The First Book of the *Pirotechnia* of Messer Vannoccio Biringuccio, in which are treated generally every kind of mineral and melting and other things: To Messer Bernardino di Moncelesi of Salo.

PREFACE TO THE FIRST BOOK

Concerning the Location of Ores.

HAVING promised you to write concerning the nature of ores in particular, I must tell you some general facts, especially those concerning the places, kinds, and manner of their existence as well as the tools which are used. However, you must know that according to good investigators these ores are found in many parts of the world. They show themselves almost like the veins of blood in the bodies of animals, or the branches of trees spread out in different directions. Indeed, careful investigators of minerals, wishing to show by analogy how ores are located in mountains, have drawn a large tree with many branches, planted in the middle of the base of a mountain. From its principal trunk extend various branches, some thick, some slender, exactly like real trees in mature forests. They think that these grow and enlarge continually and draw themselves toward the sky, ever converting into their own nature the most disposed adjacent materials so that finally the tips arrive at the summit of the mountain and emerge with clear sign, sending forth, in place of leaves and blossoms, blue or green fumosities,* marcasites with small veins of heavy mineral, or other composition of tinctures. From these things, when they are found, it is possible to make certain inference that such a mountain contains ores, and as the signs are more or less, so are the minerals plentiful and rich or poor. For this reason the prospectors for these things take heart according to the manifestations that they find, and with hope and certainty of profit they take all possible pains to mine with skill and expense those things that the signs have indicated. Often there are ores of such a kind and quality that they raise a man in wealth to the skies. For this reason men penetrate with eyes of appraisal and judgment within the mountains and see almost exactly the places where there is ore and the

* *fumosita.* This refers to the colored surface-staining of rocks by weathering, the most obvious sign of the presence of certain minerals. Biringuccio believed it to be caused by mineral vapors or fumes passing through the rocks.

quantity of it. They direct the excavation toward these, for otherwise they would go by chance, because in no other way can men understand where there is ore in the mountains, however good their judgment may be or however minutely they may have searched.

Furthermore, it is necessary to walk around, making certain from the appearance of the signs (trying to find as many as possible) and always keeping eyes and ears turned to wherever there is hope of finding some information, especially toward shepherds or other ancient inhabitants of the countryside. I tell you this because I am persuaded that good judgment concerning the first aspect of the mountain is not sufficient, for its great barrenness, its harshness, or the waters which rise there may not be strong enough to give certain sign that it contains sufficient ore to warrant the prospectors' starting to excavate with much expense and great bodily effort.

I say this also because I do not believe that one man, however strong and careful he may be, has enough strength to go about minutely examining a single mountain that might contain ore, much less all the mountains of one or more provinces. Some, because they know of this difficulty, say that they make use of necromancy. Since I consider this a fabulous thing and have no information of what it may be, I intend neither to praise nor to damn it, and yet if what they say they do were indeed true, it would be a very useful thing. However, I wish these necromancers would tell me why they do not use their art after they have found the ore and do also for the middle and the end what they do for the beginning; that is, use their art for excavating the ore and reducing it to smelted material and to the purity of its separation. Without doubt it can be believed that if they have the power to do one of the said things, they also have the power to do the others, but such operations are so fearful and horrible that they neither should nor could be practiced, nor would all men wish to do so. Such a thing is not well known, and I have never heard that it is practiced. The principal reason why it must be believed that such practices are abandoned in this part of the work is that whenever the excavation of a mine is begun, it is customary first to seek the grace of God, so that He may intervene to aid every doubtful and difficult effort; and in place of this one would be seeking the aid of the devils of hell. Whence, in order to discover ores, I think it better to abandon the way of bestial and fearless men and to choose the way of using the signs that are exhibited to us through the benignity of Nature, founded on truth and approved by all

experts because of their experience, which, as is evident, does not consist of words or promises of incomprehensible and vain things.

With this you will search the slopes of valleys, the crevices, broken pieces of rock, ridges or highest peaks of the mountains, and likewise the beds and courses of rivers; and, looking into their sands or among the ruins of ditches, where marcasites or little pieces of ore or various other metallic tinctures often appear, you will easily have indications from these things that there surely is ore in those places. Exactly where they are to be found may be determined by carefully observing the openings whence they have broken off.

After these, one has a general sign that all those mountains and other places contain ores where large quantities of fresh water spring up, water that is clear, though it has some mineral taste and changes its quality with every season, becoming warm in the winter and very cold in the summer. Even more must you believe it when you see those rough and wild mountains that are without soil or any growth of trees; or if indeed a little soil with a few blades of grass should be found, it is seen to be without its customary green color, all dry and weak. Most ores are in mountains of the kind just described to you, although some are found in mountains covered with soil and fruit-bearing trees and there is no sign to tell you of the presence of ores unless you search their slopes carefully. Of these the truest and most certain sign that can be given is when the ore shows itself clearly to the sight on the surface of the ground, either high or low.

There are some who praise highly as a good sign certain residues that waters make where they are still, and after having stood for several days, frequently warmed by the rays of the sun, they show in some parts of their residues various tinctures of metallic substances. There are others who usually take this water and cause it to evaporate or dry up entirely by boiling it in a vessel of earthenware, glass, or some other material, and they test the gross earthy substance that remains at the bottom by tasting, by the ordinary fire assay, or in some other way that pleases them. In this way (although they do not have an exact proof) they approach some sort of knowledge of the thing.

Thus you can make sure that there is sufficient ore where you are looking for it and that it is good and in large quantity, and this must be done in the best way with as much care as possible before beginning to excavate, so that the expense will not be thrown away. With great industrious care one must search in places near the roots of neighboring mountains or

on the slopes of the mountain itself and likewise all the surface where the rock is found naturally exposed, or in the watercourses, presupposing that it is almost impossible, if such mountains contain ores, that they should not send forth some vaporous exhalation. However, if they did not, it might happen that it is because the ore is of such good quality that it does not by nature form vapors, because there is but a small quantity, or perhaps because the mountain is so very large and the ore is still very deep down or so far inside that the fumes have not come through to give a sign outside. Alternatively it may be because there is interposed between the metal and the surface some rock of a thick and resistant nature, like limestone or black or white marble, which prevents it from coming to the surface. For this reason there may be trees and grass growing (as I have said) because the earth retains its powers and is able to nourish their roots since it is not consumed or burned by heat and poisonous mineral vapors, and rain waters cannot carry the earth away in its course as happens in those places that are burnt. I have seen many of these mountains with great chestnut groves on them, cultivated fields, and great woods of beech and cerris trees. Thus, to sum up, the lack of the signs of sterility and harshness does not necessarily mean that the mountains do not have ore, or that one should not search there. Since the signs vary in appearance according to the kind of mineral, I shall tell you about them more in detail where the ores themselves are treated. Here I have wished to speak of them only in general, in order to give you a certain initial light on them. Likewise, further enlightening you, I say that in all ores that are found by means of these signs or that in any way have come to hand, whether found in rock, earth, or sand, you have to consider their weight in addition to the first appearance of metallic mineral which they show. The greater the weight is, the more they show perfection, good elemental mixture of substances, and greater quantity of ore.

Suppose that by signs or other method you have found the mountains and by knowledge have also found the ore without being certain of its particular type, in order to make sure what kind of metal the ore contains, what its quantity, what its companions, and what its purity or impurity, it is necessary before any expenditure is made to assay it one or more times in the way that I shall teach you in its particular place in the Third Book. When it is known that there is an ore and what quantity of what metal it contains, and it is found by calculation that you will recover enough value in it to justify the expense, I exhort you to begin courageously and to

continue the undertaking with every care, and to start mining. In any ore material you may promise yourself the same proportion by weight as was in that which you took from the surface for assaying in order to find its substance, for you will certainly find it better the farther you go into the mountain.

Thus drawn on by the assurance of the assay and by the quantity of the thing that is shown to you by signs and by every other rational reason which would surely cause you to wish to start to mine, you must arrange to do it with the greatest celerity, so that you may soon enjoy the fruits thereof and so that if nothing is found in that place you may try your luck elsewhere.

To do this you must first choose the site where you are to make the beginning of your mine, taking care that this is as convenient as possible for the men who are to work there and above all that it is easy to make an entrance into the mountain, in order to be able to arrive under the signs that you have observed with the greatest possible saving of expenditure and in a short time. You must make the traverse wisely, working in a straight line in order to strike the largest mass of the ore, breaking through every composition of stone strata that you encounter in the course of your excavation, but always keeping as a guide the signs that were shown outside.

In addition to the choice of a place destined for the entrance and beginning of the mine, you must also choose another place, opposite, above, or at the side of this, that is near by and convenient for the construction of one, two, or more cabins for the convenience and use of your workmen. One is for their sleeping quarters, where your assistant can live in order that he may be able to observe and encourage the men in their work at all hours, and also for storing and dispensing food and for other needs. Another should be a building for the working of iron to mend broken tools and to make new ones to replace those that are lacking as the old ones are worn out or ruined by breaking.

This done, when you have a goodly provision of foodstuffs, a goodly number of miners experienced in the work you wish to do, and all the tools necessary for breaking and excavating rocks and carrying away earth, and when you have had the mountains and all your cabins and the mine baptized by a priest in the name of God and a fortunate outcome (dedicating it as is customary to the Holy Trinity or to Our Lady or in the name of some other saint whom you hold in reverence, invoking his pro-

tection), then carefully make a beginning of the mining, with the determination to continue and not to abandon the enterprise as long as the possibility of discovery justifies the expense, or until you have passed beyond the confines of the signs shown to you above.

Take care that you always begin your excavation low down and as nearly as possible at the base or root of the mountain, in such a way and manner that the mine proceeds in a straight line to cross the vein of ore in

Figure 1. Smithy and other buildings at the mine entrance.

the shortest or surest way that is indicated. For often, though the mine is well begun by the miners, it is not well followed through, because they do not know how to continue. The greatest attention must be given to this, because they are often attracted by hope into certain little branches of the ore that are encountered on the way. Although there often branch off from the main path little veins that should be followed, one should never abandon the direction of the outlined path, but always continue ahead.

In addition to the other instructions, keep this in mind: that in mining one should avoid as much as possible cutting into weakened or soft rocks, because these are liable to collapse and ore is rarely found in them; but if they are encountered and it seems unwise to avoid them, then wherever such a danger shows itself, for your own security in not losing the money expended for the mine and for the safety of the lives of your miners, I advise you to use every possible care in reinforcing the mine with arches of brickwork and transverse timbers in the form of armored beams or

else with thick and powerful upright supports made of good strong wood from oak or other trees.

This is the method by which you should proceed in excavating the mine in order to enjoy more surely the fruit of your labors. The ancients used another method, by which, as is seen in old abandoned mines, instead of beginning from the bottom at the roots of the mountains (as the moderns do), they began the mine in the upper part of the mountain where the ore appeared in light of day at the surface, and digging down as in wells they followed it to the bottom, now here, now there, as it appeared. I have thought it well to mention this, since to many people such a way seems much better and to be more certain of finding the ore than to mine on the side. They say this because there is always ahead of the mine that little or much which is found as a thread to follow with certainty in proceeding to find the large mass, just as if it could be seen. But whoever considers this matter carefully will realize that the moderns have understood the necessity of doing as they do, as is seen in regard to the greater convenience and the certainty that this method will produce more than the other. In the old method there are difficulties in descending and ascending the mine, and danger of being trapped because of the greater possibility of caving in, in addition to the greater effort in bringing forth the ore and other fragments of excavated rocks. Above all, the moderns have a better understanding because of the impossibility [in the old method] of being able to dispose of the waters which often are so abundant that they multiply the owner's expense and labors through the great number of helpers required in order to make wheels, pumps, pipes, pistons, and other similar contrivances for drawing out the water. And with all these they often cannot do enough to avoid being conquered by the water, so that they are obliged to abandon their useful and honorable enterprise. Hence, to conclude, I say (as you may well understand) that it is a much better and surer method to begin excavating at the root of the mountain rather than at the top or upper ridge and to penetrate within little by little. In order to make it easier for the waters to run off and for the workmen to carry, there should be a gradual rise of half a *braccio* every ten *canne*. Always take your bearings from the signs which are shown outside, doing this with the compass that sailors usually use as a guide to keep the excavation continually in a straight line, and using the greatest skill and art in order to arrive at the point of the greatest mass, where the cause is that has shown you the fumosity and mineral signs on the surface.

In this connection I must not fail to tell you how in the Duchy of Austria between Innsbruck and Halle I saw many years ago a large valley surrounded by many mountains, between which passed a river with much water. In almost all the neighboring mountains some kind of an ore was mined, principally copper and lead, although in almost all some silver was found. Among others in these mountains I saw one in which the people of that country, spurred on by the sight of many signs, began to mine in the said way, and as they mined they advanced little less than two miles, by my estimate, before they saw the sparkle and shadow of ore, and when they had almost arrived with the mine at a point perpendicularly beneath the signs that they had seen above ground, they encountered a vein of very hard limestone in a stratum thicker than one and a half *canne*. They passed through this with great effort and time, using strong iron tools tempered to a greater hardness than that rock, and having passed through it they encountered a very thick vein of copper ore. The mine was such that, when I was there looking, I saw a wall of the hardest limestone forming a very large open space where more than two hundred men stood working at one time, both above and below, having no other light than that of lanterns. And wherever the ore showed itself they made various cuts, assiduously working in both night and day shifts, a thing that surely seemed to me great and marvelous, as well as the mine. At the mouth of the mine I saw a great quantity of ore that had been excavated, some separated and some ready to be separated; among this was one piece of solid pure ore which was of such a grade and weight that a pair of good horses with a wagon could scarcely have moved it, let alone drawn it.

As I have said, this was an ore of copper, but in order to increase its importance they called it silver, because it contained more than a sufficient quantity of that substance to cover the expenses, and in addition they had the copper that was its companion; hence (as you can understand) they derived the greatest profit from it. Furthermore, I wish to tell you that there was in the middle of the mine a channel which collected all the waters that fell continuously from the various openings and issued in such quantities that I surely believe it would have satisfied every demand of a large mill. In going in and out of the mine I remember that because of water above and water below I was as soaked as if I had passed through a heavy rain, but this did not surprise me since I had always understood that water was the primary and peculiar companion of minerals, indeed that it was perhaps the very reason for the generation of their substance.

For this reason, as I have already said, experts in speaking of this give it as a universal rule that all mountains from which abundant waters spring also abound in minerals.

As I pondered on this the greatness of it came to my mind and I began to speak thus: if those who are owners of the present mine 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 and would not possess every convenience as they now do, nor would they have brought profit to their superiors, to their relatives, to the country where they were born, to their neighbors, or to the poor and rich of these parts, as they have done through their strength and goodness of soul and through their hope and tenacity. I therefore concluded that whoever begins such an undertaking should follow it through with the greatest courage and patience, proceeding at least as far as seems necessary according to the signs, and hoping always that by going ahead the following day, as may easily happen, may be the one in which he will discover what he is seeking and so make himself rich and happy. This (as you can understand) is a thing which may easily happen because the mountains are the matrices of all the most prized riches and the repository of all treasures, and if you know how to open the way to them with the aid of good fortune and true skill, you not only succeed in arriving at the center where such things are hidden, but also without doubt you will become as rich as the above-named persons or richer, and will adorn yourself with honor, authority, and every other benefit that riches bring, presupposing that benign Nature, who is most generous to those who seek her, promises such things and fulfills her promises abundantly.

For this reason all men who wish to have wealth should turn their attention to the excavation of mines rather than to warfare, with all its annoyances, or to commerce, which goes about outwitting the world and perhaps doing other tiresome things which may be illicit for honest men, or to going on long and weary journeys over land and water—journeys full of annoyances and discomforts, among strange and unknown peoples who are often of animal-like natures—or to applying oneself (as many do) to the fabulous philosopher's stone in the hope of enslaving its elusive service to make fixed silver or to perform magic rites, or to other things

vain and without foundation. And though I believe this gift of finding ores to be a special grace of God, it is nevertheless necessary either to be born where these things are naturally produced or to go there and by seeking try to find them, and when they are found to receive the grace by mining, aiding the favor of fortune and your own inclination with perseverance and natural good judgment. And even this is not sufficient, for, in addition to the capacity for making a beginning and then carrying it through, it is necessary to be wealthy, so that if it is not possible to do all that you wish by your own efforts you can add thereto the work of hired men.

But now leaving aside the discussion of these things and presupposing that you have made the excavation and that you not only have found the ore you were seeking but also have brought out a great quantity of it into the open, it is necessary now—indeed it is one of the first considerations which you must make before excavating—that you begin to consider and examine the availability of the things you need, and the supplies that are found there, as, for instance, the wood, water, and food supply, all of which must be abundant. There must be enough wood for the needs of the mine, to make charcoal for smelting, roasting, refining, and other fires, in addition to the wood necessary for making props for the mines, as well as for constructing machines, huts, and other similar things. Then it is necessary to see that the sites for erecting the machines have good air and plenty of water with good falls. For convenience in making charcoal it is necessary to have wood near by, but it is also necessary that it be near the mines.

But of all the inconveniences, shortage of water is most to be avoided, for it is a material of the utmost importance in such work because wheels and other ingenious machines are driven by its power and weight. It can easily raise up large and powerful bellows that give fresh force and vigor to the fires; and it causes the heaviest hammers to strike, mills to turn, and other similar things whose forces are an aid to men (as you can see), for it would be almost impossible to arrive in any other way at the same desired ends because the lifting power of a wheel is much stronger and more certain than that of a hundred men. For this reason it is necessary to take the greatest care not only as to the places where the said machine is to be constructed but also to make it as strong as necessary and as convenient as possible for bringing the ore and charcoal there, so that with each one of these operations there is a saving of time, effort, and expense. Each one

alone lightens the labor, and the nearer they are together the better. But because it is not always possible to have everything convenient, you must decide whether it is more profitable to have the charcoal or the ore close to the building; then make this as near as possible, depending on the convenience of the water. If possible, it is better that the charcoal, the machine, and the mine be all together in one unit, but this is not possible except when they are so located by chance.

Now concluding, in addition to what I have told you concerning the discovery and mining of ores and all the other considerations, I will tell you more, and I exhort you to put it into practice by seeing that you have an ore of some metal of your own, because in this way you will have the possibility of extracting those supreme riches which you desire and which your merits deserve. Then I remind you that after you have found the mountain and have begun mining you must continue ever courageously ahead with every care and diligence in order to find the ore, applying your skill with a determined spirit and good judgment, because in this work these qualities serve you in place of eyes to penetrate where your eyes cannot reach. Nor must you believe what many say, that you will find such things by digging at random, for although this might happen you must place more faith in art and good practice than in chance.

When in mining you penetrate into the mountain, remember to guide the cut of your mine so that it will cross the vein of the ore when you have arrived there, because, if you should follow along its course as you go, you would have to follow it a great distance at the thickness of a finger or perhaps less, and thus you might easily lose it without ever being able to find it again. The same thing might happen if you should begin a mine and then abandon it through cowardice because of the expense, like many others who, not finding the ore at the first strokes as they would wish, and, despairing of ever being able to find it, abandon the undertaking as a thing not only without profit but harmful, judging that they are earning something if they do not add more expense to that which they call a loss. Thus infuriated they leave it, not thinking that they may have left the fruit of their sowing to another who may continue their work, that fruit which they might have found an arm's length away or even at a palm's or perhaps at two fingers' width, or indeed beneath the very skin. Thus of their own free will they may easily leave their happiness abandoned. This has indeed happened to many.

Therefore, before beginning to mine one should decide that he will carry

it forward with all his strength, casting away every weakness and having no fear of exhaustion in his path, and at the end applying all his force with every possible care and without remorse, if he wishes honor and profit to result therefrom in place of shame and loss. To you, if you should ever do any mining, I say in addition to the aforesaid precepts that you must use all diligence in excavating, having your miners work night and day and ordering shifts every six or eight hours, depending on the number of

Figure 2. Miners' tools, ore barrows, and baskets.

workmen you have, and putting new and rested men to work, so that you may arrive as soon as possible at the designated point. For I believe that herein lies the greatest advantage and profitable contentment of whoever wishes to possess the things that he desires; and for this reason I urge you to act without restraint.

Because it is necessary to make many arrangements that it is impossible to speak of in general, you must vary the form of the tools according to the needs of the place and the nature of the ores, for there is a difference between mining ores that are found in marble, travertine, limestone, *colombino,* or other similar hard stone, and mining those in loose or soft stones. For excavating and breaking rocks strong and powerful tools are required, like large hammers and iron picks, long thick crowbars, mattocks and strong spades, picks both with and without handles, and similar iron tools, all of fine and well-tempered steel. It is not necessary to mention those used for excavating ores in softer stones, because ordinary tools are sufficient and necessity teaches which ones are to be used, although

these are chiefly hammers the length of a *braccio* and the width of a *palmo*, picks of the same size, hoes, mattocks, and shovels. There must be a sufficient quantity for every need of all the kinds that are needed both in the soft and hard stones, so that the workers may not lose time and thus may bring the greatest profit to the owners. Besides this there must be many baskets, large and small, sacks made of untanned skins, and barrows with and without wheels to carry broken pieces out of the mines. Likewise it is necessary to have great quantities of oily liquids that may be burned such as oil of olives, nuts, linseed, hempseed, resin of trees, or extracts of the fat of land animals or fish, for it is impossible to work underground without the light of fire. This fire cannot be kept alive unless the mine has some hole for air, either a wooden pipe or some other opening.

[1] THE FIRST CHAPTER

Concerning the Ore of Gold and Its Qualities in Detail.

BECAUSE gold is a compound mineral praised by philosophers and all wise men as being of the highest perfection among all mixed minerals, and because of its great beauty, it is the universal opinion that it possesses extraordinary powers which are beneficial to man. For this reason it is the thing esteemed most highly in this world, after living creatures. Hence, I, too, in order to honor it, wish to begin by speaking of it now rather than of any of the other metals, and I wish in particular to tell you of its generation and of its most obvious qualities, for, although it is a metal very widely known and one that is desired and sought after by all kinds of persons, I know of few who take the trouble to find out what its substance or natural form may be.

But, in order that you too may not be one of those who know it only by name or by the appearance that it shows outwardly to us, I tell you that its original and peculiar materials are none other than elemental substances, with the quantity and quality of each proportioned equally one to the other and very finely purified. From this union of elements which are of equal force there is born a pleasing and perfect elemental mixture,* and then after fermentation and decoction the elements finally become

* Biringuccio's ideas regarding the formation of the metals are essentially Aristotelian. The four elements, earth, air, fire, and water, or the associated elemental qualities, are drawn or forced into combination, called *mistion*, which we have translated as "elemental mixture." The true metals are formed from this, after a certain ripening period, in which the influence of the planets is sometimes assumed, though Biringuccio generally denies this. The various individual metals result from a predominance or deficiency of one or more of the elemental qualities. In some places Biringuccio talks of a primordial matter—*prima materia*—which seems to be much the same as *mistion* and becomes metal by a suitable ripening process. The idea of growth and ripening explained the formation of the more easily reduced oxidized ores near the surface of mineral deposits, above the deep-lying "marcasites" (sulphide minerals) that would not give metal on simple smelting.

Biringuccio used the unqualified word *miniera* only to cover those minerals from which metals could be extracted by the means at his disposal. *Mezzi minerali*, semiminerals, were those that possessed the color, crystallinity, luster, weight, and general appearance of a mineral, though no malleable metal could be extracted. Brittle materials like antimony were not thought to be metallic, for they lacked the malleability that was considered an essential characteristic of a metal.

In the Italian, *miniera* is used both for the ore and for the mineral contained in it. We have followed the context in distinguishing between them.

fixed, permanent, and joined together in such a union that they are almost inseparable, so that by the power of the heavens or of time or of the order of most wise Nature, or by all these together these substances are converted into that metallic body called gold.

This metal, as has been said, becomes dense because of its thorough tempering and its perfect and uniform elemental mixture, and of such a density that it is given not only an ordinary permanence but almost an incorruptibility and an incapacity to contain any superfluous material, even if it is subtle and in small amount. For this reason it does not rust, even though it be in the earth or in water for a long time, for neither of these has any effect on it, nor does fire, which has the power to reduce to ashes or dissolve every created thing; indeed gold not only defends itself from fire but continually purifies itself therein and becomes more beautiful. Likewise this aforesaid perfect union causes its body to be without phlegm or superfluous unctuousness, wherefore it is always bright and beautiful in its uniform coloring, and when rubbed against something it leaves no black or yellow mark as almost all other metals do; nor does it have any effect on the senses of smell or taste, nor is it poisonous as are some of the others if it is eaten either intentionally or [1v] by accident—indeed as a medicine it is beneficial in certain illnesses. Nature with her own virtue has endowed gold, as a singular privilege, with power to comfort weakness of the heart and to introduce there joy and happiness, disposing the heart to magnanimity and generosity of works. Many learned men say that this power has been conceded to it by the benign influence of the sun and that for this reason it gives so much pleasure and benefit with its great powers—particularly to those who have great sacks and chests full of it.

In short, this metal is malleable and of a shining color almost like that shown to us by the sun. It has in it a certain natural and intrinsic attraction which causes men to desire it when they see it. For this reason many virtues are attributed to it that make men hold it very dear. Although many cry out loudly against it, denouncing it as the seed of pestilential and monstrous avarice and the cause of many evils, yet many praise it as useful. But let us leave aside this discussion as to whether the evil or the good which it does predominates, for this would be a long and useless debate. Therefore, I repeat once more that the worthy qualities it possesses have caused me to treat it first before any of the other metals, and particularly because it seems to me that the plan of my work requires it,

so that I may better descend later to the level of the other metals. Thus, if in our country of Italy good fortune should give to you or another the possibility of working with gold, you would not find yourself without instruction. I have done this 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. Therefore in addition to what I have already told you in general, I will now tell you in particular concerning the nature and generation of gold and also, so as to omit nothing, the signs of the places where it is produced and generated. Finally, after I have told you how it is possible to find the ore I shall tell you how it is to be purified of its superfluous earthiness.

Because I cannot say that I have seen with my own eyes mountains which contain gold ores or places where the practice of such work is carried on, I shall tell you only what I have been told by trustworthy persons as I carefully tried to understand, or else what I have learned by reading various authors. From these I have gathered that it is true that most of this metal is found in Scythia* and in those regions called oriental, perhaps because the sun seems to shine forth with greatest vigor in those places. Among these it is said that the Indies hold first place, particularly those islands which as we hear are called Peru,† recently discovered by the naval armada of the sacred King of Portugal and of His Majesty the Emperor, [2] and still other places. Also, gold is found in many localities in Europe such as Silesia, many parts of Bohemia, Hungary, in the Rhine, and in the Apsa. Pliny‡ says that it is also found in Asturia and in Lusitania and that the Romans extracted twenty-three pounds every year.

And speaking thus of this precious metal I believe that it is certain that it is and can be generated in all those places where the heavens influence

* An ill-defined region to the north of the Black Sea. From Pliny.

† Pizzaro's conquest of Peru was in 1531, only a few years before Biringuccio was writing.

‡ This is an erroneous quotation from Pliny, who says, "According to certain writers, the annual yield by this method of Asturia, Gallaecia, and Lusitania amounts to twenty thousand pounds weight, of which the bulk comes from Asturia, and no other country has been ceaselessly productive for such a lengthy period." *Natural History*, Book XXXIII, para. 78 (Bailey Translation). Lusitania was roughly the same as modern Portugal while Gallaecia and Asturia lay to the north of it.

the elemental dispositions and causes. And here wishing particularly to tell you what I have heard concerning this, I say that gold is generated in various kinds of rocks in the most rugged mountains that are completely barren of soil, trees, and grasses. And of all the rocks for such metal the best is a blue stone called *lapis lazuli,* which has a blue color similar to the sapphire, but is neither so transparent nor so hard. It is also found in orpiment and even more it is found associated with the ores of other metals. Much is also found in the river sands of many regions. That which is found in mountains is in the form of veins between one stratum and another, united with the blue rock, and indeed is much mixed in with this. They say that such ore is better the heavier and the more full of color it is, and the more flecks of gold appear in it. They also say that it is generated in another rock similar to saline marble but of a duller color, and in still another rock whose color is yellow with many red specks in it. They also say that it is found in certain black rocks, scattered loosely about like small stones in a river. And furthermore they say that it is likewise found in a certain bituminous earth of color similar to clay and that such earth is very heavy and has a strong sulphurous odor. The gold extracted therefrom is very beautiful and almost completely pure, but it is very difficult to get out because it is of the finest grain, almost like atoms, so that the eye distinguishes it with the greatest difficulty. Nor can one proceed as with lapis lazuli or other rocks or as one treats river sands, for when it is found there, and even more when it is washed, it falls only with difficulty to the bottom, and, growing vitreous on melting, it becomes pasty with the matrix and its earthy matter. Nevertheless, in the end it is possible to recover it using the greatest patience with one method or another and finally with mercury.

As I told you before gold is also found in the sands of various rivers, as in Spain in the Tagus, in Thrace in the Hebrus, in Asia in the Pactolus and the Ganges, in various rivers in Hungary, Bohemia, and Silesia and in Italy in the Ticino, the Adda, and the Po. It is not, however, found throughout their beds but only in particular places where in certain bends there is some bare gravel, or where the water in times of flood leaves a certain sandy sediment in which gold is mixed in tiny particles like scales or even smaller than a grain [2*v*] of flour. In the winter when the floods pass they take and carry them almost beyond the bed of the river so that when the waters return to their normal state they cannot easily take them away again, and thus they form mounds.

Then in the summer the prospectors for gold wash them with a patient and ingenious process in order to cleanse away the earthiness. They use certain wooden tables made of elm or white nut or any other kind of fibrous wood, whose plane surfaces are shredded with a saw or other iron tool, and with a hollowed-out shovel they throw these sands with an abundance of water onto the tables, which are placed slightly inclined, one next to the other in a long row. By this means the gold, as the heaviest material in the sand, falls and, attaching itself to the bottom of those rough fibers, thus remains separated from the sand.

When they see that a goodly amount has remained they gather it up carefully, and, when collected, they put it in a wooden vessel like a boat for washing sweepings or in a large trencher hollowed out in the middle,* and wash it again in order to clean it as much as possible. Finally, they amalgamate it with mercury and pass it through a leather purse† or cucurbit‡ so that when the mercury has evaporated the gold remains like sand at the bottom. This gold is then mixed with a little borax, saltpeter, or black soap, melted and reduced to its own body, and later is given the shape of an ingot or other desired form.

This, then, is exactly the method that is used in extracting gold from river sands. Prospectors often use it in certain seasons and have great profit therefrom, all the more because this method of cleansing does not require as much expenditure as do the others for the aid of many men, buildings, fires, or other apparatus. For this method, one man is enough, together with a table, a shovel, a little mercury, and sufficient abundance of water, which is a thing pleasant to seek in the summer. Whatever you find, whether it be much or little, is gold, the value of which you well know.

But now let us cease speaking of these things because here perhaps you or someone else might like to know why such gold is carried by the water into these river sands and woods and whether indeed it is produced there-

* Agricola (*De re metallica*, p. 255) has an illustration of such a "wooden vessel like a boat" for washing ores. The hollow trencher is, of course, a batea.

† *borsa.* This is a small money bag or purse made of soft leather and tied at the top with strings. An excellent illustration of one in use for separating excess mercury from the solid amalgam is given by Ercker, page 51 (1580 edition), which we reproduce in the Appendix, Fig. I.

‡ *boccia.* No modern English word is an exact equivalent of this as used in Biringuccio's time, and we have therefore adopted the archaic word "cucurbit." The vessel was a wide-mouthed flask used for general chemical operations, but particularly for distillation. It was then fitted with an "alembic," a term that strictly applies to the head and beak only, and not, as later, to the entire assembly.

in. I have often thought about this, greatly marveling, particularly in regard to the Ticino, the Adda, and the Po, but the reason is not clear to me, since although I told you before that great floods of water carry it to where it can be extracted, there is no gold mine near those places or even one of any other metal that I know of. I am also confused because I have seen several authors who believe that it is generated in the very place where it is found; and if this were true it would not be true that the waters had brought it. But that it is generated there seems to me a very difficult thing to comprehend, since I do not understand whether it is produced by the innate properties of the waters or of the earth or indeed of the heavens, for it [3] appears reasonable that if the cause were any of these it would be found everywhere in the bed of a given river, and, seeking, one would find it everywhere at all times. If the influence of the heavens is the powerful cause that produces gold, it seems to me that it would necessarily have to operate instantaneously because it is not possible otherwise to perceive the order that Nature uses in generating metals. It would have to produce it first in the open in a place where there is a continuous flow of water, and then it would have to have the power to remove the earthy materials from place to place and also to mix with it the greatly different qualities of cold and humidity. And even if this composition and order begun by the waters of the river should not change, it seems to me that the rains or floods which pass over it would completely soften, break, and entirely spoil anything that might be conceived therein. Furthermore, if this material is generated there, I wish to be told why it is generated only in these and not in other places, and why silver, copper, lead, or one of the other metals similar to gold is not likewise generated in a similar manner, for these substances are perhaps even easier for Nature to form than gold because of the many concordances and ultimate perfections that gold requires. Moreover, in many places in the countryside near Rome particles of iron are found in the sands of several small rivers and I would like to know why this also is conceded only to certain particular parts of the river and not to all parts.

For these reasons and visible phenomena it seems more probable that gold is carried by the water than that it is generated there. Nor does our dilemma help us to ascertain the truth. For, speaking just between ourselves—not with firm conviction, but only to tell you what I think—I say that I incline toward either of two theories. Of these one is that this phenomenon occurs only in very large rivers which receive much water from

springs, streams, and other rivers and so it often happens that, with the melting of snows or the coming of heavy rains, they wash the banks and the slopes of near-by mountains, in which it may be that there is earth that, by its own particular nature, contains the substance of gold; or else the ores are located in some peak or surface where men have not yet taken the trouble to go or where access is difficult, and may then be exposed to insemination by the sun or by the coldness of the snows or by the waters, and broken up because in heavy rains anything is easily worn away and carried off to the rivers. Alternatively it might be that such earth is inside the near-by mountains or indeed in the same principal stream that has its bed hidden from our eyes. Since it is never dried up or free from continuously running water, it is not strange that in so many centuries the true origin and knowledge of such a thing should not be understood by those who live near by.

But however it may be, in the end [3*v*] the truth is that gold is found in the sands of many rivers, particularly, according to my information, in those mentioned above. Therefore, if I have marveled at this thing, I deserve to be excused, because where it is impossible to understand the certain cause of things either by reason or by direct observation, doubt always exists and new reasons for wonder are born. But I marvel even more greatly at what I have heard told many times as the truth by various persons: that in several places in Hungary at certain times the purest gold springs from the earth like grass and wraps itself like the stems of convolvulus around the young dry shoots. It is about as thick as a piece of string and about four *dita* long or even a *palmo*. Apparently Pliny in the thirty-third book of his *Natural history* refers to this or a similar thing when he speaks of ores, incidentally referring to the fact that in his time this same thing occurred in Dalmatia. If what is said be true, then indeed would the farmers in the fields reap the fruits of celestial instead of terrestrial sowing, and they would be considered blessed, since such precious and pleasing fruits would be produced by God, by the heavens, or by Nature, without any labor or skill on their part. This would indeed be a unique grace, since among all the vast amount of earth and number of possessions that are cultivated by living creatures, none but these regions are worthy of such a harvest.

What shall I say of what Albertus Magnus writes in his work *De Mineralibus,* where he says that he has seen gold generated in the head of a dead man? He says that when this was dug up by chance and found to be

extraordinarily heavy, it was seen to be full of very fine sand. Because of its weight those who saw it thought that it was metal and by experimenting finally found it to be of the purest gold. It seems to me that his words have no other significance than that the ready disposition of the thing and the great influence of the heavens had generated this precious metal. Since I heard it thus, I wanted to pass it on to you. To tell the truth it is not easy to believe this, and certainly to me it seems incredible, yet considering who tells of it and thinking how great are the forces of superior causes and of Nature, we can receive it, having faith and respect for the learning of those who relate it, since by ourselves we lack full understanding of the causes of things.

Since I have begun to tell you of such things I do not wish to omit describing still another case that I heard happened in a region in Hungary, perhaps in that place where gold is generated. To those who search for ores this may give hope of finding gold, and to those who have already found them it may give some information and encouragement in [4] continuing to find others. This is it: Once there was a peasant woman who habitually went to wash her clothes in a stream where a goodly quantity of water ran, and she rubbed her clothes on a rock there which seemed most convenient for her purpose. To her good fortune she discovered running across the rock a vein of gold as thick as a cord which had become shining and beautiful and visible to the sight from much rubbing. And when the woman saw this, not knowing what it was, she went about greatly marveling and one day told of it to the men of her household who looked at it and decided to fetch someone who understood such things better than they. Thus at last they found it to be a vein of purest gold exposed to the light of day, and moreover they found that a stratum of that rock crossed the course of the water in that stream. Immediately therefore they took the water and sent it by another way and courageously began to excavate this ore. To this day there is mining there, and already perhaps hundreds of years have passed in which gold has been continually removed, so that this thing not only enriches that region but also abundantly supplies all Christendom.

I wished to tell you of this in order to encourage you never to lack the desire to understand everything that may be useful; even if it were but a shadow, you must always give eye and ear to it and must despise nothing nor have fear of any of those things which may harm. For, as you see, if credence and due consideration had been denied to the words of the old

woman, such a useful thing would not have been found then, or perhaps never afterwards. Although they were drawn on by a reasonable hope and by the necessity of doing it in order to continue, nevertheless those who began the excavation did not lack courage in making another bed for the river that covered the gold, even though there was little to be seen.

Gold and silver, however little there may be, almost always give a profit above the expenses and always the deeper one goes into the rock, the more one finds, as with every kind of ore, although experienced searchers for gold say that this metal is never found in such large masses or in such quantities as are other metals. Perhaps they are right, but one must not believe from this that where a little is generated a great deal may not be; for if this were true the scarcity of gold would not be surprising. But to me it seems that in this world the benignity of Nature concedes a great deal, and that a great quantity of gold always has been and is found among men, especially when we think in how many places there is a continual addition thereto every day, both in mountains and in the sands of the rivers as well as in that mined in association with other metals. We have proof of this when we consider how much [4v] is consumed by painters as ornamentation for their work, by goldsmiths who make objects of solid gold as well as using it for gilding and covering other metals, also that which is consumed by weavers for tapestries and cloths, that which women in their vanity waste for their adornment, and that which the alchemists burn and send up in smoke by the force of fire and powerful action of materials. Likewise think how much is hidden by avarice in walls and in the ground, or is sealed up in strong and chained boxes with many devices and triplicate keys, in addition to that which is scattered and ever goes about through the world in the service of men and for the convenience of trade. Considering this, he who says that but a little is produced will surely see that throughout the world a large quantity is found, even though there be but few who satisfy their thirst for it as they would wish.

Speaking particularly of Italy, although a mine has never appeared here, she has been more richly endowed than many other regions through the virtues of her good and talented men in every age, even though she has been many times despoiled and torn asunder by various nations, as in our own times by the bestial hands of barbarous nations who came here more than forty years ago.* Who knows but that once again God may

* The first French invasion of Italy, under Charles VIII, took place in the autumn of 1494. Supposedly, therefore, Biringuccio was writing after 1534.

not grant us the possibility of punishing them as in other times our ancient and valorous forefathers did, and of going into their very homes in order to force them to return our possessions to us with double usury? Perhaps if He does not permit this, He may grant that some rich gold mine be discovered in our land. Considering this, and seeing that our land of Italy is full of as many other excellent qualities as heaven can concede to habitable places, I cannot believe that this gift of gold can be completely lacking to her, since she is so rich and abundant in all the other ores that Nature produces except gold and tin. But it seems to me that we must believe that these two also exist and that they have not yet shown themselves in the light of day and to man. I am persuaded of this by the gold that is found in the said rivers and also by the semiminerals that are found, some of which, one may believe, following experienced men, give almost certain indication of gold since they are one of its peculiar natural agents, and until they are found and actually handled, it cannot be said that gold does not exist.

It is true that up to now I do not know that pure gold (with the exception of that used in commerce) has been found in our region other than in two ways, both of which produce but little. One of these is that of washing the sands of rivers; and the other is that of the laborious and subtle art of separating gold from newly smelted silver, from gilded things, or from other metals that contain some gold—for as I have told you there are but few of these that do not have some particle of gold accompanying them, some more and some less, [5] depending on the elemental mixture and fixed permanency of their materials, or else on the quality and force of the planets that have influenced them.

And this, in short, is all the gold that is found in our country of Italy, unless perhaps, as curious and subtle speculators believe, there may be here some practical philosopher who might make with his art the large quantity that their books (more like recipe books that are not understood than books of philosophers) promise to their believers. Certainly I am more inclined to believe in this because of the authority of some of them than because of any good reasons for it that I have ever heard. The more I look into this art of theirs, so highly praised and so greatly desired by men, the more it seems a vain wish and fanciful dream that it is impossible to realize unless someone should find some angelic spirit as patron or should operate through his own divinity. Granted the obscurity of its beginnings and the infinite processes and concordances that it needs in order to

reach its destined maturity, I do not understand how anyone can reasonably believe that such artists can ever do what they say and promise. That this is true is shown by considering how many philosophers there have been in the world through many centuries who were most learned, informed, and experienced in things of Nature; and also how many great princes who with money and authority have had the power to have this work done and to aid all skillful men who work in this art. These men in order to arrive at such a port have equipped their vessels with sails and hard-working oarsmen and have sailed with guiding stars, trying every possible course, and, finally, submerged in the impossible (according to my belief) not one of them to my knowledge has yet come to port.

But many are quoted by the credulous, who advance the authority of hearsay in place of reasons for possible success or facts that can be demonstrated. Among others they cite Hermes, Arnold, Raymond, Geber, Occam, Craterrus, the holy Thomas, Pariginus, and a Brother Elias of the order of St. Francis—which one I don't know. To these, because of the dignity of their philosophical learning or because of their holiness, the credulous demand that a certain respect be accorded through faith so that whoever listens either is silent through ignorance or confirms what they say. But it is not in this way that such men persuade those who have good judgment that the art of alchemy is true; for it is evident that in their desire for riches they become blind with credulity, and when they seek to persuade the minds of others that this art is true, the fact of their evident poverty belies them. This is especially so since they cannot quote as their own the authority of Aristotle, that most divine scrutator of all the sciences and of every other secret of Nature, or indeed of the most learned Commentator,* or of any of those many worthy ancient philosophers who fed on no other food than speculation and the loftiness of philosophic [5*v*] blessedness, nor can they quote the authority of Pliny or Albertus Magnus, both of whom, like eager hunting dogs, have always journeyed throughout all the regions and shores of the world, seeking with all possible care to understand the wonders and powers of Nature.

And like a wheel violently turned which cannot stop when it is left alone, so I too after having fallen into this discourse cannot restrain my-

* We believe that this refers to Averroës, the twelfth-century Arab philosopher who lived in Cordoba and is usually referred to as the "great commentator" on Aristotle. This follows the 1550 and later editions, for the first edition reads "most holy (*santissimo*) commentator," who cannot be identified.

self from going on to give you in full my opinion about the matter, although I know that, if perchance some who are passionately devoted to this art should read my work, they would denounce me, accusing me of ignorance and presumption—and if I should hear them, I would patiently agree so as not to quarrel with them. But even if they are more intelligent than I am in this, I do not envy them the blessedness of their knowledge. I must tell you that with diligent study I have looked at many books containing such things and not only have I had discussions with many experienced men, but I have not refrained from attempting to make some experiments myself in order to understand it better. I have also taken care to listen to the opinion of wise and experienced persons, as I have heard them subtly arguing whether such things are true or only fantastic dreams. And finally, taking all the alchemistic principles and comparing them with the processes of Nature, and pondering on the procedure of the one and of the other, it seems to me that there is no proportion between their powers, granting that Nature operates in things from within and causes all of her basic substances to pass wholly one into the other; while art, very weak in comparison, follows Nature in an effort to imitate her, but operates in external and superficial ways, and it is very difficult, even impossible, for her to penetrate things. And presupposing that through this it were granted to men to have those basic and particular materials from which Nature composes metals, I would like to be told how they can receive at will the influence of the heavens, on which are dependent all inferior things on this convex of the world, and also how men ever know by this art how to purify those elemental substances or how to proportion necessary quantities one to the other, or finally how to carry these substances to perfection as Nature does and make metals of them. I do not believe that anyone could accomplish all this unless men were not only geniuses but also angels upon earth, and therefore I believe that those err who expend their energies on this art, standing with long and continuous vigil always ardent in their desire and in the conduct of their operations, more inflamed than the very coals in their furnaces in the effort to see whether they can bring the adamantine hardness of such fruit to ripeness. God's aid would be needed to do this and those who knew how to do such things would be called not men but gods, for they would extinguish the insatiable thirst of avarice in this world and in the extraordinary [6] excellence of their knowledge would by far outstrip the power of Nature (she who is mother and minister of all things created, daughter of God, and

soul of the world) if they should use methods that perhaps she does not possess, or, if she does have them, does not employ to such ends.

Certainly I am not deceived in this, for I see that the mothers in which they wish to find this birth have wombs of factitious glass, and the materials they use in place of sperm are things extraneously composed, and likewise the heats that they apply are intermittent and intemperate fires, very unlike natural ones since they lack a certain proportion of nourishing and augmentative substance. It is the same with the times, the measures, and the weights necessary for such results. And who doubts that the basic substances which they wish to use are secondary matter, things mixed and composed by art, whereas Nature, according to naturalists, uses nothing but the purest? What more childish folly is there than to believe that men with their wit can shorten the time of parturition of those things, when even Nature, wishing to make them perfect, cannot do this—perhaps because they have need of the specific length of time that she gives them? It would certainly be very useful to bring the sown seed to immediate fruition in order to serve human needs in time of famine.

The reason why they say this is easily understood, for our age cannot await the slow working of time, and the credulous are nourished with the hope of shortening time and are told that by means of their industrious art they can turn back the effects determined by Nature and reduce them to primary matter. They say that they withdraw spirits from bodies and make them return there at will like a blade in the scabbard. Though I believe that those substances which are called spirits in things can be withdrawn and reduced to vapor by the violence of fire, I do not believe that once drawn forth they can ever be returned, for such a thing could not be done except through knowing how to make the dead live again.

In order to puff themselves up more they say that with their art they surpass Nature in that they not only reanimate things but also give them the vegetal power of animating others and this Nature has perhaps not done because she did not know how or did not so desire. This seems to me the more difficult because, as I have said, when the metals are reduced to their ultimate perfection, it must be believed that they have arrived at a final point which exceeds the arrangement of their materials and that the basic nutritive moisture has been converted into maturity in order to attain its end, and also perhaps, by being passed through the violence of fire when it was purified, it is possible that it has had some line of life broken and has taken on a new character which it did not have before.

Ruminating on these things I remain uncertain as to how those credulous men can be of such perverted vision that they do not discern as they should these things which are so obvious and true. But the great desire [6*v*] that they have to become rich causes them to gaze in the distance and hinders them from seeing the intermediate steps because they are thinking only of the final result, folding about them the shadow of the happiness that they would derive from such a thing. And indeed if they should succeed in accordance with their dreams they could truly be called blessed, for they would possess the means of satisfying every desire, surpassing the grandeur of any great prince (whoever he might be) in force of arms, in magnificence and greatness of buildings, or in benefiting the province with virtuous and magnanimous liberality, or in conquering the Turks in war and thus exalting to the skies the Christian law, as they could. With these and other similar excellent works they could make themselves glorious and immortal.

What greater folly could men commit than to waste their time in following the other arts and sciences and to fail to study and learn this art which is so useful and so worthy, nay divine and supernatural, since it has the power to produce such precious things, indeed even more perfectly and in greater quantity than Nature herself and with more ease and in shorter time? This art is one that, if we wish, can give us estates and kingdoms and the grace of gaining entrance to heaven after we are dead by making donations and building hospitals, monasteries, and temples, and by continually helping our neighbor, not only by arranging his material well-being, but also by healing him if he is sick, and if he is old by returning him from old age to youth—even in a more perfect condition than he was before. And likewise through the power which this art has it can resuscitate the vital force of those who have almost passed into the other life. Sometimes they call this power of theirs the "Quintessence," and sometimes the "Philosophers' Stone," and sometimes "Potable Gold," and they offer to obtain from any natural thing whatever result they wish, comparing the quintessence to the nature and quality of the heavens and most powerful stars; the potable gold to the spirit and soul of things; and the philosophers' stone to the power of mighty Nature.

But in spite of all this, the fathers and inventors of the art who exalted it with such high praise are all dead and have not enjoyed even one period of youth, to say nothing of two or three; and as far as I know they are not yet raised from the dead as they promised. Certainly it would be a

glorious and fine thing and a source of greatest contentment to those who possess such an alchemistic art if they should have in their room a cucurbit or other vessel full of liquor, dust, or some petrified* thing which, with gushing abundance and certain continuous outflow, should have the power to convert quicksilver, engendering gold or silver or whatever metal they should desire, multiplying every little bit that they have to infinity. For by producing as much as they wish they will never lack either silver or gold or the power to use all those excellent and exalted virtues which such an art promises to the credulous. For this reason they should not call it by the names that they use, but, if what they say is true, they could say that they hold [7] prisoner in a bottle that God which is the creator of all these things. They could indeed ridicule Nature, as when they say that with their medicine they wish to correct her defects and faults, reducing imperfect metals to that perfection which she, in her weakness, has not been able to reach.

Now in having spoken and in speaking thus I have no thought of wishing to detract from or decrease the virtues of this art, if it has any, but I have only given my opinion, based on the facts of the matter. I could still discourse profusely concerning this art of transmutation, or alchemy as it is called, yet neither through my own efforts nor through those of others (although I have sought with great diligence) have I ever had the fortune to see anything worthy of being approved by good men, or that it was not necessary to abandon as imperfect for one cause or another even before it was half finished. For this reason I surely deserve to be excused, all the more because I know that I am drawn by more powerful reasons, or perhaps by natural inclination, to follow the path of mining more willingly than that of alchemy, even though mining is a harder task, both physical and mental, is more expensive, and promises less at first sight and in words than does alchemy; and it has as its scope the observation of Nature's powers rather than those of art—or indeed of seeing what really exists rather than what one thinks exists.

For these reasons the more I think about these works of alchemy the more discouraged I become, because I do not know nor do I believe that the true means of creating the elemental substances are known when I see that those who firmly believe that this art is true use them variously. Furthermore, I am discouraged because I know the great weakness of our intellects, from which many errors are born, especially since we cannot

* The second, third, and fourth editions read "putrified" and that of 1678, "purified."

know the intrinsic virtues and specific powers of things, and also because we do not know how to proceed in administering heats that are identical with natural ones, and because we do not have the means of providing remedies for the infinite number of hindrances that occur unexpectedly during the long and difficult process of such an undertaking. For if there are many such in any process they are excessive in this one, since such an art is forced to use many different methods, as, for instance, evenly regulated fires, provided they can be made, and special furnaces and vessels; and likewise it is necessary to have the powerful materials very pure and fine and to make good calcinations, solutions, putrefactions, and scintillations, and likewise elemental mixings, decoctions, and incinerations; and all must be accurately proportioned to the requirements of the work. Thus in order to bring these things to a good end it is necessary to make waters, oils, and divers sublimates from various minerals and herbs, and each one of these must have its perfection. If by chance a cucurbit should break or the fires should not be as constant as is necessary, or should not be diminished or increased at opportune times, [7v] or perhaps if the things taken as a basis should lack their proper quality, then the results would lack perfection. It seems to me impossible that there should be no defects, for it would not be human to be able to do all these things without some mishap.

How many alchemists have I heard lamenting, one because by some unfortunate chance he had spilled his whole composition in the ashes; another because he had been deceived by the excessive strength of the fire, so that the substance of his materials had been burned and the spirits inadvertently allowed to escape; and yet another because he had poor and feeble materials! In a word, one for one reason and one for another, in order to hide either their deception or their ignorance, all defend themselves and make excuses for their art. Finally, to conclude, not seeing anything else, I think that the hopes of their fantastic writings are but masked shadows, composed by certain itinerant herbalists in order to accredit themselves or else by other lazy people or by most unfortunate alchemists to lead the greedy into believing in them so firmly that they will aid them in their needs. 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.

For this reason I tell and advise you that I believe the best thing to do is to turn to the natural gold and silver that is extracted from ores rather than

that of alchemy, which I believe not only does not exist but also, in truth, has never been seen by anyone, although many claim to have seen it. For it is a thing whose principles are unknown, as I have told you; and whoever does not know the first principles of things is even less able to understand the end. Concerning this I shall tell you that I do not know any philosopher or clever alchemist who could accomplish enough so that I would believe that he possessed in himself sufficient power of art to be able to draw out from a metallic body or other object its vital spirit and to replace it again in the same object, as I have told you, and thus to give vegetal form to something which is not so by its own nature. And who will ever believe that bread, herbs, and fruits may be converted into flesh by any heat or artificial digestion in the same way that Nature does; and likewise that wood that is burned and converted into charcoal like the ashes of metals, or passed through the smelting fire, may begin to bud again, become green, and engender still other wood? Although I know that they give all kinds of answers to these things, and you can well imagine what they may be, it seems more appropriate to touch upon the extent of their proofs, and ignore their words. For they try to prove the possibility of their art more by example than by reason, citing the tiny seeds of grass, the grafting of plants, the multiplying of a spark of fire, the fermentation within a mass of flour mixed with water, and, for certain of their propositions, the operations which physicians perform in healing sick bodies, and other [8] similar and obvious things. In support of their power to understand and to operate they quote a passage of the Holy Scriptures, which says: *Omnia subiecisti sub pedibus eius,** interpreting it to mean that God has given them the power and authority, in addition to domination over all the things of this world, to understand and put to use all things in the other world. Among these they say that it is not only possible to understand the generation of metals but also to effect it with art, just as Nature herself does. They argue in favor of their art with a saying of Aristotle concerning the squaring of a circle, when, in order to prove to those who deny it that it may be true, he says that, although geometrically it is not found, this does not prove that it does not exist, and if it exists, it may still be possible to find it. Likewise, since the generation of metals does actually occur, it is possible for the art of alchemy to attain it.

With this and many other reasons they wish to make you believe that

* "Thou hast put all things in subjection under his feet." Hebrews 2:8.

even outside a woman's body it is possible to generate and form a man or any other animal with flesh, bones, and sinews, and to animate him with a spirit and every other attribute that he requires. And in like manner they say it is possible by art to cause trees and grasses to be born without their natural seeds, and to give to fruits separated from trees the form and color, odor, and flavor of true natural fruits; to this I cannot forbear saying that I do not believe them. And likewise I can make no answer to those who say that they transmute but do not create, and that they transmute one species into another, for this cannot be done without the total destruction of the thing that you wish to transmute.

At last to conclude and leave this discussion, I say that I believe that if these people accomplish anything they do it only in the same way as bricklayers make mortar, that is, they put it there with the desire that the mortar itself turn into stone so that the stones be better joined, for with that thought the one who was the inventor of this could be seen.* But I do not wish to consume more time in speaking of this art or to annoy you with further details, or wholly to offend the alchemists (although many things come to mind that I could say to them, thoughts that press forward in a throng like dogs happy in the chase, each one desirous of coming out first), nor do I wish that any more of these things come out in the open, since I know that the alchemists become angry with those who speak in derogatory fashion of their art. Although you are a person who understands how much good fruit could come from aiding some willing but inexperienced ones by warning them not to throw their talents unrestrainedly into such things, as many do, I am content to have done this with so little offense. 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. And thus, after such a noble and fruitful art [8*v*] is made clear and is understood by all good men of ability, they will begin to work and to make gold in the greatest abundance and so make men rich, secure, and happy. For one of the said reasons these insults of mine to the alchemists may, I think, benefit many people.

In order not to continue indefinitely, I wish now to make an end of my opinions and discourses that perhaps will seem to you to have been multiplied too greatly. It is indeed true that I am not stopping because I am tired

* Original unclear.

or satiated, but only because it has carried me too far afield from the projected subject, to which I will now return.

Although I have already told you much about the generation of gold ores and their discovery, I want now to tell you how gold must be separated from its earthy superfluities and particularly the gold that is found arranged in the form of veins. Although I have never seen the devices used for extracting gold, I will now tell what I have understood is necessary for reducing it by other processes so that if you should ever have occasion to use it in our regions of Italy, you will not be entirely without enlightenment.

Having excavated and well selected the ore, it is first necessary to consider in what kind of rock it was engendered. If it is in that rock called *lapis lazuli* you must extract the gold and save the stone, because from such a stone is made that perfect blue color which painters call ultramarine. They esteem it highly and pay a large price to whoever collects and prepares it. To do this it is necessary first to grind it well and make a powder of it. wash it with water in a boat or other wooden vessel, and then to rub mercury on it well until all the gold has been amalgamated. In this way the stone will become freed from the gold. Then by causing the mercury to pass through a leather purse or cucurbit, the gold remains separated from the mercury.

If you do not care about saving the stone you can use the common method of smelting it in a furnace or in a lead bath. If you succeed in this way, you must continue with it, but if not, then seek to experiment with other methods or else try to understand the method that is used where the work is done nowadays. In my opinion, if it is not a rock you wish to save, the best method for reducing it to purity would be to roast the ore with a slow fire in an open furnace and cause it to evaporate well. Then have it ground fine with a mill or by stamps connected with a wheel, wash it thoroughly in order to extract from it all the superfluous matter, and then purify it by smelting it [on a lead bath] in a cupeling hearth of a size depending on the quantity, or on a very hot cupel, throwing off the lead as litharge or consuming it and reducing the gold to purity.

This is the method you may use almost universally, not only for gold and its ore, but also for any other kind if you wish. I wanted to describe these methods of smelting to you here, since I think that in the places where I shall speak to you in general of other ores I shall not wish to treat of them again.

[9] THE SECOND CHAPTER

Concerning the Ore of Silver and Its Qualities.

THERE are, as I have heard, varying opinions among men experienced in minerals as to whether silver has its own mineral [i.e., occurs native] or not. Mineralogical reasons and the authority of the majority persuade me that it has, not only because I have seen the natural material separate but also because I know that in mines of gold, copper, lead, and other metals pieces of pure metal are found without admixture, and I have heard that pieces of silver, gold, and copper have been found that had been reduced to their ultimate purity by natural causes. This is also confirmed by a German, Georgius Agricola, who says* that in a mine in Saxony a piece of metallic silver was found so large that the Duke who was prince and patron of the place had a whole dining table of square German style made from it without its being enlarged or worked on by any human artifice except for the tripod legs, and he often boasted that in this he surpassed the greatness of the Emperor.

In truth I have never seen any metal except copper that was brought out from the mine pure and without any mineral, but I think that such a thing is indeed possible, since I believe in the greatness and power of Nature, who strives toward no other goal than perfection and purity. Indeed most of the minerals that I have seen have not been without admixture, not only of their earth but also of other metals, and this is more true of that which I have heard called silver than of any of the others. I except the silver that is mined in Schio in the region of Vicenza. These doubts, therefore, are not born without some shadow of apparent reason.

As I told you above I believe that silver may have and does have its own mineral, for every substance that is converted into metal can exist pure by itself in its own species, as it also exists separately even though it be mixed with others, since it is seen that in each ore its metal is generated in a single body. Therefore it happens many times that whoever speaks of the ore of silver in one breath, without distinction, speaks of that of all the other metals, because there are few ores that are not mixed. But because the most noble things always have the prerogative of including in their name that of the others, where there is gold or silver the ores are not called

* This is in *Bermannus*, Agricola's first work relating to mineralogy. It was published by Froben in 1530.

copper, lead, or iron, which are the most abundant in them, but gold or silver, even though the quantity of these is far less.

But leaving these things, I now say to you that, as far as I have observed, the more such ores are mixtures of various metals the more varied are the fumosities and tinctures that they show to our eyes as signs of their location and purity, because each one [9v] gives off its own color, staining the external rock a blue, green, yellow, or indistinct color according to the composition and mixture of the primary matter of the metals, and likewise there is more or less color depending on the quantity that is found gathered there. Now speaking particularly of this metal called silver, the natural philosophers say that it is generated from a substance that is more watery than fiery, and that all the other substances are similar and pure; not so much so, however, as are those of gold. Therefore it attains a lesser perfection, and it is as much less perfect as the influence of the moon is less than that of the sun, although it is much nearer to us.

Practical men say that silver generates itself willingly in a rock similar to limestone and also in a stone that is a dark, dull gray in color; and it is often found in another stone similar to travertine, or in travertine itself. Its mineral is very heavy and often has a shining grain; the smaller this is and the more pointed like scurf, the more perfect it is, because it shows purity and fixity. When it is found in a white and leady stone it is much better because it is easily separated from its rock and from its earthiness. And when it is found loose, almost in the skin of the earth like pebbles, they say that it is perfect, although it does not have a certain brilliant quality to the eyes as the others usually have. They say that it is also engendered in a dark gray soil, and when it is in this, it occurs in great quantities and in great perfection and there is much within the mountain. It is so much the better the more shining it is and the more rusty or red its color.

In order that you may understand the signs of the minerals of the said metal better, you must know that always before the minerals are found there are, either near them or mixed together with them, marcasites of a yellow color like gold. The yellower these are, the more they indicate burning and heat, which is opposed to the nature of their metal. For this reason it is possible to judge the fat or lean quality of such a mineral by the degree of color that they show. Now those that give good indications must approach white as nearly as possible and be of minute grain and in small quantities. This is a general rule for all marcasites, that the closer together and the finer they are the better the minerals that they point out. Often

there is found a vein of this silver mineral that is large in quantity but is so lean in value that it does not justify the expense of mining, for, although the quantity is there, it is in a hard rock like limestone which is most difficult to cut. At other times it is found in company with copper or lead, and in this case also one must not waste effort in extracting it if its value does not more than cover the expenses.

These metals are often all three found together in a single ore and when [10] this happens it is necessary to use care and the cunning of art. Supposing that you wish to separate the silver, it is necessary to increase the lead; and if you do not care to save either the silver or the lead, but only the copper, it is necessary to proceed for a long time with strong fires until the weaker materials are consumed; but this happens most often in minerals which contain iron. But, after all, in neither the one nor the other is it possible to give a general rule. It is necessary to choose according to their quality and quantity, all the more so because they are often mixed with some dry earth or a quantity of antimony or arsenic that is entirely evaporable, or combustible materials, or else they are difficult to reduce. For this reason the artisans, often weary and overcome by this difficulty, abandon the ore as useless; but many times the cause may be attributed to their inexperience with the extraordinary and long fires that are applied.

Whoever goes directly to these in the ordinary way, if he does not accompany them with things that protect them from the fire in smelting, finds that they become useless, and he encounters those effects I mentioned before. One of those substances that are burned or else are too watery is called sulphur and the other is called mercury not yet fixed, that is, arsenic. If it happens that there is an excess of one of these it burns the silver, while the other carries it away so that nothing remains of the ore except the earthiness which is often infusible. Therefore, in order to save the mineral, it is necessary to use patient skill and appropriate processes.

First, in the most commonly used method, the ores must be roasted, or, without being roasted, they must be ground finely and then washed well, and finally they must be purified, either with a very hot fire, or at least with a great lead bath. In order to do this most easily, they must be tested after they have been ground up to see whether they can be amalgamated with mercury, either in the same grinding mill or elsewhere. This is an excellent method if they are dry, and I know that it has been used by many with great profit, and particularly in that type of mineral,

rich and good, which I told you before is mined in the region of Vicenza at Schio. I tell you to test them because not every kind of ore responds to it.

And of that which I have mentioned I have heard that one piece was excavated which contained a quarter silver and another more than a half. This was found almost on the surface, loose and in open areas, and sometimes, as I have heard, that which is found under the roots of uprooted trees is rich and very perfect. I cannot, therefore, say that I have seen the best, although I have seen many mines in Venice, Carnia, and other places. Most of these, however, are of copper with some silver. Among others I once operated a mine in Mount Avanzo, where I belonged to a company formed by certain gentlemen. Since I was entrusted with the whole enterprise I took occasion to go and see other mines; and so in order to become more expert, I passed twice through upper Germany in order to see the ores which are in that country. [10v] I tried to learn by sending out for information, making observations myself, and by talking with someone whom I knew to be experienced. In this way I came to a sure knowledge that the mine which we were to excavate was good, for it contained more than three and a half ounces for every hundred of ore; and we would surely have made a good profit if the fortune of these times had not stirred up a war between the Emperor Maximilian and the lords of Venice.* Because of this it was not possible to live in the regions of Friuli and Carnia, and we were obliged to abandon our enterprise and to lose all our preparations. This war lasted such a long time that our company was broken up; but, while I followed another path, I have always followed this one in my mind, and when I had occasion to return to upper Germany, I tried more than ever to proceed with this affair. I was at Sbozzo, Bleiberg, Innsbruck, Halle, and Rottenberg, and later I was in many places in Italy. To conclude, most ores that I have seen and the best containing the purest silver are those that are found in the region of Vicenza in certain gray rocks, as I have told you.

Now I do not wish to omit telling you as a general warning that, if by chance you should start to mine ores and should find marcasites and ore mixed together, you should abandon the enterprise, for this means that the ore is near the surface and there is little of it.

Now I do not know nor can I say anything further about this ore of silver, unless I should here demonstrate to you the method of separating it

* This war lasted from 1508 to 1511.

from its earthiness and of reducing it to its metal. But because I have in mind to speak of that in detail in its proper place among smelting, I will let it go here without saying anything further in passing.

THE THIRD CHAPTER

Concerning the Origin and Nature of Copper and Its Ore.

EVERY intelligent and practical investigator of minerals says that copper ore is found in various regions of the world and that among others Italy is very rich in it. But very little is mined there, perhaps because of a cowardly Italian avarice which has the power to make us lazy and indolent in carrying out those lofty and fine designs which should reasonably make us proceed swiftly, or perhaps because we are not prone to attempt extraordinary profit but only undertake those enterprises in which we are certain of a return on our investment. The reason for this might also be found in the meager possibility of success, which, since these things are not easily attempted because they are enormous undertakings of doubtful outcome, cools the spirit of men and in place of enthusiasm introduces the fear of loss, the fear of having to sacrifice not only time but also the work and money invested; then they think of the difficulty [11] of discovery, of the impossibility of full ownership, and of the necessity of excavating the mineral marrow from the hardest bones of the mountains with the brawn and efforts of men. To this is added the fear common to many that in attempting such things they may be called fools by certain ignorant and dissolute persons, and it seems better to them to be praised for becoming rich through usury and by many other infamous and illicit methods than to lay themselves open to the danger of censure from such as these.

But there are those who deserve still greater censure, particularly princes and all rich and powerful persons, and theirs is an even more useless error than that of those who refrain for the above reasons. If the occasion and means present themselves for both attempting and continuing such a profitable and laudable affair as mining ores and if they hesitate solely because of cowardice or because they give ear to the bayings of ignorant hounds, or if because of their own willfulness they wish to remain prisoners of a detestable and ugly avarice, then this is their own loss.

Alas, how much more do they err when, in the effort to acquire riches, men brave the deep and capricious waters of the sea, the force and great contrariness of the winds, the continual unrest of body and soul and the manifest perils to their lives, and the unendurable discomforts of heat and cold, of hunger and thirst, and of so many other things that should territy both mind and eye of every reasonable and strong spirit! Besides this there is the continual anxiety and fear of falling prey to the swift sails of pirates, infidels, and other such people; for this reason it often happens that if they wish to escape with their lives or preserve their liberty they must throw themselves bodily into the arms of the horrible waves of the monstrous sea, which are often more cruel to them than their avid pursuers might have been. In these waves they find themselves with no more safety than their faith in the strength of a two-inch bit of wood, or often in less, indeed in a single peg, or a little caulking. If it happens that one of these fails them, repenting too late of their temerity, they pay for their fraud and sink deep into the sea with life and goods together, without hope of escape in the great gullet and profundity of this impious monster.

Even if these things do not happen, these men stand ever in the path of unrest, ignoring the weather and the seasons, taking no more notice of night than of day and no more of prosperous winds than of contrary ones, which always give hard battle in winter, besides the freezings which they bring. In the summer, on the other hand, when the winds fail them, they find themselves under the beating down of solar rays in such calms that they struggle against the excessive heat and almost yield to it. All the above things and many more that they see and experience every day do not discourage those who are goaded by avarice. Nor do they consider that when their sails have brought them to the intended place, they find themselves in unknown foreign lands, among people [11*v*] who are more bestial than human, whose language is not their language and whose ways and nature and political customs are completely different from those they are sensibly nourished with in our parts.

And having seen how they ignore so many riches here and abandon all these singular blessings as if they were not sufficient for their appetites or else were so unattainable that they could not possess them except in the dangerous way mentioned above, I felt that I had to digress and speak as I have in order to give vent in some measure to my feelings against these men, particularly because one can almost say that these treasures I speak of are almost by chance heaped up in their very chests. For this reason I can-

not but denounce them when I see that the thought of distant riches has prevented them from turning their eyes toward a wealth that is near by, as if foreign riches had a finer flavor than those of their own country or than those acquired without so much effort and mortal danger.

In addition to these there are others who, it seems, while they prudently avoid the said inconveniences and dangers of navigation commit an even greater error, falling into shameful faults, giving themselves wholly to thieving and defrauding and to all kinds of violence and every other evil and detestable error, obeying neither law nor faith, recognizing neither person nor time, and respecting a place only with an eye to filling up with silver or gold their deep, nay, bottomless and insatiable chests of greed. Oh how many are those who have made wealth a god, and for this reason have no respect for the true God, nor for men, cheating even their nearest relatives, despoiling hospitals and holy places, robbing temples of their sacred things and likewise if they can their own fatherland of public property. I know that some of these cheat not only others but even themselves of clothing and other conveniences as well as of their necessary daily bread, knowing neither conscience, piety, nor righteousness, recognizing neither permitted nor forbidden things; and often they care not if they soil the generous and honorable name of their family, involving themselves in affairs that even the meanest man should abhor in act as well as in thought.

But how great, shall we say, is the number of those who are called merchants, who for love of acquisition give over their possessions to persons whom they have never seen or known except from hearsay or through letters; and as soon as these persons have the property in their possession they gamble it away or spend it in debauchery or luxuries. But every adversity that comes to these merchants is fitting punishment for having committed so many mistakes in forsaking the natural, good, and just way of extracting from the earth as much fruit as can be found, granted that Nature so liberally produces it for us and for our use; nor do these blind and grossly ignorant men think how virtuous and laudable such works are. For by mining such ore it might happen that in one day, even in a single hour, without any danger or trouble to themselves, but only to their hirelings, and without so many inconveniences, [12] annoying outrages, or other things, they would become very wealthy and have gold and silver in greater abundance than from shameful usury, dangerous navigation, or any of the other unreasonable or pernicious occupations.

For this reason I say and conclude that the gifts of such copious blessings conceded by heaven should not be left to our descendants in future centuries; and those men wrong themselves, their fatherland, and the province where they were born in withholding the profitable and useful things that would reward their efforts. They also wrong Nature, for the things she has produced are as little esteemed by them as if she had generated nothing, or something only useless and vile; indeed one could say that 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.

For this we should denounce them and severely reprove them in the same terms that farmers would deserve if, when the fruits of the earth are ripe, instead of gathering them, they should leave them to rot and waste in the fields just as these men do. Surely they see, or could if they wished, the great folly they commit, especially since they are so avid for riches; and they should see their great mistake in not bending every effort toward mining ores in which their every expense is returned to them, often twice over, without peril of shipwreck or danger of so many other losses that are met in that troublous pathway of seeking wealth. Besides this, is it possible that they do not see that the harvest comes, not once a year like that of the other fruits which laborious agriculture produces, but continues throughout every season, in every month, indeed in every day and every hour? They can often harvest in whatever quantity they desire, if skill or patience or effort be continuous and sufficient to enable them to arrive where the thing is actually found.

But leaving this digression (although I could say much more about it) I wish to return in the direction of our path, from which I strayed only for important reasons. And now I tell you that copper mineral like the others is engendered in the rocks of mountains, from an elemental earthy substance that has little wateriness, together with the proper proportion of the qualities of necessary substances nourished by the influence of Venus, with those productive and generative qualities which Nature gives. Because these are neither pure nor subtle enough they are not capable of as good an elemental mixture and decoction as are those of gold or silver. Copper is judged by philosophers to be hot and dry in its innate nature and in its generation its substance is burned up and inflamed to a considerable degree, from which arises the redness of its color. Because its other substances in their impurity are not well united they cause it to be imperfect. For this reason the practicing speculators call it in itself a sick

metal, foliated and earthy, and, for its defects, ignoble, particularly because when it is worked it is converted into dross, and in the fire [12*v*] it calcines easily and melts. And they attribute its ductility, which is contrary to the nature of very earthy substances, to its great mineral unctuousness.

Putting aside these theoretical speculations I say to you that the ore shows itself in various colors, and likewise it is engendered in various kinds of rock, and with it Nature often produces silver and sometimes lead. The sign that shows to the eye that the ore is not pure is its fumosities, for when it is not pure these are blue and yellow. The places where such an ore is generated are recognized by the fractures in its rock. For the place of the generation of this metal is more worn down and fragmented than that of any other metal but gold, although that of quicksilver also does the same thing. I believe that the reason for this lies in its burned substance; for with its great heat it drives the humidity out of the parts of the adjacent stone and, being fiery and driven by the humidity and coldness of the waters below, it seeks to draw itself upwards in order to flee these opposing natures and almost by force it enters wherever it goes, even into the rocks. Thus it advances, thrusting itself in and breaking the rock, as I have said. When these things are seen they are manifest indication not only that that mountain contains ore, but also that the ore is copper and that it is abundant.

But because the eye cannot always penetrate into the interior, it is necessary to have a true knowledge of the art of assaying. For this one must excavate some of the ore that shows itself in the open and assay it one or more times with great care. If it is of a violet color in a gray rock with a few little green veins, or colored yellow, one may hope for a great profit, for this indicates a great quantity. Several other ores of the same color are also found, but not so dark that they seem black and these, like the above, are good and easy to reduce. Finally, of those that remain, that which is found in a somewhat greenish limestone and is of a violet color is the purest and the best. But be advised that if, in this or other rock, you find it of a dead color, it will be an ore of little substance.

In order that you may be more sure where such ore is to be found (in addition to those signs which I have already indicated) I do not wish to fail to tell you that to find it more easily you should search for stones lying on the surface of the mountains in which certain shiny specks, like talc, are apparent and which, besides having a certain greenish cast, have a metallic taste and in the summer are very cold, in winter, warm; and often where

they have stood they make a bed of a certain thick viscous and green putrefaction.

From these signs experienced men have not only the hope but almost the certainty of finding copper ore in such places. After it is found and mined in the said manner, prepared in the way that I shall tell you, and smelted in great quantities, you will have complete satisfaction of your wish. For even if the ore is not of great perfection, Nature compensates with quantity, [13] provident and kindly Nature who abundantly produces and offers it to us; and in order that it may be adapted to our needs she makes it flexible and disposed to smelting. When it has been thus prepared it is convenient for making endless compositions for handiworks. It is almost always the basis for all the works of the fraudulent alchemists, indeed it is the very body of their anatomy, as mercury is to the philosophic alchemists. Copper is a metal that is very well known in all countries; it is worked with great facility and with calamine or tutty is changed to a yellow color which often is such that against gold [it is confused] with it. It calcines with powdered sulphur or is altered with salt; from red it becomes white by mixing it with tin or arsenic or any other kind of poison that you may melt with it. There are those who say that by certain processes of their art, by means of cements or other materials, they extract some gold from it. It is true that it contains some, but I believe that there is little for I do not know of any elemental mixture in it similar to that of gold. Yet if they do this, it is to be esteemed that much more highly among the fair works of God and of Nature.

THE FOURTH CHAPTER

Concerning the Ore of Lead and Its Generation.

I SHALL proceed in this chapter to tell you about lead. Because this metal is overabundant in wateriness, and also because it has its other substances in poor elemental mixture, it is highly impure. It is called an imperfect, leprous, and little-fixed metal, which it clearly shows itself to be because of the ease of liquefying it and because it is easily converted largely into a dross that is almost earthy and also because of the stain that it leaves when it rubs against anything. Nevertheless, when we consider its effects, we judge it to be a metal that we are greatly indebted to. Even though Nature in creating us has put into our souls such a thirst and desire

to possess gold and silver and precious gems in great quantities, we would neither have these things nor know them if we did not have lead and we would tire ourselves in the vain effort to possess them. For without the aid of lead we would never have known how to extract gold and silver from copper, nor how to lift from precious gems the earthy and rocky veil that clouds and covers their beauty and clarity.*

In short, if Nature, most generous with her excellent things, had not created this and given it to us as she has done, we could perhaps say that we would have lacked all those things that we esteem so highly for their beauty or rarity or perhaps for some precious and excellent virtue. Therefore we must consider it as a useful thing of value equal to those things that we prize so greatly. For as I have said, it is both the cause and the means of our possessing jewels and all the most perfect metals. [13*v*] With the certainty and favor of this we have the courage to penetrate even within the hardest mountains and to seek lead in the harshest and wildest regions and places.

And since in this, as in her other works, Nature always seeks to accommodate men, she has generated it abundantly, with the result that there are few mineral locations in which or near which this ore is not found, almost as if she had offered it to us beforehand as an aid to our needs. For the substance of ores that contain gold or silver could never be extracted without it, because they are things that are invisible to our eyes and that, as you see, are joined to these like the spirit to the bodies of living things, as appears in the various elemental mixtures of metals that are useful one to the other, that is, silver, gold, copper, lead, and perhaps iron. Often the ores of all four metals are found fused and mixed together, and only by means of lead can each one be separated from the others when one wishes to save them all.

In addition to these useful effects, lead has power to serve men in many other ways; for the doctors also make use of it in many sicknesses. Women in particular are greatly indebted to it, for, with art, it disposes to a certain whiteness, which, giving them a mask, covers all their obvious and natural darkness, and in this way deceives the simple sight of men by making dark women white and hideous ones, if not beautiful, at least less ugly.

* A reference to the use of lead laps for polishing gems and to the addition of lead to tin for oxidation in making putty powder for polishing; possibly also to the use of fusible metals as mountants.

But now, not to continue too long, I shall cease narrating all its particular qualities and, returning to our path, tell you that the ore that produces and generates this metal is found in various countries and in divers rocks and soils. Some is found that has an admixture of silver, and another of silver with gold. Such a mineral is commonly found in a spongy rock called limestone [*colombino*] of a white color similar to travertine, with some black specks in it, and it is very hard to mine. It is also found in another kind of stone that has a red color similar to rusty iron that has stood in water. Furthermore, it is found in certain soils of ashy color, as in Andalusia and Aggioaga. The best of all that we know of from experience is that which is born in the said white stone, especially when it is of a very fine and clear grain, or that which is found in a certain kind of soil and is purified merely by washing it. All ores of this metal, wherever they may be, are easily mined, and, once mined, are easily cleansed of their superficial earthiness.

It is smelted with little art by means of fire, either entirely alone or often in the company of other ores either in order to save work and expense or to dispose the others that are hard to easier smelting, or else to protect them from the great burning of the fire so as to prevent the silver being burned or carried away by the arsenic.

In order to smelt it when it is pure,* a square furnace is made, open on top and as large and high as the worker wishes, of a shape similar to that which is made for melting by draft of air. And when it is necessary [14] to have a goodly quantity of the ore, a rectangle of three or four *braccia* is made, and about three-fourths of a *braccio* or a little more above the level of the ground, in place of the iron grating, I would make as many little masonry arches as the enclosure can contain, placing them about two *dita* apart. At the bottom I would make it on three sides like the inside of the lid of a pot which by its slope acts as a channel; the other side, the front, I would leave open for the entrance of the draft and the exit of the lead. I would leave this open while the lead falls in melting so that because of the channel-like shape of the bottom the lead can run down and reach a large receptacle made at the back or at the side of the opening that I told you was left for the draft, or for taking out hot coals or the earthy parts of the ore when they fall. Thus this cleansed lead in another form goes into the receptacle and is left in it to cool. Large cakes of the desired

* This method of smelting without roasting would, of course, only be suitable for pure oxidized ores.

weight are made from it. This is the common method used for extracting lead from such ores, and it can be used for others as long as they are not too sour.

In order that you may better understand the form that the furnace must have, I have shown it here in a drawing as well as I could.* In this, when you wish to use it, put a layer of wood above the little arches, and then sprinkle some charcoal on it, then a layer of ore, and so on with layers of wood, coal, and ore, until the furnace is full to the top. Then light the fire, letting it work gradually by itself. The ore that is placed in it must be in little pieces, or well crushed and washed if you wish or if you see that it is necessary. Allowing it to be separated in this way, the lead will run out, and all the earth will remain dry on the arches, or it will fall among the charcoal and ashes, useless and wretched if it does not contain any other metal. In this way, by adding new ore with wood and charcoal as the layers gradually go down, it can be continuously smelted.

In case the ore has a stony nature or contains other kinds of ore so that the said method does not fully suffice with it because of its hardness, you should take the ore and crush it well and wash it. Make a receptacle as large as you wish and shaped like a cupeling hearth; after this has been well compressed and pounded and finally dried out and made very hot with burning charcoal, place in it a quantity of pure lead, and then with wood and charcoal and the wind of a good pair of bellows make it melt very easily. Then, when you see that it is very hot, put the ore on top of the wood and charcoal so that it gradually falls down hot into the middle of the bath and melts. Make a little outlet near by so that the lead may run out as it melts, and keep the bath free of slag with an iron tool.

In case this method should not serve you because of the strong elemental mixture of the ore or because of the burned quality of the rock, and it should be necessary to use a stronger fire, [14*v*] pass it through the blast furnace according to the method used for other metals. But if you have to resort to this it will not be pure ore of lead, but a wild and harsh material with some trace of iron. Because you may not know the method of such smelting and may wish to know it, I tell you that you will find it noted in this work in the course of the present book.

Also because I have told you that it is a good thing to smelt all ores of lead with silver ore I tell you that with this wild kind this is especially true, because it needs little more fire and it becomes pasty [i.e., forms a

* There is no such illustration in any edition.

slag] with the other ore and both melt at the same time so that the silver is better protected from the fire. There are evident reasons why these ores act in this way, in addition to the fact of our experience and of having seen it every day. For Nature has made a certain alliance of friendly union between these metals and stones, by which the humidity of lead is joined to the aridness of silver, and the heat to the cold. Thus they temper each other and that which is hard becomes suitably soft and liquefiable and issues from the torment of the fire more quickly than it would have done by itself, so the silver is saved.

This lead is a metal that alloys with all the metals, but there are none to which it is joined, except tin, from which it cannot be separated. For this reason ingenious artists have discovered not only the protection of silver in smelting but also the method of extracting silver from other metals and of cleansing it from its every companion. The alchemists also make great use of it in their work, sometimes calcining it alone, and sometimes accompanied with tin although they then use the strong fires of a reverberatory furnace; yet it is often calcined with sulphur, common salt, or arsenic.

The calcination of lead in a reverberatory furnace seems to me such a fine and important thing that I cannot pass it by in silence. For it is found in effect that the body of the metal increases in weight to 8 or perhaps 10 per hundred more than it was before it was calcined.* This is a remarkable thing when we consider that the nature of fire is to consume everything with a diminution of substance, and for this reason the quantity of weight ought to decrease, yet actually it is found to increase. After it has been in the fire so long it seems reasonable that the contrary should happen, because many of its parts have been consumed as well perhaps as those of the elemental fire. Deducing reasons for such an effect, it may be answered that all heaviness tends to the center† and the denser a body is the heavier it is within its species. Since those watery and airy parts are removed by

* Biringuccio is one of the earliest to mention the increase in weight of a substance on oxidation, although the converse (diminution of weight on reduction) was mentioned by Pliny. The formation of PbO theoretically corresponds to an increase in weight of 7.7 per cent, but the formation of small amounts of higher oxides would account for the higher figure given by Biringuccio. The curiously inverted explanation of the function of airy parts reminds one that phlogiston was later supposed to have negative weight in order to explain these same facts.

† Vague expressions of the concept of gravitational force are to be found in works at least as early as Ptolemy.

the fire from this composition of lead as from a poorly mixed metal, and since all its natural porosity is closed (through which the air used to enter that by its nature and power held it suspended under its influence with a certain lightness), the lead, brought to this point, falls back into itself like a thing abandoned and lifeless. Thus it comes to retain more of its ponderosity in the same way [15] that the body of a dead animal does, which actually weighs much more than when alive. For, as is evident, the spirits that sustain life are released and, since it is not possible to understand how these can be anything but substances with the qualities of air, the body remains without the aid of that which made it lighter by lifting it up toward the sky, and the heaviest part of the element has its natural force increased and is drawn toward the center. Thus the above difficulty is resolved by this explanation.

THE FIFTH CHAPTER

Concerning Tin and Its Ore.

WHOEVER has occasion to judge tin in its whiteness from the testimony of his eyes alone would surely believe it to be purest silver, or something that comes very near to it in nature. This is even more so when, on handling, it is found to be harder than lead, to which it can be said to have a greater and closer resemblance. But whoever has actual experience with tin knows that none of the other metals is less similar to it than silver. For silver mixes with every metal, as does gold; and they unite together, and the others do likewise; and except for their color they change their natures but little. But this metal tin, wherever it is found, acts like a powerful poison which envenoms and corrupts the others; and it does this not only with large quantities but also with every small amount; indeed just the trace remaining where it has been melted is enough to embrittle silver and gold as well as iron and copper. The greater the quantity of it in these, the greater are its effects. Speculators of natural causes say that this fact arises from its great wateriness, which is very subtle and poorly decocted and almost like that of quicksilver. This wateriness, then, by means of its subtlety which joins itself with metals, imposes itself into that unctuous and viscous material which renders them flexible, and thus deprives them of their toughness

and corrupts them, excepting lead, in such a way that it almost converts them into another nature. Although tin alters lead it does not apparently act on it so much, since both have almost an equal and proportioned similarity of nature. For this reason tin is called "white lead" by the alchemists.

As you are aware, tin is a very well known metal because it serves to make many objects for human use. For wherever it is generated it is found in large quantities and it is easily worked since it melts with any kind of fire and with little effort. This metal, either pure or when mixed with lead, stands up well under the hammer, so that, if desired, it can be spread out thinner than paper. Vessels for eating and those for preserving liquids are commonly made from it by casting. Although it possesses considerable metallic odor, [15v] still it does not leave enough in whatever is placed in it to be detected either by smell or taste after it has been stirred up.

That metal is known to be purer that shows its whiteness more, or if when it is broken it shows itself granular like steel inside, or if when some thin part of it is bent or squeezed by the teeth it gives its natural cracking noise, like that which water makes when it is frozen by cold.

Although I have never seen its ore, for apparently it is engendered in few places, still, according to what I have heard from experienced men, the best and the most abundant that is found in the provinces of Europe is that which is mined in England; and I have also heard that it is found in certain places in Flanders, in Bohemia, and in the Duchy of Bavaria, but I am not able to list these exactly because of the strangeness of the names and places, though this matters little. For you it is enough to know that its ore is generated in the same way as the others in the most rugged mountains in a certain white rock. They also say that it is in several other rocks that are somewhat yellow and in others of a dark gray color. They also say that it is found in another rock that is all spongy and almost like that in which lead is generated but its stone is more soft and all full of red and gray veins. I understand that it is extracted from the earthiness of its ore in the same way that lead is, that is, in an open furnace.

As I told you above, this is a metal whose nature corrupts other metals in which it is incorporated, so that whoever puts even one part of it to one hundred parts of copper, iron, silver, or gold, changes their color and alters their tractable sweetness. What others say, that it produces no sound itself, is also true, but by hardening other metals it makes them sonorous,

just as if it puts the spirit there and vitalizes the substances. Thus by the mixture of two flexible bodies there comes the creation of a third that is neither one nor the other, indeed it is entirely different, brittle and much harder than either one of them was before. This happens, perhaps, because the parts of the tin break the parts of the copper and destroy their toughness. Because of the diversity of the natures of the metals concerned, the parts of the tin do not unite with each other as well as they were previously united, and the same thing happens to the parts of the copper when its moisture is multiplied by that of the other, or its dryness by the coldness of the other.

The whiteness that tin introduces into metals results from its spreading out in this case as a watery or very subtle thing, overcoming the redness of the copper or the yellowness of the gold and extinguishing it, making the metal very white, from red or yellow, in such a way that it shows even more whiteness than the tin itself previously showed. But although it shows itself white, it does not seem to me that it really is so, as I believe that it shows a greater whiteness just because it has greater shininess and brightness and these qualities are caused by the heightened polish that the greater hardness can receive. The hardness that the third body acquires arises because its temper is lost and the unctuous and viscous quality [16] is broken that gives toughness to metals and makes them tractable and malleable for the work of artisans. These are the reasons that, in my opinion, account for such effects.

THE SIXTH CHAPTER

Concerning Iron Ore and Its Nature.

NATURE produces iron ore abundantly in many regions of the world, especially in Italy where not only is there a great abundance of it but also there are various kinds. In these our Tuscan parts it is a very familiar thing, since we are situated close to the island of Elba which is so overflowing and rich in this ore that it surpasses every other place where it is found. Thus not only do the regions of Tuscany share its great quantity because of their proximity, but more than two-thirds of Italy as well as Sicily and Corsica are supplied, and perhaps some more distant place. In addition, this ore is of such perfection that it

is no doubt a very good reason why we do not take the trouble to mine in many places on the mainland of Italy, where a similar ore is clearly indicated by the signs and by the assays that have been made which show that whoever should mine would find great quantities of it. But seeing the excellency of this Elban ore and the ease with which it is acquired, in addition to the certain return on the investment in proportion to what is expected from the desired thing, the attempt to mine it in other places is abandoned.

Among the other words of praise, I do not wish to omit telling you of a marvelous thing about this Elban ore. For, though it has been mined in such quantities for so many centuries, and is still mined even today so that not only the mountains but even two islands like that one should have been leveled, yet nevertheless it is still mined today and is of better quality than ever before. Thus it is the opinion of many that within a certain time the ore is regenerated anew in that soil which has already been mined. If, indeed, this were true, it would be a great thing and would demonstrate a great provision of Nature or a great power of the heavens.

I have not yet told you that this ore is of such a nature that, in order to extract the iron from it and then to reduce it to purity, it is not subjected to the force of violent fires or many devices and extraordinary efforts as are the others. By merely placing it on a forge in front of the tuyère where the blast issues, a very soft and malleable iron can be extracted with an ordinary smelting fire. From this any kind of craftsman's work can be made just as if it were silver or some other very malleable metal. In these effects it clearly shows its great purity and that it contains no trace of copper* or admixture of any other metal harmful to its virtuous quality. Whence it happens that this ore does not need the powerful fires of great furnaces [16*v*] in order to purify it, as is usual for many other ores (particularly for those that are in the Brescian territory in Valcamonica in Italy), but a simple forge is sufficient, together with a pair of bellows not much larger than ordinary ones. After the ore has been broken in little nutlike pieces it is arranged on the said place in a heap and around this a circular enclosure is made of the larger pieces of ore or of other dead rocks, put there only in order to hold the charcoal and fire close together. The amount that it is wished to reduce is well covered with charcoal and

* The erroneous idea that small amounts of copper are harmful to iron is mentioned by Pliny (*Natural History*, Book XXXIV, para. 143) and persisted for nearly two thousand years.

then an arrangement of bellows connected with a water wheel which moves them is caused to blow. With a fire of only eight or ten hours' duration the ore is smelted and cleansed of the earthiness which it contains; thus the iron remains all pure in a waxlike mass. The said rocks are removed from around it and it is removed from the forge while still hot. It is broken in pieces with mallets by hand, and then each piece is reheated, carried to the forge-hammer machine, and made into blooms.* This process is done in every works twice a week and is called *il far dela cola.*† When it is finished, the said blooms of the iron thus extracted are taken again and placed on the same forge, and well reheated. When hot they are cut up by the said forge hammer and extended into the form of a bar, squares, or any other desired form.

When this work has been brought to its conclusion, the ore will be found to have lost not more than 40 or 45 per cent, the remainder being purest iron. This occurs with no other iron ore, because there are few that are not mixed with other ores, or that are not wild and sour in their own nature, or that do not need to pass through large furnaces with strong and powerful fires, consuming great quantities of charcoal and much labor, for their wildness cannot otherwise be tamed since it is caused by bad elemental mixture or traces of other metals of which they are often so full that they can scarcely be liberated. I saw this in Siena while I was still a young man, in the valley of Boccheggiano where many plants for making iron were constructed by the magnificent Pandolfo P.‡ Since I was in charge of them, I took some of the iron ores which were found near there as well as that of Elba, and I came to be experienced in both.

But I have told you enough of this Elban ore. Now I shall tell you what I have learned about this other kind which is very similar to that of Bischaia, Brescia, and Buti. First (supposing that you have found the ore and have mined a goodly amount and have roasted, sorted, well re-sorted, and washed it) you must have one or more furnaces of the type called large blast furnaces which can hold great quantities of charcoal and which are constructed on the inside like the figure I shall show you drawn here. [17] Near these is a large pair of bellows, very close to the wall of the fur-

* *masselli.*

† i.e., making a heat, or a "running down."

‡ Pandolfo Petrucci, the tyrant who virtually controlled Siena after an armed seizure of power in 1487. Under his ruthless dictatorship the city remained superficially tranquil and trade flourished. He died in 1512.

nace, like a great pair of wings. These are usually six or eight *braccia* in height and they are set in motion by a strong water wheel to which they are connected so that they have a very large extension for inflation. With their powerful blast, which enters the furnace by means of a tube about two and a half *braccia* from the bottom, the ore is smelted after the furnace has been filled up with charcoal. Depending on the kind, some ores are smelted once and others twice before they are disposed to become iron

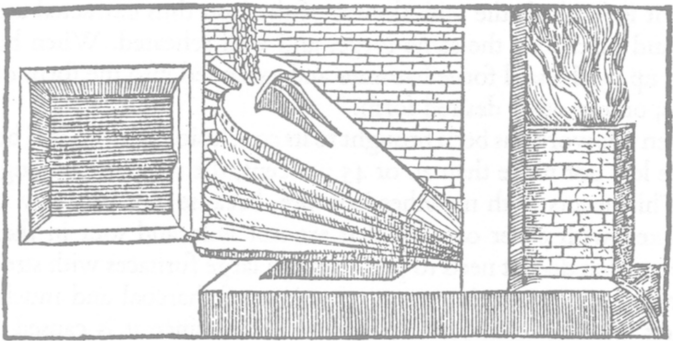

Figure 3. Blast furnace for smelting refractory iron ores.

good enough to give to the forge to be drawn out by the forge hammer. In spite of all this, it often happens that, however much care the masters have taken, it has not been possible to bring the metal to such softness that it can be worked. This is due to the malignity of its companions, which melt with it and become inseparable from it. Yet if there is anything that can aid it to separate well this is the best for most easily bringing it to perfection.

This ore is found in many different kinds and is purified in many ways depending on its species and on the knowledge and ability of the masters, among whom there is a great difference, for one extracts from the same ore a greater quantity and a softer and more malleable metal than another. There is also a very great difference apparent in the types of charcoal, for experience shows that one kind of wood works better than another. There is no doubt but that the charcoal of soft wood makes a soft and tough iron but coarse wood makes it hard, strong, and less tough.

But whoever wishes to make the iron good and soft by virtue of the ore itself, in addition to the method and the charcoal, must first provide

an experienced and intelligent sorter who will carefully sort the pure from the impure and will separate them according to the indications of their appearance and by breaking them. Then he will roast them in an open furnace and, thus roasted, he will put them in an open place so that the rains will wet and the sun will dry them out. Having left them thus for some time, he must look them over again piece by piece before they are brought to the furnace [17*v*] in order to see whether some trace of another metal has appeared. Thus by roasting and reroasting them, making them evaporate well before they are smelted, a good iron is obtained that is soft and malleable. But if, after using all possible care, it happens that the ore does not produce soft iron because of its particular nature, but is instead still hard, then it is good for making steel; indeed it is much better than soft iron. For this reason some call this the ore of steel and not of iron, but in my opinion this is an error because there is not enough difference between steel and iron to distinguish an additional ore, nor as far as I know has this been attributed to it by these speculators. I think that it can well be called ore of an iron which is more disposed to make steel than is soft iron,* as I shall tell you in detail in its own place.

Now, as you have seen, I have given you in this discourse a knowledge of the differences between iron ores and of the methods that are generally used for purifying them; without these processes they would not bear the hammer nor could they be held together or welded in making objects. I shall now tell you what its nature is and where and how it is found, but its usefulness to men you will find noted in the Ninth Book of this volume.

Now wishing to tell you where this ore is naturally found I say briefly that it is found in the most rugged mountains. The metal is called by the alchemists more ignoble than any of the others because it is made of a very earthy, coarse, and strong substance. For this reason it happens that, because of its great dryness, it is more apt to soften in the fire than to melt. Because of its poor elemental mixture and great porosity it easily produces rust, and when it is worked it consumes itself by becoming dross. For the same reason it becomes brittle and intractable if it is touched by melted tin, because this easily penetrates with the subtlety of its spirits and alters it, changing its nature.

* Is it likely that certain ores will give a sponge iron in a physical condition more able than others to absorb carbon? Although Biringuccio mentions cast iron several times and considers it to be a "corrupted" iron, he nowhere indicates that he suspected the importance of melting in contact with fuel to give hard or fusible iron.

Iron ore appears in many kinds, as I told you above. Good ore must be clear, heavy, and firm of grain, free from earth, stone, and all traces of any other kind of metal. The color of good* ores is black and those that have the color of lodestone are worth very little, because almost all of them contain a trace of copper. Those that are best known to me are of four kinds. The first is that clear kind of which I have spoken, which is heavy and perfect. The next is a shining one of fine grain that crumbles very easily and is not very good. That of black color with coarse grain is worth little because it almost always has with it a trace of copper or some other metal. The fourth is black with a fine grain and is more or less good depending on the stone in which it is found.

As I told you before, those that have a trace, if not too great, of other metals can be purified by the use of long and powerful fires. Since they are corrupt materials and are almost inseparable from each other except by these means, it is not possible to bring them to a soft perfection. Because they melt easily they are used to make cannon balls and other cast objects; these are more or less brittle as the materials are more or less corrupted by that trace [of impurity].

[18] This ore is generated, as is seen, in every kind of soil and in those mountains where an abundance of very perfect water springs forth and where the air is good. It is often generated in a white rock similar to marble; if it is smelted while joined with this it rarely gives soft iron. Iron ore is also found by itself scattered within a certain red earth, but it is very brittle and has with it some black spots and yellow shining specks. A similar ore is also found in a certain yellow earth that is somewhat soft like mud, but I advise you to lose no time with this because it is not pure. You will have more certain evidence of this when you see near to it some stones colored green or blue or when you break it and find in it little yellow grains like buttons or black ones like charcoal.

There is one more experiment that can be made in order to recognize its purity. It is this: The said ore is placed in a strong lye, then after it is taken out and put on a well-burning fire it develops the color of the fumosities which [naturally] issue from it.† Also, after it has stood in the said lye for a long time, one blows on it very gently with a small bellows or other tube

* *bruna*. Mieli proposes *buona*, which we have followed.

† This seems to be the first description to appear in print of the use of flame color to identify elements. It is mentioned, however, in the Mittelalterliche Hausbuch MS. of 1480.

and by means of the bubbles that form, its evilness is discerned in the different colors of copper that appear there.

The sign by which you can surely tell where there is good iron is the presence of bole and another earth that is also red, soft, and fat and that does not make any crackling noise when it is squeezed by the teeth. According to what practical men say, a very perfect ore is generated in this, but it does not appear in veins. To tell you what kind is most commonly found, I also add that the greatest quantity is of that nature which has a rusty color and which is not very good. I have seen this and another black kind in great quantities in the region of Siena in the valley of Boccheggiano and in other places.

I do not wish to speak here in more detail concerning the discovery of these ores, or to make further distinctions between them, because I think that I have said enough for our purpose. Furthermore, they are very well-known facts and every little bit of experience which you have will increase your wisdom as you need it. I have also said enough about their smelting. Indeed I told you about it before I showed how the ore is found, and also intend to demonstrate it to you better in the discussion on smelting, with the other metals.

THE SEVENTH CHAPTER

Concerning the Method of Making Steel.

ALTHOUGH it might seem more fitting to discuss this subject in the Ninth Book in connection with the smelting of iron where I had thought to treat of it in detail, this process of making steel appears to be almost a branch of the above chapter on iron itself; hence I did not wish to separate these two so far that they might seem to be [18*v*] different things. Therefore I wish to write of it here and to tell you that steel is nothing other 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. By the attraction of some suitable substances in the things that are added to it, its natural dryness is mollified by a certain amount of moisture and it becomes whiter and more dense so that it seems almost to have been removed from its original nature. Finally, when its pores have been well dilated and softened by the strong fire and the heat has been driven out of them by the violence of the coldness of the

water, these pores shrink and it is converted into a hard material which, because of the hardness, is brittle.

This steel* can be made from any kind of iron ore or prepared iron. It is indeed true that it is better when made from one kind than from another and with one kind of charcoal than with another; it is also made better according to the understanding of the masters. Yet the best iron to use for making good steel is that which by nature is free from corruption of other metals and hence is more disposed to melt and has a somewhat greater hardness than the other. Crushed marble or other rocks readily fusible in smelting are placed with this iron; these purify the iron and almost have the power to take from it its ferruginous nature, to close its porosity, and to make it dense and without laminations.

Now in short, when the masters wish to do this work they take iron that has been passed through the furnace or obtained in some other way, and break into little pieces the quantity that they wish to convert into steel. Then they place in front of the tuyère of the forge a round receptacle, half a *braccio* or more in diameter, made of one-third of clay and two-thirds of charcoal dust, well pounded together with a sledge hammer, well mixed, and then moistened with as much water as will make the mass hold together when it is pressed in the hand. And when this receptacle has been made like a cupeling hearth but deeper, the tuyère is attached to the middle so that its nose is somewhat inclined downwards in order that the blast may strike in the middle of the receptacle. Then all the empty space is filled with charcoal and around it is made a circle of stones or other soft rocks which hold up the broken iron and the charcoal that is also placed on top; thus it is covered and a heap of charcoal made. Then when the masters see that all is afire and well heated, especially the receptacle, they begin to work the bellows more and to add some of that iron in small pieces mixed with saline marble,† crushed slag, or other fusible and nonearthy stones. Melting it with such a composition they fill up the receptacle little by little as far as desired.

* The process consists of immersing masses of wrought iron in a bath of molten cast iron. Although Biringuccio says that both the bloom and the bath are of the same iron, that for the bath is undoubtedly carburized by the excess of charcoal mixed with it for melting.

Agricola (*De re metallica*, p. 342) copies this description almost word for word and adds an illustration showing steel bars being hammered and quenched. Unfortunately the hearth of the furnace is not shown and it is possible that it is just a forging operation that is depicted, not the steel-making process itself.

† *marmo saligno*.

Having previously made under the forge hammer* three or four blooms weighing thirty to forty pounds each of the same iron, they put these while hot into this bath of molten iron. This bath is called "the art of iron"† by the masters of this art. They keep it in this melted material with a hot fire for four or six hours, often stirring it up with a stick as cooks stir food. [19] Thus they keep it and turn it again and again so that all that solid iron may take into its pores those subtle substances that are found in the melted iron, by whose virtue the coarse substances that are in the bloom are consumed and expanded, and all of them become soft and pasty. When the masters observe this they judge that that subtle virtue has penetrated fully within; and they make sure of it by testing, taking out one of the masses and bringing it under a forge hammer to beat it out, and then, throwing it into the water while it is as hot as possible, they temper‡ it; and when it has been tempered they break it and look to see whether every little part has changed its nature and is entirely free inside from every layer of iron. When they find that it has arrived at the desired point of perfection they take out the lumps with a large pair of tongs or by the ends left on them and they cut each one in six or eight small pieces. Then they return them to the same bath to heat again and they add some more crushed marble and iron for melting in order to refresh and enlarge the bath and also to replace what the fire has consumed. Furthermore, by dipping that which is to become steel in this bath, it is better refined. Thus at last, when these pieces are very hot, they are taken out piece by piece with a pair of tongs, carried to be drawn out under the forge hammer, and made into bars as you see. After this, while they are still very hot and almost of a white color because of the heat, in order that the heat may be quickly quenched they are suddenly thrown into a current of water that is as cold as possible, of which a reservoir has been made.

In this way the steel takes on that hardness which is commonly called temper; and thus it is transformed into a material that scarcely resembles what it was before it was tempered. For then it resembled only a lump of lead or wax, and in this way it is made so hard that it surpasses almost every other hard thing. It also becomes very white, much more so than is

* forge hammer = *maglio*.

† *larte di ferro*. Mieli suggests *latte di ferro*, "milk of iron."

‡ The word "tempering" refers to the quenching operation, and not, as now, to reheating after a drastic quench. It produced a finely tempered product, however, for the quenching operation was controlled by intermittent, slow, or partial immersion to give the desired hardness directly. See also note on page 371.

the nature of the iron in it; indeed it is almost like silver. The kind that has a white, very fine, and fixed grain is the best. The kinds I have heard of that are highly praised are that of Flanders and, in Italy, that of Valcamonica in the Brescian district. Outside Christendom the Damascan is praised and the Chormanian, the Azziminan, and that of the Agiambans. I do not know how those people obtain it or whether they make it, although I was told that they have no other steel than ours. They say that they file it, knead it with a certain meal, make little cakes of it, and feed these to geese. They collect the dung of these geese when they wish, shrink it with fire, and convert it into steel. I do not much believe this, but I think that whatever they do is by virtue of the tempering, if not by virtue of the iron itself.

[19v]

THE EIGHTH CHAPTER

Concerning the Method of Making Brass.

HAVING told you about steel in the previous chapter, it seems to me necessary to speak here of brass for the same reason, for it bears the same relation to copper that steel does to iron. It is the opinion of some concerning both of these that they are true minerals because Pliny in his *Natural History* calls it *aurichalcum* and says that it has its own ore; he does not say, however, where it is found, and I have not heard from anyone else that it has been found anywhere, and, surely, if it had been found when he wrote, it would also be found today.

Since I have no knowledge other than that gained through my own eyes, I tell you as a certainty that just as steel is iron converted by art into almost another kind of metal, so also brass is copper given a yellow color by art. Surely it was a splendid discovery, for which we must praise the alchemists,* although perhaps whoever discovered it was deceived, thinking that he had made gold from copper.

Now, in short, this work requires infinite labor, and is carried out in various places, for instance, in Flanders, Cologne, Paris, and in many other countries, and also in the city of Milan in Italy, where I have seen a

* The manufacture of brass antedated alchemy as Biringuccio knew it, for it is one of the oldest alloys. Objects containing 23 per cent zinc have been found in archeological sites dated at least as early as 1000 B.C. although the alloy was not in common use until Roman times. Both Pliny and Dioscorides obliquely mention its manufacture, and describe several types of zinc oxide collected from the upper parts of brass-making furnaces. The

great quantity of it worked and colored. It is colored in this way: The masters whom I saw had made in a large room a furnace, much longer than it was wide, and built with a certain kind of stone that by its nature resisted continued firing without melting and burning up. Where the fire entered the furnace it was almost entirely open. The body of the furnace was half or more underground; the vault was low; at the top and bottom there were everywhere little airholes; and above in the vault there were two square openings through which the crucibles containing the copper to be colored could be put in and removed. These were then closed with

first competent account of the process is by Theophilus (about 1100 A.D.) who describes all essential steps, and the next is this of our own author.

The old process of brass making consisted of heating calamine (zinc carbonate, often roasted to the oxide) with charcoal and copper. The copper absorbed the zinc vapor as soon as it was formed and so permitted the reaction to proceed nearly to completion at a temperature at which the equilibrium pressure of zinc vapor from a mixture of calamine and charcoal alone would be far below atmospheric. Metallic zinc was not definitely recognized in Europe until the sixteenth century and not commercially produced until early in the eighteenth, although it was imported from the East in considerable quantities and was also obtained as an accidental condensate in the cooler parts of blast furnaces smelting lead ores containing zinc. The calamine process for making brass persisted long after zinc became available in quantity; indeed Percy in his *Metallurgy* (1861 edition) described in detail a furnace that had been operating only a few years previously.

Glauber (*De Prosperitate Germanias,* Amsterdam, 1656) seems to be the first to describe alloys of copper with metallic zinc and to recognize zinc as the metallic base of calamine. Prince Rupert, with whom Glauber was associated for a time, made extensive use of an alloy of calamine brass with metallic zinc, thus obtaining a harder alloy than could be obtained with calamine alone, without the expense that would be involved by the use of all metallic zinc. The alloys were studied in detail by Geoffroy in 1725 (*Mém. Acad. Royale des Sciences,* Paris, 1725, pp. 57–66). By examining the fracture under a microscope, he distinguished yellow, reddish, and white constituents which are none other than our alpha, beta, and gamma phases!

The first description of brass making in the English language was by Dr. Merrett in the notes to his translation of Neri, *The Art of Glass* (London, 1662). This is the best description prior to that of Galon (1764) and Diderot (*Encyclopédie,* Paris, 1751–72) but has been entirely overlooked by students of the history of brass.

Biringuccio refers to the action of calamine as one of "coloring" copper into brass. His actual word is *tegnere,* which perhaps would more accurately be translated as dyed or tinctured. The word was sometimes used in alchemical literature for transmutation. Hopkins points out (*Alchemy, Child of Greek Philosophy,* New York, 1934) that such phraseology goes back to the time when metal coloring and dyeing were practiced by the Egyptians as related decorative arts, and were regarded as being of much the same nature. Hopkins deals at some length with superficial metal coloring or patination by sulphide baths and the like, but does not refer to the production of brass. This, solid and yellow, was a veritable triumph for the dyer and one which undoubtedly played a great part in convincing alchemists that their goal was true.

little fitted clay shutters. The crucibles were made of Valencia clay, or they were brought ready-made from Vienna; they were very large and I believe that those which I saw were about two-thirds of a pound,* and I understand they had a capacity of fifty or sixty pounds of metal.

For this process they placed in each one of the vessels twenty-five pounds of German rosette copper† broken in pieces, and they filled up the rest to within two *dita* of the rim with a powder of a mineral earth, yellowish in color and very heavy, that they called calamine.‡ The rest of the empty space in the crucible they [20] filled with powdered glass. Then they put the crucibles in the vault through the above-mentioned openings and arranged them in pairs on the bed at the bottom. Then they applied a melting fire for twenty-four hours and after this time they found the material entirely fused, and the copper, which was red before, had become a smooth and lovely yellow, almost like 24-carat gold in color.

Later I saw in the same shop several apprentices and masters working at this, some of whom were hammering the said brass to make tinsel, some were laminating it to make tips for laces, some were filing it into tailor's thimbles, some were making buckles and other similar objects by casting, and there were some who were working it with the hammer into little bells, spoons, and basins, and others were turning it into candlesticks or other vessels. In brief, some made one thing and some another, so that whoever entered that shop and saw the activity of so many persons would, I think, believe as I did that he had entered an Inferno, nay, on the contrary, a Paradise, where there was a mirror in which sparkled all the beauty of genius and the power of art. Taking thought of these things with the greatest pleasure, there was not a day while I was in Milan that I did not go there and stay an hour or more. In that place I turned my eyes nowhere but I saw some ingenious novelty and beauty of craftsmanship, and thinking of the arrangement and the greatness of the new things that were shown to me, I was sometimes stupefied.

Among other things I saw a kind of workman whose method was

* *Sic; braccio?*

† *rame peloso*, the term used for the crusts of copper removed from the bath of refined metal as it solidified. (See p. 172.) *Peloso* means hairy or shaggy as applied to an animal hide, and was extended to these rough-surfaced crusts for obvious reasons.

‡ Biringuccio's description is partly incorrect, for in order to absorb the zinc vapor effectively the copper should be intermixed with the calamine or placed on top of it, not underneath. Moreover, the calamine would have to be mixed with powdered charcoal in order to reduce it, and most calamine would need roasting before being used.

entirely new to me. These were eight masters near others in a room who did nothing but mould in lute and form an infinite number of moulds of all those little objects of everyday use which can be made from brass by casting. They made these in such a fine way that I cannot fail to tell you about it. These masters took the number of patterns of all the things that they had decided to mould, that is, harness buckles, cups, belt buckles, all kinds of chain links, bells, thimbles, window fastenings, and other similar things. On one day they made all of one kind and the next day all of another, and thus they proceeded, changing the pattern every day; and having finished one that they had to mould, they began again at the beginning with another, continuing always with this easy method and process of moulding to accomplish much work.

They took a large quantity of lute mixed with cloth clippings or cane seed and, when they had beaten [20*v*] the quantity they wished to use until it was somewhat hard, they spread it out about half a *dito* thick or less on a little board which was a *palmo* in length and somewhat wider than the patterns. After having spread it out well, they dusted it with fine charcoal, and in it they moulded their patterns all attached to the gate, with vents, openings, and all the parts which are needed to make a complete mould. Some of these patterns were of tin and some of brass, accurately made, filed, and well finished, for if once the mould was well made the objects had to come out the same way. Each of these masters had also near him a small square oven of sheet iron. This was lined with bricks or covered with clay and had a little grate underneath and an open mouth the length of the oven. When a little charcoal and fire was put inside on top of the grate it heated the oven and kept it hot. Then they put the fresh half mould that they had just made to dry above the opening where there was a little grid. While it was drying they made another, and in the same manner when it was made they put it near to the first one, and so they continued up to six or eight pieces. Then they again took up the first one (which had had sufficient heat and time to become dry or nearly so) and on top of this they made the other companion, and on top of this companion they moulded other patterns on the outside.* They did the same

*The finished mould was like a multidecked sandwich, with patterns between each two layers. The lute or clay moulding composition would be hard when baked and would need no external support except wire binding. If each built-up pattern contained 60 pieces, a single mould of 20 sections would contain 1,200 small castings—a good example of quantity production before the machine age.

with all the others and then beginning again from the first one they continued on to all the others in succession, so that when the moulds were finished and were drying one on top of the other they were altogether half a *braccio* or more in height and about half a *palmo* wide, or as wide as a board or the particular pattern, for no useless space should be left around them. After these were finished and well dried in an oven like those where bread is baked, they opened them again, layer by layer, and took out the patterns. These gave twenty or more pieces to each mould, resulting in a great number, for some patterns contained as many as fifty or sixty pieces. Finally, after having closed the moulds again and sealed them up, and after having repaired or retouched the gates or any other points where it was necessary, and having given them a wash of fine ashes and water, they put the moulds together again and returned them exactly to their original position, then they bound them very well with iron wires and sealed them with the same lute. Then they took sixteen or twenty of these moulds and, standing them up on the ground all together, they made a circle of rocks around them and covering all the moulds with charcoal they baked them again. After having baked and arranged them well and having made in each part of the mould a gate which would convey the metal to the gates of all the other moulds, they took them to the furnace where the copper was colored. [21] When they took one or two of those crucibles from the furnace they filled the mass of the moulds with that well-melted, yellow-colored copper. They did this singly, or in pairs, or several at a time, according to the number of moulds, filling all the moulds made by the masters whom I have described above. They did this day and night as occasioned by the colored well-disposed material, or depending on the number of moulds ready.

Pondering on this I thought to myself that this shop alone was sufficient to furnish not only Milan but also the whole of Italy, and surely it seemed to me a splendid and fine undertaking for a single merchant. I thought that he should take great pains to keep alive all the fine undertakings that I saw in that place and continue them and surely it pleased me to see so many things being moulded continuously, and continuously being cast. I believe that no similar work is done in Flanders or in other places in Germany where they make candlesticks, cups, and many other things as they do. Many in those parts are not as advanced as we are.

I have decided to tell you in its proper place among the semiminerals about the earth that colors copper into brass by its peculiar properties.

Here I tell you only that I believe—indeed I know for a certainty—that in every place where it is found or can be easily procured it would be possible, as elsewhere, to do the same work of coloring copper into brass following the procedure which I have described. I do not know that this earth serves any other purpose than coloring copper, because the mineral matter is of bad elemental mixture and poorly fixed. Only with copper does it melt and become incorporated, because of its peculiar and occult suitability; and not only does it color copper another color, but it increases its volume so much that the workman covers the cost of the copper and the expense of coloring it, while with every other metal it evaporates and becomes ashes by itself in the fire. If you melt with the copper more than its nature can absorb it makes it more brittle, in addition to making the work a somewhat deeper yellow in color.

Having considered what I have told you concerning brass, it seems to me impossible to deny that it is one of the works of alchemy, since copper is red by nature and this redness is taken from it by art and converted into yellowness. This seems to me especially true in that by fire its fine color evaporates as with [the alchemists'] other sophistries and it is returned to red copper and almost to its former nature by four or six meltings.

In addition to the above earth, copper is also colored yellow by tutty* and there are others who color it with a certain powdered red earth that Arabian merchants mix with ginger in order that it may weigh more.

I do not wish to omit telling you likewise that with whichever of the above things this brass is made, you must be careful that it does not evaporate if you desire to preserve a good color on melting. [21*v*] But this applies more to small things than large. Since I cannot tell you every detail in the discussion on melting I thought it well to advise you and give you here the method that I have seen in my own experience. Certainly I have also learned it from the alchemists. Every time that you wish to melt, in order to prevent the color from evaporating, cover the top of the crucible or other melting vessel with crushed glass and have the blast of the bellows blown on it from beneath. I must warn you also that,

* Tutty is an impure oxide of zinc that collects about the upper parts of furnaces in which ores containing zinc are smelted. According to Löhneiss (*Bericht von Bergwercken*, 1617), Erasmus Ebener introduced the manufacture of brass from *ofenbruch* in place of native calamine at Rammelsberg in about the year 1550. This resulted in a great profit, as vast piles of this material had accumulated as the discard of many years. Ercker (1574) mentions the use of the furnace accretions from the Goslar lead ores for brass making, and describes a blast furnace with removable front to allow their ready removal.

for your own health, you must avoid its smoke when you melt, because this is very harmful and continuing over a period of time it is deadly poison; often it leaves men stunned, paralyzed, or stupid, or makes them asthmatic and gives them more diseases than I can name. This is caused by its subtle and penetrating fumes, and, because of its poor and ill-fixed elemental mixture, it exhales almost as much as quicksilver does.

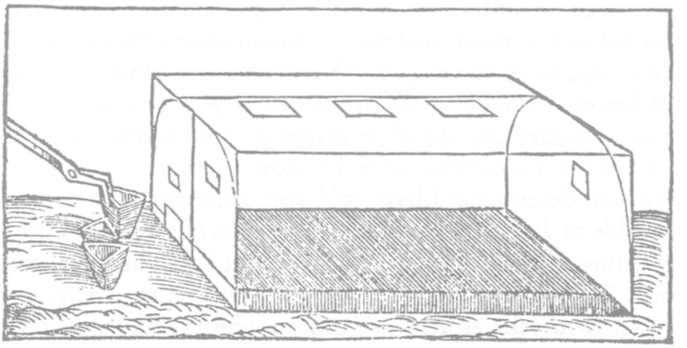

Figure 4. Furnace for making brass.