# PIROTECHNIA

## THE SEELEY W. MUDD SERIES

INDUSTRIAL MINERALS AND ROCKS
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*Edited by E. DeGolyer*

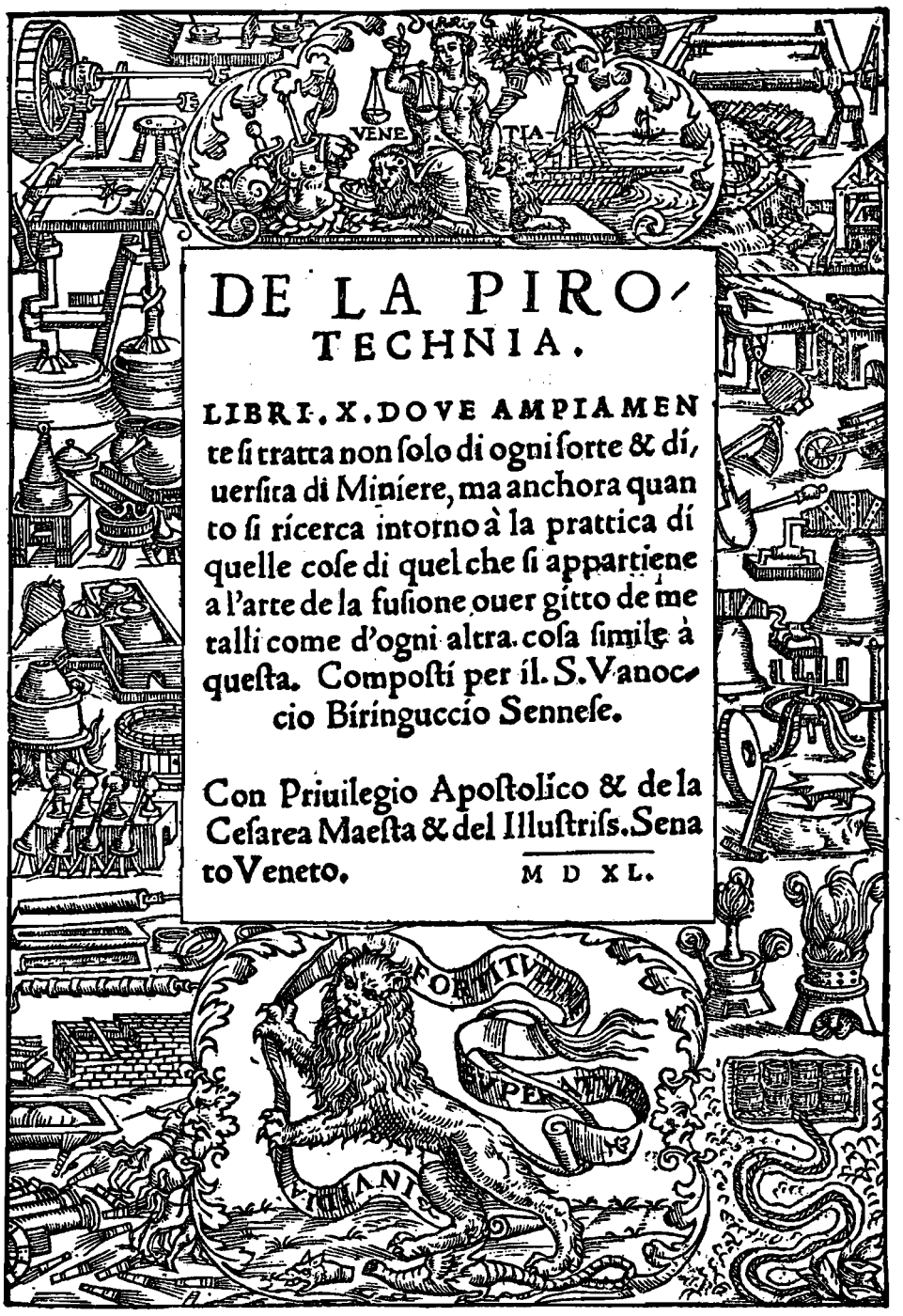
DEVELOPMENT OF MINERAL INDUSTRY EDUCATION IN THE UNITED STATES
*By Thomas Thornton Read*

THE PIROTECHNIA OF VANNOCCIO BIRINGUCCIO
*Translated by Cyril Stanley Smith and Martha Teach Gnudi*

# FIRE

AT the conclusion of our survey of the ways in which human intelligence calls art to its aid in counterfeiting nature, we cannot but marvel at the fact that fire is necessary for almost every operation. It takes the sands of the earth and melts them, now into glass, now into silver, or minium or one or other lead, or some substance useful to the painter or physician. By fire minerals are disintegrated and copper produced: in fire is iron born and by fire is it subdued: by fire gold is purified: by fire stones are burned for the binding together of the walls of houses. . . . Fire is the immeasurable, uncontrollable element, concerning which it is hard to say whether it consumes more or produces more.

*PLINY*




# DE LA PIRO-TECHNIA.

LIBRI. X. DOVE AMPIAMENte si tratta non solo di ogni sorte & diuersita di Miniere, ma anchora quanto si ricerca intorno à la prattica di quelle cose di quel che si appartiene a l'arte de la fusione ouer gitto de metalli come d'ogni altra cosa simile à questa. Composti per il. S. Vanoccio Biringuccio Sennese.

Con Priuilegio Apostolico & de la Cesarea Maesta & del Illustriss. Senato Veneto.

M D XL.

TITLE PAGE OF FIRST EDITION—1540.

# THE PIROTECHNIA OF VANNOCCIO BIRINGUCCIO

TRANSLATED FROM THE ITALIAN

WITH AN INTRODUCTION AND NOTES

BY

CYRIL STANLEY SMITH

&

MARTHA TEACH GNUDI

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# FOREWORD

AMONG the highly skilled craftsmen of the Renaissance were those who worked with ores and metals. The author of this book, Vannoccio Biringuccio, was a master craftsman in the practices of smelting and of metalworking. Contrary to the customs of a trade, Biringuccio was moved to impart his knowledge to all and thus he has given us the earliest handbook on metallurgy—in fact, the first printed book dealing with the applied metal arts and the processes of ore reduction. We should remind ourselves that metallurgy is an ancient art and then it fairly may be said that Biringuccio sought to describe the techniques that had been in course of development since the Bronze Age of western civilization. Whether Biringuccio was a man of learning or a scholar according to the standards of his time we do not know, but today we recognize him as a man of science who gave his wisdom to succeeding generations. It was not until the coming of the Power Age at the end of the eighteenth century that progress was resumed in the science of which he wrote more than two hundred years before.

Little is known of Biringuccio's training in his native Siena. It can be surmised that there, as in Florence, where his contemporary Benvenuto Cellini lived, he received his training in the craftsman shops where the industrial arts were taught and flourished alongside the fine arts. Perhaps he and Cellini were acquainted, although there is no mention of Biringuccio in Cellini's autobiography—an omission that Cellini's vast egotism makes understandable. He was the great artist, and Biringuccio was a practical, studious, unromantic figure with no favors to dispense.

In the April 1940 issue of *Mining and Metallurgy* Dr. Smith describes Biringuccio's book under the title of "A Neglected Italian Metallurgical Classic." The article, revised and extended, forms the basis of the introduction to the present volume, and I urge all who take up *Pirotechnia* to read what Dr. Smith has written in the Introduction. Biringuccio's work is a classic and in its translation Dr. Smith and Dr. Gnudi have brought to bear the high degree of scholarship that it deserves. Dr. Gnudi made the translation at Dr. Smith's request and it was then refined "in the fire" of his scientific knowledge of the subject. The result is a book which the Institute is proud to place before its members and which the Memorial Fund Committee considers it a privilege to publish.

Both in content and format the book departs from the usual run of papers of a technical society. We hope the departure will be received with approval and that the sage observations and the faculty for accurate description of the sixteenth-century Italian metallurgist will strike a responsive chord or lead to an interesting train of thought as comparisons are made between old methods and the modern manner of doing the same things. Often such comparisons will prove that, basically, the old and the new are not far different. History teaches us not to belittle but to applaud those who have preceded us in all fields of human endeavor.

HARVEY S. MUDD

*April, 1942*

# INTRODUCTION

## *Life of Biringuccio.*

BIRINGUCCIO was born in Siena in 1480, the son of Paolo and Lucrezia di Bartolommeo Biringuccio.* He was baptized on October 20 of that year with the given names Vannoccio Vincenzio Austino Luca. His father appears to have been an architect, for in 1504 he was paid 600 scudi for his work on the walls of the Communal Palace and at the same time he was superintendent of streets for the city.

The course of Biringuccio's life followed closely the checkered fortunes of the Petrucci family of Siena. A warm supporter of Pandolfo Petrucci, Biringuccio did not falter in his allegiance to the family and their party during his lifetime. It was probably to the protection and patronage of this lord that he was indebted for the opportunity to travel widely through Italy and into Germany during his early years and so to lay the foundation for the extensive knowledge of the subjects he was to describe in the *Pirotechnia*. In 1507, as he himself indicates (p. 48), he was in Friuli and Carnia in northern Italy after having traveled in Germany, and he also visited the brass works in Milan. After returning to Siena, he was sent by Pandolfo to direct the iron mines in near-by Boccheggiano.

When Pandolfo died in 1512 (in which year Biringuccio's father also died), Biringuccio continued to support the Petrucci family in the person of Pandolfo's son, Borghese, who succeeded to the rule. Under his patronage, Biringuccio was appointed to a post in the Armoury of the Siena Commune in 1513.

In 1515 a popular uprising forced Borghese and his followers, including Biringuccio, to flee from Siena. Biringuccio and the goldsmith Francesco Castori, head of the mint, were accused of having debased the coinage alloy with the knowledge and consent of Borghese. When he failed to appear in 1516 to answer these charges—which may well have been invented by the opposing political faction—Biringuccio was declared a rebel and was exiled as a traitor to the Republic. He then traveled about Italy, was in Rome and Naples, and visited Sicily in 1517.

* Facts for this sketch are derived in the main from the introduction to Vol. I of the critical edition of the *Pirotechnia* published by Aldo Mieli at Bari in 1914, and from the article on Biringuccio in the *Enciclopedia Biografica e Bibliografica Italiana*, Serie L, "*Armi ed Armaioli*," Milan, 1939.

In 1523 the Pope (Clement VII) caused the reinstatement of Fabio Petrucci, a younger son of Pandolfo; the sentence against Biringuccio was revoked and his sequestered property restored, together with his position in the Armoury. In 1524 he was granted a monopoly on the production of saltpeter in the entire Sienese dominion. But two years later, while he was in Florence on a mission, the people of Siena rose once more against the Petrucci and expelled them forever. So great was their rejoicing that for a time they dated their public books from the year of liberation. Biringuccio was again declared rebel and his property was confiscated on May 20, 1526. He took an active part in the assault on Siena that was soon undertaken by the exiled party, aided by Florentine and papal troops, but the attempt was unsuccessful and the exiles were vanquished in the battle of Porta Camollia on July 25, 1526. The sentence against Biringuccio was confirmed on August 11.

It appears that between 1526 and 1529 Biringuccio made a second trip to Germany. About this time he was also in the service of Alfonso I d'Este, lord of Ferrara, Modena, and Reggio, and in 1529 he cast the enormous culverin for the Florentine Republic which he mentions in the *Pirotechnia* (p. 233). When the numerous political factions of Siena made their peace in 1530, Biringuccio once more returned to his native city and entered the service of the Republic. In January and February of 1531 he held office as one of the Senators of the city and in 1535 he succeeded the famous Baldassare Peruzzi as architect and director of the Opera del Duomo. During the years 1531–35 he was also employed at various times to cast arms and construct fortresses for Pier Luigi Farnese of Parma, Ercole d'Este, and the Venetian Republic.

In 1536 Biringuccio was offered a post in Rome by Monsignor Claudio Tolomei, in the name of Pope Paul III. After some delay he accepted this offer and in 1538 became head of the papal foundry and director of papal munitions. It is probable that he died in Rome, although no documents exist to establish the exact place and date of his death. It is known, however, that he was dead before April 30, 1539, for a document of that date is concerned with debts owed to his heirs.

M. T. G.

## *The Background of the* Pirotechnia *and Its Place in Metallurgical Literature.*

BIRINGUCCIO's *Pirotechnia* is the earliest printed work to cover the whole field of metallurgy. There was, nevertheless, a considerable background of manu-

script and printed material that must be considered in assaying its position in metallurgical literature.*

Gold, silver, copper, and iron have all been found in archaeological excavations of sites dated earlier than 3000 B.C. and the alloy bronze dates from about 2000 B.C. Many objects of art and implements for warlike and domestic use that have been excavated in Egypt, Greece, and Rome show that considerable skill was possessed by the metalworkers of these civilizations. The contemporary written records, however, contain little information of a technical character, and practically all that is known about the techniques of these times has been deduced from an examination of the artifacts themselves.

Among Greek authors, Aristotle, Theophrastus, Diodorus Siculus, and Dioscorides mention a wide range of minerals and variously discuss their origin, nature, and use as medicaments. Other uses did not come within the scope of their interest or knowledge. The Roman literature is slightly more rewarding. The elder Pliny in his encyclopedic *Historia naturalis* gives some definite information regarding gold alloys, brass, solders, and other metallurgical products, although his descriptions always need interpretation and nowhere bear the stamp of firsthand experience.

The period from the disintegration of Rome to the sixteenth century is singularly lacking in specific metallurgical information, for there was little connection between the worlds of those who wrote and those who worked in metals. The learned men of the Church were concerned principally with theology and the nearest they came to science was in the study of etymology, for they believed that the essence of a thing was in its name. Nevertheless, here and there was to be found an unlettered smith, jeweler, or bell founder who knew how metals behaved, and, as he instructed his sons or apprentices,

* There has been no complete survey of metallurgical literature as such, although much can be gleaned from studies of the standard histories of chemistry. J. R. Partington in his *Origins and development of applied chemistry* (1925) has collected practically all available information from ancient and modern literature on the use of metals in the ancient Eurasian civilizations. H. C. & L. Hoover in Appendix B to their translation (1912) of Agricola's *De re metallica* give a valuable survey of ancient and medieval authors on mining and metallurgical matters, and have many useful notes scattered throughout the text. T. A. Rickard in his *Man and metals* (1932) treats the broader aspects of the occurrence, discovery, and utilization of metals though he does not deal with specific technical details.

The serious student will need to study G. Sarton's monumental *Introduction to the history of science*, and L. Thorndike's *History of magic and experimental science*, which provide the broad philosophic background against which individual sciences may be traced. W. B. Parsons' *Engineers and engineering in the Renaissance* provides an excellent picture not only of the state of engineering and architectural science, but also of the general conditions under which sixteenth-century technologists worked.

kept metallurgical knowledge alive by the spoken rather than the written word. Eventually there appeared a metalworker who could also write, and it was natural that he should be attached to the Church. It was a monk, Theophilus, who, somewhere around the year 1100, and probably in Germany, wrote a lengthy treatise describing the casting and working of metals and alloys, together with many other operations involved in the making of ecclesiastical works of art. This manuscript, entitled *Schedula diversarum artium,* is the earliest source* to contain descriptions written in the manner of the man who has "black'd his fingers and sing'd his beard in metallick operations." Theophilus writes for the individual metalworker, and it is the scale of operation rather than the nature of the processes that chiefly distinguishes his work from those of five centuries later. There are no known manuscripts on metalworking prior to the sixteenth century except a few copies of Theophilus.

Artists have produced representations of the metalworker, some of which provide information on the techniques employed. There are, for example, the fourteenth-century bell founders' window at York, the fifteenth-century etching of St. Dunstan in his goldsmith's shop by the anonymous Master of the Amsterdam Cabinet, two German fifteenth-century "Housebooks"† (one of which contains drawings that are probably by the same Amsterdam master), and Jost Amman's celebrated series of woodcuts‡ in 1568.

There are no books on metallurgy among the incunabula. The first printed

* The best edition of Theophilus' Latin text is that given by W. Theobald (1933) with a German translation and very comprehensive notes that are invaluable to the technological historian. An English translation was published by Robert Hendrie in 1847. The bibliographic study by D. V. Thompson, Jr. ("The *Schedula* of Theophilus Presbyter," *Speculum,* 1932, *7,* 199–220) and his review of the Theobald edition (*Speculum,* 1935, *10,* 437–440) provide a reliable discussion on the differences between the various copies and on the vexed question of the date of the original. The two earliest manuscripts extant are generally considered to have been made in the twelfth century, though certain scholars, on paleological evidence, assign one of these to the tenth century. Theobald accepts this earlier date, though Thompson does not.

† The so-called *Mittelalterliche Hausbuch* is a collection of drawings, many of which are of a technological nature and all of which show a high standard of artistic excellence, made in the year 1480. A facsimile reproduction under the editorship of H. T. Bossert and W. F. Stork appeared in 1912. The *Nürnberg Hausbuch* was a collection of drawings showing various trades made for the merchant house of Mendel over the years 1426 to 1541. No complete facsimile has appeared, but the little book, *Deutsches Handwerk im Mittelalter,* published as Insel-Bucherei No. 477, reproduces the illustrations.

‡ Jost Amman, *Eigentliche Beschreibung aller Stände auf Erden* . . . (Frankfort, 1568). The 114 woodcuts of various trades and crafts are described in brief rhymes by Hans Sachs. An edition with Latin text by Hartmann Schopper was issued the same year.

books related to our subject are the *Nützlicher Bergbüchlein* and the *Probierbüchlein* of the early sixteenth century, both of which have been discussed by the Hoovers* and by Darmstaedter.† The *Probierbüchlein* in particular must be considered in relation to Biringuccio's chapters on assaying. Five editions of this little work had appeared before Biringuccio's death, though there is nothing to indicate that he drew from them in writing his *Pirotechnia.* They contain descriptions of several different systems of assay weights, proportioned to the many local systems of weights then in use, and brief descriptions of assaying technique, exclusively for gold and silver in spite of a more comprehensive title.

Agricola's first work on mining, *Bermannus,* was published in 1530. It was known to Biringuccio, for he acknowledges it as a source for certain information on silver ores. It is mainly devoted to a correlation of the minerals known to the ancients with those found in the Saxon mines. In approach it is similar to the same author's scholastic *De Mensuris et Pondibus* (1533) which discussed Roman, Greek, and other ancient systems of weight and measure.

Starting with the *Rechter Gebrauch d'Alchimei* of 1531, and the *Drei schöner kunstreicher Büchlein* of 1532, a series of *Kunstbüchlein* or "Books of Secrets" was published in the sixteenth century in several countries.‡ These grew by a process of accretion and contained, in the form of recipes, information on everything from cosmetics to medicines and metallurgy. The most complete of these was the *Secreti* of Alessio Piemontese, first published in Venice in 1555 and frequently reprinted and translated. Biringuccio could have seen the *Kunstbüchlein* editions of 1531, 1532, 1533, 1534, 1537 (two), though it is doubtful if their brief treatment would have been helpful to one so versed in practical operations as he.

The significance of writers like Biringuccio can only be appreciated after some study of alchemy.§ The medieval alchemists devoted untold effort to the investigation of metallic reactions, yet produced very little of value to the metallurgist. To them the copper-zinc alloy produced by heating copper with a strange earth was an inferior gold and not copper with improved

* H. C. & L. Hoover, *Georgius Agricola, De re metallica* (English translation, 1912), Appendix B, pp. 609–614.

† Ernst Darmstaedter, *Berg-, Probier- und Kunstbüchlein* (1926).

‡ For bibliographic information on these works see Darmstaedter (*loc. cit.*) and Ferguson, "Some Early Treatises on Technological Chemistry," *Proc. Phil. Soc. Glasgow,* 1887 to 1912.

§ The book *Prelude to chemistry* (London, 1936) by John Read provides a fascinating summary of the literature and purposes of alchemy.

properties. A. J. Hopkins* shows how alchemy may have developed out of the Grecian metalworker's knowledge of the art of coloring metals. With the Aristotelian emphasis on qualities as the significant aspect of matter, such superficial transformations were real and fitted into a consistent and reasonable system. Toward the end of the first millennium of the Christian era, alchemy came to be overlaid with mystical theory, and the voluminous writings of the later alchemists contain very little either of intelligible information on the behavior of metals or of profitable theoretical speculation.

This, then, is the background against which Biringuccio must be appraised. First and foremost he stands out as the practical man, concerned with carrying out operations on metals for profit and for use. He realizes the advantages of large-scale operation and advises the use of power-driven machinery in place of hand labor whenever possible. The availability of adequate water power is the first thing to consider in establishing a smelter. Fuel and transportation are the next requisites. Biringuccio's work reflects an established capitalistic economy. In an amusingly naïve justification of his profession on moralistic grounds, he recommends mining as a safer way than soldiering to acquire wealth and as a pleasanter one than that of the merchant with his uncomfortable voyages to unfriendly foreign shores—in mining the danger is only to one's hired assistants. He recommends short shifts in mining (six or eight hours) but does so only because new and rested men enable the proprietor sooner to achieve profit.

Biringuccio has little respect for the authorities that enslaved literature for so long. Though he was familiar with the classics and is not averse to quoting Aristotle and Pliny on the nature and origin of ores, references to literature are meager and are sometimes given with a hint of skepticism. Albertus Magnus in particular is the target for derisive comment combined with mock respect for his authority. Biringuccio's source of information is almost entirely his own observation and experience in the shops where metals were smelted, worked, and cast. What alchemist could say with Biringuccio, "I have no knowledge other than that gained through my own eyes" (p. 70)? He obviously enjoys the application of skill and knowledge to the working of metals and finds intellectual satisfaction more in accomplishing a desired result than in contemplating the causes of things. The modern metallurgist will recognize a kindred spirit when, after comparing the foundryman to a stevedore and a fool and describing his burned and dusty clothes and muddy

* A. J. Hopkins, *Alchemy, child of Greek philosophy* (New York, 1934).

face, Biringuccio says that bronze founding is a profitable and a skillful art, and in large part delightful.

Few sixteenth-century works are so utterly devoid of superstition. Biringuccio recognizes that ill luck is nothing but ignorance or carelessness and says that the founder can assure Fortune's favoring him by careful attention to details. He laughs at those who use the divining rod and scorns the pseudo-magic of the alchemists. His evaluation of alchemy is astonishingly modern. Though he ridicules their general approach, he concedes that practical alchemists have produced a number of useful things and believes that they delude themselves more than they do others. He shares the perplexity of modern man when he sees how scientific knowledge can be used for good or ill, and wonders if men make inventions in the desire to serve mankind, or from some inner or outer necessity. He sarcastically refers to the good and lofty men of intelligence who, not satisfied with cannon and shot, devise yet more effective means to injure their fellow men.

Biringuccio's approach is largely experimental; that is, he is concerned with operations that had been found to work without much regard to why. The state of chemical knowledge at the time permitted no other sound approach. Though Biringuccio has a number of working hypotheses, he does not follow the alchemists in their blind acceptance of theory which leads them to discard experimental evidence if it does not conform. It was men like Biringuccio, the practical metalworkers, dyers, pottery makers, alum boilers, and kindred artisans, who accumulated the basic facts for a chemical science during the period in which learned men of church and university were engaged in lengthy but barren theological disputation. The artisans were the true scientists of this period, and if they lacked the flash of genius to produce a consistent theoretical framework, it must be remembered that even genius could do nothing without a reservoir of established fact. Many chemical reactions had been discovered and put to practical use long before their interrelation and significance were appreciated. If development of the chemistry of metals in this period was slow, this was a result of the small number of men interested in such things, the lack of encouragement that they received, and the difficulties of communication with each other, increased by a certain reluctance to share knowledge of possible advantage to a competitor.

Printing was just a hundred years old when Biringuccio's work came from the presses. Of the thirty thousand works printed in the fifteenth century, not one was on metallurgy and very few dealt with science of any kind. Most, indeed, were the works of men dead some centuries. Biringuccio states that

one of his objects in writing is to record information for the specific purpose of arousing intelligent minds to action, and on the basis of new information to arrive at certain conclusions that they could not otherwise approach. Many followed Biringuccio's example, and as a result of this growing literature of technological practice and experimental fact, science eventually became the concern of the educated man.

Biringuccio records those processes that he has seen working and the materials that have served him. He realizes that in other localities other materials may be more economical and hence advises experiment with whatever related substances are readily available. He advises trying out many things to see which ones work. "It is necessary to find the true method by doing it again and again, always varying the procedure and then stopping at the best." In most cases Biringuccio gives quantitative information and records appropriate weights and dimensions. He says that whatever is promised by the assay should be obtained in large-scale operation. Quantitative chemistry was well established and the law of fixed reacting proportions understood and utilized, if not expressed. The balance for weighing assays and furnace charges and the pen for computing them were as important to Biringuccio as the furnaces themselves. Weigh everything, he admonishes—and trust no one! In designing cannon and their carriages, he advises careful attention to dimensions and design in order to avoid having parts either too heavy for transport or too light for safety. To the bell founder he gives complete information on design and a linear scale of bell dimensions for any desired weight.

Although Biringuccio can be credited with the first description in full working detail of many of the arts and processes in his field, he lays no claim to being actually the originator of any of them. Of course, like any artisan worthy of his salt he must have made many minor adjustments and adaptations to local circumstances, but the broad principles seem to be those slowly accumulated throughout the previous years. Biringuccio's work is valuable primarily because it records the technical details of applied chemistry as practiced in his day, but inseparable from his account of an early stage in the growth of an experimental science is the picture of the beginnings of capitalistic industrial economy as it related to a most vital type of production. Here we have science working hand in hand with industrial organization in beginning to produce a new society. His work should be as valuable to the historian of economics as to the historian of science and technology.

It is hard to judge the influence of Biringuccio's work on the development of science. Some descriptions attributed to others are in reality copies of

Biringuccio. Georgius Agricola in his famed *De re metallica* (1556) says of him: "Recently Vannoccio Biringuccio of Sienna, a wise man experienced in many matters, wrote in vernacular Italian on the subject of the melting, separating and alloying of metals. He touched briefly on the methods of smelting certain ores, and explained more fully the methods of making certain juices; by reading his directions, I have refreshed my memory of those things which I saw in Italy; as for many matters on which I write he did not touch upon them at all, or touched but lightly."* Agricola's "refreshing of his memory" consisted of copying *in extenso,* without further acknowledgment, the earlier author's accounts of mercury and sulphur distillation, glass and steel making, and the recovery by crystallization of saltpeter, alum, salt, and vitriol together with other less important sections. Agricola usually added a superior illustration and often provided valuable additional details.

Biringuccio was certainly popular among men of his own kind, as attested by the fact that no fewer than nine editions of the *Pirotechnia* appeared over a period of 138 years. Men like Robert Hooke used it for practical information, for in 1675 when Hooke heard of the finest steel's being made by casting cemented steel and forging the ingots—this 65 years before Huntsman—he made a note† to look up more of this in "Vannuchio Beringochio." Nevertheless, references to Biringuccio in scientific literature are few. Agricola's works were soon absorbed in the snowball accretion of literature references and were quoted by almost everyone writing on metals, at first as a current authority and later as an important milestone in the historical development of metallurgy, mineralogy, chemistry, and engineering. On the other hand, Biringuccio was rarely mentioned in contemporary literature and to this day is frequently ignored by scientific and technological historians, particularly those writing in English. It seems likely that the greater popularity of Agricola was a result of his more scholarly approach and the fact that he wrote in Latin, the language of the educated throughout Europe. The German and Italian translations made him available to the nations of greatest metallurgical activity at the time. Biringuccio's best descriptions are of the more practical aspects of metalwork, and these were, for several generations, of little interest to those who wrote books. Perhaps, too, the beautiful format that the house of Froben gave to Agricola's works appealed to those who were more concerned with the physical form of books than with the knowledge to which they were the key. While Agricola was, and is, proudly owned and dis-

* Hoover translation, p. xxvii.

† *The Diary of Robert Hooke,* entry for November 12, 1675.

played, the smaller and inferior format of Biringuccio's work and its inferior literary style caused it to be placed on the topmost shelves—when, indeed, it ever got away from the company of the moulders' tools and assay furnaces that were its fit companions.

In the literature of metals, Biringuccio's *Pirotechnia* was followed by Agricola's *De natura fossilium* (1546), *De re metallica* (1556), and lesser works. Perez de Vargas' *De re metalica* (1569) was little more than a Spanish translation of parts of Biringuccio and Agricola. Somewhat later appeared Ercker's *Beschreibung allerfürnemisten mineralischen Ertzt und Bergswercksarten* (1574), a book of great importance in the history of quantitative chemistry and of interest for its forty-odd woodcut illustrations, among the most beautiful that have ever graced a technical work.

Although the seventeenth century was a period of great activity in physics and chemistry, and although metallurgical production was increasing rapidly at the time, the methods used were not much changed, and the demand for books on metals was satisfactorily met by reprints of the sixteenth-century authors, Biringuccio, Agricola and Ercker. Only one important original work appeared in the seventeenth century, *El arte de los metales* by Alvaro Alonzo Barba, which was published in Madrid in 1640. It was translated into German, French and partly into English, appearing in at least twenty-four editions.

Metallurgical information incidental to the authors' main purposes is to be found in many works. Cellini,* for example, in writing for goldsmiths and sculptors tells a lot about working, alloying and casting metals; Moxon† in instructing the printer in his craft tells how to reduce antimony sulphide to the metal and how to make and cast type metal; Boizard‡ in compiling legal information and regulations for the mintmaster appends fine instructions on the chemical, metallurgical and mechanical aspects of making coins; and Saint Remy,§ chiefly dealing with the military aspects of the use of artillery, adds chapters on copper alloys and on the whole detailed technique of the gun founder. Books on chemistry and physics, particularly those by men like Glauber, Boyle, and Hooke who were conscious of the interdependence of science and industry, frequently contained the germs that later provided

* Benvenuto Cellini, *Trattati dell'oreficeria e della scultura* (Florence, 1568).

† Joseph Moxon, *Mechanick exercises, or the doctrine of handy-works applied to the art of printing* (London, 1683).

‡ Jean Boizard, *Traité des monoyes* . . . (Paris, 1696).

§ Saint Remy, *Memoires d'artillerie* . . . (Paris, 1697).

the basis for metallurgical practice. On the whole, however, the metallurgical methods that had been developed by trial and error prior to the seventeenth century were far ahead of chemical theory, and it was not until the eighteenth century that advances in the fundamental sciences had affected metallurgical practice to an extent that required the writing of entirely new books.

While Biringuccio was perhaps unduly hopeful in using the expected longevity of his book as a yardstick for the enduring qualities of one of his fires, that of Love, there is no doubt that he has achieved a measure of immortality. The *Pirotechnia* was the first compilation of practical metallurgical knowledge to be printed and hence to achieve wide distribution. Placed thus at the apex of a widening stream—in 1942 a veritable flood—of metallurgical publications, its influence must have been felt indirectly in all subsequent works, long after the last edition (printed almost a century and a half after the manuscript was written) had been discarded by technologists as being out of date.

C. S. S.

## *The Editions of the* Pirotechnia.*

BIRINGUCCIO'S work first appeared in 1540, the year following the death of its author. Printed in Venice, the first edition bears the colophon "Stampata in Venetia per Venturino Roffinello. Ad instantia di Curtio Nauo. & Fratelli. Del M.CCCCC.XL." The dedication by Navo is to one Berriardino di Moncelesi da Salo and personal reference to Bernardino is made at the beginning of the preface and occasionally throughout the text. The same Curtio Navo, or di Navò, produced both the second edition in 1550 (printed by Giovan Padoano of Venice and dedicated to one Signor Guidotto Napio, "Bohemian"), and the third, which is dated 1558 on the title page and dedication, though the colophon reads "IN VINEGIA per Comin da Trino di Monferrato. M D LIX." This third edition is dedicated by Navo to Monsignor M. Mario Caboga, Archdeacon of Ragusa, and contains the interesting statement that the earlier editions had likewise been embellished and amended by Caboga, their various patrons being hypothetical. Although they bear the names of different printers, the three Navo editions are very similar to each other in format and pagination; all consist of 22 quarto signatures, viii + 168 leaves. The first edition is typographically inferior, for the type was worn, poorly aligned, and arranged in a solid mass, unrelieved by para-

* See Appendix C for a bibliographical description of all editions.

graphing, which is indicated—often erroneously—only by a capitalized word. Newer type of the same design and the same woodcut initials were used for the 1550 edition. A similar but thinner type and different initials were used for the 1558/9 edition. The illustrations in all three Navo editions are from the same blocks, though in the second edition a few of them are incorrectly placed. Most copies that one sees today are bound in plain untooled vellum, sometimes flexible and sometimes on boards.

Another edition appeared in the same year and town that Navo published his last edition. The title page reads "In Venetia, Appresso P. Gironimo Giglio, e compagni. M D LIX." Unlike the Navo editions, this is octavo and printed in italic. It contains many of the obscurities of the 1550 edition, on which it was obviously based. The illustrations had been recut by an inferior craftsman and frequently fail to show the proper detail. Was it perhaps these that Cellini had in mind, when, in talking of a reverberatory furnace of exactly the type described by Biringuccio, he says, "I do not intend making a drawing of it, because I have seen so many architectural drawings altered and spoiled, so I shall content myself with words only to convey what I mean"?

Over a hundred years were to elapse before the appearance of another Italian edition. In 1678 the fifth edition was printed in Bologna by Gioseffo Longhi. This was dedicated by the publisher, Natale Doriguzzi, to the Marchese Giuseppe Montecuculi, brother of the more famous Raymond. This edition follows the 1559 edition in content, size, and general format. Once more the illustrations were recut, with deficient skill and often unintelligible results. No further reprints appeared until modern times.

Aldo Mieli published in 1914 at Bari the first volume of what was to have been a modern definitive edition. Unfortunately, this ended with Chapter 6 of Book II and apparently no more is to be published. Mieli gives an account of Biringuccio's life and a valuable analysis of his background and contribution.

There are numerous minor differences in spelling and grammar between the different editions but otherwise the text is much the same. In each subsequent edition some attempt was made to clarify the language but this seldom resulted in clarifying the technical meaning. The third edition (1558/9) is the most free from linguistic obscurities. The 1540 edition was chosen as a basis of the present translation as it most likely represents Biringuccio's original words.

The only contemporary translation purporting to be complete is in French, and was made by "feu maistre" Jaques Vincent. Although the royal

privilege is dated September 1552, the book was not published until 1556. It was printed in Paris by Claude Fremy and is dedicated to Jehan de la Marche. The text is excellently printed and the cuts are well copied. The translation was reprinted under the same auspices in 1572 but by the use of smaller type the text was compressed into 168 instead of 230 quarto leaves. It was printed again in 1627 by Jacques Cailloué of Rouen in an edition that is practically a line-for-line copy of the one of 1556.

Vincent's translation is not a good one, for it is full of omission, condensation, and misinterpretation. Most English writers who have used the *Pirotechnia* in the past have referred to the French versions, thereby obtaining a false picture of Biringuccio's ideas.

A modern French translation of some of the chapters relating to gun founding was made by one Rieffel, "Professeur aux écoles d'artillerie," and published in Paris in 1856 under the title *Traité de la fabrication des bouches à feu de bronze au XVI^e siècle en Italie. . . .* This includes chapter 3 of Book V, chapters 1, 3, 5, 6, 7, 8, 8a, 10, and 11 of Book VI, and chapters 1, 5, 6, and 8 of Book VII.

It would seem that the demand for a work of this kind would have been greater in Germany than elsewhere, yet no German translation appeared until 1925. In that year a complete translation, with notes, by Otto Johannsen was published. This was constantly referred to in preparing the present translation, though we not infrequently differ in our interpretations.

Gobet* states that there was also a Latin translation of Biringuccio, published in Cologne in 1658. Beckmann, in his *Beiträge zur Geschichte der Erfindungen,*† refers to a French one published in Frankfort in 1627. Neither of these editions can today be found in the catalogues of the principal libraries.

No complete translation into any other language is known. Bernado Perez de Vargas, in his *De re metalica* published in Madrid in 1569 (Colophon 1568), gives Spanish translations of generous sections of both Agricola and Biringuccio, mainly without acknowledgment. He depends largely on Agricola for smelting and assaying, but quotes Biringuccio for details on alloys and metalworking generally.

Richard Eden, in the preface of the work to be later mentioned, says that

* N. Gobet, *Les Anciens minéralogistes de France* (Paris, 1779), Vol. 1, pages 324–326.

† J. Beckmann, *Beiträge zur Geschichte der Erfindungen* (Leipzig 1780–1792). Beckmann devotes an entire chapter to Biringuccio, whose book he considered to be of great importance. This chapter was omitted by William Johnston in making the English translation.

he intended to translate the whole *Pirotechnia* into English, and had actually finished the first twenty-two chapters (i.e., to the end of Book II) in 1552, but he had the still-common experience of lending his manuscript to one from whom he could never retrieve it. The chapters on gold and silver, now perhaps of as little interest as any in the book, were important enough in those gold-hungry times to be translated once again for inclusion in the compendium of geographical knowledge that Eden was about to publish. This was the time when the interest of all Europe was turning to the New World, and records of voyages of discovery were being read avidly by merchants, princes, and philosophers as well as by sailors. Richard Eden had previously published an English translation of Sebastian Münster's *Cosmography,* and in 1555 brought out a collection entitled *The Decades of the newe worlde or west India, containing the nauigations and conquestes of the Spanyardes. . . .* In addition to the chief work, Pietro Martires' *Decades,* this includes also letters by Amerigo Vespucci and Sebastian Cabot and a number of other descriptions of voyages and natural phenomena of use to the traveler in distant lands. Having described the Indies, Moscow, and Cathay, having proved that the world was round, and having given a method for finding the longitude of strange places, what is more natural than that Eden should recognize the traveler's real reason for his journey, and include a description of the modes of occurrence of gold and silver ores and the manner of finding them? In his own words, "It seemeth to me a thinge undecent to reade so much of golde and sylver and to knowe so lyttle or nothinge of the naturall generation thereof." For the enlightenment ōf the reader he could have used Agricola's *De natura fossilium,* published in 1546, but instead he chose our author's first three chapters, translating them faithfully with the omission only of the diatribe against alchemists. Eden evidently possessed some practical knowledge, for he occasionally expands a word into a phrase to give greater clarity. He undoubtedly learned of the *Pirotechnia* from "the ryght worshypful and of singular learnynge in all the sciences, Syr Thomas Smyth, in my time the floure of the Universitie of Cambridge and sometyme my tutor." Sir Thomas was traveling abroad during the years 1539–41 and probably brought back the newly published *Pirotechnia* to show to his eager pupil.

Eden's translation was reprinted in 1885 in *The first three English books on America* by Richard Arber. This work, which was again printed in 1895, includes most of Eden's other translations and a useful biography of him.

One of the earliest military books in English is the celebrated *Certain waies for the ordering of souldiers in battelray* by Peter Whitehorn, published in London

in 1560. Whitehorn was an accomplished Italian scholar and translated also Machiavelli's *Arte della guerra.* It has not been recognized heretofore that the chapters in the *Waies* describing mines, bombs, military fireworks, saltpeter, and gunpowder are practically nothing more than translations of Biringuccio's chapters on these topics, and are even adorned with copies of Biringuccio's illustrations though no mention is made of their source. Perhaps he contributed original matter to the section on military maneuvers, but Whitehorn deserves none of the credit he often gets for describing the manufacture and properties of saltpeter and gunpowder, or the various effects achieved with them.

Short passages from Biringuccio have been translated into English by a number of writers. John Percy in his *Metallurgy of iron and steel* (London, 1864) published a translation of the chapter on steel (Book I, Chap. 7) made at his request by no less a person than Sir Anthony Panizzi, principal librarian of the British Museum. Percy's star pupil and assistant, A. Dick, translated the chapter on amalgamation for the former's *Metallurgy of silver and gold* (London, 1880). H. C. and L. Hoover in the admirable notes to their translation of Agricola's *De re metallica* quote from Percy's works and also translate several other short passages, apparently following the French editions more closely than the Italian. E. A. Hodgkin in his *Rariora* (London, 1903) translates certain sections on pyrotechnics, obviously from the French translation with its many defects.

The combination in one individual of a knowledge of both Italian and metallurgy together with an interest in history is rare in the English-speaking world, and the task of translating the *Pirotechnia* into English, begun by Richard Eden in 1552, has remained uncompleted. The present work is the result of the collaboration of two individuals whose chief fields of activity have been, respectively, Italian literature and metallurgy.

C. S. S.

## *Remarks on the Translation.*

THE present translation has been made from the first edition of the *Pirotechnia,* published in 1540. This appears to have been printed directly from a manuscript which must have been rapidly written, uncorrected for the most part by the author, and difficult to decipher. The sentence structure is intricate and sometimes ambiguous, while the meager and faulty punctuation is not only confusing but such as to alter the meaning entirely in many passages. The

lack of almost all apostrophes and accents customary to Italian usage often causes difficulties—does *loro* mean "theirs" or "gold" (*l'oro*), does *e* stand for "is" (*è*) or "and"? The context is not always a sure guide to clarity. Misspellings, distorted and disparate spellings, as well as archaic and vernacular forms abound. At the same time, however, Biringuccio did not have to coin phrases in an obsolete tongue, and the obscurities arising from this source in Agricola's Latin, for example, are absent. The names of substances and apparatus are generally unmistakable.

Had Biringuccio lived to revise the manuscript or to advise the printer, some of the more obvious errors, especially those resulting from miscomprehension of the meaning, would undoubtedly have been eliminated and some of the obscurities of expression removed. There would have remained, however, the redundant verbosity that pervades the work, as well as the persistent Tuscanisms, or, more properly, the Sienese vernacular usages. Biringuccio can scarcely be credited with literary ability. Though clothed with some of the conventional rhetorical flourishes of the time, his work lacks the style and distinction of Cellini's writing and much of its vividness. It does, however, possess the immediacy of the spoken word. Despite its formal structure of chapters and books, the whole work has the air of a long extemporaneous discourse, expressed with the enthusiasm of a man speaking informally to friends about his chosen work. Biringuccio's blunt, direct speech is that of the practical man whose life has been passed in the active exercise of his craft; he is not interested in grammatical accuracies or in literary niceties. Eager, alert, possessed of an unquenchable curiosity and sharp powers of observation, he has traveled, worked, and experimented unceasingly, and now in his old age is intent on sharing the fruits of his experience with his friends and fellow workers.

Yet how frequently and ardently the translator finds himself wishing that Biringuccio had been more concerned, either consciously or instinctively, with the tools of his expression! The grammatical discrepancies of his work at times hang like clouds between the reader and the sun of Biringuccio's thought. Relative pronouns are flung about with prodigal and indiscriminate hand; subject pronouns are shifted, often within the same paragraph or even sentence, from "you" to "he," from "I" to "we," and from "it" to "one" or "they" with complete abandon. So, too, are tenses changed without warning from present to past or future and back again. Hence, modifications of person, number, and tense have necessarily been introduced in the translation to ensure a logical unity of time sequence and thought progression, in so far as

this seemed feasible without distorting the fundamental concept of the author. The repetition of the subject for a pronoun has often been necessary. Changes other than these grammatical ones, and doubtful interpretations are carefully noted by brackets [] or by footnotes. A few footnotes have also been added to provide historical perspective or to indicate the significance of certain of Biringuccio's operations.

*The Dizionario della lingua Italiana* of Niccolò Tommaseo and Bernardo Bellini has been the final authority for word meanings, though some of the obscure words used by Biringuccio are left undefined therein and merely illustrated by a quotation from Biringuccio himself.

The desire to keep the translation as close to the Italian text as possible has resulted in reflecting some of the faults of the original which a less literal rendition would have dissembled. Nevertheless, it has been felt that to sacrifice literary style was preferable to sacrificing exactness and the faithful reproduction of the author's ideas. What one wishes to know in reading a work of such historical importance is precisely what the author said, not what a translator of a later century thinks he ought to have said. Therefore, great care has been exercised to avoid adding to the text or subtracting anything. In the inevitable arguments between metallurgist and linguist, the latter has always had the final word, though preference has been given to a reading technically correct wherever such an interpretation is clearly justified.

Experience with other translations of a similar kind—even the best—indicates that errors and misinterpretations must be present in this. These will be most numerous in the sections other than those dealing with metallurgy, where the translators may have failed to recognize the true significance of a certain phrase or operation. The serious scholar must, as always, base his conclusions only on his own interpretation of the original text.

M. T. G.

## *Acknowledgments*

THE translators wish to record their appreciation of the help given by many individuals with whom they have discussed various details of the work. They are particularly indebted to Mrs. Anne Noble McKeachie, who initiated their collaboration; to Miss Cora Adamson, who spent many hours in making an accurate copy of a much-mutilated first draft of the translation; and to the Yale University Library which gave access to its excellent collection of books on all aspects of the history of the sciences. The reader will share with the translators their obvious indebtedness to Mr. Carl P. Rollins, Mr. James W. Boyden, and the staff of the Printing-Office of the Yale University Press.

The publication of this translation by the American Institute of Mining and Metallurgical Engineers has been made possible by a grant from the Seeley W. Mudd Memorial Fund, administered by a committee composed of Harvey S. Mudd, H. DeWitt Smith, and George Otis Smith. The translators are gratified that their work has been judged to fall within the scope of this Fund, which was established for the advancement of the sciences of mining and metallurgy by the encouragement of research and the dissemination of knowledge, and especially for the furtherance of such activities as might benefit the younger members of the profession. While Biringuccio's book would scarcely serve as a dependable text for the young mining student or metallurgist, it can give him a sense of his membership in a long-standing and honorable profession and enable him better to see his own work in true perspective.

It is hoped that this English edition of a sixteenth-century Italian work will be read by the practicing metallurgist as well as by those who have already found pleasure in exploring the past of their profession. A man always feels more at home in a foreign country with men of his own craft than in his birthplace with those of different interests: As in space, so in time, and the modern metallurgist who may be unmoved by the literary and artistic Renaissance will quickly appreciate the spirit of that exciting period as he talks shop with Biringuccio on a visit to mine, smelter, forge, and foundry; as he sees in different forms the very furnaces and machines whose operation and response he knows so well; and as he discusses with this engineer of four centuries ago such topics as the best kinds of fuel or refractory for a given operation, and the importance of adequate supplies of power and material.

# DE LA PIROTECHNIA

Ten books in which are fully treated not only every kind and sort of mineral but also all that is necessary for the practice of those things belonging to the arts of smelting or casting metals and all related subjects. Composed by Signor Vannoccio Biringuccio of Siena.

With Apostolic privilege and with that of His Imperial Majesty and of the Illustrious Venetian Senate.

MDXL

CURTIO NAVO, *To the very magnificent Messer Bernardino di Moncelesi of Salo:*

If the best things are due to those who know them best, to whom is this work more appropriate than to Your Lordship? It was composed in your name by Messer Vannoccio Biringuccio of Siena, an excellent man, and given by him to me so that it is justly yours, and truly it is due to you, since there is no one who could better know it and more rightly judge it than you, either with Philosophy (in which you are most expert) or with Mathematics or Architecture. Furthermore, I know that you will prize it because it treats fully not only every kind and sort of mineral but also all that is necessary concerning the practice of those things that relate to the arts of smelting or casting metals, as well as everything similar to this. You will also prize it most highly if you consider the spirit in which I offer it to you, and this must be considered no less if there are some things lacking herein because of some slight earthly misfortune. And with this I offer my services to you, and kiss your hands.


PER CVRTIO NAVO' ET FRA
TELLI, AL SEGNO DEL LION.

*Here begins the* TABLE OF CONTENTS *of this volume, by which every subject contained in this work can easily be found; proceeding in order from book to book, the chapters and pages are shown by number.*

## BOOK ONE
## EVERY KIND OF MINERAL, IN GENERAL



## BOOK TWO
## [THE SEMIMINERALS]



* Page numbers relate to this translation. The page numbers of the 1540 edition are interpolated in the text at the appropriate points, at the beginning of each page.

## BOOK THREE

## [ASSAYING AND PREPARING ORES FOR SMELTING]



## BOOK FOUR

## [THE SEPARATION OF GOLD FROM SILVER]

## BOOK FIVE

### [THE ALLOYS THAT ARE FORMED BETWEEN METALS]



## BOOK SIX

### [THE ART OF CASTING IN GENERAL AND PARTICULAR]



## BOOK SEVEN

### [METHODS OF MELTING METALS]

## BOOK TEN

## [ON CERTAIN ARTIFICIAL COMBUSTIBLE MATERIALS, AND THE PROCEDURES FOLLOWED IN MAKING FIREWORKS TO BE USED IN WARFARE AND FOR FESTIVALS]

# LIST OF ILLUSTRATIONS†



† This list of illustrations is not given in the original, nor do any of the woodcuts themselves bear a number or title.