


# Man, Metals and Magic: The Ancient History of Metallurgy

## “Three 16<sup>th</sup> Century Experts”

### Chapter VII

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 **OUR HISTORY OF METALS**, so far, has depended largely upon the findings of archeologists or the writings of authors not always reliable, or inexpert, if reliable; or, if expert, as historical experts rather than as metallurgists. However, in the 16<sup>th</sup> century three books were published by three men whose metallurgical knowledge was expert.

One book is *De Re Metallica*, by Georgius Agricola. Originally published in 1556, in 1929, it was most capably translated by the 31<sup>st</sup> President of the United States, Herbert Clark Hoover (1929-1933) and his wife, Lou Henry Hoover, into English and supplemented with valuable footnotes. The second book is *The Pirotechnia of Vannoccio Biringuccio*, published in 1540, translated and annotated in 1942 by Cyril Stanley Smith and M. T. Gnudi. The third 16<sup>th</sup> century book is the *Autobiography of Benevenuto Cellini*. While no one would suggest this latter book contains very much metallurgical information of value, it is, at least an interesting account of one metal worker's life.

Perhaps it would be as well to dismiss Cellini's book first. Cellini was born in Florence in 1500. Most people who knew his work acclaimed his capabilities as an artist in metals, but no one, it seems, thought quite so much of his work as Cellini did. The life story reveals a conceit and arrogance so enormous as to be amusing, but Cellini did have something to be conceited and arrogant about.

The books by Agricola and Biringuccio overlap in some sections, but are essentially complementary. Agricola considers prospecting and surveying, in addition to smelting, refining and assaying methods. While Biringuccio describes smelting, refining and assaying, he also covers casting, molding and core making, and the production of certain commodities – bells and guns, for instance. If one were to categorize their respective specialties, perhaps it would be true to say that Agricola was a miner and extractive metallurgist. Biringuccio was, rather, a fabrication man, who in those times, found it necessary to make his metal before he might use it.

Since we have often followed our metal thread through a cotton-wool industry and have necessarily left a number of subjects untouched for the sake of continuity, a survey of the books by Agricola and Biringuccio will allow us to fill in some of the details of metallurgical practice that have so far been omitted. In all fairness to Biringuccio, Agricola and their respective translators, it must be said that their texts have a completeness far beyond that which can be conveyed here. After reading them a man might survey, prospect, mine, extract, assay, found and fabricate with the confidence of a 20<sup>th</sup> century housewife making a cake after reading, “Every Woman's Cook Book.” The aim here is not to reproduce the cookbook, but to offer a crumb of the cake.

The view of Agricola and Biringuccio were advanced for their time. Agricola debunks the divining rod and writes very sensibly about the value of observing natural phenomena (outcrops, vegetation, mineral springs) for effective prospecting. He and Biringuccio were unhappy about alchemical theories and even more so about some alchemical practices.

Agricola could not accept the alchemical view that all mineral deposits were formed by the interaction of sulphur and quicksilver. In putting forward his opinion that openings in the earth were formed by eroding effect of subterranean waters and later filled by “juices,” he annoyed not only the alchemist but also those who held a literal belief in Genesis, which, of course, implies that rocks and minerals were formed at the same time.

Biringuccio's opinions of alchemy were, roughly, that he applauded the work of the alchemists in that they were practical men doing research. But he was impatient of those alchemists that strove to produce the Philosopher's Stone. He thought it more commendable to “get gold from ores rather than by alchemy.” However, if the metallurgist of those days did not

allow himself to use some of the alchemical jargon, he would be as lost for words as a contemporary physicist forbidden to use the terms “positive” and “negative.” So we should not be surprised when Biringuccio writes: *“In my opinion antimony (antimony sulphide) is a composition made by nature to create a metallic mineral that is overflowing with an undue proportion of hot and dry material and with its moisture poorly mixed.”*

There is, it seems, evidence that Agricola obtained some of his material from Biringuccio. The two men communicated with each other, and a comment of Agricola’s acknowledges that Biringuccio’s material did “refresh his memory.” The translators of Biringuccio’s book point out that this “refreshing” consisted in a literal lifting, with no acknowledgement. In fairness to Agricola it should be pointed out that he was the younger man. Whereas Biringuccio was born in Sienna in 1480, Agricola was born in Saxony in 1494 and his interests were so diversified that he must, of necessity, have cribbed a great deal of his material from other sources. Since Agricola was a student of and wrote texts on philosophy, medicine and natural sciences, we should not expect him to have so great a personal knowledge of metallurgical subjects as Biringuccio, who was essentially a metal worker. Whether Agricola was or was not guilty of lifting his information from elsewhere is of far less importance than the fact that he wrote down methodically and complete the information he acquired. But Biringuccio’s greater familiarity with his subject seems apparent in his writings.

### **Georgius Agricola and “De Re Metallica”**

As well as discarding alchemical hypotheses, Agricola refuted the popular opinion that ore veins in certain directions were the richest, with directional variations depending on the metal. The reasons behind these beliefs were connected with the effect of the planets, and more particularly with the Sun. By the middle of the 16<sup>th</sup> century these ideas were becoming shaky and Agricola disposed of them. Similar notions, equally destroyed by subsequent experience and fact, were held about rivers and streams that carried deposits.

However, Agricola’s debunking did not extend to many of the superstitions of the miners, for in describing mining conditions he refers to “demons of a ferocious aspect” that “are expelled and put to flight by prayer and fasting.” Some demons, called “kobalos” because of their habit of mimicking miners, were supposed to be of a gentle nature, unless roused. Nevertheless, German miners who sustained injuries from certain corrosive minerals held that these little men were responsible, and hence the mineral was associated with them, and was called “kobalt.” This is one account, and a pretty one, of the derivation of the worked “cobalt.”

While some demons were relatively harmless, and others might be exorcised, others apparently were always troublesome, although some of the more tangible unpleasant features of mining had begun to be eliminated. Since the time of the Athenian mines -- where if ventilation was provided at all, it was by fires lighted at the bottom of the shafts -- more efficient devices had been introduced. Fresh air was blown into the top of the shaft by fans or by bellows actuated by manpower or by the wind or a water wheel. It is significant that water wheels at the time, used for this purpose and for blast furnaces, were of the overshot type: that is, water was directed from a stream to the top blades of the wheel, which did not dip into a stream like the mill wheels of a later yesterday.

Mining machinery was still crude, but had improved over the centuries. The Archimedian screw pump was used to drain mines in some localities, but the lift pump was more widely applied to mine drainage, either in the usual reciprocating form or as a continuously operating machine. The motive power for these pumps, and for windlasses that drew buckets of ore from the mine, was provided by water wheels, or by men who might work a kind of treadmill, or by horses trotting a never-ending circle.

The mines were accessible by descending on a rope, or by a sloping shaft where one might find steps or not, or by sitting on the dirt and sliding down. In the mines, the tools used were of iron, but in design they had not altered much over 2000 years. When all is said and done, a spade is a spade. Until real mechanization with its pneumatic drills and power driven cutters was introduced, mining tools could not be very much changed. Some manual tasks had been eased and in most cases trucks that ran on wood rails were used to convey the ore to the surface.

Although gunpowder had been invented 100 years before the stocktaking date of 1560, it was not used in German mining practice until after Agricola’s death. In England, its use in this

connection was delayed for a further 100 years. The method of breaking up rock was by wedges and hammers, and also by fire setting, which was known since the days of the ancient Egyptians. This involved lighting a fire under the rock to be broken so that expansion would cause it to crack. If it were obstinate water would be thrown over the heated surface. The practice was a dangerous one and difficult to control. There was always the risk of a fall and also the hazard of asphyxiation from the fire's smoke and the fumes from the hot rock.

There had been little change by the 15<sup>th</sup> century in the methods used for breaking up the ore before it was sluiced with water to wash away the earthy material. The primitive crushers were either small hand-operated pestles and mortars or millstones that could be turned by men or horses or waterpower. Then, in the late 15<sup>th</sup> century, the stamp mill was invented. It consisted of a row of vertical shafts, each with a heavy iron shod block at the bottom that dropped on an iron plate. By a system of cams, each shaft was lifted and allowed to fall freely, crushing the material on the iron plate. In any crushing operation, ancient or modern, it is ideally necessary to separate each particle of earth from each particle of mineral so that subsequent concentration, by washing, for example, can work efficiently. Depending upon the nature of the ore deposit, this may have necessitated grinding the material from the stamp mill between millstones in order to make it sufficiently fine.

The ways in which the crushed ore was treated to concentrate the mineral were many variations of a simple enough theme. Essentially, all the methods consisted of subjecting the powder to a stream of water so the lighter, earthy material was washed away, while the heavy mineral sank and could be collected. Such a method was applied to ores of gold, silver, copper, lead and tin, and had been known for thousands of years, for gold washing dates back to about 4000 B.C. By the 16<sup>th</sup> century the water carrying the ore was directed through channels down chutes into tubs, and out of spouts in a way that would delight even the most surrealist plumber. Although the method had been made more elaborate and more efficient, the principle was unchanged.

Agricola described in some detail the ways in which ores should have been assayed in order to tell whether they were worth mining and extracting. Although the value of an ore deposit depends upon many local features and prevailing economic conditions, it is dependent in the first place on the amount of metal it contains. The science of assaying grew naturally from the time that a metal was obtained from its ores by anything more than an accident. By the appearance of a deposit, the miner and metal smelter might get a good idea of its value. The alchemists, with their introduction of chemical apparatus and experimental methods, made the next step. By the 16<sup>th</sup> century there had grown the idea of assaying an ore by putting it through a small-scale process similar in most respects to the smelting operation that would be used to extract metal from it. In all probability such a method may have been employed long before, but none of the techniques was recorded until the early 16<sup>th</sup> century.

Agricola was the first to write a comprehensive scheme of assaying for gold, silver, lead, copper, tin, quicksilver and bismuth (the minerals of which were known, while its metallic properties seem to have been in some doubt). As some assays used today depend upon the same fundamental of extracting the metal from a known weight of ore, and so determining its percentage, it is not surprising the methods Agricola described are very similar to modern methods. Even though solution and precipitation processes were known to 12<sup>th</sup> and 13<sup>th</sup> century alchemists, they were not applied to assaying until some time later.

That assays should have been made by the 16<sup>th</sup> century was natural and inevitable, but that they should have been systematically described in a way that still bears critical reading is one of the first signs of metallurgy taking on a scientific aspect.

The smelting of copper, lead, tin and iron was usually carried out at the time in small blast furnaces about 5 feet high and 2 or 3 feet square, with six furnaces built into the same structure so they could be conveniently attended. The hearths were made of rammed clay and charcoal, and in front of the tap hole was an open hearth of the same material, from which the smelted metal was eventually collected. The bellows house was situated behind the furnace structure, and by the 16<sup>th</sup> century bellows had reached the surprising size of about 6 feet in length. In design they were very similar to those that were used domestically in the days before firelighters.

Chambers were sometimes built over the tops of furnaces where solid material in the smoke was deposited for later collection, while the gases, relieved of some of their solids, passed out through a chimney at the top. Today the collection of suspended matter from smokes is a highly important

economy in most works. It is interesting that, despite the much inefficiency of older techniques, this practice was common in Agricola's time – and it was by no means new then. Agricola described the smelting processes and explained the ways in which gold and silver, produced by cupellation, could be separated.

*De Re Metallica* contains a complete account of the method of extracting silver from copper that remained standard practice until early in the 20<sup>th</sup> century. The process involved melting the silver-rich copper with lead, in an air-free atmosphere, and casting the resulting metal into cakes, which were subsequently heated to a temperature above the melting point of lead, but below that of copper. The lead gathered the silver from the copper, which was sufficiently concentrated in silver to be run off and cupelled, while the copper was taken to be refined.

From the nature of his remarks on iron making and their comparative brevity, it seems likely that Agricola was not perfectly familiar with recent developments. He referred to a furnace like the blast furnaces he had previously described, but of a greater size, and he spoke of its producing molten iron. Further, he wrote, "*from this kind of [iron] ore once or twice smelted, they make iron that is suitable for reheating in the blacksmith's forge,*" which, as the translators point out, might well allude to a process introduced in his time of making a malleable iron from the brittle product of the blast furnace. This technique, known as "fining," involved melting cast iron in a hearth where it was mixed with charcoal and oxidized by an air blast and iron ore. The process is a horrible one to analyze, for while the carbon content of the cast iron was reduced by oxidation, so must carbon have diffused into the metal from the hot charcoal that surrounded it. Nevertheless, the carbon content of the iron was reduced and the melting point was thereby raised. When the charge became pasty it was removed and forged. Agricola was wisely brief in dealing with so strange a process that was, in fact, very widely used until the middle and late 19<sup>th</sup> century.

### The Pirotechnia of Vannoccio Biringuccio

We can now take up the story from Biringuccio's book. As appropriate an introduction to it as any is the description of the founder:

"The founder is always like a chimney sweep, covered with charcoal and distasteful sooty smoke, his clothing dusty and half burned by the fire, his hands and face all plastered with soft muddy earth. To this is added the fact that for this work a violent and continuous straining of all a man's strength is required, which brings great harm to his body and holds many definite dangers to his life. In addition, this art holds the mind of the artificer in suspense from regarding its outcome and keeps his spirit disturbed and almost continually anxious. For this reason they are called fanatics and are despised as fools. But, with all this, it is a profitable and skillful art and a large part is delightful."

Biringuccio gives us our first insight into methodical foundry practice. That is, insofar as foundry practice was, or one might add, is methodical. Good founding is not a matter of fortune, he points out but requires skill and diligence. Good clay must first be obtained but an assessment of its qualities must depend upon trials. It should be "neither unctuous nor lean, neither wholly tender nor rough." It should dry without cracking, hold its shape and resist fire.

As to gating and venting molds, Biringuccio is frank: "*The more vents you make in your molds and the wider the entrances, the surer you will be of a good result in your casting, if you have melted well. I neither know nor am able to say any more about this.*"

That a careful selection of alloys could produce a better product was emphasized: "*It is possible with alloys to reduce considerably the ordinary measure hitherto used and to make guns lighter, a thing that results in easier moving of them and a great saving in expense to the patron who has them made.*" While Biringuccio seemed to appreciate the unpleasantness of gun making, he described it in detail, as well as the manufacture of iron cannon balls.

In a section on bell making, Biringuccio's book contains a surprising description of how cracked bells may be salvaged by welding them. The bell is laid in a pit and a core is fitted inside the bell. A furnace is constructed so its flame impinges on the cracked part of the bell and, when it reaches the right temperature, melted bell metal is poured on.

Following are a few comments of Biringuccio's on diverse subjects – and remember they were made over 500 years ago – which indicate a clear perception of his subject.

**On Alloys:** *“Alloy signifies nothing but the mixture of one metal with another in friendly companionship.”*

**On Steelmaking:** *“Steel is nothing more than iron, well purified by means of art and given a more perfect elemental mixture and quality by the great decoction of the fire than it had before.”*

**On Wire making:** *“Wire is drawn of every metal excepting tin and lead because of the need of strong bindings, which must enter the fire while bound.”*

We close this chapter with a fascinating chapter heading quoted from Biringuccio's book -- although perhaps some of its wistfulness is due to translation.

*“Discourse and Advice on how to operate a mint honestly and without profit.”*

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