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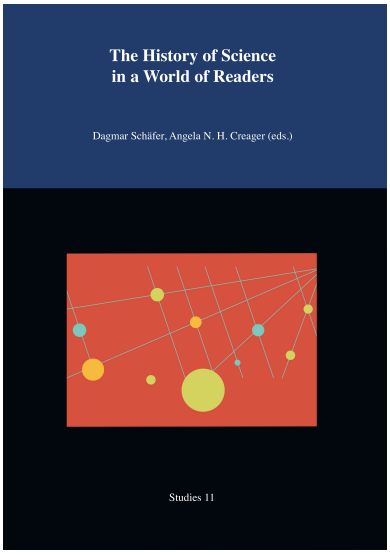
Pamela O. Long:

The Openness of Knowledge: An Ideal and Its Context in 16th-Century Writings on Mining and Metallurgy



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Chapter 1
The Openness of Knowledge: An Ideal and Its Context in 16th-Century Writings on Mining and Metallurgy

Pamela O. Long

The scientific societies of the 17th century emphasized the importance of openness for scientific methodology. A significant goal was to facilitate communication among appropriate persons interested in the new experimental philosophy.[1] My underlying presupposition in this article is that the explicit endorsement of openness in the natural sciences and its association with empiricism were significant "events" in intellectual history and in the development of scientific methodology. Openness was by no means universally accepted as an approach to empirical knowledge in the early modern period. Practitioners within the highly respected discipline of alchemy, for instance, usually endorsed esoteric transmission to a small group of initiates. How then did the opposite value of openness become so central to the stated methodology of experimental philosophy? Herein I suggest that a particular group of 16th-century authors on mining and metallurgy made an important contribution to such a viewpoint. I further argue that the views expressed in their writings emerged from a social and economic context that shaped authorship in very specific ways.

This article constitutes a study of the practice of authorship, not the practice of science or technology per se. Openness as a stated value and openness in practice can be two very different things. A clearly written treatise is open only to those who are literate and can read the particular language in which it is written. A craft procedure can be described in writing, but often it is truly accessible only to those who have practiced the technique with their own hands. Steven Shapin's recent essay on experiment within the Royal Society underscores the point that openness can be a highly complex matter, that it can depend on differences between private and public space, on degrees of access, and on the social status of participants.[2] Alice Stroup's work shows that the ideal of openness sometimes conflicted with secrecy and exclusionary practices in the Parisian Royal Academy of Sciences.[3] Recent investigations

[1] See Middleton (1972, 91) where the academy's statement of purpose includes the hope that others would be encouraged to repeat experiments "with the greatest rigor"; that they wished "for nothing else but a free communication from the various Societies"; that, when members repeated the experiments of others, they "always cited the authors"; and, finally, that, from the first days of the society, they had always shared the experiments with anyone passing through who wanted some account. For the Royal Society, Henry Oldenburg (1665, 1–2) noted that there was "nothing more necessary for promoting the improvement of Philosophical Matters, than the communicating to such, as apply their Studies and Endeavours that way, such things as are discovered or put in practise by others… To the end, that such Productions being clearly and truly communicated, desires after solid and usefull knowledge may be further entertained, ingenious Endeavours and Undertakings cherished, and those, addicted to and conversant in such matters, may be invited and encouraged to search, try, and find out new things, impart their knowledge to one another, and contribute what they can do to the Grand design of improving Natural Knowledge, and perfecting all *Philosophical Arts*, and *Sciences*."

[2] Shapin (1988).

[3] Stroup (1990, 199–217).

and controversies illustrate the point that the ideals of both openness and accurate credit of authorship within science are sometimes very far indeed from the realities of scientific practice.[4]

Nevertheless, the development of the explicit ideal of openness within the empirical sciences is worthy of study in its own right. The belief that knowledge should be openly transmitted in writing belongs to a complex tradition that originates in antiquity.[5] I treat here only one part of that larger history. Implicit in my discussion are two claims. The first is that writings on the practical and mechanical arts are important sources not only for the history of techniques, but for intellectual history as well. The second constitutes a revision of the traditional view that associates science with openness and technology with secrecy in the premodern era.[6]

1.1 Mining and Authorship in the 16th Century

The 16th century was the great age of mine and metallurgical literature both in terms of quantity and originality.[7] I have found it useful to divide these writings into three separate categories—recipe books, alchemical writings, and exoteric mining and metallurgical treatises. In making these divisions I impose what I consider to be a useful typology. However, it is important to emphasize that the categories are overlapping to some extent, and that there is significant diversity within each. It is the third group, exoteric treatises, with which this article is primarily concerned.

Recipe books, the first category, are often referred to as books of "secrets," or Kunstbüchlein. They contain recipes for assaying and separating metals, as well as for other procedures such as dyeing and mixing medicinal remedies. Recipe writings belong to an ancient tradition that continued to flourish in the 16th century and beyond. The printing press gave particular impetus to their production. Although some medieval examples of this genre, such as the *Mappae Clavicula,* contain limited evidence for craft secrecy, it should not be assumed that books of "secrets" necessarily contained secrets. Rather, they outlined well-known techniques and recipes usually as mnemonic aids to practitioners.[8]

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[4]See especially Hull (1988); Nelkin (1984), and *Science, Technology, & Human Values* (La Follette 1985), an issue devoted to openness and secrecy in science and technology.

[5]A useful discussion is Eamon (1985a). However, I differ with Eamon both in his placement of the origins of the concept of scientific openness in the early modern period and in his overly comprehensive identification of the medieval period with secrecy. Key early texts elaborating the ideal of openness are the Roman architect Vitruvius's *De architectura* (n.d., 3.preface 1–3, and 7. preface 1–18); and the 12th-century monk Theophilus's treatise (1961, 1–4).

[6]See Solla Price (1975, 117–35); and McMullin (1985), both of whom associate science with openness and technology with secrecy.

[7]Useful discussions of this literature and its context include Koch (1963, 19–59) for the 16th century; Baumgartel (1965) and Wilsdorf (1954). For the technology background, see Bromehead (1956) and Forbes (1956); Smith and Forbes (1957); Tylecote (1987). Molloy (1986) is particularly useful for some of the older, relatively inaccessible works on the history of German mining.

[8]The pioneering bibliographical work on the pamphlet tradition was done by John Ferguson (1882, 1883, 1886a, 1886b, 1888, 1890, 1894, 1909, 1911, 1912). (These articles are collected in a reprint edition; see Ferguson (1959).) His work was furthered by Ernst Darmstaedter (1926). For English translations of three of the booklets with useful notes, see Grünhaldt Sisco and Smith (1949) and "On Steel and Iron: The Anonymous Booklet, 'Von Stahel und Eysen…' (Nuremberg, 1532)" (1968). See also Eamon (1977; 1985b; 1979). Also see Paisey (1980). For references to secrecy in the Mappae Clavicula, see Smith and Hawthorne (1974, 28, 31, 32, 35). The genre is

The second group, alchemical writings, formed a tradition that had originated in late antiquity. Alchemy overlapped with craft traditions, particularly those of the goldsmith trade, and it developed its own laboratory techniques for processing metals and other substances. It also was imbued with a complex group of religious and philosophical ideas from the ancient Near East. In the 15th century, influenced by Ficino's Neoplatonism, it enjoyed a surge of popularity and would remain a respected art until the 18th century. Here it is sufficient to emphasize alchemy's view of transmission as an esoteric process, in which an authority transmitted alchemical knowledge to a few initiates usually within an apprenticeship relationship. The cryptic writing of the alchemists is well-known as a method whereby alchemical knowledge was hidden from the uninitiated. Alchemical authorship could be hidden as well. The real author of all alchemical writings was considered to be the ancient Egyptian god Toth. The attribution of alchemical books to the highest authority was a customary practice.[9]

A third type of mining and metallurgical book, the more formal exoteric treatises and pamphlets, appeared for the first time in the 16th century. Although these books were indebted to both recipe writings and the techniques of alchemy, they were distinct from both traditions. They include pamphlets such as the *Bergbüchlein* on ores and the *Probierbüchlein* on assaying; elaborate treatises such as the *Pirotechnia* by the Sienese Vannoccio Biringuccio, the famous *De re metallica* by the humanist Georgius Agricola, and the *Treatise on Ores and Assaying* by Lazarus Ercker; and less well-known works such as Ercker's pamphlets on assaying and on minting, the books on assaying by Ciriacus Schreittmann, Modestin Fachs, and Samuel Zimmermann, and, finally, the *Schwazer Bergbuch*.[10]

The authors of these books came from varied backgrounds. Some, like Biringuccio and Schreittmann, were practitioners. Others, like Calbus of Freiberg (author of the *Bergbüchlein*) and Georgius Agricola, were university-educated physicians and humanists. Moreover, the books themselves are diverse in physical form. Some were printed. Others, such as Lazarus Ercker's early pamphlets and the *Schwazer Bergbuch*, were hand copied. Yet, as I shall elaborate, authors from different backgrounds expressed similar views concerning authorship and openness. They also shared a common context that included the early modern capitalist expansion of mining.

Exoteric mine and metallurgical writings represent a flowering of technical authorship that demands inquiry beyond the "explanation" that they were written for artisans or the suggestion, partially true but insufficient, that they were a by-product of the printing press.[11] Further questions need to be addressed. Who were the authors? What backgrounds did they come from? What motivated them to undertake technical authorship? And, finally,

represented today by such household manuals as "Hints from Heloise," and, now as then, the "secret" to, say, removing a particular kind of stain refers to the details of a technique more than to hidden knowledge as such.

[9]On the relationship between alchemists and assayers, see Halleux (1986). For an introduction to alchemy and the large bibliography on the subject, see especially Halleux (1979) and also Eliade (1978, 142–68) on initiation and secrecy; Holmyard (1957, 153–64) on signs, symbols, and secret terms); and Multhauf (1966).

[10]The three major treatises and their respective English translations are as follows: Biringuccio (1977; 1959); Agricola ([1912] 1950; 1556); Ercker (1960; 1951). The other treatises mentioned and further bibliography are specified in the footnotes below.

[11]Elizabeth Eisenstein (1979, esp. vol. 2, 520–635) has elaborated in detail the importance of the printing press for technical and scientific literature. Although the press is obviously of paramount importance for any printed work, it constitutes only a partial explanation for the dissemination of technical literature. As will be elaborated, mining and metallurgical literature was published only in certain geographic areas. Moreover, there were a significant number of manuscript treatises written (and sometimes copied) but never published in the 16th century.

who constituted their patrons and prospective audience? What has emerged is that these 16th-century mining and metallurgical books seem to have been among the products of a European mining boom. In terms of authorship, patronage, prospective audience, and explicit attitudes, they can best be understood in the context of particular developments in late medieval mining.

Well before 1350 European mining had reached a peak of productivity. Thereafter, metal production began a decline that was to last for more than a hundred years. The catastrophic plague that swept through Europe between 1348 and 1350 decimated the population by one-third to one-half and left many mines abandoned. A rapid recovery was inhibited because efficient exploitation of existing mines required greater depth. But deeper mines presented engineering difficulties involving water and ore removal, difficulties not solved in the early 15th century. Then the devastation of the Hussite Wars (1419–34) between the Holy Roman Emperor Sigismund and the followers of John Huss in Bohemia brought to stagnation the most productive mines of Europe —those of Bohemia and Saxony.[12]

Gradually, as the population achieved some recovery in the first half of the 15th century, demand for metals needed for both specie and guns exceeded the supply. The shortage made mining and metallurgy a profitable business, providing the motivation to solve technical and organizational problems that had stultified late medieval mining. The result was a central European mining boom. Between 1460 and 1530 the production of silver, copper, and other metals in central Europe and elsewhere increased several times over, sometimes fivefold. Expanded production brought with it rapid changes in technology and organization. Deeper mines, more costly to construct and operate, necessitated greater outlays of capital. As John U. Nef described it, these developments caused a striking cleavage between capital and labor. Small cooperative groups of miners were replaced by wage earners paid increasingly by the absentee shareholders who provided needed capital and also reaped profits. Sharing the wealth were princes and others who held regalian rights over the land. Miners lost most of the special privileges that had been granted by princes and overlords in the 12th and 13th centuries.[13]

On the other hand, wealthy investors with little specific knowledge of mining and metallurgy and holders of regalian rights both became ready patrons and consumers of mining literature. Authors of mining and metallurgical books wrote for these rulers and other wealthy investors who wanted to maximize the productivity of their mines, as well as for the expanded number of new practitioners whose skill in prospecting, mining, and processing metals provided the key to the profits of their employers. Local craft knowledge transmitted orally no longer sufficed for a far-flung group of literate but inexperienced investors. Princes and others seeking wealth from mining bestowed their patronage on individuals who were able and willing to explain mining and metallurgical practices in writing. Technical authors often obtained rich rewards from these patrons. The belief in the openness of knowledge and its written transmission, in fact and as an ideal, was an important by-product of the commonality of interest among wealthy investors and the authors of mining and metallurgical books.

[12] See Miskimin ([1969] 1975, 112–15).

[13] Two good general accounts are Kellenbenz (1976, 79–88 and 106–18) and Nef (1987). The fundamental study of capital investments in German mining is Dietrich (1958; 1959; 1961). For Goslar, see also Schmidt (1970). The best single introduction to more recent research on German mining is Kroker and Westermann (1984). Articles in this collection particularly relevant to the general developments discussed herein include Gleitsmann (1984); von Stromer (1984); Ludwig (1984). For technical innovation in mining and metallurgy during this period, see Braunstein (1983); Molenda (1988); Suhling (1980; 1984; 1978).

Early modern mining and metallurgical literature was thus fueled by the rapid expansion of mine investments—an essential aspect of the growth of industrial capitalism in the first half of the 16th century. Mining of precious metals such as silver and gold, of other metals such as copper, tin, lead, and iron, and of substances such as saltpeter, an essential ingredient of gunpowder, and alum, needed to stabilize dyes used in the textile industries, had long existed in many parts of Europe, including France, Italy, Sweden, Poland, and England.[14] Yet working mines by no means led invariably to writings on mining and metallurgy. Indeed, the great majority of 16th-century mining books were written by Germans in the regions of the empire where the capitalist transformations of mining were most pronounced —the Harz Mountains near Goslar, the Erzgebirge Mountains in Saxony and Bohemia, and the Tyrolian Alps to the south.[15]

The most important exception to the rule of the German provenance of 16th-century mining literature, the Italian treatise by Biringuccio, was written by one who had visited mines in the empire and was exhorting his compatriots to expand their investments in Italian mining in imitation of the Germans.[16] Historians of mining and metallurgy agree that the great age of mining literature was over by the end of the 16th century.[17]

1.2 Authorship and Audience in Two Early Pamphlets

The author of the first printed book on mining, the anonymously published *Bergbüchlein*, is accepted on 16th-century evidence as Ulrich Rülein von Calw, known as Calbus of Freiberg (d. 1523). Calbus studied medicine at the University of Leipzig and then became the town physician of Freiberg, a great mining boomtown in Saxony. He was a mathematical practitioner who assisted with the site planning and measurement of two new mining towns, Saint Annaberg and Marienberg. He was active in the city government of Freiberg and as *Bürg-*

[14]For France, see Benoit and Braunstein (1983); Braunstein (1987; 1984); Gille (1947); Hesse (1986); Laube (1964). For Italy, see especially Braunstein (1965; 1977). See also Menant (1987) and Tucci (1977). For Sweden, see Svanidze (1981). For Poland, see Molenda (1984; 1985). For England, see Donald (1955); Gough (1967); Hamilton (1967); Hatcher (1973); Lewis ([1908] 1965); Penhallurick (1986). See also Kellenbenz (1977); Multhauf (1978); Richards (1983); Delumeau (1962); Jenkins([1936] 1971); Singer (1948); Sprandel (1968); Westermann (1971a).

[15]The large specialized bibliography on mining in the empire includes the following: Wilsdorf and Quellmalz (1971), suppl. 1 of Prescher (1955–1974), in which the work by Wilsdorf and Quellmalz is an encyclopedia of German mining organized by region and place-name; Wächtler and Engewald (1980); Kellenbenz (1981); Westermann (1986). For the Harz, see Bornhardt (1927; 1931); Boyce (1920); Brüning (1926); Henschke (1974); Kraschewski (1984); Rosenhainer (1968); Westermann (1971b). For the Erzgebirge region and Bohemia, see Wagenbreth and Wächtler (1986); Laube (1974); Sieber (1954, 1–75). For the Tyrol, see Egg (1958); Palme (1984); Reichsritter von Wolfstrigl-Wolfskron (1903); Worms (1904).

[16]For some of Biringuccio's German travels and observations, see Biringuccio (1959, 20, 48, 93–94, 110, 144, 166, 431). Also of Italian provenance was the late 16th-century Latin treatise on mineralogy by Mercati (1717). Mercati was a physician whose papal service included supervision of the Vatican botanical garden. He arranged his treatise as if in the same order as the specimen cases of the Vatican collection of minerals and fossils. The work was not published until the 18th century. See especially Accordi (1980) and Premuda (n.d.).

[17]See Sisco and Smith (1951, xiv–xv); and Koch (1963, 60). Much of the 17th-century literature is derivative, with the important exception of the Spanish treatise on metals by Alvaro Alonso Barba, published in 1640. Barba wrote his book in the context of the mine boom enjoyed by the Spanish crown in the new world. See Barba (1923); Smith (n.d.); and Barnadas (1986), which supersedes all previous accounts and adds significantly to our knowledge of Barba's life. For a discussion of the larger context, see Cross (1983).

ermeister he helped to establish a humanist Latin school. He was also a miner (i.e., a mine investor) at various locations and enjoyed considerable prosperity as a result.[18]

The dialogue form of the *Bergbüchlein* provides clues about Calbus's prospective audience. Daniel, "the mining expert" (Saint Daniel was a patron saint of miners), elaborates his knowledge of ores to Knappius, a young miner. Writing to comply with Knappius's "frequently expressed wish and…persistent request," Daniel bases his information on "the books of ancient philosophers and the experience of practicing miners." The illustrated pamphlet treats the birth and growth of ores such as silver, gold, tin, copper, iron, and lead through the influences of the heavenly bodies and the ways that those ores could be discovered, including the possible directions of their veins and stringers. Knappius is described as an investor in mining, for whom the book will provide useful information on how to locate potentially productive veins and on the characteristics of metals. Thus, as Knappius himself notes, "I shall be given a reasonable understanding which mines can be worked gainfully so that my investment will not be wasted but will show a profit."[19]

The interlocutor, Daniel, insists on the close relationship of knowledge and practice and emphasizes that his general principles must be applied with great skill to particular cases. Such advice was highly appropriate for a potential investor in need of practical knowledge. Knappius agrees that to become an expert he would need practice. The young miner's lack of knowledge is evident from his question concerning the divisions of a mine, which he assumes to be determined by location rather than by percentages of the mine's yield. Daniel, having enlightened his student on this score, admonishes him not to mind if the book "uses simple words and unpolished phrases." They convey something useful, which should be valued more than the "smoothness of words."[20] Clearly, Knappius the miner is not an artisan but an uninformed potential investor who stands in great need of useful, practical mining knowledge in order better to realize profits.

A second metallurgical pamphlet, the *Probierbüchlein*, is an anonymously authored work on assaying. It consists of a group of recipes for testing metals that suggest a preexisting collection. Perhaps recipes used by a practicing assayer were later organized (whether by a printer or assayer is unclear) for publication.[21] Evidence from various editions suggests an audience of both practitioners, including those concerned with minting and coinage, and individuals with an interest in mine operations. The title asserts that the work was "compiled with great care for the benefit of all mintmasters, assay masters, goldsmiths, miners [meaning, we can assume, mine investors like Knappius], and dealers in metals."[22]

Some editions of the *Probierbüchlein* contain an anonymous dedication to one Hans Knoblach, an administrator of the Harz Mountain mining operations of Elizabeth, duchess

[18]For a facsimile and transcript of the first edition of the *Bergbüchlein*, as well as a detailed discussion and documentation of the life of Calbus, see Pieper (1955). See also Darmstaedter (1926, 13–24); and, for an English translation and further discussion, Sisco and Smith (1949, 17–56); and Mendels (1953).

[19]Daniel replies that knowledge of the generation of metals was most important, but "as a mere side issue" profits should not be spurned. Yet, if "his aim is solely and predominantly profit and gain" rather than knowledge about minerals, it would "cheapen and condemn this little book and the art." If one really values profits more than art, one will have to do without both (Sisco and Smith 1949, 17–19). This prohibition against unadulterated avarice was a nicety that would be dropped in subsequent mining literature wherein large profits are repeatedly invoked as the chief incentive for investment in mining.

[20]Sisco and Smith (1949, 19).

[21]See Darmstaedter (1926, 25–36); and Sisco and Smith, (1949, 157–78 for the editions and 179–90 for technical content).

[22]Sisco and Smith (1949, 70).

of Braunschweig (Brunswick) and Lüneburg. Duchess Elizabeth (1435–1520?), the widow of Duke William the Younger of Wolfenbüttel, was a key figure in the renewal of iron mining and the introduction of steelmaking in the upper Harz. Her efforts, which brought economic prosperity to the entire region, led to her being eulogized as, among other things, *inventrix metallorum*. The dedication to the booklet on assaying informs us that Elizabeth's mine administrator Knoblach had encouraged the unknown author to publish his collection of information on the assaying of ore, which he had gathered "from writings and from his own experiments."[23] Clearly the active promotion of mining and metallurgy and the encouragement of technical authorship went hand in hand.

1.3 Biringuccio: Advocate of Openness and Investment in Mining

Far more ambitious than these German pamphlets was the Italian treatise *Pirotechnia* by the Sienese Vannoccio Biringuccio (1480–ca. 1538), which was published in 1540, after the author's death. Biringuccio wrote with remarkable freshness and self-confidence, largely from his own practical experience.[24] His expertise is evident in the technical descriptions and explanations of a treatise that contains a wealth of information on ores, assaying and smelting, the separation of gold and silver, alloys, bronze casting, metal melting, guns, furnaces, fireworks for warfare and festivals, and numerous related topics.

Biringuccio's expertise in mining, metallurgy, and gun founding led to his varied and successful career supported by the patronage of the nobility. One of his earliest patrons, Pandolfo Petrucci (d. 1512), aggressively exploited mining wealth by constructing many iron plants in the Boccheggiano Valley near Siena.[25] Biringuccio himself, during his lifetime, traveled widely in the German states and in Italy, gaining firsthand knowledge of mining and metalworking operations. His positions at various times included overseer of a silver mine in Carnia in northern Italy, supervisor of the iron mines in the Boccheggiano Valley, head of the Sienese armory and of the Sienese mint, director and architect of the *Opera del Duomo* in Siena (following Baldassare Peruzzi), and head of the papal foundry and munitions in Rome, where he died about 1538. He also worked for Italian princes, such as the Farnese of Parma and Ercole d'Este, and for the Florentine and Venetian republics. At one point he was given a monopoly for saltpeter in the territory of Siena.[26]

Biringuccio's audience included his noble patrons and wellborn potential investors. Notwithstanding Friedrich Klemm's statement that Biringuccio wrote for technical workers, evidence from the text points to a readership that included the unpracticed wellborn. The Sienese author noted that he had written extensively and in detail "because I have thought

[23] *Probir buch/leyn tzu Gotes lob/unnd der werlth nutz geordent* (*Probir buch/leyn tzu Gotes lob/unnd der werlth nutz geordent* 1524, dedication): "auss erfarnheit der schrifft und selbst versuchung." See also Sisco and Smith (1949, 159–60). For Duchess Elizabeth's mining activities, see Boyce (1920, 20–22).

[24] Both the Italian edition and the English translation contain useful introductions and notes. See also Brunella (1985). For references to Biringuccio's own experience, see Biringuccio (1959, 20, 48, 63, 70, 72, 75,93, 110, 131, 144, 166, 168, 215, 233, 251–52, 272, 275, 289, 291, 306, 308, 317, 444).

[25] Biringuccio (1959, 63).

[26] For biographical information with further references, see Tucci (1968) and Biringuccio (1977, xxxv–lix).

that you [the identity of the person addressed is unknown] had not hitherto had the slightest shadow of knowledge of what I have described in this treatise of mine."[27]

An early and eloquent partisan of industrial capitalism, Biringuccio advocated the aggressive exploitation of mineral resources and harshly condemned as a poor substitute the commercial capitalism of merchants. He noted that every knowledgeable investigator agreed that Italy was rich in copper, but little was mined there "perhaps because of a cowardly Italian avarice" that had "the power to make us lazy and indolent in carrying out those lofty and fine designs which should reasonably make us proceed swiftly." Biringuccio elaborated the various (and to him unacceptable) reasons that Italians hesitated to invest in mining. He particularly deplored "princes and all rich and powerful persons" who refrained from "the profitable and laudable affair" of mining ores. If they hesitated solely because of "cowardice" or because they listened to "the bayings of ignorant hounds" or "if because of their own willfulness" they wished "to remain prisoners of a detestable and ugly avarice," then that was their own loss.[28]

Although Biringuccio condemned usury (a decidedly old-fashioned view by the 16th century), he was unmoved by ancient prohibitions against mining. Men could mine copper, for instance, "without any danger or trouble to themselves, but only to their hirelings," whereby they could gain wealth "in greater abundance than from shameful usury, dangerous navigation or any of the other unreasonable or pernicious occupations." He considered minerals and metals to be "copious blessings conceded by heaven" and believed that men "wrong themselves, their fatherland, and the province where they were born" in failing to mine them. They "also wrong Nature" for they regard what she has produced as nothing or "something only useless and vile," and, finally, "they wrong all living beings both present and future, since they do not avail themselves of the universal creation as we are bound to do."[29]

On the positive side, Biringuccio praised the courage and persistence needed for successful mining operations. Turning to the empire for exemplars, he described a copper, lead, and silver mine in Austria where the owners persisted despite a layer of very hard limestone. He was amazed by their habit of "working in both night and day shifts," a thing that "surely seemed … great and marvelous." If these owners "had begrudged the expense, or the long road, or if through fear of not finding they had despaired of it and cowardly abandoned the undertaking or had stopped before penetrating that hard rock, they would have thrown away in vain all their money and all their efforts both physical and mental, and they would not have become very rich… ."[30] Moreover, they would not have profited their superiors, relatives, native country, or poor and rich neighbors. But they did profit them "through their strength and goodness of soul and through their hope and tenacity." Theirs was an example to follow if one wanted to become rich and to have "honor, authority and every other benefit."[31]

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[27]Klemm (1964, 135). For the citation, see Biringuccio (1959, 329). Further evidence for a well-born prospective audience is the chapter on precious stones (pp. 119–25), included because "it is a fine accomplishment for a gentleman to have some knowledge concerning gems" (119).

[28]Biringuccio (1959, 49).

[29]Biringuccio (1959, 49–52), for a remarkable denunciation of commercial and seafaring capitalism and usury, and an equally passionate apology for mining. For ancient prohibitions against mining and the rites surrounding it, see Eliade (1978, 53–64, 71–78) and Merchant (1980, 29–41).

[30](1959, 20–21).

[31]Biringuccio (1959, 21). See also pp. 33–34 for another example in which Biringuccio cites courage and persistence in excavation after the discovery of gold by a washerwoman in Hungary.

A practitioner and overseer writing for potential patrons and investors, Biringuccio insisted that technical knowledge should be open. Discussing gold ore, he elaborated his reasons for writing: "I have done this [writing] willingly in order that you may acquire more learning and because I am certain that new information always gives birth in men's mind to new discoveries and so to further information. Indeed, I am certain that it is the key that arouses intelligent men and makes them, if they wish, arrive at certain conclusions that they could not have reached without such a foundation, or even nearly approached."[32] His own openly written account, Biringuccio here suggests, would lead to an increase in knowledge.

Biringuccio also condemned secrecy. He particularly disliked the secret operations of alchemy. He had derided the alchemists, he explained, so that the inexperienced might be prevented from throwing away their talents by following the same path, and so that alchemists themselves might be encouraged to share their knowledge openly: "I am also content because, in order to show my ignorance to the world, the desire may come to some worthy philosopher and alchemist to bring to light at least the open arguments for their art, if not the completed work." If this were done, Biringuccio jested, great utility would result because the art would be made clear and "all good men of ability" would begin to make gold in great quantities and thus "make men rich, secure, and happy."[33]

The accurate crediting of authorship, in Biringuccio's view, was an important aspect of openness. He expressed incredulity at the alchemical custom of disguising the true authorship of a work with a fictitious (usually more authoritative) author. The hopes of the alchemist's "fantastic writings are but masked shadows," and "in order to lend authority to their recipe books they head them with the name of an author who not only did not write them but perhaps never even thought about the subject."[34]

Biringuccio's scorn extended to those who protected craft secrets. Having noted the differences of opinion on how to make the chamber of a gun, he suggested that secrecy was used fraudulently to suggest expertise and special technique that did not exist: "Under this veil [of differing opinions about how to make gun chambers] these men pretend to have a great secret and puff up their reputations by telling lies which deer could not leap over, promising that from their guns not only balls but lightning flashes will issue."[35] In the end, Biringuccio concluded, they make only what others have made, and, when asked what theory is behind their work, they give "only a surly answer."[36]

Indeed, Biringuccio happily revealed craft secrets, seemingly at every opportunity. Referring to metal melting, he promised to tell "some methods that are held as secret by the masters."[37] Concerning techniques of the goldsmith, he did not wish "to fail to tell you of some things concerning their operations which they withhold from most people almost like secrets, so that you may know these as well."[38] In a section on ironwork, he listed what he called "secrets," which the editors suggest may be from editions of the *Kunstbüchlein* that might have been known to him.[39] Finally, tarsia work was "a very great secret and one still

[32] Biringuccio (1959, 28).
[33] Biringuccio (1959, 35–43 and passim; citation on p. 43). For a discussion of Biringuccio's antialchemical stance, see Rossi (1970, 43–46).
[34] Biringuccio (1959, 41).
[35] Biringuccio (1959, 241).
[36] Biringuccio (1959, 241).
[37] Biringuccio (1959, 323).
[38] Biringuccio (1959, 364).
[39] Biringuccio (1959, 371).

not known to me although I have practiced it diligently in order to learn it."[40] Biringuccio even described how he paid to learn the secret of using mercury to extract gold and silver from sweepings, in what is the earliest clear discussion of an amalgamation process: "Wishing to know this secret, I gave to the one who taught it to me a ring with a diamond worth twenty-five ducats, and I also pledged myself to give him the eighth part of whatever profit I should gain from this operation." In turn, Biringuccio wanted to reveal the secret to the reader "not in order that you would repay me for teaching it to you, but in order that you should esteem and value it so much more."[41]

1.4 Georgius Agricola and Humanist Mining Authorship

Whereas Biringuccio was a practitioner who had unusual access to the rich and powerful, his younger contemporary Georgius Agricola (1494–1555) was a learned humanist who benefited from the generous patronage of the Saxon electors Maurice (1521–1553) and Augustus (1526–1586) but who also had lifelong connections to practitioners. Agricola was born in Glauchau, Saxony, at the time when the region was experiencing a tremendous expansion of metal mining (particularly silver) to the great enrichment of the Saxon princes and many other residents. He came from an artisanal family but was himself (along with two brothers) university trained. His family gave him a close and lifelong association with artisans, a social circumstance undoubtedly central to his appreciation for empirical knowledge and practical techniques. His father (probably Gregor Bauer) was a dyer and woolen draper, a profession also followed by his younger brother Christoph. Two of his sisters were married to dyers. His first wife, Anna (née Arnold), was the widow of Thomas Meiner, director of the Schneeberg mining district. His second wife, Anna Schütz, was the daughter of a guild master and smelter owner, Ulrich Schütz.[42]

Agricola's matriculation at Leipzig University at the age of twenty was uncommonly late for the time, but consonant with his social background and upwardly mobile status. He received a bachelor's degree in 1515, remaining to lecture on elementary Greek. His first work was a booklet on grammar. He later traveled to Italy, stopping at Basel to visit Erasmus. He studied medicine in Bologna, Padua, and possibly Ferrara and remained three years in Bologna and Venice to help edit the Aldine editions of Galen and Hippocrates. Thus steeped in humanist culture and editorial practice, he returned to the empire. He first went to Saint Joachimsthal (now Jáchymov, Czechoslovakia), a mining town on the eastern slope of the Erzgebirge in Bohemia close to the Saxon border, one of the most productive mining areas of central Europe. As town physician and apothecary, Agricola tended the sick but also visited mines and smelters day and night, learning as much about mining and metallurgy as about the diseases of miners. In 1533 he moved to the quieter town of Chemnitz in Saxony to become town physician. While continuing his medical work and his scientific and technical writing, Agricola also invested in mining. His knowledge allowed him to profit —by 1542

[40] Biringuccio (1959, 373).
[41] Biringuccio (1959, 384–85).
[42] The influence of Agricola's family connections on his writing is pointed to by Eberhard Stimmel (1966, 377), who suggests that Agricola probably described his father-in-law's copper smelter in detail in *De re metallica* (1556, book 11). For Agricola's life, see Wilsdorf (1971, , esp. pp. 82–98) for his family background. For brief summaries, see Wilsdorf (n.d.); Agricola ([1912] 1950, vi–xii). For bibliography before 1963, refer to Michaelis and Prescher (1971). A particularly insightful discussion is Suhling (1983).

he was one of the twelve richest inhabitants of Chemnitz. Given a house and plot by the Saxon prince Maurice in 1543, he was made *Bürgermeister* in 1546 by command of the prince. At this time he was also appointed a councillor in the court of Saxony and sent on various diplomatic missions on behalf of Charles V.[43]

Agricola wrote his first metallurgical book while working as a physician in Joachimsthal. The *Bermannus sive de re metallica*, published initially in 1530, is a little dialogue among the physicians Johannes Naevius and Nicolaus Ancon and a mine overseer, Bermannus, as they stroll through the mountainous region near the town. The book mainly consists of a discussion of regional ores and those mentioned in ancient writings. The introductory letter by Erasmus was obtained by Petrus Plateanus, a distinguished teacher who at that time was rector of the local Latin school. In addition to his Latin-German glossary, Plateanus contributed his own letter of introduction dedicated to Heinrich von Könneritz, the region's mine superintendent.[44]

The introductory letters of the *Bermannus* emphasize the ideal that knowledge should be open. Erasmus praised the work for its vivid descriptions of "those valleys and hills and mines and machines" almost as if one had seen rather than read about them.[45] Plateanus further explicates the ideal of openness through writing. None are more deserving "than those who transmit to posterity through writings the secrets either of the arts or of nature invested by oneself or by others." Although men are endowed with powers of reason, understanding, and knowledge, making them superior to the mute beasts; although they are capable of virtue and of various skills and disciplines; and although they are even able to be inventors and therefore can "penetrate into every very concealed thing of nature," nevertheless knowledge would be completely narrow if it were limited to one person's experience. Plateanus pointed to the very learned men of former ages who had made discoveries after much work and had committed them to writing. In turn he condemned those predecessors who had lost these writings or allowed them to be destroyed. He admonished that we should take care that the same fate does not overcome our writings or those of successors. There are many ingenious and learned men in our own age, but they are often reluctant to publish the "records of their genius" either because of modesty or because of fear of criticism. We should give our caring to any of the noble men who suffer this shame or fear so that their work, which aids public studies, is not cut off.[46]

[43] Wilsdorf (1971, 99–275); Agricola ([1912] 1950, vi–xii); Suhling (1983, 157–60). For a list of Agricola's writings, their subsequent editions, and translations with bibliography, see Horst (1971). A cogent discussion of one aspect of Agricola's work that provides useful context is Ruffner (1985).

[44] The edition I have used is Agricola (1541). I have also consulted Agricola (1955a). The "condensed" English translation made from the 1955 German translation (Paul 1970, 252–311) contains many omissions and should not be relied on. For a history of the text itself, see Horst (1971). For discussion and documentation of Plateanus's role in securing the support of Erasmus, see Wilsdorf (1971, 184–88). Heinrich von Könneritz and Plateanus's careers and relationships to Agricola are summarized in Agricola (1955a, 295–312). For Plateanus see also Kaemmel (1888, 241–43). Agricola named at least two of the interlocutors after friends. Lorenz Bermann, about whom little else is known, translated Agricola's *De bello adversus Turcam suscipiendo*, an oration against the Turks, into German for its first publication in 1531. Johannes Naevius was a physician who, like Agricola, attended the University of Leipzig and spent some time in Italy. Nicolaus Ancon is unknown—the editors suggest it may be a pseudonym for a student friend in Italy. For the three interlocutors, see Agricola (1955a, 271, 306–8, 268, respectively).

[45] Erasmus (1541, 3): "valles illas & colles, & fodinas & machinas." Since the work contains no description of a machine, one wonders how carefully Erasmus read it.

[46] Plateanus (1541, 5–6): "quam illi, qui vel arteis vel naturae arcana, per se aliosque inventa, literis ad poteriate[m] transmittunt"; "ad abstrusissima quaeque natura[e] penetrare"; "ingenij sui monumenta."

Agricola's own view of openness in this relatively early work was profoundly influenced by his experience of editing humanist texts. He placed openness in opposition not to craft secrecy or to the failure to write or preserve past writings, but to the corruption of terminology that rendered obscure what once had been clear. He lamented the damage not only to natural and man-made things, but also to names. Either they had been changed ineptly or barbarisms had been substituted in their place. Because of this obscurity of language, darkness had been drawn over good studies and excellent art, forgetfulness had crept in, much destruction had followed. Metallurgical studies had made progress only because divine providence had intervened to excite the industry of every favorable person. These people had taken pains with high and extraordinary efforts "to lead back into light, those things snatched away from darkness, to call back into memory, those things freed from oblivion, to liberate into freedom, those things preserved from extreme devastation… ."[47]

Agricola's aim was to integrate ancient knowledge with contemporary information, in part by developing a uniform technical vocabulary. He suggested that eloquence and purity (as opposed to precise terminology) were flourishing in both the Latin and Greek languages but that knowledge of things had been neglected for the most part until the present. He particularly condemned the physicians who used the names of metals so often and the apothecaries who dispensed them, both without knowledge of substances.[48]

Elaborating his own reasons for writing, Agricola stressed the value of openness. He had written the *Bermannus* to give the studious a taste of a work to come. He also wished to motivate his contemporaries to more diligent investigations. Finally, he wanted to bring to light useful things to be found in German mines that had been unknown to antiquity.[49] As for the ancients, they provided a model not only by their learning, but particularly also because they had transmitted their own knowledge and that of others to their successors in writing: "For if the Greeks, the most learned people of all, have transmitted not only their own written accounts [*memoriae*] but even those of foreigners, it is shameful for us that our things through our own negligence and idleness indeed now are almost concealed by darkness and lack their own light."[50]

In his own time, Agricola portrays the interlocutor Bermannus as a model of one who combines direct observation and experience with knowledge of ancient texts. Only near the end of the dialogue do we learn that he is the overseer of a particular mine. And while he leaves his new friends briefly to talk to the mine captain, the other two praise him for, among other things, his openness in sharing his knowledge: "that which he discovers with great labor, he explains very easily and very diligently to others, and by no means is one who, with a certain envy, conceals, as in mystery and arcana, a very bad habit of not a few."[51] Openness was a central value, a necessary condition for Agricola's study of ancient invention and authorship and contemporary data.

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[47] Agricola (1541, 10): "eas e tenebris ereptas, in lucem reducere: Ab oblivione vindicatas, in memoriam revocare: ab extrema clade servatas, in libertatem asserere…"

[48] Agricola (1541, 11–12). See also Halleux (1983). I have not yet been able to see the recent *Belles Lettres* edition with French translation and commentary: Agricola (1990).

[49] Agricola (1541, 13–14).

[50] Agricola (1541, 14): "Si enim Graeci gens omnium doctissima, non sua solum, sed etiam externa, memoriae tradideru[n]t, turpe nobis sit res nostras per socordiam & ignaviam nostram etiam nunc tenebris quasi obrutas esse & sua luce carere."

[51] Agricola (1541, 100): "ea quae magno labore invenit aliis facillime & dilligentissime explanat, ac minime qui non paucis mos est pessimus, invidentia quadam ta[n]quam mysteria & arcana celat."

In the *Bermannus*, the encouragement of capital investment in mining is explicit. When Ancon, the physician trained by scholastic methods, suggests that miners lose money, Bermannus scoffs and points to miners in the area who had begun to excavate with little means and had become wealthy as a result.[52] Ancon later elaborates that he would not pay money just for hope —that mining involves great expense for such hopes, and he would not spend "what was certain for uncertain things" and rashly give up his fortune. In a rejoinder worthy of any 20th-century stockbroker, Bermannus insists that Ancon is too cautious and that such extreme caution would always be in his way. Ancon's attitude reveals a good Aristotelian, but he would never be a good miner or a rich man. If a farmer had such a view, fearing catastrophe, he could never sow; if a merchant had it, fearing a shipwreck, he could never trade; nor could anyone go to war because of the uncertainty of the outcome. On the other hand, "all hope for good and often it turns out well. No one truly with an abject and timid soul ever did anything or indeed ever will do anything."[53]

Agricola's attitude toward wealth represents the endpoint of a continuum that begins with the medieval ideal of Franciscan poverty and develops into the more positive evaluation of the Italian humanists whose dialogues presented the positive as well as the negative effects of riches.[54] For Agricola, wealth was unambiguously good. He elaborated in his *De veteribus et novis metallis, Lib. II*, a small treatise on ancient and contemporary metals published with a group of other writings in 1546. Defending authorship on metallurgical subjects, he also encouraged the activity of mining itself. Quite simply, mining will make one rich. Or so might be the conclusion drawn from Agricola's list of those who had acquired wealth thereby. His examples ranged from the highest princes to ordinary people, including one Conradus, "*cognomento pauper*" whose economic status had been radically transformed by the discovery of some silver in the Jura Mountains.[55]

Steeped as he had been in the values and practices of humanism during his years in Italy, Agricola's views concerning openness and authorship were influenced by the Romans. Vitruvius, Pliny, and Columella emphasized respect for past authorship, advocated open written transmission, and condemned plagiarism. Although these Roman values developed in very different contexts, they were apposite to Agricola's own environment. Without following him slavishly, the 16th-century author adopted Pliny's lead in appending the names of relevant past authors to some of his treatises. As he noted in his treatise on mineralogy, "Pliny gives credit openly and frankly to those whose writings he uses and likewise I shall give credit by name to those whom I quote."[56]

In his masterpiece, *De re metallica*, published posthumously in 1556, Agricola's acknowledged model text was the *De re rustica* of the Roman agricultural author Columella. Columella's unusual skill in balancing respect for past authorship with the ability to maintain a critical stance is everywhere apparent in Agricola's own writings. Columella was an

[52] Agricola (1541, 16–17).

[53] Agricola (1541, 27–28): "quae certa erant, incerta"; "bene sperant omnes & foeliciter saepius p[rae]cedit, nemo vero animo qui abiecto & timido fuit, unqua[m] re[m] fecit, aut etia[m] faciet."

[54] See, e.g., Bracciolini (1978). For views toward wealth in this period, see especially Baron (1938); and, for the medieval background, see Little (1978).

[55] Agricola (1546, 384–85), for a defense of writing on metals, and pp. 394–95, for the list of individuals enriched by mining. For a discussion of Agricola's defense of mining, see Vogel (1955).

[56] Agricola (1955b, 1–2), where Agricola summarizes his attitude toward Pliny and other past authors. For the views of Roman technical authors toward openness and authorship, see especially Vitruvius (n.d., 7. preface 1–10); Columella (n.d., 1.1.1–20) (where he discusses past authors); and Pliny (1938, 14–15).

important influence not only for the structure of the *De re metallica*, but also for many of its most significant values. The 16th-century treatise, which was dedicated to the Saxon princes Augustus and Maurice, included an eloquent defense of mining modeled on Columella's defense of agriculture. Following Vitruvius's similar requirements for the architect, Agricola listed the disciplines necessary to the miner —philosophy, medicine, astronomy, surveying, arithmetic, architecture, drawing, and law. He defended mining against every critic. He dismissed those who emphasized the dangers and unhealthiness of mining. A physician of miners who was in a position to know better, Agricola suggested that accidents were rare and caused by the carelessness of workmen. He believed that mining was profitable to the competent and useful to the rest of mankind, and he emphasized the uses of wealth against those who pointed to its evils. The dignity of mining and of investment in mining was greater than that of commerce and equal to —although more profitable than —that of agriculture.[57]

In addition to his defense of mining, Agricola advocated openness and credit to authorship. Past writers should be properly credited: "No one should escape just condemnation who fails to award due recognition to persons whose writings he uses, even very slightly." As before, the value of openness was centered on the clarity of technical language. Alchemists were to be condemned particularly because all of their writings are "difficult to follow, because the writers upon these things use strange names, which do not properly belong to metals, and because some of them employ now one name and now another, invented by themselves, though the thing itself changes not." Beyond its obscurity, Agricola complained about the lack of efficacy of alchemy (which consistently failed to produce riches) and about alchemical frauds. Finally, he condemned the alchemical practice of assigning false authorship.[58]

1.5 Assaying and Authorship in the Postboom Decades

By the mid-1550s the mining boom of the German states had spent itself. As the rich veins became less productive, efficient methods of assaying and of extracting and refining metals became increasingly crucial to overall productivity. Not only was the removal of ores from poorer veins more costly, but also the growing influx of precious metals from the New World tended to lower the value of the gold and silver that were extracted. The oversupply of precious metals both from the German states and from the New World contributed to the inflationary trend known as the price revolution. Exacerbating the problems of the declining value of money was the chaos of specie that had long been the rule in the German states and had encouraged widespread fraud in minting. The mint became a particular focus of attention. In addition to attempts to reform the coinage, accurate assaying in the mint became a priority. Although the mining boom was over, the clock could not be turned back. Capitalist mining and metal production continued, while the literature that it produced focused increasingly on efficient methods of assaying and metal processing, on the effective organization of labor, and on the minting of specie.[59]

[57] Agricola ([1912] 1950, 1–24). For Vitruvius's list of disciplines necessary to the architect, see Vitruvius (n.d., 1.1 3–10). The publication history of *De re metallica* is outlined in Horst (1971, 741–831).
[58] Agricola ([1912] 1950, xxvi–xxix).
[59] For a general discussion of the decline of mining and the confusion and widespread fraud in the mints, see Janssen (1910, 70–106). Harry A. Miskimin (1977, 35–43), discusses the decline of mining in relationship to the

The *Probierbüchlein* by Ciriacus Schreittmann is an intriguing example of technical writing in the 1550s. All we know about the author is that he was an assayer in the service of Johann Abel von Weissenburg from Weissenburg-am-Rhein in Bavaria. Johann's son, Valentin Abel, undertook publication of the booklet in 1578 more than twenty years after it was written and after the death of both his father and Schreittmann.[60] Above all, Schreittmann was concerned with accurate weighing and measurement. The first part of the pamphlet concerns the construction, testing, and accurate use of an assay balance. As Cyril Stanley Smith has shown, the second part contains a striking innovation in its elaboration of a decimal system of weights for assayers.[61] Not until the third and last section does Schreittmann get around to discussing the assay of metal in both specie and ores, the construction of assay ovens, and the like.

In his dedication to Georg Friedrich of Brandenburg (1539–1603), Valentin Abel elaborated the theme of openness. He praised the ancients for their foresight in having bequeathed and communicated their many useful discoveries to successors. He noted the utilitarian value of the arts, including the mechanical arts, and insisted on their ongoing progress and contribution to civil society. He questioned whether we should "hide in ourselves and bury in the darkness of ignorance" the art of assaying. Unfortunately, assaying had been wholly abandoned for a time by Germans, who considered it useless speculation. The particular reason for this was that very few had sufficient understanding to write down the results of what had been learned. An exception was Ciriacus Schreittmann. Yet his beloved father Johann Abel had kept this author's book in secret for more than twenty years. He, Valentin, was now publishing it because it had such great uses for every lover of skill. Many rulers and nobles were now decreeing that all the arts be written about. Nothing on earth was begun without favor from God and the protection of the princes and nobles. On the other hand, he did not doubt that some jealous artisans would be "very grieved against this instruction on assaying without favor from God and the protection of the princes and nobles. On the other hand, he did not doubt that some jealous artisans would be "very grieved against this instruction on assaying, as if on account of it some damage to their livelihood would follow," and would believe that the subject should not be made public.[62]

Schreittmann himself wrote a preface to the reader, an indication that he had intended to disseminate the work beyond his employer. He noted the many books already published on his subject that he honored greatly. Nevertheless, it took trouble, work, and time to read them because they were "written so obscurely and in a scattered way." The person who improved a known subject was more to be praised than the first who discovered it. Further,

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price inflation. Production statistics documenting the decline are occasionally available—see Westermann (1971a, 313–15).

[60] I have used the 1580 edition—Schreittmann (1580). See also Darmstaedter (1926, 189).

[61] Smith (1955). As Smith noted, Schreittman's system provided an elegant and simple substitution for the complicated legal weight systems in which 16th-century assayers worked. It also furnished a method whereby assayers could convert from one system to another. Schreittmann, who clearly used the new system in his own work, proposed it years before Simon Stevin's much better known elaboration of a decimal system of weights and measures, Stevin (1585). The failure of Schreittmann's system to be taken up by other assayers presents an important case for the study of innovation vs. tradition in the history of technology.

[62] Valentin Abel, "Den Hochwirdigsten/Durchleuchtigsten/…," in Schreittmann (1580, n.p.): "in unns verborgen/ und in finsternuss der unwissenheit begraben"; "wider diese anleytung dess probirens sehr bekämmern/als ob ihnen der halben etwas abbruchs ihrer Nahrung darauss folgen wirdt." The ruler to whom the work is dedicated is not mentioned initially. However, at the end of the preface the date is given as 39 years after the birth of Georg Friedrich, margrave of Brandenburg.

bad things had sometimes been written in old books and learned carefully to the detriment of the art. Through his book, Schreittmann believed that he could cut many costs and avoid trouble and fruitless work. He had written it for the inexperienced who could learn assaying from it, for the more skilled for their greater understanding, and "for those seeking with subtle understanding" (i.e., the learned). Finally, he encouraged his readers not "to gnaw at my writings with envious teeth," but to use them and "to correct and make [them] better."[63]

Modestin Fachs, a master of the mint at Leipzig, wrote an assay book in the 1560s in which he praises metals as gifts of God that have many human uses. Fachs suggests that God has openly disclosed what is necessary for the preparation of gold, silver, and other metals, and he insists that handwork is essential for learning proper assaying. He points out that he has shown no one "obscure" alchemical ways that are "deceptive and untrue." In his first chapter Fachs gives detailed instructions for constructing an assay oven. He continues with specifications for handling various types of ores and metals and includes sections on weights. His interests are technical, but also historical. He concludes with chapters on assaying and coinage from biblical times to the present (1569). His book was published posthumously in 1595 at the behest of his son, Ludwig Fachs, who dedicated the work to Mathias Geyerbost, duke of Anhalt, and noted that his father had served the dukes of Anhalt for many years.[64]

Samuel Zimmermann published his book on assaying in Augsburg in 1573 and included as part of his introduction a poem on the five senses.[65] Zimmermann's emphasis on the senses was consistent with his belief in clear, open, and visible assaying, and his opposition to the obscure, fraudulent, and often false operations of the alchemists. Initially, he had been undecided about writing his book because of the "heaped up meanderings" in many alchemy books. He had questioned the value of publishing or even of further reading. Little truth had been discovered by "present-day supposed philosophers and alchemists," and many had died before even one had become rich. He himself had transformed copper, lead, and tin to make them look like gold, but such change was only a vision, a counterfeit, or a shadow, as if a reflection in a mirror or water. Just as one is duped by such reflections, so the alchemical art is illusory. Even where transmutations are possible (Zimmermann gives examples of changing iron and lead to copper, copper into brass or lead, iron and steel into lead), the cost of the attempt is greater than the value of the resulting metal. Although alchemy is the source of many mechanical and medical skills, supposed alchemists are, nevertheless, often the source of deceptions concerning metal, minting, and previous stones.[66]

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[63] Schreittmann (1580, "Vorrede zu dem Leser," n.p.): "so dünckel und weitläufftig beschrieben sind/"; "die begerenden/mit spitzfünderigem verstandt."; "mein ausschreiben/mit neidigen Zänen zernagen"; "corrigiren unnd bessern."

[64] Fachs (1595, "Vorrede des Authoris/ an den kunstliebenden Leser"): "ungewisse," "betriegliche unnd unwarhafftige Wege."

[65] Zimmermann (1573, n.p.). The poem, "Beschreybung der füinff Synnen/ darinn der gantz Inhalt dises probier Büchs/ auffs kürtzest begriffen/ und in Reymen weiss gestalt," appears after the letter to the reader. The treatise is described by Darmstaedter (1926, 89–90). I have not been able to discover any biographical information on Zimmermann beyond his own statement (p. 88) that he also wrote a book on gun projectiles (Büchsen geschoss) and the fact that (as Samuel Architectus) he wrote a dedication letter for Paracelsus's treatise on the diseases of miners, *Von der Bergsucht oder Bergkranckheiten drey Bücher…*(1567). For the latter, see Sudhoff ([1894] 1958, 138–40).

[66] Zimmermann (1573, "Dem kunstliebhabenden Leser…," n.p.): "haussen umbfahren"; "jetzigen vermainten Philosophen und Alchimisten." Elsewhere (pp. 99–102), Zimmermann elaborated that he believed that the transmutation of metals occurred but through the grace of God, not the skill or knowledge of men. Later (pp. 128–31) he decried the lying and shouting over the philosopher's stone and suggested that the obscurity of alchemical writings

Zimmermann decided to publish his own book so that "both the correct and the false, the good and the bad become recognized." He believed that he would encounter two kinds of hostility. The first would be from "untrue artisans who help themselves and are needy of these things, and do not wish that such things become public." The second would be from "very false people and swindlers who beget namely a particular secret hatred and hurl envy on me, meanwhile I discover their false intelligence and their fraud sufficiently." Despite this hostility, the author assured his readers that he would explain things clearly, but he also reminded them that, as in any handwork, practical experience was necessary for true understanding.[67]

True to his promise, Zimmermann attempted to expose fraudulent metallurgical practices. He described how some made assay needles of brass, copper, and lead to look like gold, and of copper to look like silver, thereby deceiving "pickers and farmers."[68] He pointed to fraudulent alchemists who, with a "transmuting powder," convinced people that they could transform silver, copper, tin, and lead into gold, when in fact there was already gold in the powder. In order not to be deceived "by such so-called alchemists … with their false assays and powders" he advised that everyone do their own assay and that assayers make their own powders rather than use those given by others, by which "many princes and honorable people" are deceived. He has revealed the methods of these deceivers, so that you "know how to injure, to ward off and thereto also to warn other people before them."[69] Finally, he treated precious stones, through which "so many splendid aristocratic people" had been deceived, as their descendants still were being deceived, so that some had fallen from great wealth into total ruin. Zimmerman's purpose was to see that "the true cheats and deceivers with their false truths" were truly recognized and laid open so that they themselves are roused to desist.[70]

1.6 The Role of Authorship in the Career of Lazarus Ercker

The rewards of technical authorship in the mid 16th-century empire are particularly evident in the career of Lazarus Ercker (ca. 1530–1594), a skilled practitioner and overseer of mining and mint operations. Ercker was born in Saint Annaberg, Saxony, the boomtown that one of his predecessors, Calbus of Freiberg, had helped to lay out. He attended the University of Wittenberg in 1547–1548. His marriage in 1554 to Anna Canitz led to his appointment in 1555 as assayer at Dresden. He was chosen by Elector Augustus through the intervention of his wife's relative Johann Neef, whom we can recognize as the interlocutor Naevius in Agricola's *Bermannus*. Neef had been the town physician of Annaberg since 1527 and

was a result of the fact that alchemy comes from God, not man, thus making it impossible for man to "describe [it] clearly, transparently and perfectly" (klar/hell/und volkommenlich beschreiben (p. 130)).

[67] Zimmermann (1573, "Dem kunstliebhabenden Leser…," n.p.): "beyde das gerecht/ und falsch/ güts und böses erkendt wurde"; "den untrewen Künstlern/die sich diser dingen behelffen und nören müsen/und nicht wöllen/das soliche ding gemain werden"; "felscher und betrüger seind/ die werden fürnemlich ein sondern haimlichen hass un[d] neid auff mich werffen/dieweil ich iren falsch anzeig/un[d] iren betrug genugsam entdeck." See also p. 36 for a further discussion on the importance of actual handwork.

[68] Zimmermann (1573, 4–5): "die Lazen und Bauren."

[69] Zimmermann (1573, 111–15): "ein Transmutier pulfer"; "von sollichen vermainten Alchimisten… /mit sollichen irhren falschen proben/und pulvern"; "vil Herzen und Redlicher Leüt"; "schaden/wissest zuverhütten/unnd darzu auch andere Leüt vor inen gewarnen."

[70] Zimmermann (1573, 115–16): "sovil Statlicher/ fürnem[m]er Leüt"; "die wahr felscher und Betrieger/ mit irer falschen wahr."

physician to the electors Maurice and Augustus since 1544. The Saxon princes had already bestowed many favors on Georgius Agricola. Augustus in particular was an enthusiast of mine, metallurgical, and alchemical operations; his resident castle at Dresden contained a well-equipped smelting and assaying room that was the site of numerous metallurgical and alchemical experiments.[71]

Less than a year after his appointment, Ercker completed his first technical book, *Das kleine Probierbuch*. Hand copied by a scribe and dedicated to Augustus, it is a practical handbook that includes instructions for the construction of an assay oven, directions for assaying, and discussions of weights and measures, of cementation, and of the assaying of coins and other aspects of minting. It also provides assorted metallurgical recipes. Although the manuscript remained unpublished, it soon had the desired effect. Shortly after Ercker presented it to the elector, he was appointed general assay master for all matters relating to the mineral arts and minting for Freiberg, Annaberg, and Schneeberg.[72]

Although he was demoted (for unknown reasons) to warden of the Annaberg mint, Ercker found a new patron in Prince Henry of Braunschweig who appointed him assay warden at the mint at Goslar in the Harz mountains. Prince Henry (1489–1568), the grandson of Duchess Elizabeth, had continued his grandmother's work of expanding the productivity of the region's mines. Much of the reign of this Catholic prince was spent in armed conflict in an effort to gain or regain and consolidate territory under his own power. Although the conflicts in which he was involved were episodes of the struggles brought about by the Protestant Reformation, his own religious affiliation seems to have been motivated by the desire for the political support of the emperor. For him the consolidation of political and territorial power and the development of his most important economic base—mining—were prime motivations and went hand in hand. Encouraged by his friend Duke George of Saxony (1471–1539), the father of Augustus and Maurice, he had revived the ancient silver mines of the upper Harz, investing his own income and encouraging other investors. In 1552, after years of struggle, he conquered the imperial (but Protestant) city of Goslar and from that time on controlled the mines in the Rammelsberg, a mountain to the south.[73]

Ercker found himself, therefore, in a familiar environment—working in a mint, the appointee of a prince deeply interested in and dependent on the productive exploitation of mining. Once again he turned to technical authorship as a way of achieving advancement. He wrote the *Münzbuch*, a treatise on minting, which he presented in 1563 to Henry's son Julius, duke of Braunschweig-Wolfenbüttel (1528-89). By 1563 the enmity between Henry and his son Julius (brought about in part by Julius's conversion to Protestantism) had ameliorated. At his succession in 1568 Julius, by right of the religious peace of Augsburg, introduced Lutheranism into his duchy.[74]

Less dramatic but just as important was the continuity represented by Julius's intense interest in the aggressive exploitation of mining in his territories. Most significant economically by this time were the iron mines and the accompanying manufacturing industries, particularly of artillery, to which Julius contributed numerous inventions and experiments.

[71] Beierlein (1955, 12–18); Hubicki (n.d.); Ercker (1968, 9–11).

[72] See Ercker (1968, 5–144), for a transcription of *Das kleine Probierbuch*, and pp. 145–214 for a facsimile of the manuscript. See also Beierlein (1955, 14–16, and 56–68).

[73] Bornhardt (1931, 147–54); Boyce (1920, 23–65); Henschke (1974, 24–26, and passim (see "Personenregister," s.v. "Heinrich der Jüngere, Herzog von Braunschweig-Wolfenbüttel")); Schmidt (1969).

[74] Beierlein (1955, 19–68); see Ercker (1968, 267–326), for an introduction to the *Münzbuch* and a transcription of the text. For Julius, see Kraschewski (1978).

The duke, who was intensely interested in metallurgy and alchemy, opened many new mines, expanded old ones, and made administrative reforms to prevent corruption. Julius also had a hand in technical authorship. The finely illustrated *Instrumentenbuch*, which, according to the subtitle, was "in part conceived by Julius and drawn and painted by his own hand," exists in a single manuscript copy. It concerns machines for removing ores from mines and transporting them. A second section that includes material on ships has recently been reported. Ercker apparently understood Julius's interests well when he dedicated his *Münzbuch* to him in 1563. Shortly thereafter he was promoted to master of the Goslar mint.[75]

In the *Münzbuch* Ercker elaborated why he was presenting a practitioner's knowledge of minting to a ruler. If nobles and potentates who control mines and mints are not well-informed of such practical operations, they will be taken advantage of by unfaithful servants and indeed will be unable to distinguish between true and untrue employees. Conversely, if they understand metallurgical practice, they can cast off false subordinates, appreciate true service, and not be subject to overreaching from unfounded hope. Ercker insisted that his information, based on the efficacy of experience, would be many times used and useful to nobles and dukes in relation to new mines.[76]

In writing down craft knowledge for a ruler, Ercker was acting on the side of openness. Yet his criticism of alchemy, which becomes explicit in the *Münzbuch*, is based not on its secrecy but on its lack of practical results. Ercker admitted that many of the practices of assaying, silver and gold refining, and similar arts had their origins in alchemy. Yet few alchemists of his own time had kept assaying a useful art by practicing it correctly and becoming experienced in it. Concerning the mint, Ercker supported its traditional secrecy. He cautioned Prince Julius "not to let this my work come before everyone so that it remains a beautiful art as up to now it has been."[77] Secrets of craftsmen and secrets of state were very different matters.

Ercker was once again seeking employment in the mid-1560s. After the death of his first wife, he married Susanne, daughter of a Dresden official. His new brother-in-law Caspar Richter was a minter in Prague. Through him Ercker was appointed control assayer (*Gegenprobierer*) in Kutná Hora (Kuttenberg), Bohemia. Susanne herself also served for many years as the manager of the mint in the same place with the title "manager-mistress." They had two sons, Joachim and Hans, both of whom became assayers.[78]

Ercker remained in Bohemia for the rest of his life and continued to advance himself by means of technical writing. He wrote a little book on testing ores, *Zkoušeni rud*, in 1569.[79] His masterpiece, *Beschreibung der allervornehmsten mineralischen Erze und Bergwerksarten*, first published in 1574, was dedicated to the Emperor Maximilian II (1564–1576).

[75]For Julius's mining activities, see Kraschewski (1978, 151–65). Julius's *Instrumentenbuch* (1575) is in the Niedersächsisches Staatsarchiv, Wolfenbüttel, 2 Alt 5228. See Spies (1978); Moran (1981, 261–62). The second part of the *Instrumentenbuch* is in the Staatsarchiv Magdeburg. I rely here solely on newspaper reports of a lecture in Wolfenbüttel by Gerd Spies for notice concerning this second part, "Vortrag über Technik der Renaissance: Vom Harz zur Nordsee" (8 August 1989) and "400 Todestag von Herzog Julius" (1989).

[76]Ercker (1968, 284). Indeed, Ercker's book on minting is organized very much from a ruler's point of view in that Ercker begins by describing the various offices of mining and mint operations and their respective duties (pp. 285–96) before discussing practical aspects of assaying and minting.

[77]Ercker (1968, 284–269): "diese meine arbeit nicht vor Jeden komen lassen, uff das es eine schöne Kunst, wie bieshero bleibe."

[78]Beierlein (1955, 24–34); Hubicki (n.d.).

[79]See Hubicki (n.d.). I have not seen this booklet, which apparently remains unpublished and exists in manuscript form in the National Archives, Prague, MS 3053.

Ercker elaborated that he wrote for the benefit of the emperor's vast mineral resources and of those who made their living from them, in the hope that these resources would be further developed and long maintained "through serious effort stimulated by complete information." The information he provided concerned the ores and assaying of silver, gold, copper, lead, tin, and saltpeter. Ercker's masterpiece undoubtedly was inspired by Agricola's *De re metallica*. Unlike his previous works, most of which remained in manuscript, this was a comprehensive, illustrated treatise clearly intended for publication. At the outset, Ercker boasted that his experience was greater than that of his predecessors (the allusion to Agricola is unmistakable). Soon after its publication, the emperor named Ercker courier for mining affairs and a clerk in the supreme office of the Bohemian crown. Maximilian's successor, Rudolf II (1576–1612), appointed him chief inspector of mines. He was knighted in 1586.[80]

1.7 The *Schwazer Bergbuch*: Emblem of Noble and Capitalist Mining Interests

The form of the beautifully hand-copied and illustrated *Schwazer Bergbuch* is very different from printed mining and metallurgy books. The treatise consists of an extensive compilation of mining law, customs, and regulations, and also contains more than a hundred hand-painted miniature illustrations, probably by Jörg Kolber. Unpublished until the 20th century, the work exists in at least seven manuscript copies. It is the most important 16th-century source for Tyrolian mining law and custom, mine technology, and the conditions and responsibilities of mine officials and workers. The author was almost certainly Ludwig Lässl (d. 1561), an official in a mine court in Schwaz in the Tyrol between 1543 and 1555.[81]

Erich Egg has reconstructed some aspects of the life of Ludwig Lässl. Born into a peasant family, Lässl's career exemplifies the upward mobility that the 16th-century mining industry could sometimes provide. Lässl obtained his post as clerk of the mining court through his father-in-law, Hans Möltl, who occupied the position before him. His appointment as mine clerk and his later retirement (with pension) because of ill health are recorded in the papers of the archduke Ferdinand (1503–1564), ruler of Austria and one of Lässl's patrons. Lässl is also known as the founder of the first paper mill in the Tyrol.[82]

Egg has suggested that the *Schwazer Bergbuch*'s emphasis on the localities of particular mines (which is irrelevant to mining law) strengthens the presumption that the work was not written primarily for mine workers. He has proposed that the prospective audience was much farther afield and was conceived in the context of a financial crisis in the early 1550s. Capital investments for Tyrolian mining came primarily from commercial firms in Augsburg, most importantly the Fuggers, but also many others. In 1552 two Tyrolian mining firms, plagued by the overextension of credit and the high costs of deeper mines, went bankrupt. Creditors from Augsburg were pulling back. In 1553 the Augsburg firm of Baumgartner, the most important investor next to the Fuggers, gave up its Schwaz mining interests. Egg suggests that the *Bergbuch* was intended to rouse both Augsburg investors and rulers to provide financial help in the form of mining investments.[83]

[80] Ercker (1960); Ercker (1951, citation on pp. 3–4). See also Armstrong and Lukens (1939) for the great influence of Ercker's treatise; and Beierlein (1955, 32–55) for Ercker's career in Bohemia, and pp. 68–97 for subsequent editions and translations of the work.

[81] See Winkelmann (1956, v–viii) for a useful introduction. See also *Der Anschnitt* 9 (1957), an issue largely devoted to the *Schwazer Bergbuch*; Berniger (1980); Kirnbauer (1956).

[82] Egg (1957).

[83] Egg (1957, 18).

Lässl's text supports such a view. He argued that the wealth produced by mines was a gift of God and pointed to the great riches and improvements brought about by mining. Many dukes and others had risked great sums and goods to build more extensive mines. Not only had workers and miners received benefits, but so also had all other persons of high and low station, as well as towns and businesses. Many had gathered in lightly populated areas, property values had increased fivefold, land had been developed, what once had been worth little or nothing was bought and sold for much money. All this showed that mining was a divine gift, created for the sustenance and benefit of man. Because of its great benefits, Lässl insisted that the welfare and rights of mine workers should always be considered. He was writing because over the years mine laws and decisions had become confused. Often two or more regulations referred to the same topic. He was correctly laying out the old regulations in new form.[84] As Lässl brought order to mine regulations, he also created an emblem for the riches that mining might bring in a book beautifully copied and illustrated by hand, a book fit for the libraries of wealthy burghers and kings. The shrewd intelligence evident in his text can be seen elsewhere as well, for in this postboom decade of the 1550s, Lässl put his own money not into mining but into paper manufacturing.

1.8 Conclusion

The exoteric tradition of mine and metallurgical writings encompassed great diversity in the books themselves and their authors. It included printed books and hand-copied manuscripts. Authors included practitioners from artisanal backgrounds and university-educated humanists. Such diversity suggests that there were also some differences in the aims of authorship and in intended audience, differences sometimes apparent within the corpus of a single author's writings. Lazarus Ercker wrote his early works for specific patrons with promotion undoubtedly in mind. In his masterpiece, on the other hand, he recognized from Agricola's example that he could achieve even more, namely fame, from a printed and illustrated treatise disseminated to a larger audience. Agricola himself wrote primarily for the world of humanist learning and aimed to legitimize mining and metallurgy as one of the learned disciplines.[85] Other authors such as Biringuccio and Ludwig Lässl were writing as much for wealthy potential investors as for noble patrons.

Yet, as soon as a practitioner took pen in hand to elaborate his technical skill in writing, he undertook also a new craft, one traditionally associated with more "learned" subjects. On the other side, the learned humanists Calbus of Freiberg and Georgius Agricola sustained a lifelong interest in the details of practice. Sixteenthcentury mine and metallurgical authors occupied a border area between learned, elite, and craft cultures. To a greater or lesser degree they were familiars of both worlds. Those with artisanal backgrounds were not only literate, but engaged in literary practice as well. Those who were university trained had acquired extensive knowledge of mining and metallurgical technology. This study confirms that the gap between the scholar and the craftsman was not as great in the early modern period as has sometimes been suggested.[86]

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[84] Winkelmann (1956, 10–12).

[85] A point stressed by Owen Hannaway in the seminar "Technologia," Folger Institute, spring 1989. In this regard, see also the perceptive essay by Suhling (1977) and also Roger (1979).

[86] Recent scholarship that has emphasized the early modern interaction between scholar and craftsman includes the following: Bennett (1986); Eisenstein (1979, esp. vol. 2, pp. 520–635); Keller (1985); Rossi (1970, 1–62); Vasoli

Despite their diversity, these authors shared the context provided by the capitalist expansion of mining. As a result, they elaborated a group of seemingly unrelated attitudes from a remarkably consistent point of view. Their affirmation that knowledge should be transmitted openly was closely associated with beliefs related to early modern mine and metallurgical capitalism: wealth is a positive good; investment in mining should be encouraged and would pay off in riches; clear technical language and understandable discussions of technical processes, careful measurement, honest and precise assaying, and practical skill all are necessary to high productivity. They criticized alchemy not on the basis of whether transmutation occurred, but in terms of the criteria of clarity, openness, honesty, and productivity. They also condemned craft secrecy.

All of these authors except one (Julius of Braunschweig) were from artisanal or middle-class backgrounds. All for whom we have biographical information were upwardly mobile. Many found patrons in those rulers whom Bruce Moran in his ground-breaking studies has called "prince-practitioners."[87] The prince-practitioners (Julius is a prime example) supported exoteric mine and metallurgical authorship, but often they patronized the esoteric discipline of alchemy as well.

For "openness" did not necessarily refer to wide public dissemination of knowledge. Rather it could signify the act of writing down orally disseminated craft knowledge, making it accessible to an unskilled learned and noble audience. It could mean (as it did for Agricola) the development of a clear technical vocabulary. It meant for most of the authors a clear explanation of metallurgical techniques (in opposition to alchemy) as a way of increasing the productivity and efficiency of metallurgical operations. In a context of great social and economic fluidity, the idea of "openness" entailed the elevation of certain practical arts through authorship. Thus they were more accessible to a reading (as opposed to a skilled) audience, including the prince-practitioners. The princes of course did not need to choose between the exoteric and the esoteric since they themselves now had access to both.

Exoteric mining and metallurgical authors elaborated notions that had an important influence on 17th-century science. Particularly significant in this regard was the ideal that knowledge should be transmitted openly in writing and the association of that ideal with empirical practices. The influence of these 16th-century writers on 17th-century experimental philosophy has been obscured, I believe, by some of Francis Bacon's influential views. The close relationship of Bacon's "great instauration" to prior writings on the practical arts is suggested by his project of the histories of the trades. These histories were to be complete written accounts of the products and operations of the mechanical arts. Scholars would compile them by seeking out and thoroughly inspecting all of the crafts. They would be "unincumbered with literature and book learning" because the sciences transmitted through books were stagnant. On the other hand, the mechanical arts, which Bacon described as outside the written tradition, had "some breath of life" and were "continually growing and becoming more perfect."[88] Bacon also admonished, "Never cite an author except in a matter of doubtful credit."[89] In his rejection of book learning and in his view of the mechanical arts as the product of an oral tradition of nonliterate practitioners, Bacon disregarded the

(1974). Pamela O. Long (1985) discusses the ideal of the unity of theory and practice in architectural writings. For some of the older discussions, see Zilsel (1942); Hall (1959); Houghton, Jr. (1957).

[87]Moran (1981), and, for a discussion of one particular court, Moran (1985).

[88]Bacon (1960, 6–8). Bacon was particularly interested in mining and metallurgy and wrote inquiries on these subjects. See Webster (1975, 346).

[89]Bacon (1960, 274).

extensive prior tradition of writings on the practical arts. He failed to acknowledge that for many of the trades, including mining and metallurgy, extensive histories had already been written.

In the 1660s, inspired by Baconian ideas, the Royal Society of London set out to write histories of all the trades. Robert Boyle initiated the history of mining and metallurgy by positing an elaborate series of more than a thousand questions, which were published in the *Philosophical Transactions* of the Royal Society.[90] With the help of the questions, scholars or philosophers were to go out and interview illiterate craftsmen. Both would thereby benefit. The craftsmen could contribute a wealth of particulars otherwise inaccessible to the scholar, and the scholar with a broader overview could suggest improvements to the trades.[91]

When Boyle initiated this Baconian project, he also followed Bacon's admonition concerning credit to authorship. For he failed to mention that his elaborate series of questions on mining were derived, not from interviewing craftsmen, but from one of the most comprehensive histories of a trade ever written, the *De re metallica* of Georgius Agricola.[92] Subsequently, members of the Royal Society at times attempted to make prior writings such as Ercker's *Treatise on Ores* available in translation. However, they also frequently failed to cite their 16th-century written sources when they used them.[93]

Yet those sources had an important influence. Mining and metallurgical writers consistently urged that knowledge be open. They parlayed craft knowledge into openly written form and condemned the obscurantism of alchemy. The economic and social context in which they wrote encouraged them to oppose both artisanal and alchemical secrecy. Although credit for their authorship was rapidly obscured by some of the myths of 17th-century science, the actual presence of their influence is evident in the connections made then and now between openness, empiricism, and the progress of the sciences.

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[90] Boyle (1966a). For a systematic study of the histories of the trades see Ochs (1981; 1985).

[91] For his ideas about the histories of the trades, see Boyle ([1772] 1966b).

[92] Robert Boyle's groups of questions often reveal line-by-line correlations with passages of *De re metallica,* Agricola's statements having been changed into interrogatory form. Such comparison leaves no doubt that Agricola's masterpiece was one of Boyle's important sources.

[93] See Armstrong and Lukens (1939). An example of indebtedness of a mining industry to a 16th-century source is Samuel Colepresse's description of the Devon and Cornish tin mines (1671). The introduction to this history (which discusses the flood) is too close to the 16th-century antiquarian Richard Carew's introduction to the same subject to be accidental. Compare Carew ([1602] 1969, 7). See Ochs (1985, 137) for a discussion of Colepresse's account.

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