Agricola and the study of early metallurgy

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Abstract

This paper is an appreciation of the life and work of Georgius Bauer, Agricola, on his 500th birthday, concentrating on his most famous work, *De re metallica.* The importance of this work to modern archaeometallurgy is assessed, together with an overview of the Renaissance world of intellectual curiosity and enquiry in which Agricola was a leading figure.

1994 is the 500th anniversary of the birth of Georgius Bauer, better known in the latinised form as Agricola, author of numerous books on geology and mining, and whose crowning achievement was *De re Metallica,* published at Basle in 1556.

This work is pivotal to the study of early metallurgy, it is the first comprehensive work on mining and metallurgy, written in a modern form, but still sufficiently close to antiquity to be of inestimable value in understanding their much more poorly recorded processes. As Tylecote states in the introduction to *The Prehistory of Metallurgy*[1] 'The prehistorical period of ... metallurgy ... can be said to end with the appearance of Agricola's *De re Metallica* — the first real treatise on metallurgy — in 1556'.

Before considering Agricola's contribution to the study of metallurgy, a brief biographical note will be useful to establish the context in which his works were produced. The introduction to the English edition of Hoover and Hoover[2] contains a useful biography which has been followed here; the standard biography by Wilsdorf was published in 1956[3]. Little of Agricola's work is available in English apart from *De re Metallica;* the complete edited works have been published, translated from their original Latin into German, by the State Geological Museum of Dresden under the general editorship of Dr Hans Prescher[4].

Agricola was born on 24th March 1494 in the small town of Glauchau in Saxony. Little is known of his parents, but they were able to send their son to the University at Leipzig, where he took his degree in 1517. After this he taught Latin and Greek at the municipal school at Zwachau. Within three years, while still only 26, he was head of the school and had published a Latin grammar. However the life of a provincial schoolmaster clearly did not appeal and in 1522 he was back at Leipzig studying medicine. There the new learning of the Renaissance attracted him and within three years he was studying at the universities of northern Italy where he was to spend a further three years. From surviving correspondence it is obvious that he was already engaged in research, apparently preparing a new edition of the works of the late Roman physician Galen.

On his return from Italy he was appointed town physician at Joachimsthal in the Erzgebirge mining region of Bohemia in 1527. The mines of the Erzgebirge were the most important in Europe, producing a wide range of non-ferrous metals, and at this time the mines were undergoing a rapid expansion with considerable interest and investment in new methods. In fact the mines were probably the most advanced in the world, and had already overtaken the technologies of the ancients in both mining and smelting. Joachimsthal epitomised this expansion: the town was a rapidly expanding boom town established just a few years previously, and it is very likely that the main attraction for Agricola was the proximity of the mines and the opportunity they afforded to study the geology of the deposits and the technology of the processes. Indeed he later claimed that he spent all his free time studying them, together with the works of the ancient authors on scientific matters, above all the *Natural History*[5] of Pliny. At this time Agricola began his serious writings on geology and metallurgy, including *De re Metallica.* The first metallurgical work to appear was *Bermannus the Miner*[6], a didactic dialogue concerning geology, mineralogy and mining. This includes some quite hard-headed discussions on the interpretation of some of the metallurgical terminology used in the Natural History. For example Agricola discusses at some length the apparently confused description of the basic silver-smelting process given by Pliny at Book 34.47, where he states that the first smelting yielded *stagnum,* the second *argentum,* leaving a dross of *galena.* The problem arises with *stagnum* and *galena,* especially when taken in conjunction with the use of the same terms elsewhere in the *Natural History.* Agricola finally came to no firm conclusion, which is still perhaps the best course to take, and is certainly much better than for example the totally erroneous translations in the standard modern English text[7]. The debate in *Bermannus* was the first serious critical discussion of an ancient technical process to be published, and Agricola's ideas on the

processes used by the ancients in this and other works are still relevant today[8].

After only three years he left the small town, perhaps understandably, first to study more mines and processes elsewhere in the Erzgebirge, but in 1533 he was appointed city physician to Chemnitz where he was to stay and prosper for the rest of his life.

He married, raised a family and entered public life, being appointed Burgomaster on four occasions, and was entrusted with several important diplomatic missions by the rulers of Saxony. His official medical appointment was of course important and would automatically have given some status, but clearly respect for him went well beyond this, and it seems certain that it was his geological and metallurgical knowledge and judgement that commanded such regard. Much of the wealth of Saxony derived from its mines and metals, and the Elector Count Maurice directly encouraged his work, granting him amongst other things a fine residence. Agricola was also consulted by neighbouring rulers on mining matters, though it must not be thought that his advice was only of a general abstract nature, or just for others to follow. He himself invested in a mine (the God's Gift mine at Albertham), which then as now was always a risky venture. However he could later claim in a rather self-satisfied manner that 'we, as a shareholder, through the goodness of God have enjoyed the proceeds of this God's Gift since the very time when the mine first began to produce such riches'.

It was in these later years that the majority of Agricola's work appeared in print, including the *De Ortu et Causis Subterraneorum,* which is the first modern treatise on geology, which included sections dealing with the geneses of ore bodies. He correctly postulated that most metalliferous ores had originally been deposited from aqueous solution in pre-existing cracks in the country rock, and this alone would have earned him an important place in the history of mining geology. The form of many ore bodies is very suggestive of this hypothesis as exposed in the mines, but almost certainly Agricola was the first scholar to have direct experience of a mineral deposit; it is most unlikely that Aristotle, his illustrious predecessor in the field of geological theory, ever went near a mine. Indeed this direct experience of a subject such as mining neatly encapsulates the profound difference of approach between the classical philosophers and the medieval schoolmen, and the true spirit of universal scientific enquiry which arose in the Renaissance amongst men like Agricola. Thus his life-long friendship with Erasmus is entirely appropriate, and, as editor in chief of the great publishing house of Froben, Erasmus encouraged Agricola's writing and Froben published many of his works including *De re Metallica.* Whilst the other books were being published, work on *De re Metallica* continued, and it seems that through the long years of preparation Agricola and his friends recognised that this work was of especial importance. It appears to have been substantially complete by 1550, and was with Froben by 1553, there to be delayed whilst the illustrations were prepared by Basil Wefring and others.

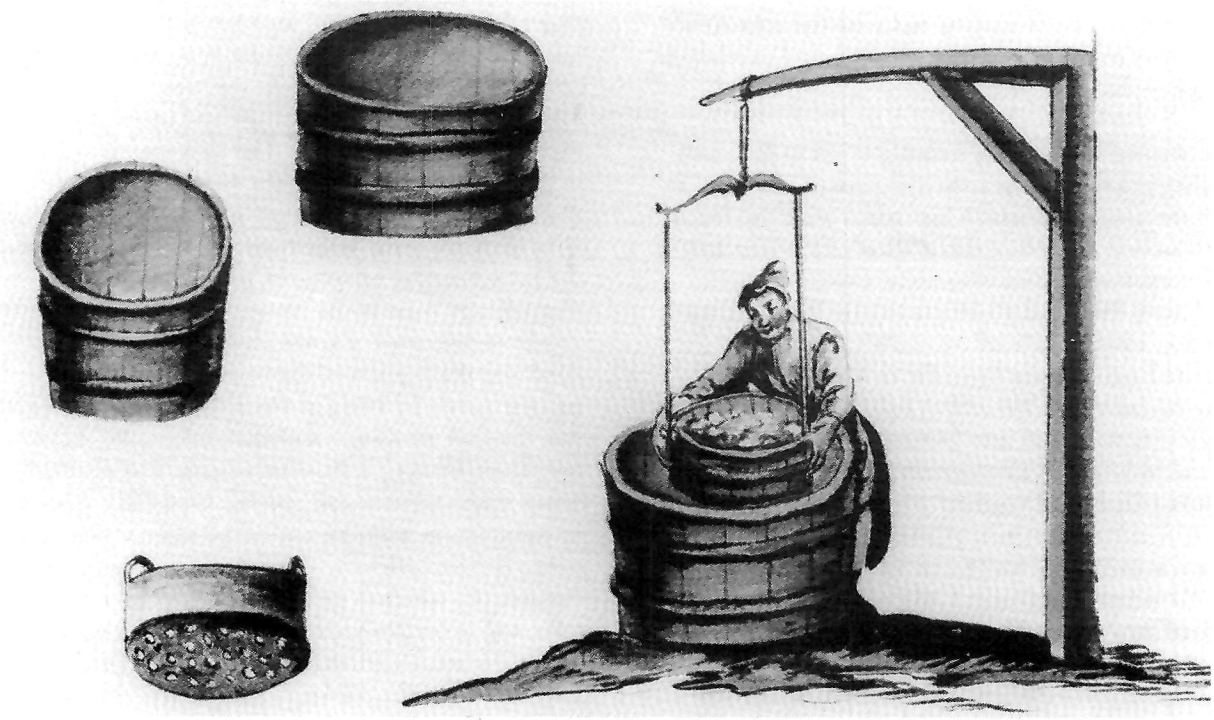
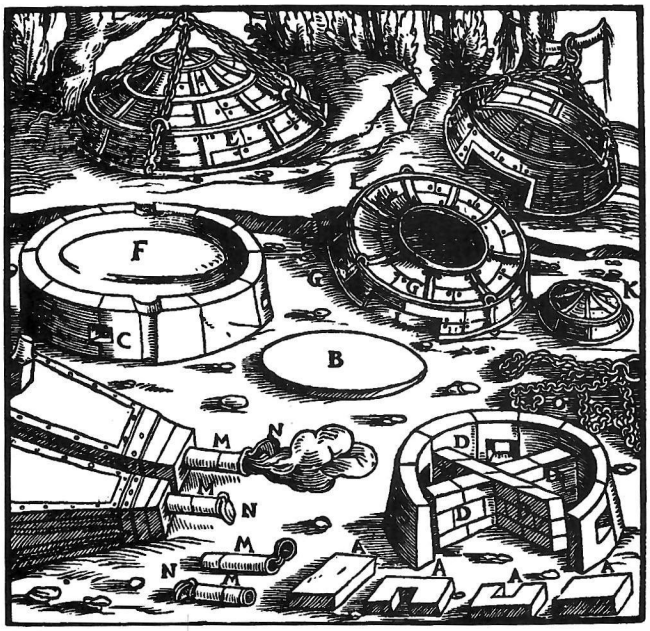


Figure 1: Illustration of ore separation by jigging with a sieve in a trough of water. Taken from the contemporary Schwarzer Bergbuch *in the Deutsches Museum in Munich*[19].

These woodcuts must be amongst the most familiar and widely used technical illustrations of all time (including of course the front covers of *Historical Metallurgy*). Some technical books were already illustrated[9] (Fig 1) but here the clarity, attention to detail, technical accuracy as well as the number of illustrations are unsurpassed. Very often in order that complex apparatus be fully understood it is depicted under construction with all the components clearly exposed (Fig 2). Agricola must have worked closely with his artists to achieve the desired result, but for all their detailed labelling the illustrations are never referred to directly in the text. This would suggest that the illustrations were begun when the text was substantially complete, although it seems likely that illustrations were intended from the outset. The woodcuts are not just technical drawings but animated scenes of life and work; looking through them the reader is struck by the number of times the miner's dog appears, either trotting along behind his master or curled up asleep by the furnace (Fig 3).



A—Rectangular stones. B—Sole-stone. C—Air-holes. D—Internal walls. E—Dome. F—Crucible. G—Bands. H—Bars. I—Apertures in the dome. K—Lid of the dome. L—Rings. M—Pipes. N—Valves. O—Chains.

Figure 2: Agricola's illustration of a cupellation furnace shown under construction so the components may be more clearly revealed.

De re Metallica was finally published in 1556, a year after Agricola's death, and was immediately recognised as the outstanding work on the mining and extractive metallurgy of the non-ferrous metals. The book went through four Latin editions in the next century, and was translated into German and Italian and probably Spanish relatively soon after its first appearance. However it was not translated into English until the 20th century, too late to have any influence on mining in this country, although Ercker's treatise published in 1574, which concentrates on the refining of metals, was translated into English in 1683[10]. The post-medieval resurgence in mining and extractive metallurgy in Britain is always ascribed to the Germans, and of course German miners were certainly brought over to Cumbria to mine and smelt copper in the 16th century. What is less clear is whether they were the source of all subsequent innovation, and also what was the long term influence and prestige of German mining technology generally[11]. It is perhaps significant that no one felt it necessary to translate the acknowledged premier text of German mining practice into English whilst it might still have been of some practical use.

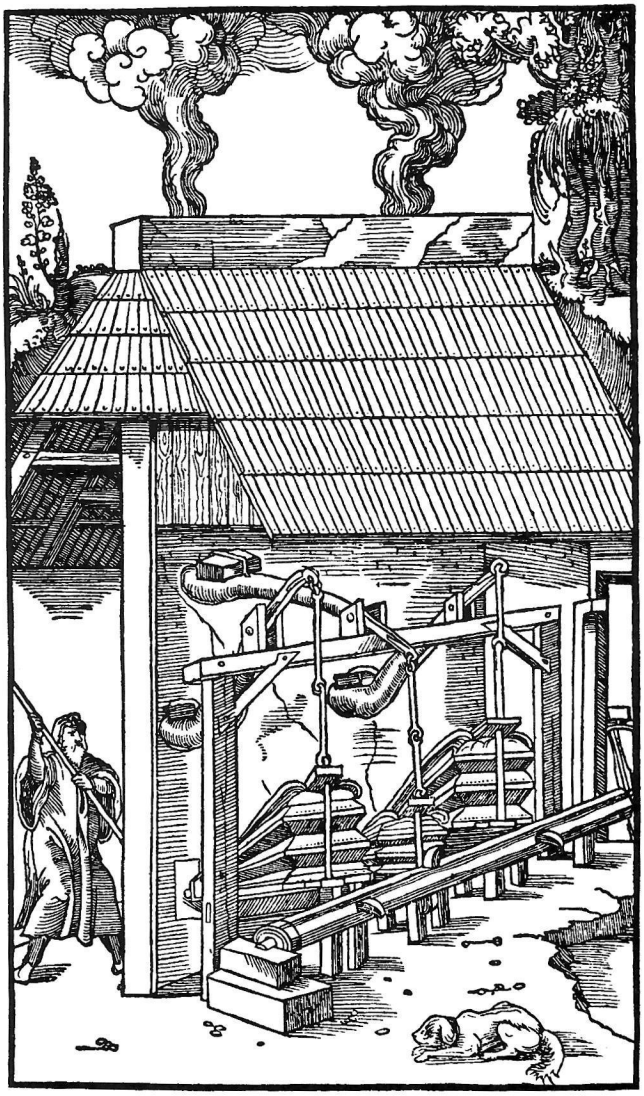


Figure 3: Agricola's illustration of bellows system, complete with sleeping partner!

The first and only English edition to appear was that prepared by the mining engineer and latterly President of the United States of America, Herbert Hoover, and his wife Lou in 1912. The edition is a monumental triumph of scholarship in its own right, quite

appropriate to the scale of the original work. The edition contains copious footnotes and appropriate quotations from the classical authors, expanding and developing Agricola's themes. Indeed the Hoovers' familiarity with a very wide range of Classical sources and their judicious use of them is rather humbling; in the last eighty years or so understanding of classical metallurgical practice has advanced very little! Thus the Hoover and Hoover English edition of *De re Metallica* is also an important source work for the interpretation of classical metallurgy in its own right.

Agricola's work is of unique importance to the study of early mining and extractive metallurgy. Mining and smelting had never been adequately described before. Classical authors, notably Pliny, where they mentioned the subject at all treated it in a very detached manner, clearly intended for intellectual diversion rather than for practical instruction. The alchemists and later schoolmen with few exceptions[12] are practically unintelligible, and as far as real metallurgical knowledge was concerned one suspects that they were out of their depth, with ignorance and confusion hidden, perhaps even from themselves, by obscure language and oblique references. There were a few exceptional technical writings even in the medieval period, such as the treatise on metalworking by the pseudonymous monk Theophilus[13] which was probably compiled in the 12th century. Theophilus deals clearly and in great detail with all aspects of metalworking with which he would have been familiar within the confines of his monastic workshop, but he is much more vague, and sometimes misinformed, when dealing with the mining and smelting of metal with which he clearly had no experience at all.

In the past the general perception of mining and extractive metallurgy suffered under a double disadvantage. First, mines were associated with heavy manual labour under difficult conditions, the labour of slaves and of condemned prisoners — no one bragged of being a miner in antiquity. Secondly, mines were usually situated in mountainous regions, sufficiently remote and hostile to be feared and shunned in themselves. The prevailing romantic idea of the wild as being in any way beautiful is of recent origin and would have been incomprehensible to the ancient or medieval mind.

The universal curiosity of the Renaissance changed all that and, as already noted, Agricola was the epitome of the Renaissance scholar, grounded in the classics but bent on personal observation and measurement. His carefully ordered thoughts were expressed with clarity. Every subject relating to mining and non-ferrous smelting and refining is dealt with, and not a few of the older notions and superstitions investigated and firmly dismissed. Thus the diviners rod gets short shrift as a prospection method and all aspects of alchemy are derided. The following rather sarcastic piece taken from the Preface is typical:

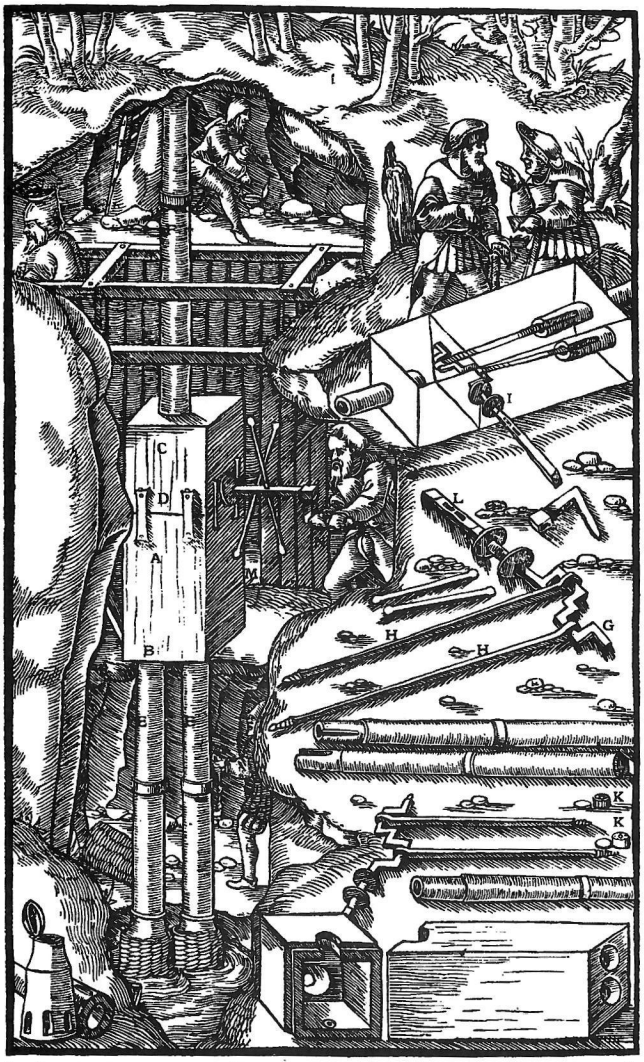
> 'whether they (the alchemists) can do these things (make precious metals) or not I cannot decide; but seeing that so many writers assure us with all earnestness that they have reached that goal for which they aimed it would seem that faith might be placed in them; yet also seeing that we do not read of any of them ever having become rich by this art, nor do we see them growing rich, although so many nations everywhere have produced, and are producing, alchemists, and all of them are straining every nerve night and day to the end that they may heap a great quantity of gold and silver, I should say the matter is dubious. But although it may be due to the carelessness of the writers that they have not

A—Chamber of the furnace. B—Its bed. C—Passages. D—Rammer. E—Mallet. F—Artificer making tubes from litharge according to the Roman method. G—Channel. H—Litharge. I—Lower crucible or hearth. K—Stick. L—Tubes.

Figure 4: Agricola's illustration of removing litharge from a cupellation furnace by wrapping it around a stick.

transmitted to us the names of the masters who acquired great wealth through this occupation, certainly it is clear that their disciples either do not understand their precepts, or if they do understand them, do not follow them; for if they do comprehend them, seeing that these disciples have been and are so numerous, they would have by today filled whole towns with gold and silver'.

A nice put-down, but Agricola goes on to complain of the attention that the nonsensical outpourings of the alchemists receive, compared with an almost total lack of interest in serious mining and metallurgy — a complaint that has all too familiar echoes in the present day interest in pseudo-science and the ultimately dangerous decline in science based on observable, measurable and repeatable phenomena.



A—Box. B—Lower part of box. C—Upper part of same. D—Clamps. E—Pipes below the box. F—Column pipe fixed above the box. G—Iron axle. H—Piston-rods. I—Washers to protect the bearings. K—Leathers. L—Eyes in the axle. M—Rods whose ends are weighted with lumps of lead. N—Crank.

Figure 5: Suction pump for raising water from mines. This is one of many pumping systems described, and quite obviously Agricola was familiar with every detail; one has immediate confidence that this is a practical working piece of machinery.

As already noted, the work of Agricola is pivotal, looking both back to classical antiquity and forward to the Industrial Revolution. The processes he described were already much more sophisticated than those of antiquity, but they are clearly in the classical Roman tradition, a fact much appreciated by Agricola and also by the Hoovers. The processes so clearly described by Agricola are thus invaluable in the interpretation of both the textual and excavated remains of classical metallurgy. Thus he describes and illustrates (Fig 4) how litharge was removed from the cupellation hearth by winding it around sticks making small cylinders, pointing out that this was an obsolete process but one which Pliny described in the *Natural History.* Such cylinders have been found at ancient silver smelting sites such as Rio Tinto and Laurion[14].

A—Mortar. B—Upright posts. C—Cross-beams. D—Stamps. E—Their heads. F—Axle (cam-shaft). G—Tooth of the stamp (tappet). H—Teeth of axle.

Figure 6: Stamp mill. The water-powered trip hammer stamp mill was probably a late Medieval invention[20]. As with many other processes and machinery associated with mining and smelting shown in Agricola's works, this is the earliest known illustration.

Conversely the recent developments described in such detail by Agricola document the beginnings of modern science and a crucial stage in the machine age. The descriptions and illustrations of a range of mine pumping and raising systems are outstanding (Fig 5). Similarly the long sections on crushing and sorting methods, hitherto overlooked, are of the first importance in the history of beneficiation, including for example the earliest illustration of a water operated stamp mill (Fig 6).

Thus with the publication of *De re metallica*, together with other German works on mining such as the *Schwarzer Bergbuch*[15] or the *Probier Buch*[16] and better known works such as the *Pirotechnica*[17] of Biringuccio, published in 1540, and Ercker's *Treatise on Ores and Assaying*[18], published in 1576, the world of mining and metallurgy at last left its prehistory behind.

References

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2 H C and L H Hoover (trans and ed) *Georgius Agricola: De re Metallica* (London 1912). Reprint of the original 1912 edition published by Dover, New York 1950 and happily still in print.

3 H Wilsdorf, *Georg Agricola und seine Zeit* (1956 Berlin).

4 H Prescher (ed), *Georgius Agricola – Ausgewahlte Werke* (Berlin 1956 *et seq*).

5 H Rackham (trans), *Pliny: The Natural History IX* Loeb edition (London 1952).

6 R Halleux and A Yans (eds), *Agricola: Bermannus (le mineur)* (Paris 1990).

7 In the Loeb edition *argentum* is translated as argentiferous lead, which is unsupportable on any philological or technical grounds. At Book 33.95 *galena* is described as a lead ore which the Loeb edition unconsciously equates with the modern specific mineral of lead sulphide, PbS. This is very different from any dross of the silver smelting process as described at Book 34.47, where the Loeb edition translate the term as impure lead. The problems can be resolved if it is realised that most of the argentiferous lead ores were likely to have been the oxidised carbonates, such as cerrusite which of course resembles litharge, PbO, both physically and chemically. Thus the process could be interpreted more logically by sticking to the accepted usual meaning that the first smelting gave an argentiferous lead, *stagnum,* this was smelted or cupelled a second time to give silver, *argentum.* The dross of this process was litharge, which resembled lead ore and could be smelted back to recover the metal in the same way.

8 The first serious informed discussions in English of the classical texts on chemistry and metallurgy are to be found in Richard Wilson's *Chemical Essays,* published in the 1780's by Evans, London. Vol 4 (1786) is especially good.

9 The *Schwarzer Bergbuch* for instance, written in the 16th century, and of which a number of hand-written copies survive. Some of the illustrations from the copy in the Deutsches Museum are published in E H Berninger (ed), *Das Buch vom Bergau* (Dortmund 1980) The first full edition of the whole work has recently been published, H Winkelmann (ed), *Schwarzer Bergbuch* (Graz and Essen 1988)

10 A H Sisco and C S Smith (trans and eds), *Lazarus Ercker's Treatise on Ores and Surveying* (Chicago 1951).

11 R Burt, 'The international diffusion of technology during the early modern period; the case of the British non-ferrous mining industry', *Economic History Review* 44:2 (1991) 249-71. See also D Kiernan, 'Twenty Thousand Miners can't be wrong', *Bulletin PDMHS* 11:5 (1992) 249-253, and further exchanges in the subsequent issue 11:6, 283-4.

12 Zosimos, who lived in Alexandria in the third century AD, wrote some of the few technically intelligible and useful texts. See M Berthelot, *Collection des Anciens Alchemistes Grecs* (Paris 1888) and *La Chimie au Moyen Age* Vols 1-3 (Paris 1893) for the most complete translation of the texts relating to his work on everything from the first good description of the Indian crucible steel processes to the true nature of Corinthian bronze.

13 J G Hawthorne and C S Smith (trans and eds), *On Divers Arts: The Treatise of Theophilus* (Chicago 1963).

14 C E Conophagos, *Le Laurion Antique* (Athens 1980).

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16 A G Sisco and C S Smith (trans and eds), *Bergwerk- und Probierbuchlein* (New York 1949).

17 C S Smith and M T Gnudi (trans and eds), *The Pirotechnia of Biringuccio* (Cambridge, Ma. 1942).

18 see ref 10

19 This illustration taken from the Taschenbucher edition of 1980 (see ref 9).

20 Note that one has recently been discovered at the Roman gold mine of Tres Minas in north Portugal.

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