

PROFILES IN TOXICOLOGY

Georgius Agricola (1494–1555): Scholar, Physician, Scientist, Entrepreneur, Diplomat

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The second half of the 15th century marks the births of a number of personalities who have shaped what we consider modern times: Leonardo da Vinci (1452–1519), Erasmus of Rotterdam (1469–1536), Nicolas Copernicus (1473–1543), Martin Luther (1483–1546), Paracelsus (1493–1541), and Georg Bauer (1494–1555), to name a few.

Bauer was born in Glauchau, Saxony, as the son of a prosperous clothier. He attended the University of Leipzig, Saxony, from 1514 to 1517, originally with the intent of becoming a priest. One of his professors, Mosellanus, a former student of the great humanist, Erasmus, may have enticed Bauer to study ancient languages and become a teacher instead. During this time, according to the scholarly tradition of his days, Bauer Latinized his name to Georgius Agricola.

His first assignment was at the public school in Zwickau, Saxony, where he advanced rapidly to vice-principal and principal. In this capacity he reformed the curriculum thoroughly, transforming the religion-oriented school into a modern educational institution.

In 1520, Agricola returned to the University of Leipzig to study medicine and science. There, he came into close contact with a circle of humanist scholars who maintained a lively exchange of ideas with Erasmus, and this initiated a lifelong friendship between Erasmus and Agricola. In simplistic terms, humanism put the dignity and importance of the human individual at center stage, allowing development of one's intellect and knowledge to the full, without constraints imposed by religion.

The most famous universities of Agricola's days were in Italy. Consequently, Agricola went to Italy in 1524 to complete his degree. He attended lectures of Pietro Pomponazzi, a professor of philosophy, who taught that man achieves happiness and virtue through practical, morally impeccable acts rather than piety. Amazingly, Agricola incorporated all these ideas, made them the foundation of his future way of thinking, yet remained a deeply reverent Catholic throughout his life. This seeming dichotomy did not paralyze him, but allowed him to

become one of the pioneers of rational scientific argumentation.

In 1526, Agricola returned to Saxony and in the following year accepted the position of town physician in St. Joachimsthal, Bohemia. It is located in the midst of the Erzgebirge, "ore mountains," then the most important mining area in central Europe. St. Joachimsthal issued a silver coin known as a "Joachimsthaler," soon truncated to "Taler," and for many years it was one of the most popular currencies. Eventually the name was Anglicized and lives on as "dollar."

In the same year, 1527, Agricola married the widow of a mine tithe official. It is fair to speculate that his wife brought into the marriage a sizeable number of shares from the nearby silver mine, Gottesgab, or "God's gift." Now being co-owner of a mine had a profound effect on Agricola's further life: he would devote any spare time off his tight schedule as town physician to matters of mineralogy. It met well with his interest in natural, mineral-based remedies. Within 3 years he published his first scientific work, *Bermannus sive de re Metallica*. It describes a physician, Bermannus, traveling with two friends through the Erzgebirge mining district, discussing matters of geology and mining that were representative of that very region. The work was published by Froben in Basle, Switzerland, the publisher's chief editor being none less than Erasmus himself, who wrote an enthusiastic dedication to the work.

In 1531 Agricola moved to Chemnitz, Saxony, just about 30 miles north of St. Joachimsthal, and stayed there for the rest of his life. He assumed the position of town physician in 1533, and during the remaining twenty-plus years of his life he wrote at least 15 more major works and, in addition to mineralogy, metallurgy, and mining jurisprudence, covered such topics as religion, politics, history, the plague, putrefaction of the human body, medicinal springs, and earthquakes.

Evidently Agricola played his cards as town physician and entrepreneur well and became the richest man in Chemnitz. In his last published work, *De Re Metallica* (Of Metal Matters), he disclosed some of his secrets. All the following verbatim statements are taken from the only English translation of *De Re Metallica* (Agricola, 1950). It was translated, with extensive technical and historical notes, in 1912 in London, by a young

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American mining engineer and his Latin-trained wife. Their names were Herbert Clark and Lou Henry Hoover.

Furthermore, there are many arts and sciences of which the miner should not be ignorant. First there is Philosophy, that he may discern the origin, cause, and nature of subterranean things, for then he will be able to dig out the veins easily and advantageously Secondly, there is Medicine, that he may be able to look after his diggers and workmen . . . , that he himself may be able to heal them or may see that doctors do so. Thirdly, to follow Astronomy, that he may . . . judge the direction of the veins. Fourthly, there is the science of Surveying that he may be able to estimate how deep a shaft should be sunk to reach the tunnel which is being driven to it Fifthly, his knowledge of Arithmetical Science should be such that he may calculate the cost to be incurred in the machinery and the working of the mine. Sixthly, his learning must comprise Architecture, that he himself may construct the various machines and timber work required underground. Next, he must have knowledge of Drawing, that he can draw plans of his machinery. Lastly, there is the Law, especially that dealing with metals, that he may claim his own rights . . . , that he may not take another man's property . . . , and that he may fulfill his obligations to others according to the law" (Book I).

And he had advice for the investor in mines: "It is complained that some sellers and buyers of the shares in mines are fraudulent. I concede it. But can they deceive anyone except a stupid, careless man, unskilled in mining matters?" (Book I) and more of it in Book II:

Neither ought miners to be altogether distrustful of fortune, as we see some are, who as soon as shares of any mine begin to go up in value, sell them, on which account they seldom obtain even moderate wealth" and this: "Indeed, . . . it is important that the owner, who is diligent in increasing his wealth, should frequently himself descend into the mine, and devote some time to the study of the nature of the veins and stringers, and should observe and consider all the methods of working, . . . for sometimes he should undertake actual labour, not thereby demeaning himself"

In 1546, Maurice, Elector of Saxony, made Agricola the Mayor of Chemnitz, a one-year term that he held again in 1547, 1551, and 1553. This appears surprising, since Agricola was Catholic, whereas the Elector (who had been instrumental in promoting Luther's Reformation) and the people of Saxony were predominantly Protestant. Maurice was quite a turncoat when it came to choosing allies in the religious wars of his days, but in the end he prevailed. It was a stroke of political genius to employ the highly renowned, yet Catholic, Agricola as a diplomatic emissary.

Agricola died in 1555, according to legend from a stroke that he suffered during a heated religious debate (von Randow, 1994). His hometown rewarded him poorly for his economic and political achievements: they refused burial to the lifelong Catholic, and so he lies buried in the cathedral church of Zeitz, Saxony. This refusal had sad repercussions, in that Agricola's heirs then refused to surrender his unpublished work, and at least eight of his major works are lost to posterity.

What is it that makes Agricola stand out high above his peers? Most certainly it is his ability to strictly use logical deduction rather than ancient tradition and dogma. In his own words, "I have omitted all those things which I have not myself

seen, or have not read or heard from persons upon whom I can rely. That which I have neither seen, nor carefully considered after reading or hearing of, I have not written about" (*De Re Metallica*, Preface).

Agricola's works on mining and related sciences were not the only ones available in his time. However, all other works were steeped in the ideas of alchemists, of whom Agricola had a low opinion. Logical, rational, or scientific thinking were hardly to be found in his world. Despite the Renaissance and Humanism, superstition was still rampant in Agricola's day, but he emancipated himself from religious constraints.

In his 1546 published work on mineralogy, he set initial standards for the science of the future. Knowing nothing of atomic theory, stoichiometry, or crystallography, it was a colossal achievement to refute the ancient theory of the four elements: earth, water, fire, and air. For a classification of minerals, he used criteria of outward appearance such as hardness, color, consistence, solubility, smell, or taste. To the then-recognized seven metals, gold, silver, copper, tin, iron, lead, and mercury, he added bismuth and antimony. He was the first to recognize the difference between igneous and sedimentary rock, and he comprehended that ore deposits were formed by precipitation from solutions that had seeped into fissures in their surrounding rocks.

De Re Metallica was completed in 1553 and published by Froben in the year following Agricola's death. He had taken 20 years to write the book on prospecting, surveying, metallurgy, logistics, mine and smelter construction, mining tools and machinery, and mining-related health problems. It comprises 12 books (chapters), including hundreds of woodblock prints, some of which depict nothing less than the early industrial revolution! He brought forth an achievement that was beyond anything contemporary and it remained the miner's handbook for almost 200 years.

The most fascinating quote appears in Book I of *De Re Metallica*, and makes it worth reading the whole opus: ". . . there is no compensation which should be thought great enough to equalize the extreme dangers to safety and life." Not the kind of statement one expects from a Renaissance businessman. Could he also have cared about the environment? Read this:

And when the woods and groves are felled, then are exterminated the beasts and birds, very many of which furnish a pleasant and agreeable food for man. Further, when the ores are washed, the water which has been used poisons the brooks and streams, and either destroys the fish or drives them away. Therefore the inhabitants of these regions . . . find great difficulty in procuring the necessities of life . . . (*De Re Metallica*, Book I).

This was written in the middle of the 16th century! And it should be added that Agricola vehemently rejected slavery, endorsed social plans for the poor, and stated that mines should be operated in a 5-day workweek with 3 shifts of 8 hours each per day; he also included a recommendation to not run the late (3rd) shift. Additionally, he advocated that miners should not

work two shifts per day because of the increased risk of occupational injury.

With respect to occupational science, however, one must focus on Book VI of *De Re Metallica*, for it is the one that deals with the diseases of miners. After describing the tools and machinery of mine operation, including quite modern ventilation equipment, Agricola continued: "It remains for me to speak about the ailments and accidents of miners, and of the methods by which they can guard against these, for we should always devote more care to maintaining our health, that we may freely perform our bodily functions, than to making profits."

Miners of his time wore a smock with belt, breeches, a short apron, and a pointed cap. If they appear reminiscent of gnomes—those are modeled after medieval miners! Agricola knew about personal protective clothing. He recommended elbow-high leather gloves for work with aggressive minerals, and a veil worn before the face to protect from dusts. He thought highly of rawhide boots for workers standing in cold water, evidently cognizant of gout and arthritis. About the dangers of dusts he reported: "The dust which is stirred and beaten up by digging penetrates into the windpipes and lungs and produces difficulty in breathing, and the disease which the Greeks call asthma. If the dust has corrosive qualities, it eats away the lungs, and implants consumption in the body . . ." (*De Re Metallica*, Book VI).

It has been said that Agricola recognized cancer caused by radon, the latter being found frequently in the mines of the Erzgebirge, as he wrote of "an angel choking old miners to death." It is very unlikely, however, that he had the diagnostic abilities to differentiate the various occupational respiratory diseases. But he knew of the gas that sinks to the bottom of mines, extinguishes candles and takes away the breath of miners (carbon dioxide) as well as a stinking gas that kills people (hydrogen sulfide). He also reported on a gas that reeks of garlic (arsine). About mercury smelters, he wrote that inhaling the fumes, which have a sweet smell, makes the teeth fall out (fulminant mercury poisoning).

Agricola provided a vivid description of two kinds of arsenic poisoning. The one known as black foot disease causes gangrene, whereas the other, acute poisoning, makes the extremities swell without causing pain. He advised that miners must leave the mine immediately once such a condition has been recognized.

Agricola thought that mine foremen bore most of the responsibility for their workmen's safety. They had to make sure ladders and shaft walls were kept in excellent condition, and that all machinery was always fully operable. He advised keeping the cold north winds out of the mineshafts so that the rungs of ladders could not freeze over—deadly falls were evidently as common as mudslides and collapsing tunnels. He admonished the miners, for the sake of their own safety, to be highly circumspect in their workplace surroundings.

All this said, Agricola was not free of mistakes. He knew metallic arsenic and zinc, but like everybody else considered them lead-tin and lead-silver alloys, respectively. He wrote about *cadmia* and *cobalt*, not knowing that these poorly defined, mostly lead- and arsenic-containing minerals, held new metals as minor constituents. He used the term *molybdaena* indiscriminately for a variety of minerals, by which means he defied his best purpose and created considerable confusion.

At the very end of Book VI, with reference to his earlier work on subterranean life forms (*De Animantibus Subterraneis*, 1549), he insisted on the existence of underground goblins or imps, harmless ones as well as malevolent ones called *Kobold*, closely associated with the very harmful mineral *cobalt*. Still, this must not detract from the fact that Agricola's contribution to modernity is, basically, to have pushed wide open the gates to modern science.

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