<u>Second section</u>. Of sulphur- or iron-pyrites

<u>Fourth division</u>. Of the salts

<u>Fifteenth chapter</u>. Of the acid salts

<u>First section</u>. Of vitriol

<u>Second section</u>. Of alum

<u>Sixteenth chapter</u>. Of the alcaline salts

<u>Seventeenth chapter</u>. Of the neutral salts

<u>Fifth division</u>. Of petrifactions and figured mineral bodies

<u>Eighteenth chapter</u>. Of petrifactions of the animal kingdom

<u>First section</u>. Of petrified terrestrial animals

<u>Second section</u>. Of petrified sea- or aquatic animals

<u>Nineteenth chapter</u>. Of petrifactions of the plant kingdom

<u>First section</u>. Of petrified terrestrial plants

<u>Second section</u>. Of the petrified sea plants

<u>Twentieth chapter</u>. Of petrifactions whose origin is unknown.

<u>Twenty-first chapter</u>. Of peculiarly shaped and constituted stones, that do not have an unknown origin

<u>Twenty-second chapter</u>. Of druses or geodes

<u>Sixth division</u>. Of stones and earths

<u>Twenty-third chapter</u>. Of the precious stones

<u>Twenty-fourth chapter</u>. Of the semi-precious stones

<u>Twenty-fifth chapter</u>. Of the fire-resistant stones and earths

<u>Twenty-sixth chapter</u>. Of calcareous stones and earths

<u>First section</u>. Of true calcareous stones and earths

<u>Second section</u>. Of gypseous stones and earths

<u>Third section</u>. Of spurious calcareous stones and earths

<u>Twenty-seventh chapter</u>. Of glassy or fusible stones and earths

APPENDIX XII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF AXEL FREDRIK CRONSTEDT, 1758*

First class. Earths

First order. Calcareous kinds

A. Pure

1. In form of powder

2. Friable and compact

3. Indurated or hard

B. Satiated or united with the acid of vitriol (gypsum)

1. Loose and friable

2. Indurated

C. Satiated with acid of common salt (sal ammoniac)

D. Calcareous earth united with the inflammable substance

1. Calcareous earth mixed with phlogiston alone (foetid stone and spar)

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*This synthetic list of the major elements of Cronstedt's classification scheme, which was first published anonymously in Försök til Mineralogie, eller Mineral-rikets upställning (Stockholm: 1758), was extracted from the English translation: Axel Fredrik Cronstedt, An Essay towards a System of Mineralogy, by Axel Fredric Cronstedt. Translated from the Original Swedish, with Notes, by Gustav von Engestrom. To Which Is Added a Treatise on the Pocket-Laboratory, Containing an Easy Method, Used by the Author, for Trying Mineral Bodies, Written by the Translator. The Whole Revised and Corrected, with Some Additional Notes, by Emanuel Mendes da Costa (London: Printed for Edward and Charles Dilly, 1770). Several of the minor subdivisions have been omitted.

2. Calcareous earth united with phlogiston and the vitriolic acid

E. Calcareous earths blended with an argillaceous earth (marle)

1. Loose and compact

2. Semi-indurated

3. Indurated

F. Calcareous earth united with a metallic calx

1. Calcareous earth united with iron

2. Calcareous earth united with copper

3. Calcareous earth united with the calx of lead

<u>Second order</u>. Siliceous kind

A. Diamond

1. Colourless (the diamond properly so-called)

2. Red (ruby)

B. Saphire

C. Topaz

1. Yellow

2. Yellowish green

3. Bluish green topaz (the beryll)

D. Emerald

E. Quartz

1. Pure

2. Impure

F. Flint

1. Opal

2. Onyx

3. Chalcedony (white agate)

4. Carnelian

5. Sardonyx

6. Agate

7. Common flint

8. Chert

G. Jasper

1. Pure

2. Jasper containing iron

H. Rhombic quartz (feltspat)

<u>Third order</u>. Garnet kind

A. Garnet

1. Garnet mixed with iron

2. Garnet mixed with iron and tin

3. Garnet mixed with iron and lead

B. Cockle or shirl

<u>Fourth order</u>. Argillaceous kind

A. Porcellain clay

1. Pure

2. Mixed with phlogiston, and a very small quantity of inseparable heterogeneous substances

3. Mixed with iron

B. Stone marrow (lithomarga)

1. Of coarse particles

2. Of very fine particles

C. Boles

1. Loose and friable boles, or those which fall to a powder in water

2. Indurated

D. Tripoli

E. Common clay, or brick clay

1. Diffusible in water

2. Indurated

<u>Fifth order</u>. Micaceous kind

A. Colourless or pure mica

1. Of large parallel plates

2. Of small plates

3. Of particles like chaff, or chaffy mica

4. Of twisted plates, crumpled mica

B. Coloured and martial mica

1. Of large parallel plates

2. Of fine and minute scales

3. Twisted or crumpled

4. Chaffy

5. Cristallised

<u>Sixth order</u>. Fluors

A. Indurated

1. Solid, of an indeterminate figure

2. Sparry

3. Cristallised

<u>Seventh order</u>. Asbestus kind

A. Asbestus which is compounded of soft and thin membranes

1. Of parallel membranes

2. Of twisted soft membranes

B. Of fine and flexible fibres

1. With parallel fibres

2. Of broken and recombined fibres

<u>Eighth order</u>. Zeolites

A. Solid, or of no visible particles

1. Pure

2. Mixed with silver and iron

B. Sparry

C. Cristallised

1. In groupes of cristals in form of balls, and with concentrical points

2. Prismatical and truncated cristals

3. Capillary cristals

<u>Ninth order</u>. Manganese kind

A. Loose and friable

B. Indurated

1. Pure, in form of balls, whose texture consists of concentric fibres

2. Mixed with a small quantity of iron

3. Blended with a small quantity of iron and tin (wolfram)

<u>Second class</u>. Salts

<u>First order</u>. Acid salts

A. The vitriolic acid

1. The pure vitriolic acid

2. The vitriolic acid mixed or saturated

a. With metals (vitriols)

b. The acid of vitriol mixed or saturated with earths

c. Vitriolic acid united with phlogiston (sulphura)

d. Vitriolic acid saturated with alcaline salt (neutrals)

B. Acid of common or sea-salt

1. Pure

2. Mixed or satiated acid of sea-salt

a. With earths

b. With alcaline salts

c. United with phlogiston (amber)

d. United with metals

<u>Second order</u>. Alcaline mineral salts

A. Fixed in the fire

1. Alcali of the sea, or common salt

2. Borax

B. Volatile alkali

1. Mixed with salts

2. Mixed with earths

<u>Third class</u>. Mineral inflammable substances

A. Amber grise

B. Amber

1. Opake

2. Transparent

C. Rock-oil

1. Liquid

a. Naphta

b. Rock-oil

2. Thick and pitchy rock-oil, or Barbadoes tar

3. Hardened rock-oil

D. Mineral phlogiston, or bitumen, united with the vitriolic acid (sulphur)

1. Native sulphur

2. Sulphur that has dissolved, or is saturated with metals

E. Mineral phlogiston united with earths

1. With a calcareous earth

2. With an argillaceous earth

F. Mineral phlogiston mixed with metallic earths

1. With copper

2. With iron

Fourth class. Metals

First order. Metals

A. Gold

1. Native gold

2. Mineralised gold

B. Silver

1. Native or pure

2. Dissolved and mineralised

a. With sulphur alone

b. With sulphur and various metals

C. Platina del pinto

D. Tin

1. In form of a calx
2. Mineralised with sulphur and iron (black lead)

E. Lead
1. In form of a calx
a. Pure
b. Mixed
2. Mineralised

F. Copper
1. Native
2. In form of a calx
a. Pure
b. Mixed
3. Dissolved and mineralised

G. Iron
1. In form of calx
a. Pure
b. Mixed with heterogeneous substances
2. Dissolved or mineralised iron
a. With sulphur alone
b. With arsenic (mispickel)
c. With sulphurated arsenic
d. With vitriolic acid
e. With phlogiston
f. With other sulphurated and arsenicated metals

<u>Second order</u>. Semi-metals

A. Quicksilver

1. Native, or in a metallic state
2. Mineralised

B. Bismuth

1. Native
2. In form of calx
3. Mineralised

C. Zink

1. In form of calx
2. Mineralised

D. Antimony

1. Native
2. Mineralised

E. Arsenic

1. Native
2. In form of a calx
3. Mineralised

F. Cobalt

1. In form of a calx
2. Mineralised

G. Nickel

1. In form of a calx (nickel ochre)
    a. Mixed with the calx of iron
2. Mineralised
    a. With sulphurated and arsenicated iron and cobalt
    b. With the acid of vitriol

APPENDIX XIII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JACQUES CHRISTOPHE VALMONT DE BOMARE, 1762*

Premiere classe. Eaux

Ordre I. Eaux communes, ou eaux simples

Genre I. Eaux de l'air

Genre II. Eaux terrestres

Ordre II. Eaux minérales ou composées

Genre III. Eaux minérales froides

Genre IV. Eaux minérales, ou eaux thermales

Seconde classe. Terres

Ordre I. Terres argilleuses

Sous-division I. Terres en poussiere

Genre V. Terre franche ou terreau

Sous-division II. Terres grasses

Genre VI. Argille proprement dite

Ordre II. Terres alcalines

Sous-division III. Terres minérales ou composées

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*This synthetic list of the major elements of Valmont de Bomare's classification scheme was extracted from the more detailed enumeration in Jacques Christophe Valmont de Bomare, Mineralogie, ou nouvelle exposition du regne minéral. Ouvrage dans lequel on a tâché de ranger dans l'ordre

APPENDIX XIII

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JACQUES CHRISTOPHE VALMONT DE BOMARE, 1762

First class. Waters

Order I. Ordinary waters, or simple waters

Genus I. Waters of the air

Genus II. Terrestrial waters

Order II. Mineral or compound waters

Genus III. Cold mineral waters

Genus IV. Mineral waters, or thermal waters

Second class. Earths

Order I. Argillaceous earths

Subdivision I. Earths in the form of dust

Genus V. True earth or humus

Subdivision II. Unctuous earths

Genus VI. Clay properly so-called

Order II. Alcaline earths

Subdivision III. Mineral or compound earths

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le plus naturel les individus de ce regne, & où l'on expose leurs propriétés & usages méchaniques. Avec un dictionnaire nomenclateur et des tables synoptiques (Paris: Chez Vincent, 1762), I, tables B, D, E, F, G; II, tables H, I, K, L, M.

Genre VII. Terres métalliques, ou ochres

Genre VIII. Craie, terre calcaire

Genre IX. Marne

Troisieme classe. Sables

Ordre I. Sables

Genre X. Sable de pierres

Genre XI. Sables vitrifiables

Genre XII. Sables calcaires

Genre XIII. Sable argilleux

Genre XIV. Sable métallique

Quatrieme classe. Pierres

Ordre I. Pierres argilleuses

Genre XV. Asbeste, ou amyanthe

Sous-division I. Asbeste

Sous-division II. Amyanthe

Genre XVI. Mica

Genre XVII. Talc

Genre XVIII. Pierres smectites ou stéatites, ou pierres ollaires

Genre XIX. Roche de corné

Genre XX. Ardoises ou schistes

Ordre II. Pierres calcaires

Sous-division I. Pierres calcaires opaques & non crystallisées

Genre XXI. Pierre à chaux, ou pierre à ciment

Genre XXII. Le marbre

Sous-division II. Pierres calcaires crystallisées & transparentes

Genre XXIII. Spath

Genus VII. Metallic earths or ochers

Genus VIII. Chalk, calcareous earth

Genus IX. Marl

Third class. Sands

Order I. Sands

Genus X. Gravel

Genus XI. Vitrifiable sands

Genus XII. Calcareous sands

Genus XIII. Argillaceous sands

Genus XIV. Metallic sands

Fourth class. Stones

Order I. Argillaceous stones

Genus XV. Asbestus or amiantus

Subdivision I. Asbestus

Subdivision II. Amiantus

Genus XVI. Mica

Genus XVII. Talc

Genus XVIII. Soapstone or steatite, or pot-stone

Genus XIX. Hornstone

Genus XX. Slates or schists

Order II. Calcareous stones

Subdivision I. Opaque and uncrystallized calcareous stones

Genus XXI. Limestone

Genus XXII. Marble

Subdivision II. Crystallized and transparent calcareous stones

Genus XXIII. Spar

Genre XXIV. Pierres formées dans l'eau

Ordre III. Pierres gypseuses

Genre XXV. Gypse

Genre XXVI. Pierres médiastines crystallisées

Ordre IV. Pierres vitrifiables

Genre XXVII. Cailloux

Sous-division I. Cailloux opaques & grossiers

Sous-division II. Agathes, ou cailloux demi-transparens

Genre XXVIII. Grais, ou pierre de sable

Genre XXIX. Quartz

Genre XXX. Crystaux & pierres précieuses

Sous-division I. Crystaux de roche

Sous-division II. Pierres précieuses

Genre XXXI. Pierres composées, ou roches

Sous-division I. Pierre de roche grossiere

Sous-division II. Roche en masse

Sous-division III. Pierre de roche de couleurs vives

Cinquieme classe. Sels

Genre XXXII. Alun

Genre XXXIII. Vitriol

Genre XXXIV. Sel alkali

Genre XXXV. Sel neutre

Genre XXXVI. Nître

Genre XXXVII. Sel commun, ou sel marin

Genre XXXVIII. Sel ammoniac

Genre XXXIX. Borax

<u>Genus XXIV</u>. Stones formed in water

<u>Order III</u>. Gypseous stones

<u>Genus XXV</u>. Gypsum

<u>Genus XXVI</u>. Crystallized mediastinum stones

<u>Order IV</u>. Vitrifiable stones

<u>Genus XXVII</u>. Flints

<u>Subdivision I</u>. Opaque and common flints

<u>Subdivision II</u>. Agates, or semi-transparent flints

<u>Genus XXVIII</u>. Sandstone

<u>Genus XXIX</u>. Quartz

<u>Genus XXX</u>. Crystals and precious stones

<u>Subdivision I</u>. Rock crystals

<u>Subdivision II</u>. Precious stones

<u>Genus XXXI</u>. Compound stones or rocks

<u>Subdivision I</u>. Coarse rock

<u>Subdivision II</u>. Massive rock

<u>Subdivision III</u>. Rocks of bright colors

<u>Fifth class</u>. Salts

<u>Genus XXXII</u>. Alum

<u>Genus XXXIII</u>. Vitriol

<u>Genus XXXIV</u>. Alcali salt

<u>Genus XXXV</u>. Neutral salt

<u>Genus XXXVI</u>. Saltpeter

<u>Genus XXXVII</u>. Common salt, or sea salt

<u>Genus XXXVIII</u>. Sal ammoniac

<u>Genus XXXIX</u>. Borax

<u>Genre XL</u>. Sel de tartre

<u>Sixieme classe</u>. Pyrites

<u>Ordre I</u>. Pyrites ou pierres à feu

<u>Genre XLI</u>. Pyrite sulfureuse

<u>Genre XLII</u>. Marcassite d'arsenic

<u>Septieme classe</u>. Demi-métaux

<u>Sous-division I</u>. Demi-métaux solides

<u>Genre XLIII</u>. Arsenic

<u>Genre XLIV</u>. Cobalt

<u>Genre XLV</u>. Bismuth

<u>Genre XLVI</u>. Zinc

<u>Genre XLVII</u>. Antimoine

<u>Sous-division II</u>. Demi-métal fluide

<u>Genre XLVIII</u>. Mercure ou vif-argent

<u>Huitieme classe</u>. Metaux

<u>Ordre I</u>. Métaux imparfaits ou ignobles

<u>Sous-division I</u>. Métaux mols & faciles à fondre

<u>Genre XLIX</u>. Plomb

<u>Genre L</u>. Etain

<u>Sous-division II</u>. Métaux difficiles à fondre

<u>Genre LI</u>. Fer

<u>Genre LII</u>. Cuivre

<u>Ordre II</u>. Métaux parfaits ou nobles

<u>Sous-division III</u>. Métaux parfaits

<u>Genre LIII</u>. Argent

<u>Genre LIV</u>. Or

<u>Genus XL</u>. Tartar

<u>Sixth class</u>. Pyrites

<u>Order I</u>. Pyrites

<u>Genus XLI</u>. Sulphurous pyrite

<u>Genus XLII</u>. Arsenical marcasite

<u>Seventh class</u>. Semi-metals

<u>Subdivision I</u>. Solid semi-metals

<u>Genus XLIII</u>. Arsenic

<u>Genus XLIV</u>. Cobalt

<u>Genus XLV</u>. Bismuth

<u>Genus XLVI</u>. Zinc

<u>Genus XLVII</u>. Antimony

<u>Subdivision II</u>. Fluid semi-metal

<u>Genus XLVIII</u>. Mercury

<u>Eighth class</u>. Metals

<u>Order I</u>. Imperfect or ignoble metals

<u>Subdivision I</u>. Soft metals easy to melt

<u>Genus XLIX</u>. Lead

<u>Genus L</u>. Tin

<u>Subdivision II</u>. Metals difficult to melt

<u>Genus LI</u>. Iron

<u>Genus LII</u>. Copper

<u>Order II</u>. Perfect or noble metals

<u>Subdivision III</u>. Perfect metals

<u>Genus LIII</u>. Silver

<u>Genus LIV</u>. Gold

Neuvieme classe. Substances inflammables

Ordre I. Bitumes & soufres

Genre LV. Bitumes

Sous-division I. Bitumes écailleux & non liquéfiables

Sous-division II. Bitumes liquides, mols, terreux & friables

Sous-division III. Bitumes durs, cassans & susceptibles du poli

Sous-division IV. Bitume d'une nature particuliere

Genre LVI. Soufres

Genre LVII. Productions de volcans

Dixieme classe. Fossiles etrangers a la terre

Genre LVIII. Végétaux changés en pierre

Sous-division I. Pétrifications végétales

Sous-division II. Plantes imprimées sur la pierre

Sous-division III. Végétaux devenus terre

Sous-division IV. Végétaux changés en minéraux

Genre LIX. Pétrifications animales

Sous-division I. Pétrifications d'insectes

Sous-division II. Poissons pétrifiés

Sous-division III. Oiseaux pétrifiés

Sous-division IV. Quadrupedes pétrifiés

Sous-division V. Animaux imprimés dans la pierre

Sous-division VI. Animaux minéralisés

Genre LX. Calculs

Genre LXI. Pierres figurées, appellées jeux de la nature

Ninth class. Inflammable substances

Order I. Bitumens and sulphurs

Genus LV. Bitumens

Subdivision I. Scaly and non-liquefiable bitumens

Subdivision II. Liquid, soft, earths, and friable bitumens

Subdivision III. Hard, brittle bitumens susceptible to polish

Subdivision IV. Bitumen of a particular nature

Genus LVI. Sulphurs

Genus LVII. Volcanic productions

Tenth class. Fossils extraneous to the earth

Genus LVIII. Plants changed into stone

Subdivision I. Plant petrifactions

Subdivision II. Plants impressed on stone

Subdivision III. Plants turned into earth

Subdivision IV. Plants changed into minerals

Genus LIX. Animal petrifactions

Subdivision I. Petrifactions of insects

Subdivision II. Petrified fish

Subdivision III. Petrified birds

Subdivision IV. Petrified quadrupeds

Subdivision V. Animals impressed in stone

Subdivision VI. Mineralized animals

Genus LX. Calculi

Genus LXI. Figured stones, called sports of Nature

APPENDIX XIV

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JEAN BAPTISTE LOUIS DE ROMÉ DE L'ISLE, 1772[1]

Première partie. Cristaux salins

I. Sels vitrioliques (l'acide vitriolique combiné avec différentes bases et substances métalliques[2])

II. Sels nitreux (l'acide nitreux combiné avec différentes bases et substances métalliques)

III. Sels marins ou simplement sels (l'acide marin combiné avec différentes bases et substances métalliques)

IV. Sels phosphoriques (l'acide phosphorique combiné avec différentes bases et substances métalliques)

V. Sels sulfureux (l'acide sulfureux volatil combiné jusqu'au point de saturation avec l'alkali fixe végétal)

VI. Sels tartareux (l'acide du tartre combiné avec différentes bases et substances métalliques)

VII. Sels acéteux (l'acide du vinaigre combiné avec différentes bases et substances métalliques)

VIII. Sels végétaux (inconnu)

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[1]This synthetic list of the major elements of Romé de L'Isle's classification scheme was extracted from the more extensive discussion in Jean Baptiste Louis de Romé de L'Isle, Essai de cristallographie, ou description des figures géométriques, propres à différens corps du regne minéral, connus vulgairement sous le nom de cristaux. Avec figures et développemens (Paris: Chez Didot jeune; Knapen & Delaguette, 1772). Romé de L'Isle patterned the subdivisions of his première partie after the classification of salts given in the following: [Pierre Joseph Macquer], Dictionnaire de chymie, contenant la théorie & la pratique de cette science, son application à la physique, à l'histoire naturelle, à la

APPENDIX XIV

SYNOPSIS OF THE CLASSIFICATION SCHEME OF JEAN BAPTISTE LOUIS DE ROMÉ DE L'ISLE, 1772

First part. Saline crystals

I. Vitriolic salts (vitriolic acid combined with different bases and metallic substances)

II. Nitrous salts (nitrous acid combined with different bases and metallic substances)

III. Sea salts or simply salts (acid of the sea combined with different bases and metallic substances)

IV. Phosphoric salts (phosphoric acid combined with different bases and metallic substances)

V. Sulphurous salts (volatile sulphurous acid combined to the saturation point with fixed vegetable alcali potash)

VI. Tartareous salts (the acid of tartar combined with different bases and metallic substances)

VII. Acetous salts (the acid of vinegar combined with different bases and metallic substances)

VIII. Vegetable salts (unknown)

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médecine & à l'economie animale. Avec l'explication détaillée de la vertu & de la maniere d'agir des médicamens chymiques; et les principes fondamentaux des arts, manufactures & métiers dépendans de la chymie (Paris: Chez Lacombe, 1766), II, 430-41.

[2]Some of the bases were: l'alkali végétal, l'alkali minéral, l'alkali volatil, les terres calcaires, and les terres argilleuses. Some of the substances métalliques were: le cuivre, le fer, l'étain, le plomb, le mercure, le régule d'antimoine, le bismuth, and le régule de cobalt.

IX. Sels végétaux empyreumatiques (inconnu)

X. Sels animaux empyreumatiques (inconnu)

XI. Sels du borax (le sel sédatif combiné avec différentes bases et substances métalliques)

XII. Sels arsenicaux (l'arsenic combiné avec différentes bases et substances métalliques)

XIII. Sels neutres alkalins (les sels alkalins combiné avec différentes bases et substances métalliques)

XIV. Sels essentiels[3]

Seconde partie. Cristaux pierreux

I. Cristaux spathiques

II. Sélénites ou cristaux gypseux

III. Spaths fusibles ou cristaux fluors

IV. Cristaux micacés

V. Cristaux quartzeux dits cristaux de roche

VI. Cristaux-gemmes

VII. Cristaux basaltiques

VIII. Cristaux de zéolite

Troisiéme partie. Cristaux pyriteux, ou sulfureux et arsénicaux

Quatrième partie. Cristaux métalliques

I. Demi-métaux

Genre I. Mercure

Genre II. Antimoine

Genre III. Zinc

Genre IV. Le bismuth

Genre V. Le cobalt

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[3]"Toutes les matieres salines concretes, qui conservent l'odeur,

IX. Empyreumatic vegetable salts (unknown)

X. Empyreumatic animal salts (unknown)

XI. Salts of borax (the sedative salt combined with different bases and metallic substances)

XII. Arsenical salts (arsenic combined with different bases and metallic substances)

XIII. Neutral alcaline salts (alcaline salts combined with different bases and metallic substances)

XIV. Essential salts

<u>Second part</u>. Stony crystals

I. Sparry crystals

II. Selenite or gypseous crystals

III. Fusible spars or fluospar crystals

IV. Micaceous crystals

V. Quartzose crystals <u>called</u> rock crystals

VI. Crystals-gems

VII. Basaltic crystals

VIII. Zeolite crystals

<u>Third part</u>. Pyritic crystals, or sulphurous and arsenical [crystals]

<u>Fourth part</u>. Metallic crystals

I. Semi-metals

<u>Genus I</u>. Mercury

<u>Genus II</u>. Antimony

<u>Genus III</u>. Zinc

<u>Genus IV</u>. Bismuth

<u>Genus V</u>. Cobalt

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la saveur & les autres principales qualités des Corps dont elles sont tirées. ..." Romé de L'Isle, p. 102.

II. Métaux

<u>Genre I</u>. L'etain

<u>Genre II</u>. Le plomb

<u>Genre III</u>. Le fer

<u>Genre IV</u>. Le cuivre

<u>Genre V</u>. L'argent

II. Metals

<u>Genus I</u>. Tin

<u>Genus II</u>. Lead

<u>Genus III</u>. Iron

<u>Genus IV</u>. Copper

<u>Genus V</u>. Silver

APPENDIX XV

SYNOPSIS OF THE CLASSIFICATION SCHEME OF ABRAHAM GOTTLOB WERNER, 1789*

<u>I) Klasse</u>. Erd- und Steinarten

- a) Kieselarten
- b) Thonarten
- c) Talkarten
- d) Kalkarten
  - A) Luftsaure Kalkgattungen
  - B) Phosphorsaure Kalkgattungen
  - C) Boraxsaure Kalkgattungen
  - D) Flusssaure Kalkgattungen
  - E) Vitriolsaure Kalkgattungen
- e) Schwerarten

<u>II) Klasse</u>. Salzarten

- a) Vitriolische Salze
- b) Salpetersaure Salze
- c) Kochsalzsaure Salze
- d) Alkalische Salze

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*This synthetic list of the major elements of Werner's classification scheme was extracted from the more detailed enumeration in

APPENDIX XV

SYNOPSIS OF THE CLASSIFICATION SCHEME OF

ABRAHAM GOTTLOB WERNER, 1789

<u>First class</u>. Earthy and stony kinds

- a) Flinty kinds
- b) Clayey kinds
- c) Talcky kinds
- d) Calcareous kinds
    - A) Carbonates
    - B) Phosphates
    - C) Borates
    - D) Fluates
    - E) Sulphates
- e) Heavy kinds

<u>Second class</u>. Saline kinds

- a) Vitriolic salts
- b) Nitrous salts
- c) Muriatic salts
- d) Alkaline salts

[Abraham Gottlob Werner,] "Mineralsystem des Herrn Inspektor Werners mit dessen Erlaubnis herasugegeben von C. A. S. Hoffmann," <u>Bergmännisches Journal</u>, I (1789), 373-86.

III) Klasse. Brennliche Wesen

a) Erdharze

b) Schwefelarten

c) Graphit

IV) Klasse. Metallarten

a) Platin

b) Gold

c) Quecksilber

d) Silber

e) Kupfer

f) Eisen

g) Blei

h) Zinn

i) Wissmuth

k) Zink

l) Spiesglas

m) Kobelt

n) Nikkel

o) Braunstein

p) Molybdän

q) Arsenik

r) Scheel

Third class. Inflammable substances

a) Bitumen

b) Sulphureous kinds

c) Graphite

Fourth class. Metal kinds

a) Platina

b) Gold

c) Mercury

d) Silver

e) Copper

f) Iron

g) Lead

h) Tin

i) Bismuth

k) Zinc

l) Antimony

m) Cobalt

n) Nickel

o) Manganese

p) Molybdena

q) Arsenic

r) Sheele

APPENDIX XVI

SYNOPSIS OF THE CLASSIFICATION SCHEME OF

ABRAHAM GOTTLOB WERNER, 1817*

Erste Klasse. Erdiche Fossilien

1. Demant-Geschlecht
2. Zirkon-Geschlecht
3. Kiesel-Geschlecht
4. Thon-Geschlecht
5. Talk-Geschlecht
6. Kalk-Geschlecht
    A. Luftsaure Kalkgattungen
    B. Phosphorsaure Kalkgattungen
    C. Flussaure Kalkgattungen
    D. Vitriolsaure Kalkgattungen
    E. Boraxsaure Kalkgattungen
7. Barit-Geschlecht
8. Stronthian-Geschlecht
9. Hallith-Geschlecht

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*This synthetic list of the major elements of Werner's classification scheme was extracted from the more detailed enumeration in Abraham Gottlob Werner, Abraham Gottlob Werner's letztes Mineral-System. Aus

APPENDIX XVI

SYNOPSIS OF THE CLASSIFICATION SCHEME OF ABRAHAM GOTTLOB WERNER, 1817

First class. Earthy minerals

1. Diamond genus
2. Zircon genus
3. Flint genus
4. Clay genus
5. Talc genus
6. Limestone genus
   - A. Carbonates
   - B. Phosphates
   - C. Fluates
   - D. Sulphates
   - E. Borates
7. Barite genus
8. Strontian genus
9. Halite genus

---

dessen Nachlasse auf oberbergamtliche Anordnung herausgegeben und mit Erläuterungen versehen (Freyberg und Wien: bey Craz und Gerlach und bey Carl Gerold, 1817), pp. [1]-26.

Zweite Klasse. Salziche Fossilien

1. Kohlensäure-Geschlecht
2. Salpetersäure-Geschlecht
3. Kochsalzsäure-Geschlecht
4. Schwefelsäure-Geschlecht

Dritte Klasse. Brennliche Fossilien

1. Schwefel-Geschlecht
2. Erdharz-Geschlecht
3. Graphit-Geschlecht
4. Resin-Geschlecht

Vierte Klasse. Metallische Fossilien

1. Platin-Geschlecht
2. Gold-Geschlecht
3. Queksilber-Geschlecht
4. Silber-Geschlecht
5. Kupfer-Geschlecht
6. Eisen-Geschlecht
7. Blei-Geschlecht
8. Zin-Geschlecht
9. Wismuth-Geschlecht
10. Zink-Geschlecht
11. Spiesglas-Geschlecht
12. Silvan-Geschlecht
13. Mangan-Geschlecht
14. Nikkel-Geschlecht
15. Kobold-Beschlecht

Second class. Saline minerals

1. Carbonates
2. Nitrates
3. Muriates
4. Sulphates

Third class. Combustible minerals

1. Sulphur genus
2. Bituminous genus
3. Graphite genus
4. Resin genus

Fourth class. Metallic minerals

1. Platina genus
2. Gold genus
3. Mercury genus
4. Silver genus
5. Copper genus
6. Iron genus
7. Lead genus
8. Tin genus
9. Bismuth genus
10. Zinc genus
11. Antimony genus
12. Sylvan genus
13. Manganese genus
14. Nickel genus
15. Cobalt genus

16. Arsenik-Geschlecht
17. Molibdän-Geschlecht
18. Scheel-Geschlecht
19. Menak-Geschlecht
20. Uran-Geschlecht
21. Chrom-Geschlecht
22. Cerin-Geschlecht

16. Arsenic genus

17. Molybdena genus

18. Sheele genus

19. Menachine genus

20. Uran genus

21. Chrome genus

22. Ceria genus

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