Chemistry and Metallurgy in Portugal in the Eighteenth Century – The Cases of Gold and Silver

Manuel S. Pinto,[a] *Isabel Malaquias*[a,b]

Various Portuguese-speaking authors wrote about docimasy and metallurgy of several metals either in books or in manuscripts in the eighteenth century; these are valuable sources that need to be studied from the point of view of the history of technology and of the history of chemistry. The present paper aims at giving notice of the most important of such authors and about their ideas on the extraction of gold and silver from their ores. Their works are of the upmost interest although many of them are not easily accessible as in the case of the manuscripts.

Before the eighteenth century, a long tradition of mining and metallurgical activities related to gold and other metals already existed in Portugal. Tin and copper ores were extensively mined and processed in the sixteenth century in order to produce bronze for the manufacture of cannons and other guns. Also deserving mention are the gold and silver mining and processing activities carried out during the occupation of the Iberian Peninsula by the Arabs (roughly from the 8th to the 14th centuries) and those during the earlier occupation of the Peninsula by the Romans (from the 1st to the 5th centuries approximately) when the province of Lusitania, comprising parts of present day Portugal and Spain, was established. Georgius Agricola (1494-1555) refers to tin smelting and to gold mining by the Lusitanians in his *De Re Metallica*, published in 1556. Archaeological evidence of mining and processing works related to copper, tin and iron from pre-Roman times is abundant. In Brazil, a Portuguese colony since 1500, the search for gold and silver started immediately after the arrival of the Portuguese and the search for silver was much increased as soon as it was discovered in Spanish America.[1]

The eighteenth century – authors and works

In 1711 the Italian Jesuit priest Giovanni Antonio Andreoni (1649-1716) published under the pseudonym of André João Antonil a book, *Cultura e Opulência*

[a] Centro de Estudos de História e Filosofia da Ciência e da Técnica/SACSJP. *mspinto@ua.pt*
[b] Departamento de Física/CIDTFF. Universidade de Aveiro, 3810-193 Aveiro, Portugal. *imalaquias@ua.pt*

do Brasil por Suas Drogas e Minas, that described the types of occurrence of gold in Brazil (placer gold, gold in veins), some of the physical properties of the metal (colour, shape, purity) and the gold mining procedures (prospecting, extraction, dressing, panning) in use there. Silver mines in Brazil were also described by Antonil, but such information has been considered doubtful in terms of their existence and economic importance.[2] The author himself wrote on the front cover of his book that it contained information on how to discover silver mines in the colony thus giving the impression that they were not known at the time. He also referred to how to prospect for silver in veins, to various rock types containing silver and to two metallurgical methods of silver extraction using lead and mercury that is, applying the smelting method and the amalgamation method. The circulation of the book was quickly forbidden by the Portuguese authorities, mostly because it described in detail the routes to reach the mines, and this gives a measure of the secrecy with which these matters were dealt with by the Portuguese Crown.

Obtaining silver by subjecting ore to fire was already in use by the Native Americans when the Spaniards arrived in America and the latter continued to use the smelting method until it was replaced around 1556 by the amalgamation method (patio process). In the Potosí mines (then in Peru, now in Bolivia) the patio process was replaced by the faster pan process invented by Alvaro Alonso de Barba (1569-1662) in 1609. In the pan process the ore was mixed with salt and mercury and heated in shallow copper vessels. Most probably Antonil´s description of the extraction of silver was based on Barba's *Arte de los Metales*, first published in 1624, and perhaps also on information obtained from the Jesuit missions, which existed not far from Potosí.[3] Since no silver occurrences of economic importance had been discovered in Brazil at the time, Antonil's book possibly expressed the hope that the metal might exist in the colony, similarly to what had happened in Spanish America.

This book, dedicated to the sugar and tobacco producers and to the owners of gold mines, is a valuable source of information about gold mining and about silver metallurgy in Brazil in the 17th and at the beginning of the 18th centuries.

In *Elementos de Chimica,*[4] published in Coimbra in 1788 (part I - theoretical chemistry) and in 1790 (part II - theoretical and practical chemistry), the Brazilian-born Vicente Coelho de Seabra S. Telles (*ca.* 1764-1804), presented a classification of the "corpos" (bodies) where gold and silver are considered to be ductile species of the gender metals of the order of the non self-combustible bodies –that is they may suffer "calcinação" (calcination) but only if subject to extreme heat (and so they were considered to be perfect metals)– in turn includ-

ed in the class of the combustible bodies. The elective affinities of both metals and their oxides were shown in tables: both elements have affinities with mercury and their oxides affinities with several acids. The author stressed the fact that gold and silver had very little affinity with oxygen and that their oxides were easily reduced. Elective affinity was defined as a kind of selection that a body *b* in a compound *ab* makes to combine with *c*, leaving *a* aside and originating a new compound *bc*. The physical and chemical properties of both metals were presented and used by Seabra to describe some metallurgical and docimastic procedures. According to the author, metallurgy, or the "arte" (skill) of extracting, smelting, purifying and mixing metals, was considered to be one of the most essential branches of chemistry and a specific science related to mining. Docimasy, or "arte" of assaying metals in ores, is the "arte" of knowing through laboratory procedures the nature and the average contents of metals in ores. Three docimastic methods of determining the contents of a given metal were presented by Seabra: one to be applied to hard and refractory ores using fluxes, like borax, followed by smelting, calcination or acid attack; a second one, the physical method of panning, to be used when particles of the metal are mixed with grains of sand for instance; and a third one to be applied to easily ground ores that, after grinding, were subject to dressing, then to fire, leading first to roasting and then to fusion, after what certain reagents should be added to the melt in order to separate any metal that might be mixed with the metal of interest. Seabra described clearly two methods for gold and silver analyses. A detailed description of a procedure for gold was given to assess its purity (gold assaying): through cupellation gold and silver were separated from the other metals (parting) and then the separation of gold from silver can be accomplished using *aqua fortis* and muriatic acid. As for the metallurgical methods Seabra mentioned large scale dressing and panning procedures for the processing of native gold in Brazil and to the crushing, grinding, dressing, roasting and purifying/refining steps in case the metal of interest was combined with other metals ("mineralizado") or mixed with impurities like rock material. Even after all these steps the metal might not be totally pure and so gold and silver amalgamation should be used, a method that Seabra referred to only very briefly, amalgam being defined as the mixture or combination of mercury with any metal.

Elementos de Chimica was written as a textbook, based on Lavoisier's concepts, to be used at the University of Coimbra. Seabra was successively appointed demonstrator of the Chair of Chemistry (in 1791), that included topics of metallurgy, lecturer to the same Chair (1793) and substitute-lecturer of the Chairs of Botany and Zoology (1795) and was promoted in 1801 to substitute-Professor of the Chair of Chemistry. Seabra wished that his book could be also used in Brazil,

but the impact of the book was negligible both in Portugal and in the colony, in terms of chemical metallurgy.[5]

In three memoirs about mineral resources in Portugal and colonies, published in 1789, and in two more, written most probably in 1792, one about the Portuguese Mint and the other one about gold mining in Brazil,[6] **Domenico Vandelli** (1735-1816), an Italian Professor who held the Chairs of Chemistry and of Natural History at Coimbra University and was director of several laboratories in Coimbra (University) and in Lisbon (Ajuda complex, Academy of Sciences, Portuguese Mint), presented a wealth of information about docimasy and the metallurgy of gold. The following is a summary of the key points in these memoirs:

a) About the occurrence of gold in Portugal, he referred to the alluvial gold in the river Mondego, in the northern half of Portugal, and to the geographical areas where gold in rocks (forming veins and masses) might occur and be the source of alluvial gold. Mention was also made of alluvial gold in the river Tejo, in central Portugal, and to the gold and silver in the Iberian Peninsula, exploited in Roman times.

b) Vandelli wrote extensively about the occurrences of gold in Brazil, either native or "mineralizado", about the shapes of the metal (flakes, lumps, etc.), about the rocks and minerals to which it was associated and about the mining procedures for alluvial gold and for gold in veins or masses in the colony, giving technical advice about prospecting and the use of machinery.

c) He noted that from lead occurring in Portugal he had extracted silver and also antimony, useful for laboratory purification of gold. Mercury, also found in Brazil, deserved his attention, too. Vandelli was the first to mention the association of platinum to gold in certain Brazilian gold ores, the so called "ouro preto" (black gold).

d) Vandelli mentioned that the most common method of gold extraction in use in the Brazilian mines (washing/dressing and panning) was the one described by Agricola and by Antonio de Ulloa (1716–1795) and that the Castilians used the amalgamation method instead of panning. He stated that the amalgamation method was more expensive and less useful than the smelting method for the purpose of obtaining the gold not easily separable from gravel, sand or earth, or from rocks where it was seen in streaks. He described in detail the metallurgical method that involved smelting, cupellation and parting using either "agoa forte" or "agoa regia" (*aqua regia*), the gold becoming finally free from the imperfect metals, from lead (used in the smelting process) and from silver that was commonly combined with gold. Vandelli stated that sometimes not

even by amalgamation was possible to separate the metal from some of the very fine sand grains with which it was mixed and so it was lost.

e) The particular cases of extractive techniques of gold from silver-bearing pyrites, from copper-bearing pyrites, either rich or poor in copper, and from gold-bearing pyrites were given special descriptions by Vandelli. These involve roasting, cupellation, cementation and parting. Pyrite was, according to the author, a very common component of the sands ("esmeril") with which gold particles were mixed. Authors referred to by Vandelli were, among others, J. G. Lehmann (1719-1767) and J. G. Wallerius (1709-1785).

f) Docimastic methods for gold occupied a large part of the memoirs about gold mining in Brazil and about the Portuguese Mint. A detailed description of the gold assaying procedures used in the Mint, involving smelting and the use of nitre, corrosive sublimate, *aqua fortis*, and copper, was given. The methods were strongly criticised by Vandelli who suggested that the method described in the *Mémoires de l´Académie des Sciences de Paris* of 1727, involving smelting and the use of bismuth, lead, corrosive sublimate and borax, should be used instead. He was very critical about the careless use of nitre and of *aqua fortis* and the ignorance of the assayers about the presence of platinum in gold which would affect the fineness of the latter.

g) Vandelli also described the very old method of purifying gold with antimony and sulphur, which would result in a very pure metal. He recommended a simple laboratory procedure using "acido de nitro fumante" (fuming nitric acid) to assess the presence of gold in common pyrites and in arsenic-bearing pyrites. Authors referred to by Vandelli in this context were, among others, H. T. Scheffer (1710-1759), B. G. Sage (1740-1824), P. J. Macquer (1718-1784), A. L. Lavoisier (1743-1794), A. Baumé (1728-1804), C. M. Cornette (1744-1794) and C. L. Berthollet (1748-1822).

The memoirs by Vandelli are particularly important because of the technical advice he gave on gold mining (which had practically no impact on the mining industry in Brazil mostly because the mine owners were adverse to the introduction of new procedures and preferred to keep mining activities based on slave labour that was less expensive) and on laboratory procedures related to gold and several of its ores (which had some impact on the procedures in the Portuguese Mint). At the beginning of his memoir about the Portuguese Mint he wrote that chemistry, after leaving aside the attempts to transmute metals, had reached a true state of perfection from which several "artes", in particular metal refining,

did benefit, and made special mention of the good procedures in use in the Mints of England, France and Italy.

A former student of Vandelli, the Brazilian-born Manoel Ferreira da Camara (or Manoel Ferreira da Camara Bethencourt e Sa) (*ca.* 1762-1835) was sent, together with J. B. Andrada e Silva and J. Fragoso de Siqueira (see below), also former students of Vandelli, as naturalists affiliated to the Lisbon Academy of Sciences and paid by the Portuguese Crown, to travel for several years in various countries in Europe. The aim of their mission was to attend courses in Paris given by A. F. de Fourcroy (1755-1809) (chemistry), B. G. Sage (1740-1824) (mineralogy and docimasy) and J.-P.-F. Guillot-Duhamel (1767-1847) (mining) and to stay at the Academy of Freiberg to study geology and mining with W. A. G. Werner (1749-1817), metallurgy with W. A. Lampadius (1772-1842) and other subjects, and also to visit mines, smelters and other Academies related to mining and metallurgy. After returning from their travels they were to be involved in the reorganisation and improvement of mining and metallurgy procedures in Brazil and in Portugal.[7]

In an account presented to the Lisbon Academy of Sciences in 1789,[8] Camara wrote about the amalgamation method used in Brazil for native gold and about the smelting method used for "mineralizado" gold and non-native gold. The smelting method as practised in the "Casas de Fundição" (Government institutions where gold smelting, gold assaying and gold tax collection were carried out that existed in several mining districts in Brazil) was subject to strong criticism because of the way the purity of the gold was assessed (by visual comparison of the colour of the melt with the colour of some gold needles). Camara regretted also that, contrary to what happened in Sweden, Germany and Hungary, much gold of the "mineralizado" type was not properly extracted from its ores because of lack of skills, commenting that in those countries gold and the imperfect metals were extracted at the same time with great advantage. On the amalgamation method, Camara listed the four principles on which it was based and promised to describe in the very same memoir models of machinery and instruments for improving the combination of mercury and gold and also to describe the appropriate means of mercury mining, but such information was not given in the document.

In 1795 Camara published in Vienna, an 80 page book, *Rapport des Résultats des Expériences Chimiques et Métallurgiques Faites dans l´Intention d´Épargner le Plomb dans la Fonte des Minerais d'Argent*.[9] This was just an outline of a more detailed book that he intended to write one day, for the benefit of his country and fellow citizens.

In the *Rapport* he described a docimastic investigation on galenas, aiming at testing two different types of assaying and also a metallurgical experimental study on silver-bearing ores aiming at establishing a better method for their smelting by which lead would be saved and also improving the recovery of silver. For him, docimasy was a branch of metallurgy; he also stated that if the chemical mineralogist must work on each individual ore in order to know its components and the form in which these are, the metallurgist, on the contrary, has to work on the ores as they are found in nature that is mixed up.[10]

Camara engaged in the docimastic study in order to determine if the results of the assay by means of potash used in Harz were in agreement with the Freiberg results where the "flux noir" (a mixture of nitre and tartar) was used instead and also in order to know which assay was preferable in case of discrepancy of results.[11] After comparing the results of some tests that were conducted by him and by another assayer and after expounding some ideas on the physical and chemical aspects of the whole technical process, he concluded that he could not decide which the best assay was. He stated that a method that might be considered good for assaying all the types of galena was yet to be found and that the subject deserved to be better studied in order to discover an accurate, precise and easy method.[12]

The metallurgical investigation was a long and time consuming one that he had started because he knew, before his arrival at Freiberg, that the loss by combustion and volatilisation of lead, extensively used in the traditional way of processing the silver-bearing ores, was huge, and that the amount of silver lost in the scoriae (the leftovers of the smelting process that were thrown away) was also considerable. Having had confirmation of such information in Freiberg he decided to study the problem from a theoretical and a practical point of view, based on concepts and findings of Fourcroy, L. N. Vauquelin (1763-1829), B. Pelletier (1761-1797) and others. Camara's ideas and the experimental work were focused on: the nature and composition of the mixtures of ores (silver ores, silver-bearing lead ores and silver-bearing copper ores) that were subject to smelting; the role of some elements present in them (sulphur, arsenic, phosphorus); the chemical processes involved (oxidation, reduction), and on the role of heat produced by the reverberating furnace that he considered the best one for the purpose. His conclusions and his suggestions to improve the method and the furnace are too long to be reproduced in full, but a paragraph summarizes the main results from Camara's experiments: it was possible to simplify the smelting of the silver ores 1st by oxidation or combustion of the ores that contained the metal not too strongly bound; 2nd by smelting these very same ores without adding anything combustible except lead;

3rd by the fusion in furnaces applying just the heat or the caloric needed for the smelting and for the vitrifying of the metals to be obtained after separation from the silver.[13]

Lampadius considered that the *Rapport* deserved to be translated into German and promoted the publication in 1797 of the translation, with comments. The result was a 95 page book with Lampadius' comments (in footnotes and in a final summary), disagreeing in many aspects with Camara's ideas.[14]

In 1796 Camara wrote a memoir (which was never published) about the methods used in the foundries of Zalathna, in the Principality of Transylvania, of mineral dressing and of smelting which were famous all over Europe.[15] Ores containing both gold and silver were subject to smelting following lines that had been adopted after some testing and that led to a high degree of metal extraction even from low-grade ores. Native gold was subject to amalgamation. In the memoir Camara stated that the amalgamation method in use in Saxony at the time should be applied in Zalathna to silver-bearing minerals and even to gold-silver-bearing ores. He expressed this view possibly because he knew, before his arrival at Zalathna, that high amounts of gold in the scoriae and other losses of gold had been detected. This problem would not occur, in his view, if a "gold standard" ("padrão de ouro") was used in frequent testing of the smelting process.

Camara deserves to be commended for his continuous interest on metallurgy and docimasy, crystallised by his experiments in Freiberg and by his firm ideas.

Joaquim Pedro Fragoso de Siqueira (?–1833) was the author of a manuscript in Portuguese written in 1796 and kept at the Lisbon Academy of Sciences[16] about how silver was refined in the Halsbrück foundries, near Freiberg, in a laboratory called "das Brennhaus". The silver obtained either by cupellation or by amalgamation in the Halsbrück foundries and in the "Basse-Mulde" laboratory (see below) contained lead and copper as impurities. In the manuscript a very detailed description was given of how a very pure melt of silver was obtained by the careful use of a coal fired reverberating furnace and special crucibles that led to the oxidation of the imperfect metals present in the silver which were removed as a final operation. To facilitate the refining process additional lead and copper were added to the melt. The purity of the silver in the melt was assessed by visual inspection.

Siqueira was also the author of 107 page bi-lingual book (in French and in German) where he described the amalgamation and smelting procedures in use in

the foundries of Halsbrück[17] for silver. The book, according to what may be read on the front cover, was intended to serve as a guide for foreigners who wanted to visit the premises and for the youngsters who wanted to study the subject in Freiberg. The very descriptive text, accompanied by a couple of drawings, was in two parts, and an appendix. The first part, about amalgamation, included chapters on, the history of the method in Saxony; the choice, preparation and composition of the minerals to be amalgamated; the roasting of the minerals; the method of sieving, grinding and pulverizing them, and the amalgamation and mercury distillation procedures. The second part, on smelting, had ten chapters on, the roasting and smelting of various silver-bearing lead ores, of copper ores and of the products of such operations; the refining ("affinage") of silver from the lead ores and from the amalgamation process; the re-smelting and the refining of the lead materials resulting from such operations, and (last chapter) the second refining of silver. This last chapter is practically the translation of the 1796 manuscript referred to above. In the appendix mention was made of a pilot laboratory called *Basse-Mulde* intended for amalgamation operations to be conducted before the smelting procedures; two other foundries in Freiberg; published works about amalgamation in the Saxony and about foundries in Freiberg, and to notable things that could be seen in the city. Siqueira's book, although purely descriptive (he does not express any views about what he saw) was published in Germany in the two important technical languages of the times.

Manuel José Barjona (1758–1831) wrote in Latin (*Metallurgiae Elementa*) the first book on metallurgy ever published in Portugal.[18] This was in 1798, whilst in Coimbra, when he was substitute-Professor of Chemistry and Physics teaching mainly Experimental Physics. After the start in 1787 of an academic career he reached the top in 1801 when he became Professor of Metallurgy. The book, after a short introduction on some aspects of the history of metallurgy, was divided in two parts, the first on metallurgy and the second on docimasy (1st section) and montanistic, or the "arte" and science of exploiting ore deposits (2nd section). Docimasy was defined by the author as the science that deals with laboratory assaying using small amounts of ores in order to determine their contents in metals. Metallurgy was defined as the science that, based on the findings of docimasy, dealt with methods by which metals and semi-metals are extracted from ores in large amounts, having in mind their uses by Man.

The first chapter of part I of the book was about the metallic substances in general (their physical and chemical properties, in which he used concepts from Lehman, A. F. Cronsted (1722-1765), H. Cavendish (1731?-1810) and Lavoisier,

among others), and the classification of the forms in which the substances were found in nature. Gold and silver were genders of the order of the perfect metals (those that if subject to friction do not originate any taste or smell). Seven compounds ("espécies") of gold and thirteen compounds of silver were listed, in both cases established on the basis of their combination with other metals or semi-metals. In the second chapter Barjona describes the physical and chemical operations (comminution, smelting, refining, parting, etc.) to which ores are subject, as well as the instruments used for that purpose. In chapter three the basic rules, mostly chemical, that must be used in metallurgical and docimastic procedures were presented.

Part II of the book starts with a chapter on objectives and types of docimasy (either dry or humid) and on general operations, some twenty names of authors being listed. Barjona concluded that humid docimasy was preferable to the dry type. The second chapter is about the chemical analysis of metals and the procedures for all the species of gold and silver are described in detail. The third and last chapter of this section was about cupellation and parting of the perfect metals. For Barjona silver was the easiest metal to subject to cupellation. Parting of silver from gold was described in detail. The second section (on montanistic) started with a chapter on the geology and mining of veins containing metals. The following, last chapter was about metallurgical works and in it he described the washing, grinding and amalgamation procedures relative to native gold and silver, as well as the operations to extract both metals from their various species by the smelting method.

A facsimile edition of *Metallugiae Elementa* edition containing a translation into Portuguese and also comments by Prof. A. Morais Cerveira (Universidade do Porto) and Prof. M. Portugal V. Ferreira (Universidade de Coimbra) was published in 2001.[19] The points made in the comments were that, a) the book was clearly the work of a man much more interested in physics than in mineralogy, mining or chemistry (he uses concepts from the phlogiston theory and from Lavoisier's chemistry); b) Barjona was much more prepared to write about docimasy than about metallurgy, but in both cases he relied heavily on many authors, mainly when writing about metallurgy; c) the structure and the general tone of the book, as well as the fact that it was written in Latin in a time when other textbooks were in Portuguese, reveals his conservatism, although as far as the new Statutes (1772) of the reformed university was concerned, the textbooks should be written in Latin; d) the book anticipated the creation of the chair of Metallurgy. After the reform of the University, the Congregation of the Faculty of (Natural) Philosophy recommended that the Professors should publish textbooks on their

disciplines; Barjona's book is one of the rare examples of compliance; f) no reference to *Elementos de Chimica* is made by Barjona.

The Brazilian-born José Vieira Couto (1752–1827), also a former student of Vandelli, was the author of a memoir dated 1799 about the "capitania" (administrative territory) of Minas Gerais, Brazil, where he presented his ideas on how metallurgical activities should be conducted in Portugal.[20] Couto was sent there by the Portuguese government in order to make an inventory of the mineral resources of the area and see what gain Portugal could get from their exploitation and from the discovery of new mines. At the time, the Brazilian gold (and diamond) mines were already in a state of decadence that had started in the 1750/1760's, in spite of the efforts of the Portuguese Crown.[21] Couto thought that Portugal, having already the mines, the miners and vast areas to be prospected for minerals mostly in Brazil, should have a metallurgical industry that in his view, should start with the preparation of a treatise about three types of metallurgical works, namely: a) "metalurgia mecânica" (mechanical metallurgy), dealing with mineralogy, geology and mining methods to be applied mainly in the gold mines, the author making a brief mention of the amalgamation method and to smelting method using lead to extract the metal; b) "metalurgia pirotécnica" (smelting and the previous preparation of ores) related to other metals and dealing also with non-metallic substances used in metallurgy; c) "metalurgia docimástica" (docimastic metallurgy), or the "arte" of gold and silver assaying, aiming at giving: i) the assayers the necessary training to work in the "casas de fundição" and in the mints; ii) those working in the foundries and in the mines the necessary training to become able to assess properly in a recurrent way the results of their technical activities. The chapter of Couto's memoir dealing with metallurgy ended with a small list of requirements that the potential author of the treatise should fulfil: be good in physics and in mineralogy, have been in Brazil and have seen the mines in Saxony, Hungary, Transylvania and Austria. Possibly he was thinking of either Camara or Andrada e Silva. A second fundamental step to establish a metallurgical industry, according to Couto, would be the construction of foundries to produce iron that was absolutely necessary for the mining activities.

Couto in a sense was an idealist since apart the suggestions above, he gave others including the reduction of holidays to increase productivity of the mines.

In 1801 a Chair of Metallurgy was created at the University of Coimbra, thus separating it from Chemistry, and it was occupied for some twelve years, from 1801

to 1813, by the Brazilian-born José Bonifácio de Andrada e Silva (1763–1838) who had spent ten years in Europe and had gained an excellent reputation as a mineralogist. As professor in Coimbra he apparently was not the most assiduous member of the teaching staff as far as classes were concerned and also tended to miss faculty meetings. A sort of laboratory (the "Gabinete de Metalurgia") was established in 1801 under his direction. He promoted the preparation of a dissertation on the amalgamation of silver ores by one of his post-graduate students in 1805. He never published any book or paper on metallurgy.[22]

In 1801, a chemical laboratory, the Royal Chemistry Laboratory, was established in the Portuguese Mint in Lisbon as a section of the University of Coimbra. Andrada e Silva was its first director. The next year a chair of Docimasy was created in the Mint and was taken by João António Monteiro (1769-1834), also a former student of Vandelli, and substitute professor of Metallurgy from 1801 to 1804 at Coimbra. However, being most of the time in Paris working with the great mineralogist R.-J. Haüy (1743–1822), Monteiro never paid too much attention to the Chair.[23]

Concluding remarks

The number of written works on metallurgy and docimasy (six books and nine memoirs) that were prepared in the 18th century by the seven Portuguese-speaking authors is probably much larger than one could expect from a country in the periphery of science and technology. Except the textbook by Seabra (on chemistry) all the others are technical ones. The quality varies a lot from work to work; in the opinion of the present authors the names of Seabra and Camara followed by Vandelli and Barjona stand out. Three of the books deserved to be published in Vienna and in Dresden, the rest were published in Portugal, either in Coimbra or in Lisbon. As for the memoirs, only four of them, by Vandelli, were then published, by the Lisbon Academy of Sciences. This in a sense gives support to the idea that if academic or formal science was not a strong point in Portugal at the time, technical applications were of much interest in Portugal and Brazil.[24]

The last fifteen years of the century was in fact the period when such publishing activity took place in force: from 1788 onwards all the memories and books, except Antonil's were printed. It was certainly expected that the advanced metallurgical techniques described in them for the extraction of gold and silver (either contained in lead ores or native) from ores in Brazil and Portugal would be put in practice. Most of the works contain detailed descriptions of the smelting and

amalgamation methods as they were practiced in Europe.[25] None of them describes in detail the amalgamation procedures as used in Brazil and so we have to rely for the purpose on W. Eschwege´s *Pluto Brasiliensis*, the original edition of which was published in 1833. The authors of the works referred to in the previous sections were all well aware of what was going on abroad, they cited numerous authors, books and memoirs; many of them were of great reputation. Even so, their works had no visible impact either in Brazil or Portugal. For one reason, no industrial foundries for gold and silver existed in Portugal and Brazil and even the Portuguese Mint and the "Casas de Fundição" in Brazil did not change their procedures much right after the publishing of the books and memoirs. We believe that two factors contributed to this state of affairs: one of them was that the abundance of native gold was still sufficient for it to be collected by the traditional procedures of panning; the other factor was that its replacement by new techniques would not bring any advantage as compared with the slave labour used both in mining and agriculture.

It is interesting to note that various authors (Seabra, Camara, Couto) and the naturalist related to metallurgy, Andrada e Silva, were Brazilian-born and also that in general they dedicated their works to their fellow citizens and to Brazil. At the time many students from Brazil would go to Coimbra, the only university in Portugal, and showing special interests in Natural Sciences they enrolled in the Faculty of (Natural) Philosophy.

The metallurgical processes in use up to 18th century were mainly understood as physical ones in the sense that the amalgams were considered to be mixtures and methods in foundries depended on the use of fire, even if heat had a double role, physical and chemical. It was in the 18th century that a strong impulse arose to understand the chemistry of such processes (oxidation, reduction, etc.). Only later on, with the development of chemistry, were the chemical mechanisms involved in the processes of extracting the noble metals from a great variety of ores, many of them of complex nature, fully understood. Improvements on the extraction of gold and silver from their ores had resulted mostly from experience and experimentation such as the work by Camara, with the several types of silver-bearing ores, and of Vandelli, with the several types of gold-bearing ores, demonstrate.

The Portuguese Crown, influenced by the physiocratic ideas coming from the rest of Europe, was the ultimate promoter of the technical development that Portugal urgently needed to revitalise the mines in Portugal and Brazil and discover new ones, not only the gold mines, but also the iron, coal and mercury mines. Sending naturalists who had graduated in Coimbra either to the colonies to carry out the so called "viagens geognosticas" (geognostic travels)[26] or to the best European cen-

tres where mining and metallurgy were taught and practised were two important decisions taken by the Crown. At the same time the Crown was happy to receive technical reports about amalgamation and smelting from the Portuguese legations abroad, namely in Turin, Vienna and Copenhagen, as happened between 1793 and 1795.[27,22] The Crown had forbidden the circulation of information related to the gold mines in Brazil, as in the case of Antonil's book and probably as in the case of the memoir by Vandelli on the Brazilian gold that was not published, contrary to what was normal, in the *Memorias Economicas* of the Lisbon Academy, being published only 100 years later, in Brazil.

The authors thank Prof. Helmut Malonek for his help in dealing with the works in German.

Notes

[1] Important references to the history of mining and metallurgy in Portugal are: G. Agricola, *De re metallica* (New York: Dover Publications, 1950); J. C. Allan, "A Mineração em Portugal na Antiguidade", *Boletim de Minas* 2, 3 (1965): 139-17; A. Castro, "Desenvolvimento das Actividades Produtivas", in *História de Portugal 1245-1640*, dir. José H. Saraiva, 2 (Lisboa: Publicações Alfa, 1983): 209-222; C. Fabião, "O Passado Proto-histórico e Romano", in *História de Portugal*, dir. José Mattoso, 1 (Lisboa: Círculo dos Leitores, 1992): 77-299; M. F. Rodrigues and L. M. Mendes, *História da Indústria Portuguesa – da Idade Média aos Nossos Dias* (Mem Martins: Publicações Europa, 1999); A. C. F. Silva, "A Idade dos Metais em Portugal", in *História de Portugal Origens – 1245,* dir. José H. Saraiva, 1 (Lisboa: Publicações Alfa, 1983): 101-148; C. Torres, "O Garb-Al-Andaluz", in *História de Portugal*", dir. José Mattoso) 1 (Lisboa: Círculo dos Leitores, 1992): 363-416. See at *www.pmt.usp.br/notas/notas.htm* a concise history of metallurgy in Brazil: F. J. Landgraf, A. P. Tshipschin and H. Goldenstein, "Notas sobre a História da Metalurgia no Brasil (1500-1850)".

[2] André João Antonil, *Cultura e Opulência do Brasil por Suas Drogas e Minas* (Lisboa: Publicações Alfa, 1999). Doubts about the existence and the economic importance of the silver mines as described by Antonil are expressed in W. L. Eschwege, *Pluto Brasiliensis* (Belo Horizonte: Livraria Itatiaia Editora, Lda. and S. Paulo: Editora da Universidade de São Paulo, 1979) and also in A. Mansuy, *Cultura e Opulência do Brasil por suas Drogas e Minas* (Institute d' Hautes Études de l´Amérique Latine, Paris: 1968).

[3] In the 17th century a link did exist between the Portuguese settlers from S.Vicente, in Brazil, and Potosí, using a land path through Guairá, where a Jesuit mission operated.

[4] Vicente Coelho de Seabra, *Elementos de Chimica* (Real Officina da Universidade): MDCCLXXXVIII). A facsimile edition was published in 1985 by the University of Coimbra, the cover of which mentions that Part I was printed in 1788 and Part II in 1790.

[5] D. Thornburn Burns, Maria Filomena Camões, António M. Amorim da Costa, "Distinguished People and Places Important in the History of Portuguese Analytical Chemistry", *Microchim Acta*, 152, (2005):137-151, write, on 139, that the book "… was written with the intention of being

used in a course be taught by the Sociedade Literária do Rio de Janeiro but which never took place". It has been pointed out that M. J. Barjona did not make any reference to Seabra's book, published 10 years before. And M. P. Ferreira (see note xxii) comments that the book had been received with indifference by his colleagues.

[6] The references for the five memoirs are as follows: D. Vandelli, "Memoria sobre Algumas Produções Naturais deste Reino, das Quais se Poderia Tirar Utilidade", *Memorias Economicas da Academia Real das Sciencias de Lisboa* I (1789): 176-186; D. Vandelli, "Memoria sobre Algumas Produções Naturais das Conquistas, as Quais ou São Pouco Conhecidas, ou não se Aproveitam", *Memorias Economicas da Academia Real das Sciencias de Lisboa* I (1789): 187-206; D. Vandelli "Memoria sobre as Produções Naturais do Reino, e das Conquistas, Primeiras Matérias de Diferentes Fábricas, ou Manufacturas", *Memorias Economicas da Academia Real das Sciencias de Lisboa* I (1789): 223-237; D. Vandelli, "Memoria III Sobre as Minas de Ouro do Brazil", *Anais da Biblioteca Nacional do Brasil* 20 (1898): 266-278; D. Vandelli, "Memoria sobre a Casa da Moeda e Prejuízo que Sofre a Real Fazenda e o Publico pela Falta dos Conhecimentos Quimicos", in "*Domingos Vandelli, Aritmética Política, Economia e Finanças*" dir. J. Vicente Serrão (Lisboa: Banco de Portugal, 1994): 85-90.
The importance of "Memoria III", published in 1898 and more recently in Domingos Vandelli, *Memórias de História Natural*, Introd. and Edit. Coord. José Luís Cardoso (Porto, Porto Editora, 2003): 29-42 has been pointed out in M. Serrano Pinto, "D. Vandelli e a inventariação dos recursos minerais brasileiros", *Actas do 1º Congresso Luso-Brasileiro de História da Ciência e da Técnica*, (Évora: Universidade de Évora, 2001): 214-225.

[7] For details about these travels see Manuel S. Pinto, "A Experiência Europeia de Manoel Ferreira da Camara e seus Reflexos no Brasil - Algumas Notas", in "*Geological Sciences in Latin America - Scientific relations and exchanges*", org. S. Figueirôa e M. Lopes, (Campinas, 1994): 245-264.

[8] Manoel F. Camara, "Memória de Observações Físico-económicas acerca da Extracção do Ouro nas Minas do Brasil", *manuscript in the British Museum, Catalogue Addit. Manusc. 1841* - 1845, MSS # 15191: 94-122, London. The memoir is reproduced in M. C. Mendonça, *O Intendente Câmara* (S. Paulo: Companhia Editora Nacional, 1958).

[9] Manoel F. Camara, *Rapport des résultats des expériences chimiques et métallurgiques faites dans l´intention d´épargner le plomb dans la fonte des minerais d´argent* (Vienne: Imprimerie de Patzowsky, 1795).

[10] Camara *Rapport*: "…si le chymiste minéralogue doit opérer avec chaque individu pour faire connoitre ses parties constituantes, et l'état dans lequel elles se trouvent, le métallurgiste au contraire doit agir avec les minerais tels qu'ils se trouvent dans la nature, c'est à dire, melangés." 38.

[11] Camara *Rapport*: "...si l'essai par moyen de la potasse usité au Hartz concordoit avec celui qu'on fait par le moyen du flux noir usité à Freyberg … et pour connoitre lequel de deux, dans le cas de discordance, étoit préferable." 70.

[12] Camara *Rapport*: "…qu'on est encore loin d'avoir trouvé une méthode qui puisse étre considerée comme bonne pour essayer toute sorte de galenes; que cette matière… merite d'être travaillée et approfondie, à fin de trouver une méthode sûre, invarible [sic] et facile…" 80.

[13] Camara *Rapport*: "D'après ces expériences j'ai vû qu'on pourroit, comme je l'avois pensé, simplifier beaucoup la fonte des minérais d'argent et cela 1º. par oxidation ou combustion des minérais qui le contiennent poussé pas trop loin. 2º. Par la fonte de ces mêmes minerais sans addition d'autre corps combustible que de plomb. 3º. Par la fusion faite dans des fourneaux ou on

employroit seulement la chaleur ou le calorique comme necêssaire à la fonte et à vitrifier les métaux à avoir après le depart de l'argent." 40.

[14] Manoel F. Câmara, *Resultate chemischer und metallurgischer Erfahrungen in Absicht der Bley-esparung bei dem Schmelzprozess* (Dresden: Waltherischen Bofbuchbanblung, 1797).

[15] Manoel F. Câmara, "Nota sobre a Extracção nas Minas do Transilvânia Escrita em Zalathna aos 5 de Março de 1796", *manuscript, Arquivo Nacional da Torre do Tombo, Núcleo do Ministério dos Negócios Estrangeiro, caixa 526, Lisbon*. See Manuel S. Pinto "A Memoir Written in 1796 by Manoel Ferreira da Câmara about Mining in Transylvania", in *INHIGEO Meeting Portugal 2001 ´Geological Resources and History´*, *Proceedings* (Aveiro, Universidade de Aveiro, 2003): 363-372.

[16] Joaquim Pedro Fragoso de Siqueira, "Memoria sobre o Modo de Refinar a Prata em Grande, como se Pratica em Freyberg, na Saxónia Eleitoral", *manuscrito Série Azul 374, Academia das Ciências de Lisboa.*

[17] J. P. Fragoso de Siqueira, Description Abrégée de Tous les Travaux, tant d'Amalgamation, que des Fonderies qui Sont Actuellement en Usage dans les Ateliers d'Amalgamation et des Fondries de Halsbrück, près de Freyberg (Dresden: 1800).

[18] Emmanuel Josephus Barjona, *Metallurgiae Elementa* (Conimbricae: Typis Academicis, MDCCXCVIII).

[19] The facsimile edition with the title "*Elementos de Metalurgia*", published in 2001 by the University of Coimbra, has a "Apresentação" by Prof. A. Morais Cerveira (p. V to IX) and is followed by the translation into Portuguese ("*Elementos de Metalurgia*") that has a "Posfácio" by Prof. Martim Portugal Vasconcelos Ferreira (p. 3 to 7).

[20] José Vieira Couto, *Memória sobre a capitania das Minas Gerais; seu território, clima e produções metálicas* (Belo Horizonte: Fundação João Pinheiro, 1994).

[21] About such efforts see for instance Manuel S. Pinto, "Aspectos da História da Mineração no Brasil Colonial", in *Brasil 500 anos - A Construção do Brasil e da América Latina pela Mineração,* ed. CETEM/MCT (Rio de Janeiro, 2000): 23-40.

[22] M. Portugal Ferreira, "José Bonifácio d´Andrada e Silva (mineralogista, académico, mineiro do início do século XIX)", *Memórias e Notícias, Publ. Mus. Lab. Mineral. Geol., Univ. Coimbra* 106 (1988): 19-32. See also Martim R. P. Vasconcelos Ferreira, *200 Anos de Mineralogia e Arte de Minas* (Coimbra: Universidade de Coimbra FCTUC, 1998).

[23] Burns, *et al.*, *Microchim Acta*, 152, (2005):137-151, on 138. See also M. Portugal Ferreira, O Museu de História Natural da Universidade de Coimbra (Secção de Mineralogia e Geologia) desde a Reforma Pombalina (1772) até à República", *Memórias e Notícias, Publ. Mus. Lab. Mineral. Geol., Univ. Coimbra* 110 (1990): 53-76.

[24] About this topic see Carlos Filgueiras, "Havia Alguma Ciência no Brasil Setecentista?", *Química Nova* 21, 3 (1998): 351-35.

[25] See Donata Brianta, "Transmissione del Sapere Técnico nell'Industria dei `Non Ferrosi´ e Circolazione dell' Ingegnere Minerario in Europa e in América Latina (Meta XVIII-Metà XIX Sec.) 1750-1850", *Richerche di Storia Sociale e Religiosa* 58 (2000): 127-246.

[26] W. Simon, *Scientific Expeditions in the Portuguese Overseas Territories (1783-1808)*, (Lisboa: Instituto de Investigação Científica Tropical CECA, 1983).

[27] Pinto, "A Experiência Europeia", 258.