THE MYTH OF *EL DORADO*. MAKING AND APPLYING GOLD IN THE IBERIAN PENINSULA (15TH-16TH CENTURIES)

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Abstract

This work aims at analysing the techniques involved in the manufacture of gold leaf and gold inks and also in their application to different surfaces. First, we examine the techniques put into practice for refining the gold, so it can be reduced to thin leafs or dust; afterwards, we focus on the description of the process of goldbeating for the manufacture of gold leaf and also on the recipes used for concocting gold inks; finally, we describe the process of application of these leafs and inks to the most commonly used surfaces (parchment, leather, metal, wood, bone and textile fabrics). This analysis is based on information contained in Spanish archive documents, recipe books and technical manuals from the 15th and 16th centuries[1].

Keywords

Technology, Gold, Gilding, Metallurgy, Illumination.

Capitalia Verba

Technologia, Aurum, Dauratura, Metallurgia, Illuminatio.

The application of golden decoration to art works and everyday objects was a common activity in medieval metallurgy. At a time when the cost of pure gold dinner services, jewellery, coffers and many other items was beyond the means of most people, the manufacture of objects with cheaper materials (parchment, leather, base metals, wood, bone and textile fabrics) and the subsequent application of a thin layer of gold to their surface became an efficient alternative; the external appearance of the resulting item was as shiny as though it was made of solid gold.

The making gold leaf and other substitutive materials was carried out by specialist metal workers. In addition, their application involved a wide variety of techniques depending on whether the supporting object was made of metal (in which case the gold decoration was applied by a process akin to soldering, with gold acting as the solder and the other metal —iron, copper, brass— as the base) or of other types of material such as leather and parchment (for example, with the illumination of manuscripts), wood and textile fabrics, because in these cases the addition of binders to ensure the adherence of the gold became necessary.

1. Gold Refining

As a rule, the gold intended for use on manuscripts was beaten into thin layers called *panes*. In order to be amenable to reduction to thin layers without tearing, the gold used must be over 20 carats in purity. The goldsmiths involved in the production of gold leaf thus had to control the necessary processes to ensure that the resulting gold was 23 carats or over in purity. Since most jewellery, coins and other gold items at the time were of lesser purity, illuminators and goldbeaters had to know the procedures involved in gold refining; that is, the techniques used to separate gold from the other metals present in its alloys (generally silver and copper), thereby increasing its purity[2].

The most commonly used gold refining method during the Middle Ages was known as cementation. Used throughout the medieval period, it is described in Theophilus' manual (12th century), in Francesco Pegolotti's, *Pratica della mercatura*

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2. This first section is based on the chapter *El ensayo del oro*, part of: Córdoba, Ricardo. *Ciencia y técnica monetarias en la España bajomedieval*. Madrid: Fundación Juanelo Turriano, 2009: 285-299, with the addition of new references. I would like to thank Marisol Cardenas, Professor of Analytical Chemistry at the University of Cordoba, and Marisa Gómez, chemical analyst at the Instituto del Patrimonio Cultural de España, for reviewing the manuscript for this paper and improving it with their advice.

(14th century) and in several Spanish and Italian 15th century manuscripts. The technique is also assiduously mentioned in 16th century metallurgical treatises, including the well-known writings by Agricola (Georg Bauer) and Lazarus Ercker, and in Juan de Arfe's and Juan Fernández del Castillo's Spanish treatises, to cite but a few examples[3].

This procedure involved heating gold layers or granules between beds of a clayey substance. Under oxidising conditions, heating volatilised the oxides of base metals, but not gold, the melting point of which was higher; noble metals, such as silver, separated by precipitation in the form of silver chloride. Silver chloride can only be dissolved through the action of ammoniac which was prevented by adding a sulphate such as copperas and alum. The clayey substance, known as *cimiento real*, was made of brick or tile dust and salt; according to some Medieval texts, such as those of Theophilus and Pegolotti, no other ingredient was necessary. Although common salt, such as sea salt, could be used, the use of well crushed and sieved mineral salt was recommended. Equally, the brick or tile had to be thoroughly crushed into a fine dust and sieved to prevent the presence of particles of earth and sand[4]. Reduction in particle size favours the reactions involved in the process, by increasing the physical contact between reactives, and thus the speed of the process.

In other cases, these basic ingredients were complemented with other materials such as copper sulphate, alum, salammoniac, saltpetre, quicksilver and Armenian bole, aimed at increasing the stringent qualities of the compound and the efficiency of the process by raising the purity of gold with fewer losses. Vitriol is sulphuric; alum is a double sulphate, combining a monovalent and a trivalent metal, generally aluminium; salammoniac can cause the dissolution of precipitate; this solution can turn back into a precipitate with the addition of common salt (sodium chloride) or vitriol; saltpetre is sodium nitrate ($NaNO_3$) and potassium nitrate (KNO_3); live argentum is mercury amalgamated with gold which, by raising the temperature, becomes a gas. These additives contribute to the separation of base metals, mostly

3. *Theophilus' On Divers Arts. The foremost medieval treatise on painting, glassmaking and metalwork*, eds. John G. Hawthorne, Cyril S. Smith. New York: Dover Publications, 1979; Pegolotti, Francesco. *La pratica della mercatura*, ed. Allan Evans. Cambridge (Mass.): The Academy of America, 1936 (1st edition: Florence, 1340); BNCF. Pal., ms. 814 (*Trattato anonimo del raffinare, fondere e partire l'oro*, f. 1r-39v; Arfe, Juan. *Quilatador de oro, plata y piedras*. Madrid: 1572 (ed. of 1678); Fernández del Castillo, Juan. *Tratado de ensayadores*. Madrid: 1623; Agricola, Gregorius. *De Re Metallica*, ed. Carmen Andreu. Madrid: Ediciones de Arte y Bibliofilia, 1992; Ercker, Lazarus. *Lazarus Ercker's Treatise on Ores and Assaying*, Anneliese G. Sisco, Cyril S. Smith, eds. Chicago: The University of Chicago Press, 1951 (1st edition: Prague, 1574). A general overview of the process can be found in: López, Eva. *Estudio de los materiales y procedimientos del dorado a través de las fuentes literarias antiguas: aplicación en las decoraciones de las pinturas castellanas sobre tablas*. Madrid: Universidad Complutense de Madrid (PhD Dissertation), 2007: 126-127 <available at http://biblioteca.ucm.es/tesis/bba/ucm-t29743.pdf >.

4. *Theophilus' On Divers Arts*...: 109; Pegolotti, Francesco. *La pratica della mercatura*...: 333. Because of the wide dissemination of this technique, the inventories of instruments in use by goldsmiths in Medieval mints often include mortars to crush the tiles and salt used for gold refining. See for instance Spufford for the London and Canterbury mints in 1327 (Spufford, Peter. "Mint Organisation in late medieval Europe". *Later Medieval Mints: Organisation, Administration and Techniques*. Oxford: British Archaeological Research, 1988: 11; Campbell, Marian. "Gold, Silver and Precious Stones". *English Medieval Industries*. London: Hambledon Press, 1991: 110).

in the form of a sulphide, improving the net efficiency of the process. This is the case of Castilian and Italian recipes from the late 15th and early 16th centuries; for instance, the ms. H490 in the Faculty of Medicine, Montpellier, a Spanish document with recipes dated to the reign of the Catholic Monarchs, recommends the use of red tile, common salt and copper acetate; one of the recipes in the ms. 858, Fondo Palatino, Bibloteca Nazionale Centrale, Florence, suggests adding copper acetate, salammoniac, alum, saltpetre and verdigris, while another suggests the addition of alum, salammoniac, rock salt and quicksilver; finally, manuscript 945 in the same collection includes mention of a mixture of Roman copper acetate, verdigris, *ferrete*, salammoniac, alum and Armenian bole. *Ferrete* is copper sulphate, verdigris is copper acetate and vitriol is sulphuric acid[5].

Regarding proportions the treatises show significant differences. For example, Juan de Arfe, Ensayador Mayor de Castilla during the reign of Philip II recommended in his work *Quilatador* the use of a cement with two thirds of brick dust and one third of ground common salt, along with a pinch of *almohatre* (salammoniac), a similar formula to the one set forth by Theophilus (two thirds of brick and one third of salt). On the other hand, Fernández del Castillo recommends the use of one half of brick dust and another one of salt, along with some *almohatre* or, if this cannot be found, tartar (tartrate of potassium); manuscript 814 in the Fondo Palatino, Biblioteca Nazionale Centrale de Firenze suggests the use of three quarters of brick and one of salt; Lazarus Ercker recommends a mixture with two parts of brick dust, one of salt and half of *acije* (vitriol); Agricola indicates that several recipes can be followed for the production of the cement (half a pound of brick dust and a quarter of salt, one ounce of saltpetre and half of salammoniac and another of mineral salt; and half a pound of brick dust and a third of mineral salt, one ounce of saltpetre and half of common salt); finally, Álvaro Alonso Barba suggests the addition of three parts of brick dust and one of mineral salt along with half an ounce of salammoniac[6].

The differences reflected in the technical treatises are to a degree connected with fashions, with local traditions and with the availability of raw materials at any given time and place, but mostly with the purity of the gold being refined. According to Francesco Pegolotti, the refining of 12 to 16 carat gold demanded a cement with four parts of brick to one of salt; for 16 to 20 carat gold, however, the

5. *Cementum sic fit. Accipe sal comune, praeparatum azeche, tegulam rubeam bene tritam et criuatam ante, totum mixtum* (Faculty of Medicine Montpellier. Ms. H490, f. 234r; also in: Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV: el manuscrito H-490 de la Facultad de Medicina de Montpellier". *En la España Medieval*, 28 (2005): 33-34 and 47); *A cimentare oro di carete 18 qual cresca per fino a carate 22 e ½,... piglia vitriolo romano rubificato, sal armoniaco on. 2, allume jameni on. 1, salnitro et verderame on. 1* (BNCF. Pal. 858, Segreti diversi, XVI sec, f. 89r); *A cimentare oro di mità, togli sal armoniaco, sal gema, lume di rocca, argento sublimato on. 1, et on. 1 d'oro et argento, fatto inlaminare et cimenta, poi fondi et avera oro de carati 24* (BNCF, Pal. 858, f. 90v); *Cimento optimo d'oro di metà. Togli vitriolo romano parte una, verderame parte una, ferretto di Spagna parte meza, sal armoniaco parte una, alume iameni parte meza, alume di rocca parte una e ½, bol armenio parte una* (BNCF. Pal. 945, Segreti diversi, XVI sec, ff. 11r-v).

6. Arfe, Juan. *Quilatador de oro, plata y piedras*...: 35-37; *Theophilus' On Divers Arts*...: 109; Fernández, Juan. *Tratado de ensayadores*...: 58-59; BNCF. Pal. 814, f. 39v; *Lazarus Ercker's treatise on ores and assaying*...: 184; Agricola, Gregorius. *De Re Metallica*...: 463 and 466-467; Alonso, Álvaro. *Arte de los Metales*. Madrid: Imprenta Imperial, 1640 also reedited: Valencia: Librerías París-Valencia, 1993: 196-197.

ideal proportion was three parts of brick to one of salt; finally, 20 to 24 carat gold required two parts of brick and one of salt, because "the more salt it has, the harder the cement will be, and the purer the gold is, the harder cement it demands" due to the higher degree of separation of silver in the form of silver chloride. The *Treatise on the origin, nature, law, and alterations of money*, published in England around 1350, makes a similar statement; although the only ingredients mentioned are brick dust and salt (in agreement with Theophilus and Pegolotti), the work points out that "the purer the metal is the more salt must be put in"[7]. After mixing the ingredients, liquid was added to the resulting paste to increase its malleability. In most cases vinegar was used, as recommended by some 16th century treatises and manuscript 858 in the Fondo Palatino, although human urine was also used, as suggested by Theophilus's treatise and manuscript 945 in the Fondo Palatino. Ercker's treatise also contemplates both options for adding liquid to the mixture[8].

After the gold had been reduced to thin sheets it was laid out inside a ceramic vase in alternation with layers of cement. Ms. H490 in the Faculty of Medicine, Montpellier, and Theophilus also mention the possibility of using two concave trays or tiles instead of the vase, but most authors, including Juan de Arfe and Francesco Pegolotti, recommend the cementation of the gold in a new —it had to withstand considerable heat and pressure during the process— clay vase. The bottom of the vase was covered with a layer of cement as thick as a finger ("packed very hard at the bottom of the vase", says Arfe) followed by a first layer or thin film of gold dust. The remaining layers continued to alternate between cement and gold ("as though adding cheese to a lasagne", in Pegolotti's own words). The cement layers could not be too thick; just enough to cover the gold. If the gold was introduced in the form of thin films it was convenient to wet them slightly with vinegar according to Fernández del Castillo, or water according to Pegolotti, before they were put inside the vase, because according to Pegolotti "if they are wet, they take the cement better"[9].

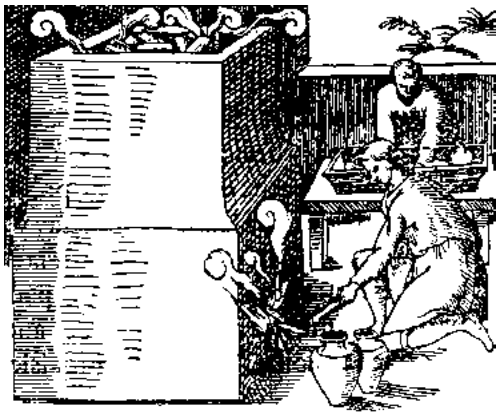

Illustration 1. Engraving of a cementation furnace, reproduced in Juan de Arfe's *Quilatador de oro, plata y piedras* (1572).

7. Pegolotti, Francesco. *La pratica della mercatura*...: 333; Johnson, Charles; Oresme, Nicole. *The De Moneta of Nicholas Oresme and English Mint Documents*. London: Nelson, 1956: 84.

8. *Trito sottilmente ogni cosa, cosimul misce e poi bagnalo con un poco d'aceto* (BNCF. Pal. 858, f. 89v); *Theophilus' On Divers Arts*: 109; *Trita un poco ogni cosa e inpastalo con urina de puber vergine in modo di pasta* (BNCF. Pal. 945, f. 11v); *Lazarus Ercker's treatise on ores and assaying*: 184.

9. *Et fac vnum lectum dictorum pulvum et pone desupra unam plantulam et coopri de dicto pulvere et pone aliam et coopri et sic usque quo uolueris. Et pone totum inter duas tegulas concavas* (Córdoba, Ricardo. "Un recetario

The vase was then covered with a clay lid and lined with mud on the outside. One of the recipes in Ms. H490 also suggests the use of a substance called *luto sapiente*, used to seal the joints in vases exposed to the fire and frequently mentioned in metallurgy treatises of the period[10]. It was a paste made by mixing soil, manure and *tundizna* (wool scraps, soil and manure, often also with the addition of clay or lime). It is frequently mentioned in 15th century Italian manuals because it was not only used in metalworking but also in the manufacture of coral objects and precious stones, among many other applications. For example, the Naples Manuscript records the use of clay, ass manure and *tundizna*; the ms. Ashburnham 349, Biblioteca Laurenziana, Florence, indicates that' if you want to make *luto sapiente* you must take some soil, which must be thoroughly dried, well ground and mixed with water; afterwards, you must take some horse manure, reduce it to dust, mix it with egg white and stir well; finally put both mixes together, and you have *luto sapiente* with which to seal the vase'; number 1243 in Biblioteca Riccardiana says that "in order to make *luto sapiente* you must take some white clay, ox manure, gum, quicklime, salt, egg white and ash"; number 2645 in the same library says "in order to make a perfect *luto sapiente* you must mix white soil, ox manure, Arabic gum, lime, hair, salt, flour, egg yolk and ash"[11].

The fire was kindled with dry grass and wood shavings, the firewood being added progressively to ensure a low but constant heat. The manuals of Juan de Arfe and Fernández del Castillo, following the older texts of Theophilus and Pegolotti, suggest the use of firewood without any other specification, but Agricola expressly recommends using oak or holm oak, which are ideal for providing the slow and consistent heat required by the operation. Also, a recipe in ms. H490 specifies *Et post pone in igne suavi bene coopertum ex utraque parte et dimicte per 2 vel 3 horas vel plus secundum que videris expedire*; along similar lines, ms. 858, Fondo Palatino, recommends "to kindle a little fire which is not too strong, so the vase is always red hot; the fuel must not be coal but firewood". An excessive temperature, resulting from the use of a highly calorific fuel such as coal or by the addition of an excessive amount of firewood, would cause the gold to melt, aborting the process. According to Lazarus Ercker, molten gold would mix with the silver and the copper in the cement, ruining the composition of the cement and the lamination of the gold. If the temperature was too low, on the other hand, the cement would not absorb the

técnico castellano del siglo XV...": 35 and 47); *Theophilus' On Divers Arts*...: 109; Arfe, Juan. *Quilatador de oro, plata y piedras*...: 35-37; Pegolotti, Francesco. *La pratica della mercatura*...: 331-333; Fernández, Juan. *Tratado de ensayadores*...: 58-59.

10. *Et pone totum inter duas tegulas concavas et luta eas cum luto sapientiae et dimicte sic stare donec siccetur* (Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 35-36 and 47).

11. *Bene lutari de bona argilla, bene speciata cum stercore asinino et cum zimatura pannorum* (Brunello, Franco. *De Arte Illuminandi e altri trattati sulla tecnica della miniatura medievale*. Vicenza: Neri Ponza, 1975: 56); Biblioteca Medicea-Laurenciana di Firenze. Fondo Ashburnham, ms. 349, f. 20v; Biblioteca Riccardiana di Firenze. ms. 1243, f. 29v and ms. 2645, f. 32r. For a study on the composition and use of this substance in the Middle Ages see: Thomas, Nicolas. "De la recette à la pratique: l'exemple du *lutum sapientiae* des alchimistes", *Craft Treatises and Handbooks. The Dissemination of Technical Knowledge in the Middle Ages*, Ricardo Córdoba, ed. Turnhout: Brepols, 2013: 249-270.

alloy of silver and copper; in Juan de Arfe's words, it was necessary "to prevent the gold melting for too much fire and the cement not working for too little"[12].

This low and constant fire had to be kept running for 24 hours —"a day and a night" in Theophilus's and Pegolotti's words. Agricola indicates that if the kiln had been preheated for two hours before introducing the vases cementation would require 24 hours, but if the kiln was cold to begin with the operation had to be maintained for 26. Although Fernández del Castillo affirmed that the gold increased in purity by three to four carats every 24 hours, Pegolotti and Barba agreed on lowering this amount to two carats; the former says that "metalworkers agree that the gold goes up by one carat every twelve hours, but sometimes it does not take as long". The purity of the resulting gold was not only dependent on the temperature but also on the number of times the operation was repeated. All authors recommend stopping the operation after 24 hours, but there was no limit to the number of times it could be replicated. Depending on the degree of refining desired, two or three 12- or 24-hour operations could be performed. The ms. 858, Fondo Palatino, clearly indicates that in order to increase the gold's purity from 18 to 22 carats the vase must be put to the heat for twelve hours "repeating the operation twice, and this should suffice"; the document also says that if the process is repeated three or four times, that is, if the vase is kept in the fire for a total of two days, 24 carat gold will result[13].

Another common procedure used to refine gold was that of amalgamation with mercury. The technique is based on the strong affinity that exists between gold and mercury, resulting in easy amalgamation and the forming of a gold and mercury alloy, which literally involves the gold melting into the mercury. For this process to occur effectively, the metals must be free from impurities. This method is therefore often recommended for the *cimiento*; that is, for the gold and silver absorbed by the brick and salt mix used in the previous system. Under the title "to depurate all the soil contained in the metal", a recipe in ms. H490 recommends combining the resulting earth mix in a trough with vinegar and mercury (if vinegar is not available, tartar and salt are a good substitute); afterwards, the mix must be rubbed in vinegar with half a brick or a rough stone, driving the gold to adhere to the mercury. The rubbing must continue until the mix becomes soft, adding more mercury, because if it remains as *amalgama dura* it means that there is still metal inside it. This method is already described in the *Mappae Clavicula* and is also similar to the system recommended by Pegolotti (the *cimiento* must be mixed with mercury and rubbed with a stone or a piece of wood, and once the gold has adhered to the mercury the resulting mix must be warmed up inside a vase "so the hot mercury goes up in smoke, leaving the solid

12. Arfe, Juan. *Quilatador de oro, plata y* piedras...: 35-37; Fernández, Juan. *Tratado de ensayadores*...: 58-59; *Theophilus' On Divers Arts*...: 109; Pegolotti, Francesco. *La pratica della mercatura*...: 331-333; Agricola, Georgius. *De Re Metallica*...: 466-467; Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 36 and 47; BNCF. Pal. 858, f. 89v; *Lazarus Ercker's treatise on ores and assaying*...: 186.

13. *Theophilus' On Divers Arts*...: 109; Pegolotti, Francesco. *La pratica della mercatura*...: 332; Agricola, Georgius. *De Re Metallica*...: 466-467; Fernández, Juan. *Tratado de ensayadores*...: 58-59; Alonso, Álvaro. *Arte de los Metales*...: 196-197; BNCF. Pal. 858, f. 89v (*Ma come lo volessi fare tre volte o 4 venerà a carate 24*).

gold at the bottom"). Fernández del Castillo's and Álvaro Alonso Barba's treatises also suggest this procedure to recover the silver absorbed by the *cimiento*: the earthy mix is introduced into a vase and combined with mercury; it is then kneaded with a rolling pin or a stone until the silver adheres to the mercury, which is afterwards evaporated and separated from the silver with heat[14].

Another "classic" procedure for gold refining —known since the Greco-Roman period and mentioned in multiple 15th century texts and all major metallurgical treatises published in the 16th century— used sulphur or antimony. The latter was, in fact, stibnite or antimony sulphide, which has similar effects to sulphur, reacting with any gold and silver alloy, causing the formation of silver sulphide (which does not mix with the metal), while the remainder of the sulphur contained within the antimony sulphide drags the gold to the bottom of the vase[15]. Antimony is swiftly eliminated by heating because of the formation of a volatile oxide. One of the recipes contained in ms. H490 suggests a mixture with two parts of sulphur to one part of salt. This mixture is laid out in a vase in alternate layers with the gold reduced to thin sheets. The closed and sealed crucible is then put on the fire. Once the metal has melted, the crucible is struck several times to ensure that the molten gold seeps to the bottom, separating from the silver and the other metals. If the method does not work as desired it can be repeated with the addition of more sulphur (three parts sulphur to one part salt) and a sixth part of lead (which reduces the melting temperature) or antimony ("which is better" in the author of the recipe's own words)[16]. Alfonso X's *Lapidario* also reflects this technique, indicating that, "should the gold be mixed with a vile body [a base metal] it must be heated with sulphur and rubbed with the stone called *marcasita*. This drives all other metals and filth away, because sulphur burns everything but gold, and *marcasita* is like sulphur"[17].

Other European texts, such as ms. Sloane 1754, British Library, include similar recipes for the use of sulphur in gold refining. Recipe number 100 in ms. Pal. 941, Biblioteca Nazionale, Florence, entitled *A partire l'oro de l'argento*, describes a related recipe, suggesting the introduction of the gold inside a vase with the sulphur. Afterwards, the vase must be heated and then left to cool down and heated again for the gold to melt "to the bottom". The process is similarly described in Pegolotti's manual under the heading *A partire oro da ariento*, where sulphur is added progressively to the silver as the coal-fuelled fire increases in temperature,

14. Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 38-39 and 47; Pegolotti, Francesco. *La pratica della mercatura*...: 334; Fernández, Juan. *Tratado de ensayadores*...: 60; Barba, Álvaro. *Arte de los Metales*...: 197. Theophilus' recipes for the separation of gold by amalgam of mercury have been studied by: López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 123-124.

15. On the use of this technique in Antiquity, see: Forbes, Robert. "Metallurgy", *A History of Technology vol. II: the Mediterranean Civilizations and the Middle Ages*, Charles Singer, Eric Holmyard, eds. Oxford: Clarendon Press, 1956: 42. See also Theophilus's and Archerius's recipes in: López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 127.

16. Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 38-39 and 47.

17. *Primer Lapidario del rey Alfonso X el Sabio*, facsimile edition of codex h.I.15, Biblioteca de San Lorenzo de El Escorial, Madrid, 1982: f. 21v.

after which process the gold will be found in solid state at the bottom of the base, whereas the remaining metals, mixed with the sulphuric vapours, stay at the top[18].

The *Probierbüchlein*, published in 1500, also include several recipes for using sulphur or antimony in this process. Number 70, called "On how to separate silver and gold", recommends mixing the silver-gold alloy with one part of antimony, one of copper and one of lead. The mix must be put into a crucible and the crucible covered, to prevent the escape of vapours, and heated. After cooling, the gold will be found at the bottom. Recipe 85 specifies that the substance employed to separate the gold and the silver is made with one pound of sulphur, half of salt and a pinch of salammoniac. Recipe 102 recommends an even more similar method to the Castilian way; under the heading "Separating gold and silver", the recipe suggests the mixing of two pounds of sulphur and one of salt at the bottom of a crucible, on top of which mix the silver-gold alloy must be placed, followed by alternating layers as in the cementation system. After firing and cooling, the gold will have melted to the bottom of the crucible[19]. This process to separate gold and silver with sulphur and antimony is also described in Biringuccio's manual, under the heading "Method for the separation of gold and silver with sulphur or antimony", in Lazarus Ercker's *Beschreibung* and in Álvaro Alonso Barba's, "Other methods to separate gold and silver". The latter explains that the ground sulphur must be put into a vase and that, after firing, "the gold will seep to the bottom while the silver remains at the top, mixed with the lead, the copper and the sulphuric vapours". The process for performing the separation with antimony instead of sulphur is also explained[20].

A final method for gold refining used diluted hydrochloric acid, also used in tanning and other industries. The aim of this process was the solution of gold by the formation of a soluble gold chloride and the separation of silver through precipitation in the form of silver chloride. All manuals stress that the acid used for this technique must be very strong, because "if it is not, the gold is not properly purified"[21]. Once the gold had been introduced into the vase and covered in acid, it was put on a slow fire and let to simmer; if the mixture started smoking and the nitric acid to flash it meant that the acid "has lost its strength and can eat silver no longer" (it could not form more silver chloride) and had to be poured into another vase. This operation was repeated up to three times. When the gold was ready it would give out signals ("leaping a bit"). It was then taken away from

18. Campbell, Marian. "Gold, Silver and Precious stones...": 110, quoting page 205 of said manuscript; BNCF, Pal. 941, "Ricette dal XVI secolo", f. 15v; Pegolotti, F., *La pratica della mercatura*...: 336-337.

19. *Bergwerk und Probierbüchlein*, eds. Anneliese G. Sisco, Cyril S. Smith. New York: Yale University Press, 1949: 114, 120 and 125 (1st edition: 1500).

20. Biringuccio, Vannoccio. *The Pirotechnia of Vannoccio Biringuccio. The Classic Sixteenth-Century Treatise on Metals and Metallurgy*, eds. Cyril S. Smith, Martha T. Gnudi. New York, 1959: 201-202, chap. 6, book IV; *Lazarus Ercker's treatise*...: 195-196; Alonso, Álvaro. *Arte de los Metales*...: 192-193, chapters 11 and 12, book III.

21. Fernández, Juan. *Tratado de ensayadores*...: 30v.

the fire for good and rinsed in clear water, after which it could be extracted from the vase[22].

The acid used in this operation could be prepared with different ingredients, especially mordants and mineral salts, resulting in the separation of the precious metal from the alloy in which it was combined, favouring the reduction of gold salts present. Álvaro Alonso Barba suggests that the ingredients often included copperas, alum, saltpetre, Armenian bole, orpiment and cinnabar, with which different mixes could be concocted. Orpiment is arsenic sulphide and cinnabar contains mercury sulphide; both compounds are important for these processes. Afterwards, the resulting mix was heated in a kiln while the acid passed through a still. Equally, Guillermo Céspedes del Castillo indicates that, according to the regulations of American mints, the mix must be made with copperas, alum and saltpetre, sometimes with the addition of salammoniac (ammonium chloride, a common ingredient in compositions with which silver and copper, among other metals, can effectively be dissolved)[23].

No known Castilian recipe directly refers to the preparation of acids for use in industrial processes, and this issue is also absent from Joanot Valero's dyeing manual, dated to the late 15th century. Some recipes can, however, be found in a later Catalonian dyers' manual, the *Remallet de tinturas*, published in the 17th century. The text indicates that the red colour was prepared with 50 pitchers of clear water heated to boiling point, after which they were poured into a pool with the addition of five *arrobas* of thick bran, letting the mix sit for two days. Finally, the mix must be stirred every two hours for three days. Another recipe explains that the acid used for the production of scarlet colours is made with two ounces of orpiment, two of verdigris, two pounds of refined saltpetre, three of rock alum and six ounces of Roman vitriol, all of which must be placed inside a well-sealed still ("with the clay which potters use to seal the kilns") to ensure a reducing atmosphere, and heated on a slow fire. A third recipe from this manual explains the procedure used for dying scarlet wool clothes in Catalonia: twenty pitchers of water and six measures of bran are boiled in a marmite and poured into a pool. After an hour another ten measures of bran are added, followed one hour later by four pounds of alum, four of arsenic and for ounces of ground glassy stoneware or rocksalt. Finally, five hours later, white vinegar is added to the mix, which is left to sit covered for one full day and uncovered for four. [24]

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22. Arfe, Juan. *Quilatador de oro, plata y piedras*...: 34-35; Fernández, Juan. *Tratado de ensayadores*...: 30v and 33r.

23. Alonso, Álvaro. *Arte de los Metales*...: 185-192, chapters. 7 to 10, Book III, with illustrations of the kilns and stills mentioned, p. 188; Céspedes, Guillermo. *Las casas de moneda en los reinos de Indias, vol. 1, Las cecas indianas en 1536-1825*. Madrid: Fábrica Nacional de Moneda y Timbre-Museo Casa de Moneda, 1996: 127-130.

24. *Remallet de tinturas y breu modo de donar-las á totas robas de llana, teles y fil, ab lo modo de beneficiar alguns ingredients necessaris per los arts de la tintura y perayria, recullit de differents receptes de totas las parts de Europa per Phesio Mayo* [pseud. of the printer], eds. Narcís Feliu de la Penya and Bernat d'Aimeric-Cruïlles. Barcelona: Josep Moià, 1691: 15-19.

2. Preparation of gold leaf and its substitutes

2.1. Gold leaf

The reduction of metal to very thin layers is known as "beating", because it was fundamentally carried out by hammering, and the specialist artisans that carried it out as "goldbeaters"[25]. As mentioned previously, goldbeating demanded gold with a purity of 23 carats or over, because a lesser quality metal could not be reduced to such fine leafs without tearing. For this reason goldbeaters had to be experts in the refining processes described above in order to extract the necessary gold from the lower purity gold used in coins and other objects[26].

First, the gold ingot or bar has to be reduced to a relatively thin sheet. This was achieved by hammering the metal bar resulting from the melting of the refined gold This is followed by the main stage in the preparation of gold leaf, the beating as such, which was carried out through a technique called *soldada y molde* (cutch). The technique relies on a series of small square-shaped cuts of animal intestine, placed in alternation with metal sheets and cut with the aid of the *caire*, a little square of iron used by goldbeaters as a pattern to cut the animal intestine sheets and the gold squares[27]. The use of this technique is mentioned in the local regulations from Córdoba (16th century) and Barcelona (18th century)[28].

The gold sheet is also cut into (smaller) square shapes and placed between two of the "tripe" squares, forming a sort of sandwich. These sandwiches are piled up and wrapped with parchment to form a packet ready for further hammering. Upon beating, the metal square expands within the mould. The operation is delicate, because the beating must be homogeneous to ensure that the metal extends evenly in all directions and has the same thickness throughout, without tearing or breaking[29].

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25. A set of local regulations from Cordoba, dating to the 16th century and detailing the main goldbeating techniques, have been preserved; Córdoba, Ricardo. *La industria medieval de Córdoba*. Cordoba: Caja Provincial, 1990: 253-257; Córdoba, Ricardo. "Los batihojas y las técnicas de ornamentación en metal (siglos XV-XVI)". *Estudios sobre Historia de la Ciencia y de la Técnica*, Esteban Piñeiro, ed. Valladolid: Junta de Castilla y León, 1988: 755-772; see also: de Quinto, María Luisa. *Los batihojas, artesanos del oro*. Madrid: Editora Nacional, 1984; Genís, Ramon. "El antiguo gremio de batihojas, oropeleros y guadamacileros de Barcelona". *Boletín de la Asociación Química Española de la industria del cuero*, 8 (1957): 210-214.

26. "Workers must be encouraged to use good gold, 23 carats or over, not below" (*Ordenanzas de batidores de Córdoba*, chapter. 4; quoted in: Córdoba, Ricardo. "Los batihojas y la técnicas de ornamentación en metal...": 762, note 18); equally, 15th century goldbeaters in Barcelona also had to work with a minimum purity of 23¼ carats (Bonnassie, Pierre. *La organización del trabajo en Barcelona a fines del siglo XV*. Barcelona: Consejo Superior de Investigaciones Científicas, 1975: 143).

27. According to the goldbeaters' regulations in force in New Spain in the 18th century the *caire* was a square sheet measuring 81 x 81mm and used as template to cut *telillas* and gold leafs (Gañán, Constantino. *Técnicas y evolución de la imaginería polícroma en Sevilla*. Seville: Universidad de Sevilla, 1999: 194).

28. For 18th century Barcelona, Ramón Genís mentions a merchant who held exclusive rights for the commercialisation of "certain bull intestines or hides" used by goldbeaters "to beat gold and reduce it" (Genís, Ramón. "El antiguo gremio de batihojas...": 214).

29. The difficulty of this operation, which was executed with only hammer, has been highlighted by Carrere with regard to the goldbeaters in the city of Barcelona (where they were known as *batifullers* or

Once the sheet has expanded to the limits of the mould, the wrapping is removed and the metal sheets separated from the *telas*. Then, the squares are trimmed into smaller squares and the whole operation is repeated once more, resulting in the much thinner final gold leaf. The regulations from Córdoba establish that the artisan wishing to receive the title of master goldbeater must know how to cut the *telas* for the preparation of gold and silver moulds and also know how to prepare the mould with the parchment: during the examination, he had to prepare two moulds for gold and another two for silver, a thousand silver leafs, a thick layer of gold and a thousand leafs of the same metal[30].

This operation, which was already described in Theophilus' manual, was performed without variation in the whole of Europe throughout the Middle Ages; appears well described in chapter 23 of Book I of Theophilus, dedicated to the preparation of gold leaf, and in early medieval recipes books as *Compositiones Lucenses* or *Mappae Clavicula*[31]. According to Marian Campbell, "Goldbeating was a slow task; the coins were hammered into foil, which was further beaten with a variety of hammers between vellum (or parchment) leafs known as goldbeaters" skin. These served to protect the foil and maintain an even thickness. A square of gold was placed in the middle of a sheet of vellum with another piece of vellum on top. When hammering had caused the metal squares to spread to the edge of the parchment, the goldbeater cut up each piece of metal into further squares, and repeated the process'. Mark Clarke, who has examined the surviving medieval descriptions of the process, stresses that most recipes mention a first beating executed over an anvil and a second one carried out with the aid of parchment or leather sheets; some of these recipes are very detailed, and even describe the sort of hammer to be used, the motions involved and the direction of the strikes[32].

ILLUSTRATION 2. GOLDBEATING AND SETTING OF THE GOLD LEAF TO A BOOK, AS REPRODUCED IN JOST AMMAN'S *BOOK OF TRADES* (F. 40).

batidors de fulles d'or e d'argent); Carrere, Claude. *Barcelone, centre économique à l'époque des difficultés 1380-1462*. Paris-La Haye: Mouton et Cie, 1967: 389.

30. Córdoba, Ricardo. *La industria medieval de Córdoba*...: 256; Córdoba, Ricardo. "Los batihojas y las técnicas de ornamentación en metal"...: 760.

31. López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 221-223.

32. *Theophilus, On Divers Arts*...: 109; Campbell, Marian. "Gold, Silver and Precious Stones...": 131; Clarke, Mark. *Mediaeval Painters' Materials and Techniques: The Montpellier Liber diversarum arcium*. London:

The colour acquired by the gold during the lamination process could be rectified through the application of different products aimed at intensifying its original hue. One of the recipes included in ms. H490 and entitled "gold re-cooking" explains how to give the gold sheet a more intense golden shine by the application of a mixture of verdigris (copper acetate), salammoniac, saltpetre and urine to the gold sheet (previously washed with salt and vinegar and dried); the gold sheet smeared with mixture was then warmed on a charcoal fire until it acquired a dark colour. In the final stage of the process, it was left to cool and rinsed in urine[33].

Due to its extreme thinness and frailty, gold leaf cannot be manipulated by hand, because the slightest of touches and any contact with human fat can easily break it. The leafs must therefore be removed from between the vellum sheets with tweezers and immediately fixed into booklets for commercialisation. This operation is perfectly illustrated in one of Jost Amman's famous engravings, dating to the second half of the 16th century. The scene represents a goldbeater in the process of striking at what looks like a mould with a hammer, while another artisan removes the gold leaf from the mould with a pair of tweezers and attaches them to a book; this is also described in later written texts[34].

2.2. Oropel

This was the name given to fine brass leaf similar in appearance to gold leaf, but much less costly, which explains its popularity. In the Middle Ages, brass was made by mixing zinc oxide (calamine) or carbonate (smithsonite) with copper, to which they were said to add colour[35]. The zinc compound and the copper are heated together in a crucible set on a slow fire, eliminating the oxygen and separating the zinc. After some hours the zinc vapour condenses on the surface of the copper in a process known as cementation, although condensation would be a more accurate description. Once the condensation occurs, the heat is increased for a while in order to embed the zinc vapous into the surface of the copper, which thus loses its characteristic reddish colour to adopt a yellowish hue. For this reason, brass

Archetype, 1991: 131; González-Alonso, Enriqueta. *Tratado del dorado, plateado y su policromía. Tecnología, conservación y restauración*. Valencia: Universitat de València, 1997: 127.

33. Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 22 and 44.

34. Amman, Jost; Sachs, Hans. *The Book of Trades (Ständebuch)*, ed. Benjamin A. Rifkin. New York: Dover Publications, 1973: plates 28 (the use of the rectangular brush) and 40 (hammering of the mould preparation of the leaf books). The inventory of the possessions of an 18th century goldbeater from Palencia includes several common tools of his trade, such as moulds, soldering irons, four little working tables for the preparation of the books, 19 *caires* of different sizes (18 of pinewood and one of metal), eleven hammers for the beating, four stones for use as base for the beating, 90 frames "where the *telas* for the moulds are cut", 184 old books "for the gold", 42 100-leaf books and 22 books for *oro subido* (Barrio, José Luis. "El inventario de los bienes de Dionisio Sánchez Escobar, un batidor de oro palentino en el Madrid de Felipe V (1746)". *Publicaciones de la Institución Tello Téllez de Meneses*, 76 (2005): 516).

35. Tanelli, Giuseppe; Benvenuti, Marco; Mascaro, Isabella. "Aspetti giacimentologici dei minerali estratti in età preindustriale", *Archeologia delle Attività Estrattive e Metallurgiche*. Florence: All'Insegna del Giglio, 1993: 275.

was known as *cuivre jaune* in French, *gelbkupfer* in German and *arambre amarillo* in Spanish (for example, in Alfonso X's *Lapidario* and *Libro de Astronomía*). Not all calamines were suitable to make brass, because calamine deposits are often rich in lead which, by also mixing with the copper during cementation, results in a brass that cannot be worked in thin layers (lead does not dissolve in brass, causing the former to separate in the shape of small globules which reduce the mechanical resistance of the alloy, leading to tearing during handling). In this regard, Theophilus mentioned the need to work with lead-free copper, but did not mention the calamine, which was often the agent that carryied it into the process[36].

Brass could be shaped as bars or ingots, for melting and moulding, and also as thin sheets for cold hammering and beating, as with copper and precious metals. Melting and moulding was carried out in standard tinker forges and with equally common tools: apart from the forge and the bellows, the operation demanded percussion tools such as clamps, anvils, chisels and hammers, fastening tools such as pliers, bolts and scissors, cutting tools such as adzes, axes and sharpeners, and melting tools such as crucibles, ladles, moulds and blocks[37].

The working of brass sheets started with a solid beating to expand the ingot until the desired thickness was achieved. Afterwards, the sheet was cut into strips with sreference to the size of the final object pursued, and these strips were hammered again against an anvil. Although hammering had to be performed carefully in order to avoid tearing and piercing, the evidence does not document the use of the tripe *telillas* used with gold because brass sheets were never hammered as thin as gold leaf. The sheet was always heated before hammering to improve malleability. Hammerheads were often very broad and rounded to maximize the hammering surface[38].

Accurate hammering resulted in extremely thin brass sheets, called *oropel*, later applied as decoration upon other materials, most commonly leather; in fact, the term *oropel* originally refers to this particular use. At any rate, the brass sheets were often manufactured by goldbeaters, even if their application on the leather was left to specialised *oropeleros*, as recorded in the agreement signed in November 1505 by Luis de Rueda, *oropelero* from the parish of Santa María in Córdoba, and Fernando de Córdoba, goldbeater in the same city, to create a company for the production and commercialistion of oropel for two years. According to the agreement Luis de Rueda

36. *Theophilus' On Divers Arts*...: 140. In Jaén the brass was produced in crucibles with a mixture of used copper, calamine and charcoal, heated inside an underground conical kiln (Parejo, Mª Josefa; Tarifa, Adela. "La minería en el reino de Jaén a fines de la Edad Media". *Actas de las I Jornadas sobre Minería y Tecnología en la Edad Media Peninsular*. Madrid: Hullera Vasco-Leonesa, 1996: 296).

37. A good description of copper and copper-alloy working techniques can be found in: Pernot, Michel. "Archéométallurgie de la transformation des alliages à base de cuivre". *L'innovation technique au Moyen Age*, Patrice Beck, ed. Paris: Édition Errance, 1998: 123-126; and a list of the instruments used by tinkers in: Córdoba, Ricardo. *La industria medieval de Córdoba*...: 246-247.

38. The hammering of tin sheets is described in numerous medieval texts (*Compositiones Lucenses*, *Mappae Clavicula*, Theophilus). They were instilled with a golden colour by immersing them in alum and vinegar or by covering them with saffron and vinegar. The hammering of oropel sheets is described in the Manuscript of Bologna (López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 229-233).

committed to contribute with 2920 mrs., the necessary leathers "and other things pertaining to the trade, apart from the tools", while Fernando de Córdoba agreed to give another 2920 mrs. in cash and the aforementioned tools. The former also committed not to purchase gold or silver leaf from any other goldbeater[39].

2.3. Golden inks and imitations

Metallic golden inks and their imitations were also very commonly used for decoration, most particularly illumination and lettering of manuscripts (chrysography). According to Stefanos Kroustallis the process used to concot the inks started with the refining of the gold, for which the same methods explained in previous pages were applied. After refining, the gold was ground to a very fine grain or to dust to facilitate its incorporation into the ink. This was also a common process before refining, because it facilitated the increase in the purity of the metal above 18 or 20 carats, below which beating was not possible. This made it a common procedure in mints, as recorded in the registry books from the mints of Barcelona and Iglesias, in the crown of Aragon. These books record the purchase of coal and vats for the ground metal[40].

Francesco Pegolotti describes the most commonly used method to ground gold in medieval times. The first step is to heat a vase full of water while the gold is kept molten in a crucible. Once the water starts to boil, the molten gold is poured in bit by bit "because if you put it in all at once it would become one block, and not separate into grains"; upon entering the water the gold solidifies into the shape of small buttons; the last step is to empty the vase through a sieve to collect the ground gold[41]. Once ground, the gold has to be mixed with a certain amount of salt, potassium nitrate and mercury or gum Arabic, to avoid the formation of lumps, and washed repeatedly. The last stage, to be carried out just before use, only involves the mixture of the resulting golden dust with a binder[42]. Recipe number 77 in the Manuscript of Lucca indicates that, for the preparation of golden ink, pure gold had to be filed and ground with vinegar in a stone mortar. Salt had to be added when the mixture acquired a blackish colour. Recipe 79 describes a similar process, with the addition of a final step according to which the mix must be diluted in a measure of orpiment and another of tetterwort juice[43].

Medieval recipe books often describe the preparation of golden inks with minerals such as sulphur and orpiment. The latter (*auripigmentum*) was a yellow pigment

39. 1505. 11. 15. AHPCO. Protocolos Notariales de Córdoba, Legajo 14143P, hand 10, f. 24r.

40. Córdoba, Ricardo. *Ciencia y técnica monetarias*...: 167 (n. 234).

41. Pegolotti, Francesco. *La pratica della mercatura*...: 331.

42. Kroustallis, Stefanos. "*Quomodo decoratur pictura librorum*: materiales y técnicas de la iluminación medieval". *Anuario de Estudios Medievales*, 41 (2011): 760-761; Kroustallis, Stefanos. "La escritura y sus materiales", *El Soporte de la Lengua*. Logroño: Gobierno de La Rioja, 2008: 158.

43. Caffaro, Adriano. *Scrivere in oro. Ricettari medievali d'arte e artigianato (secoli IX-XI). Codici di Lucca e Ivrea*. Naples: Liguori Editore, 2003: 111.

used in the illumination of manuscripts since at least the 8th century[44]. Although highly toxic and incompatible with most other pigments used in illumination it remained very popular[45]. The Castilian mss. II/1393, BPR, and 9226. BNE includes a recipe entitled "To make golden letters without gold", where the ink is obtained with an ounce of orpiment and an ounce of very finely ground glass, which are diluted in egg white, which acts as binder[46].

Other golden inks were prepared with vegetal and animal by-products, such as saffron and bile[47]. The use of yellow vegetal colorants such as saffron, reseda and, less frequently, tetterwort, is often reffered to in medieval recipe books[48]. The preparation of inks with saffron was fairly simple: the flowers are macerated in water, sometimes with the addition of ash, and later mixed with egg white. According to Cennini's *The Craftman's Handbook*, saffron-based inks are highly suitable for use on parchment, although the colour tends to fade after a prolongued exposure[49]. On the other hand, bile —a yellowish liquid segregated by the liver of certain animals— needs to be crushed and mixed with a white substance (white clay, gypsum, white lead); the most commonly used bile was extracted from large fish, goats and turtles, among others[50].

Castilian recipes, in ms. 9226, Biblioteca Nacional de España, and ms. II/1393, Biblioteca del Palacio Real, also suggest the use of saffron and bile for the preparation of golden inks. The former, entitled "Ink that looks like gold but without gold", mentions the mixture of one part of saffron juice or dust with one part of orpiment and goat or fish bile; it is left to ferment in a glass warmed in manure for a few days, resulting in a golden ink which the recipe describes as "very pretty". The second recipe comes under the heading "For writing that looks like gold", and recommends the mixture of earwax and saffron, in equal measure, with goat bile. As in the previous recipe, the mix is left to ferment and thicken in an eggcup set on warm ashes, resulting in an ink that "is proven to be good for writing"[51].

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44. Eastaugh, Nicolas; Walsh, Valentine; Chaplin, Tracy; Siddall, Ruth. *Pigment Compendium: A Dictionary and Optical Microscopy of Historic Pigments*. Oxford: Elsevier Butterworth-Heinemann, 2008: 291.

45. Kroustallis, Stephanos. "*Quomodo decorator pictura librorum...*": 789. Its use has been recorded in medieval manuscripts such as the *Book of Kells* (Fuchs, Robert; Oltrogge, Doris. "Colour material and painting technique in the Book of Kells", *The Book of Kells: Proceedings of a conference at Trinity College, Dublin, September 6-9*, Felicity O'Mahony, ed. Brookfield: Scolar Press, 1994: 133-171).

46. BNE. ms. 9226, f. 33; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial en la España medieval*. Cordoba: Universidad de Córdoba (PhD Dissertation), 2013. (<http://helvia.uco.es/xmlui/handle/10396/8628?show=full>).

47. Kroustallis indicates that "gold" and "silver" were used to refer to precious metals and also to colours, and the use of any substance with the shine and colour of gold, but without gold, was therefore permitted (Kroustallis, Stephanos. "*Quomodo decoratur pictura librorum...*": 791).

48. Clarke, Mark. *Mediaeval Painters' Materials and Techniques*...: 186-187; Clarke, Mark. "Colours versus colorants in art history: evaluating lost manuscript yellows". *Revista de História da Arte*, 1 (2011): 139-151; Kroustallis, Stephanos "*Quomodo decorator pictura librorum...*": 789.

49. Kroustallis, Stephanos. "*Quomodo decoratur pictura librorum...*": 790-791.

50. Kroustallis, Stephanos. "La escritura y sus materiales...": 158.

51. BNE. ms. 9226, f. 33; BPR. ms. II/1393(6), f. 4r; cited in: Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 371.

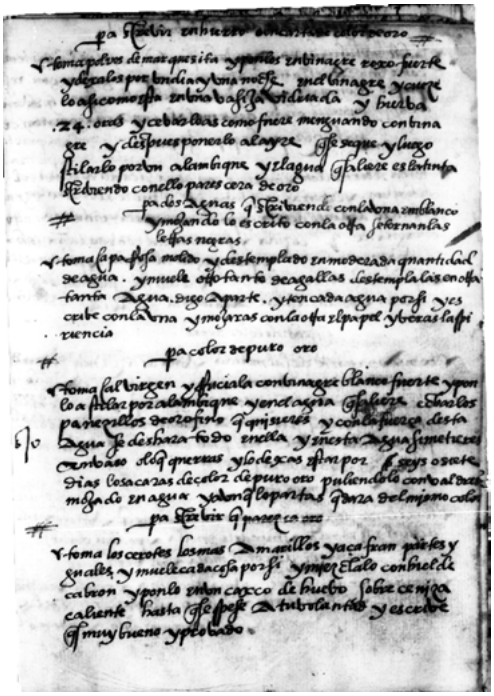

Illustration 3. Recipes *Para screbir en hierro o en carta de color de oro*, *Para color de puro oro*, *Para scribir que parezca oro* in BPR, ms. II/1393, f. 4r.

Castilian recipes are very similar to Italian ones, such as numbers 80 and 134 in the Manuscript of Lucca or some in the manuscripts in the Fondo Palatino, Biblioteca Nacional, Florence, describing the preparation of golden inks by using mineral, mostly orpiment, and vegetal raw materials, such as saffron, tetterwort and resin, mixed with a binder such as gum, turtle bile and egg white. Other European manuscripts also include analogous recipes, for example the *Mappae Clavicula* or Heraclius' treatise[52].

A last recipe, on the ms. II/1393, Biblioteca del Palacio Real, mentions a different way to prepare "Golden ink to paint" by using vegetal raw materials. The recipe suggests taking three pounds of flax oil and two pounds of pine resin and boiling them separately with a goose feather each. They must boil until the feather burns, and are later mixed with two ounces of yellow Socotra aloe per pound as binder, stiring until the mix is even and storing in a jar[53].

52. Caffaro, Adriano. *Scrivere in oro*...: 113 and 150; Brunello, Francesco. *De Arti Illuminandi*...: 171; Pomaro, Gabriella. *I Ricettari del Fondo Palatino della Biblioteca Nazionale Centrale di Firenze*. Milan: Giunta Regionale Toscana-Editrice Bibliografica, 1991: 117-118, for example Pal. 796, f. 10r; López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 242-244.

53. BPR. ms. II/1393, f. 10v; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 371.

2.4. Mosaic gold

The most common imitation of gold leaf in recipe books and treatises during the 15th and 16th centuries involves the preparation of a tin sulphide, a sort of dusty glitter, known as *aurum musicum* or mosaic gold. This pigment was produced with tin disulphide and was similar to oropel sheets in serving as a substitute of real (and more expensive) gold for writing, drawing and illuminating[54].

There are several theories, and many doubts, regarding the origins of the name, but most experts follow Milanesi, who suggested that the name came from the use of this pigment in the decoration of mosaic tesserae[55]. Its use in the illumination of manuscripts presented two problems: first, it is made with tin sulphide and not with actual gold, so the resulting colour is sometimes darker than desired; second, the mixture could be unstable once applied, and Cennini's *The Craftman's Handbook* recommends using it sparsely[56]. This did nothing to prevent its popularity; in fact, the analysis of the pigments used in 15th century German manuscripts have shown that the use of mosaic gold was very common in miniatures, attesting to the correspondence between the recipes contained in the manuscripts and workshop practices[57].

Among the Castilian recipes for the preparation of this compound we must highlight number 37 in ms. H490, entitled "to make mosaic gold". This recipe recommends taking a pound of tin and adding, once the tin is molten, another of mercury; then, a pound of sulphur and another of salammoniac are ground together. All four ingredients are then mixed in a flask "with a long neck", which is sealed with mud and left to dry. Once dry, it is put on the fire for two hours or more "and it becomes like gold". Before use, this compound must be mixed with gum. The yellow color obtained at the end of the process is due to the formation of tin sulphide. Identical recipes can be found elsewhere: Manuscript of Naples, *De Arte Illuminandi*; el *Libro de cómo se fazen as cores* (recipe "Para fazer o oro de musico con

54. Doerner, Max. *Los materiales de pintura y su empleo en el arte*. Barcelona: Reverte, 2005: 268; Matteini, Mauro; Moles, Arcangelo. *La química en la restauración*. Donostia: Nerea, 2008: 90-91.

55. Milanesi, Carlo. *Dell'Arte del vetro per mosaico. Tre trattatelli dei secoli XIV e XV*. Bologna: 1864: 133. Medieval recipes in Latin refer to it as *aurum musicum*. The earliest known explicit mention to this material is found in the so-called De Rossi manuscript, a collection of Hebraic recipes written in Portugal in 1262, and currently catalogued as manuscript 945, Biblioteca Palatina, Parma (Blondheim, David. "An Old Portuguese Work on Manuscript Illumination". *Jewish Quarterly Review*, 19 (1968): 97-135; Abrahams, Harold. "A Thirteenth-Century Portuguese Work on Manuscript Illumination". *Ambix*, 26 (1979): 93-99; recipe 48 in *Codex Matritensis*, dated to the 12th century, however, already suggests the preparation of a similar substance based with tin and mercury (Burnam, John M. *Recipes from Codex Matritensis A16 (ahora 19)*. Cincinnati: Cincinnati University Press, 1926: 20); Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 27.

56. Cennini, Cennino. *El Libro del Arte*, ed. Franco Brunello. Madrid: Akal, 1988: 159.

57. From the 14th century onwards the recipes for the preparation of mosaic gold became common throughout Europe and, most particularly, in German-speaking regions (Schiessl, Ulrich. "Musivgold. Eine pigmentgeschichtliche Skizze". *Maltechnik Restauro*, 87/4 (1981): 219-229; Fuchs, Robert; Oltrogge, Doris. "Utilisation d'un livre de modèles pour la reconstitution de la peinture de manuscrits. Aspects historiques et physico-chimiques", *Pigments et colorants de l'Antiquité et du Moyen Age. Teinture, peinture, enluminure, études historiques et physico-chimiques*. Paris: Centre Nationale de la Recherche Scientifique Éditions, 2002: 314-315).

que escrevas"); the *Liber de coloribus iluminatorum*, Sloane Manuscript 1754 (f. 213, "Ad aurum musicum faciendum"); the third treatise published by Gaetano Milanesi in his work *Dell'Arte del Vetro* (1443 recipe, 'A fare purpurino overo oro musico'); chapter 159 of Cennini's *The Craftman's Handbook*, recipes 141 to 145 in the sixth chapter of the Manuscript of Bologna, edited by Mary Merrifield; and some recipes in the manuscripts in the Fondo Palatino, Biblioteca Nazionale, Florence (796, 811, 851, 866, 934, 1072). Often these recipes refer to mosaic gold as "glitter"[58].

Two Castilian recipes in ms. II/1393, Biblioteca del Palacio Real, Madrid, mention the preparation of a concoction akin to mosaic gold, but with the substitution of tin for other metal compounds, such as brass or verdigris. The first suggests mixing two ounces of brass with one of sulphur and one of mercury, which are heated inside a vase for four hours. Before use, the ink must be diluted in white wine and a water and gum mixture; the second recipe recommends mixing one ounce of verdigris, an ounce of sulphur and two of white vinegar inside a brass cauldron. This mixture is to be heated until reduced by one third and then left to cool. A pinch of saffron must be added before use[59].

3. The application of gold

As a general rule the surface on which the gold or its substitute is to be applied has to be treated to ensure the stability of the decoration. This includes a wide variety of substances and application techniques, largely depending on the material with which the artisan has to work; illuminating parchment involves a very different process to, for example, applying gold decoration on metal or wood. In any case, all these procedures had three objectives in common: outlining the area to be decorated, ensuring a good adherence for the decoration (regardless of whether this was gold leaf, ink or dust) and setting the conditions for a better and shinier final result[60]. As a second step, the decoration is treated with heat to provoque the chemical reactions conducive to its final fixation and stability.

58. Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 26-27 and 45-46. All of these recipes suggest the mixture of tin, mercury (quicksilver), sulphur and salammoniac. After heating, it must be diluted in gum Arabic or egg white: Brunello, Francesco. *De Arte Illuminandi*...: 57-59; Thompson, Daniel. "Liber de Coloribus Illuminatorum sive Pictorum from Sloane Manuscript nº 1754". *Speculum*, 1 (1926): 280-307; Thompson, Daniel. *An anonymous fourteenth-century treatise: De Arte Illuminandi*. New Haven: The Yale University Press, 1933: 37; Cennini, Cennino. *El Libro del Arte*...: 180; Manuscript of Bologna, chapters 141-145 and 168 (*Original Treatises dating from the Twelfth to the Eighteenth Centuries on the Arts of Painting*, ed. Mary Merrifield. New York: Dover, 1967: 458-477); Pomaro, Gabriella. *I Ricettari*...: 100-102 and 118). Theophilus's Chapter 30, Book I, explains how to use tin to imitate gold; after crushing the tin to a thin grain it is diluted in gum and applied. It is later burnished with a tooth and covered for one day with the kind of saffron used to dye silk (*Theophilus' On Divers Arts*...: 37). Also: González-Alonso, Enriqueta. *Tratado del dorado*...: 138-139; López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 249-251.

59. BPR. ms. II/1393, fol. 5r: cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 370-371.

60. González-Alonso, Enriqueta. *Tratado del Dorado*...: 155.

3.1. On parchment

The last step before applying the gold to the parchment was the preparation of the base or *sisa*. The base must have good adhesive qualities and had therefore to be reduced to a very fine texture. Fine plaster, white lead, chalk and Armenian bole were for this reason the most common materials in use. On the other hand, the base had to stay smooth over time, to avoid altering the gold set upon it. Small amounts of plastic binders such as fish tail, leather glue, pitch and resin. The glue that is recommended most often in medieval treatises on art technologies is egg white, although gum Arabic and plum tree gum (*gumma cinea*) are also described as excellent for illuminating parchment. The use of protein-based glues (extracted from fish, parchment or leather) was especially recommended for chrysographic works or whenever the gold was applied in dust form. Softening substances, such as sugar, honey, fig-tree sap, vinegar and earwax, rich in latex, were also frequently added to increase the flexibility and resistance of the painting; in addition, vinegar was added to glues and sugars to prevent crystalisation. In order for the white colour of the *sisa* not to show if the golden film thinned or tore, the base could also be coloured with a yellowish or orangish substance, often a mixture of saffron[61].

Several Castilian recipes give instructions for the preparation of the *sisa*, including a wide variery of techniques. Recipe number 38 of manuscript H490 in the Faculty of Medicine, Montpellier, suggests using two parts of gypsum, one of Armenian bole and one of sugar, forming a mixture that will be macerated for twenty four hours in tail or hide glue. Finally, saffron is added and the resulting mix is left to dry; recipe number 39 in the same manuscript mentions using gypsum (an amount equivalent to the size of an egg), bole (as much as a walnut), saffron (three strands) and *cicotrí* aloe (so called because of its origin in the African island of Socotra; the plant gives a very bitter resinous juice with similar binding properties to the tail glue used in the previous recipe, and of which "as much as a small chickpea" is added); in both cases the *sisa* is stored in small nuggets and has to be diluted in egg white or water with gum before use[62].

The European texts suggesting similar recipes for the preparation of the *sisa* include the Manuscript of Naples, where the section entitled "Of the gypsum to fix gold on parchment" recommends mixing "the boiled and clean gypsum that painters use to fix gold on canvas, that is, as fine as possible, and a fourth part of the best Armenian bole, ground on a porphyry stone with liquid glue and as much honey as seems fit"; Cennino's *The Craftman's Handbook*, in recipes 157 and

61. On the use of binders in the illumination of manuscripts: Kroustallis, Stephanos. "*Quomodo decoratur pictura librorum*...": 791-794; on raw materials used and processes carried out in the preparation and application of the *sisa*: Gilissen, Léon. "L'or en enluminure". *Pigments et colorants de l'Antiquité et du Moyen Age*...: 203-204; Borradaile, Viola; Borradaile, Rosamund. *The Strasburg Manuscript. A Medieval Painters' handbook*. London: Alec Tiranti, 1966: 59; Brunello, Francesco. *De Arte illuminandi*...: 100-103; Blondheim, David. *Livro de como se fazen as côres*. New York: Columbia University Press, 1930: 80; Clarke, Mark. *Mediaeval Painters' Materials and Techniques*...: 117; López, Eva, *Estudio de los materiales y procedimientos del dorado*...: 301-305.

62. Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 29-30 and 46.

158, suggests the mixture of gypsum with lead, bole and sugar, and a later dilution in egg white; the Manuscript of Bologna, in its recipe 160, prescribes the use of gypsum, bole, glue, sugar and earwax; finally the manuscripts in the Fondo Palatino, Biblioteca Nazionale, Florence (for example, numbers 934 and 1001) suggest the use of gypsum, bole, white lead and honey, diluted in egg white and with the final addition of saffron[63].

In order to apply the *sisa*, the parchment must be perfectly cleaned and stretched out. Recipe 39 in ms. H490 indicates, on the preparation of the parchment on which the *sisa* is going to be extended, that if the surface is excessively greasy it must be energetically rubbed with bread crumbs, because the excess of grease could prevent the correct adherence of the *sisa*. The base was simply mixed with vinegar, applied and left to dry before the gold leaf could be set upon it. If the sisa had been in storage for a while, one of the recipes in ms. 9226, Biblioteca Nacional de España, recommends boiling in vinegar before application and, again, left to dry afterwards. Should the *sisa* lack the necessary mordant to ensure a good adherence of the gold leaf, this recipe continues, it could be softened with human breath. Once extended, the base must be totally smooth, for which most recipes suggest the use of a knife to "shave" it as thin as practicable; number 38 in ms. H490 in Montpellier also prescribes applying the *sisa* on the surfaces to be decorated with gold, scraping it with a knife and polishing it before applying the decoration. The final step in the preparation of the parchment was polishing the sisa to guarantee that there were no cracks or creases that could tear the gold; the recipes in ms. 9226 recommend the use of cotton: "once dry, clear with cotton" and "wipe everything that was not fixed"[64].

According to Stefanos Kroustallis there were two techniques for applying the gold to the *sisa*: the "wet" system, in which the parchment was first left to dry and then humidified with a binder before applying the gold; and the dry system, which relied on honey or sugar as binders, resulting in a sticky surface, on which the gold was applied by pressure. It was also possible to apply the gold or the golden inks not to the *sisa*, as we have described, but more directly onto the parchment, in which case the binders used were fish tail, garlic (mixed with gum Arabic) and egg white —profusely dyed yellow (with saffron) or red (with vermillion) to avoid sharp contrasts with the colour of the gold[65]. Some of the Castilian recipes included in ms. 9226, Biblioteca Nacional de España, mention the preparation of a base using not mineral, such as gypsum or bole, but vegetal raw materials, for example garlic juice and the sap extracted from lettuces and fig trees. Specifically, one of these

63. Brunello, Franceso. *De Arte Illuminandi*...: 83-85 and 168-169; Cennini, Cennino. *El Libro del Arte*...: 179-180, chapters 157 and 158; Manuscript of Bolonia, chap. 160 (Merrifield, Mary, ed. *Original Treatises*...: 466; Pomaro, Gabriella. *I Ricettari*...: 120-122).

64. BNE. ms. 9226, f. 34, 38 and 41; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 368-369; Córdoba, Ricardo. "Un recetario técnico castellano del siglo XV...": 29-30. Cennini also says that, once dry, the sisa must be scraped with a knife in order to clean the gypsum (Cennini, Cennino. *El Libro del Arte*...: 180, chap. 158). Gilissen claims that the tools used to burnish the sisa were the same as those used to polish gold, such as dog or wolf teeth, agathes and haematites. This operation gave the gypsum a shine that enhanced that of the gold (Gilissen, León. "L'or en enluminure...": 204).

65. Kroustallis, Stephanos. "*Quomodo decoratur pictura librorum*...": 795; Caffaro, Adriano. *Scrivere in oro*...: 151.

recipes suggests peeling and crushing three garlic heads to release "as much juice as you can get", adding a pinch of saffron and rubbing the surface of the parchment with the mixture. Once dried, a soft heat was administered before applying the gold leaf; another recipe mentions the use of bitter lettuce sap, fig tree sap or gummed water, mixed with aloe (acting as binder) and stone sugar (as softener). The mixture had to be left so simmer until reduced by half and left to dry on the parchment[66].

Other Spanish recipes, in ms. 9226, Biblioteca Nacional, and II/1393, Biblioteca del Palacio Real, are even more simple because they skip the preparation of the base and prescribe the application of binders and softeners directly on the parchment. The first recipe in ms. 9226, entitled "To fix gold leaf", recommends mixing equal measures of gum Arabic and salammoniac and then diluting the mixture in vinegar before "treating with it what needs to be decorated, and applying the gold before it is dry"; the second one, under the heading "To make the *sisa* for golden letters", suggests mixing a nugget of salammoniac, half of bile, sugar and honey, in a glazed bowl. After diluting this mixture in vinegar and boiling it "until it has the necessary mordant" it is sieved through a piece of cloth. With regard to the recipes contained in ms. II/1393, under the heading "Writing with gold or silver", the first recommends the application to the parchement of a mixture of gum diluted in water and honey, then "before it is dried apply the gold"; the second simply prescribes the application of sugar[67].

The recipes included in ms. H490, Faculty of Medicine, Montpellier, and ms. II/1393, Biblioteca del Palacio Real, indicate that the gold, once fixed, was treated with a burnisher made of animal teeth or stone (agathe, haematite), using earwax to repair possible cracks[68]. The burnishing was generally carried out by illuminators, who usually started around the edges and left the central sections for the end; the recipes recommend burnishing to be executed vigorously[69].

3.2. On leather

One of the most common techniques in *guadamacileria* (the decoration of leather objects) was the application of thin oropel sheets. Generally, the first step was *granir*, or giving the leather a dense granulated texture with a rocker (a flat, micro-dented

66. BNE. ms. 9226, f. 34 and 126; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 368-369. Similar recipes for the use of garlic juice diluted in gum for the preparation of the *sisa* can be found in the *Compositiones Lucenses* and Cennini's *The Craftman's Handbook* (cited in: Brunello, Francesco. *De Arti Illuminandi*...: 167); garlic juice contains an essential oil —mostly composed of organic sulphides (allyl disulphide and trisulphide)— with strong binding properties (Gañán, Constantino. *Técnicas y evolución de la imaginería*...: 131).

67. BNE. ms. 9226, f. 38 and 41; BPR. ms. II/1393, f. 5r; cit. Criado, Teresa. *Tratados y recetarios de técnica* industrial...: 368-369.

68. BPR. ms. II/1393, f. 5; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 368-369; Córdoba, Ricardo. "Un manuscrito técnico castellano del siglo XV...": 29.

69. Gilissen, León. "L'or en enluminure...": 206.

specialised tool), followed by a thorough polishing of the surface thus treated[70]. After this, the oropel was simply set on these surfaces —during which process, according again to the guild regulations, the metal sheets often tore— and burnished. In 1501 Diego de Jaén, a goldbeater from the parish of Santa María in Córdoba, agreed to supply the *guadamacilero* Juan de Palencia with three dozen pieces of golden oropel every Saturday, at a price of 224 mrs. "doubly golden and good for *guadameciles*"; the goldbeater also committed to supply his customer with 10 pounds of fat burnish and another 10 of resin —used to polish oropel— within ten days of the agreement[71].

A different version of the technique involved the treatment of the leather with a mixture of binding and adhesive substances. There are no known Spanish recipes for this technique, but there are several from Italy. Heraclius, for example, includes a recipe for a concoction of ochre, glue and egg white, which needs to be burnished after application; the *Mappae Clavicula*, on the other hand, prescribes rubbing the leather and applying a mixture of egg white and tragacanth while the leafs are being treated with flax oil, glue and saffron; Audemar recommends treating the leather with a mordant composed of gum Arabic, plum glue and egg white; the Manuscript of Lucca, in its recipe number 81, suggests preparing the leather with pumice, washing it with warm water and treating it with egg white or gum with a sponge before applying the gold leaf; recipe 111 in the same document, on the other hand, prescribes rubbing the leather with flax oil and saffron. Along the same lines, ms. 1001, Fondo Palatino, Biblioteca Nazionale, Florence, recommends rubbing the leather with a a mixture of flax oil, pine resin, Socotra aloe and yellow incense; afterwards, the metal sheet is applied and rubbed four or five times with a stone, to achieve the desired shine[72].

3.3. On metal

As stated at the beginning of this section, the materials upon which golden decoration was set had to be prepared in some way to ensure its adhesion, and metal is no exception. The application of a metal decoration to metal objects, generally iron or copper alloys, was a form of metal welding, and for this reason the technical recipes dedicated to the application of gold decoration on metal are akin to those on

70. The regulations published by the guild of decorated leather workers (*guadamecileros*) in Córdoba in 1543 established that, in order to gain a mastership, the artisans must know how to granulate a piece of *guadamecil*; those dating to 1528 determined that the leather used as base for silver decoration could not be too thin, because it would otherwise be pierced during granulation (Córdoba, Ricardo. *La industria medieval de Córdoba*...: 215).

71. 1501.s.d., AHPC. PNCo, Legajo 14140P, Hand 7, f. 20r. In another contract, Alfonso de Jaén, *oropelero* and also from the parish of Santa María, agreed to supply the *guadamacilero* Pedro de Soria, with 20 dozen sheets of golden opopel within 20 days, for a price of 1000 mrs. According to the agreement, Pedro de Soria was to supply the leather (1502.07.28, AHPC. PNCo, Legajo 14141P, Cuaderno 22, f. 10v).

72. Caffaro, Adriano. *Scrivere in oro*...: 113 and 135; Pomaro, Gabriella. *I Ricettari*...: 143-144; López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 301-303.

welding techniques[73]. In general, the idea behind the process is to ensure that the gold will be securely fixed, or in welding terms, that the filler metal (gold) coalesces with the base metal (iron, copper, bronze, etc.); for this to occur the surface of both metals must be completely clean, because impurities may affect the process of coaslescence. Since exposure to air causes oxidation in nearly all metals, and since the thinnest layer of rust may prevent the coalescence of the metals, it is essential to use a flux compound, to isolate the contact point from air, dissolve oxides and facilitate the process of coalescence[74].

Historically, the most commonly used, and most efficacious, fluxes and reductants were resins and mineral salts, such as borax and fluorides (alkaline acids). This includes vegetal fats, such as pitch, mastic and oil, but mostly mineral fluxes such as borax, alum, vitriol, salt and salammoniac, widely used in ancient and medieval metallurgy for the manipulation of gold, tin, copper and other metals. The use of borax, for example, is amply documented in welding, melting before the filler metal and facilitating and accelerating the coalescence of this and the base metal. Anna-Catherine Robert-Hauglustaine has, in fact, stressed the use of borax in welding as a critital innovation in medieval metallurgy[75].

According to the evidence provided by local 15th century regulations and notarial contracts from Córdoba, the first step for fixing the metal leafs to a metal object (iron, copper, brass or bronze) was to file the surface of the object to be decorated, because the smallest crack or patch of roughness could tear the metal sheet or cause it to be incorrectly fixed. After preparing the base, the leaf was then applied with heat and pressure and vigorously polished with agate or haematite[76]. It seems likely that the word *añirar* refers in 15th century Castilian texts to this polishing operation aimed at fixing and polishing the metal leaf; strangely, this operation which the 17th century regulations from Seville recommend to be carried out with good quality *añir* (indigo) and which is also documented in many inventories of gold-decorated objects, is not mentioned in technical recipe books[77].

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73. On welding techniques as described in recipe books from the period see: Córdoba, Ricardo. "Técnicas de soldadura de metales según recetarios italianos de los siglos XV y XVI", *Estudios en homenaje al Profesor Emilio Cabrera.* Córdoba: UCOPress, 2015: 139-150.

74. Giachino, Josseph W.; Weeks, William. *Teoría y Práctica de la soldadura*. Barcelona: Reverte, 1995; Jeffus, Larry. *Soldadura. Principios y aplicaciones*. Madrid: Paraninfo, 2008.

75. Lipinsky, Angelo. *Oro, argento, gemme e smalti. Tecnologia delle arti dalle origini alla fine del Medioevo*. Florence: Olschki, 1975: 223; Robert-Hauglustaine, Anna Catherine. "Le soudage de l'or: études à partir des textes antiques et médiévaux", *Outils et ateliers d'orfèvres des temps anciens*, Christiane Eluère. ed. Saint-Germanin-en-Laye: Musée des Antiquités Nationales, 1993: 113-114 and notes 45-47, where she points out its presence in medieval technical recipe books, for example in the *Liber Sacerdotum* and in Theophilus' and Benvenuto Cellini's handbooks. See also: Sánchez, Julio. *De minería, metalurgia y comercio de metales*. Salamanca: Universidad de Salamanca, 1989: 163.

76. Córdoba, Ricardo. *La industria medieval de Córdoba*...: 259-260. The tools used by Juan Rodríguez de Soria, a knife maker from Córdoba, to apply golden decoration to the knife handles included a polishing stone and a hard brush (1507.03.22, AHPC. PNCo, Legajo 11827P, f. 238r).

77. 15th century inventories often mention golden and *añirados* metal objects. A good example of this is the contract signed in September 1494 by Martín Ruiz, leather artisan in San Nicolás de la Axerquía, and Lope de Valpuesta, from Toledo, who were thereby to be sold 100,000 mrs. in merchandise "in horse

One of the recipes included in ms. 2019, Biblioteca Nacional de España, details the procedure used to apply gold leaf to iron objects by heat and pressure, as described above. First, it recommends cleaning and filing the iron surface thoroughly, with a file first and then "with a steel object called a scraper"; following this, the metal was put on the fire, covered with coals and not retrieved until it was red hot. Subsequently, the object was cleaned and burnished with a polishing stone before applying the gold leaf and rubbing again. After taking the object out of the fire, it was left to cool down, the ashes wiped away with a cloth, and polished again until the desired shine was achieved; "this is repeated two or three times for better effect, and if some of the gold is torn away, apply another bit and polish it". This was the simplest technique and also the most akin to a true weld[78].

A second technique, as popular as the previous one if not more, was based on the application of a mercury and gold alloy (amalgam) and the administration of heat, upon which the mercury would volatilise leaving the gold sitting on the metal surface[79]. This operation involved two stages: first, the object to be decorated was immersed in a mixture which many writings refer to as "gilding water", where the metal object was prepared to better assimilate the amalgam; afterwards, the mercury and gold amalgam was applied to the surface. After the administration of heat and the consequent evaporation of the mercury, the remaining gold needed only to be polished. Some Italian recipes specify the compounds used to prepare the metal, which played the same role as the *sisa* on parchment, including orpiment, verdigris, vitriol, alum, tartar, saltpetre, salammoniac and, sometimes, vinegar[80].

One of the recipes included in ms. 2019, Biblioteca Nacional de España, describes this technique under the heading "Dorar de molido"; the explanation begins by clarifying that this method is employed "to gild small images and figures that cannot be otherwise cleaned with irons or polished with stones" and that it is more costly

harnesses and other leather goods" including some silver and *añiradas* stirrups, valued in 305 mrs., and some golden and *añirados* bits, valued in 95 mrs. According to the agreement, the merchant from Toledo would receive, towards the mid of the following month of October, 80,000 mrs. worth of plated metal pieces and 20.000 mrs. worth of reins, straps and other leather objects (1494.09.02, AHPC. PNCo, Legajo 13670P, f. 932v).

78. BNE. ms. 2019, f. 61r: cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 143.

79. This technique is documented in the Iberian Peninsula from the second half of the 1st millennium BC. For a discussion of the origins and dissemination of this technique in prehistory see: Martiñón-Torres, Marcos; Ladra, Lois. "Orígenes del dorado por amalgama. Aportaciones desde la orfebrería protohistórica del noroeste de la Península Ibérica". *Trabajos de Prehistoria*, 68 (2011): 187-198, with new ideas on the notions previously set forth by: Lins, Andrew; Oddy, Andrew. "The Origins of mercury Gilding". *Journal of Archaeological Science*, 2 (1975): 365-373; Oddy, Andrew. "A history of Gilding with particular reference to statuary", *Gilded Metals: history, technology and conservation*, Terry Drayman-Weisser, ed. London: Archetype, 2000: 1-19.

80. Among the many recipes in the Fondo Palatino, Biblioteca Nazionale, Florence, which refer to these compounds, we may mention ms. Pal. 885, f. 263, "To make water to gild iron and swords"; Pal. 1021, f. 103r, "Making water to gild iron"; Pal. 915, f. 15r, mixes rock alum, vitriol and salt; Pal. 869, f. 95r, where the concoction includes an ounce of vitriol, an ounce of alum and half of salt, all boiled in white wine; or common salt, tartar, rock alum, salammoniac and Roman vitriol; and Pal. 858, f. 58r, which recommends diluting eight ounces of vitriol, two of alum and one of salammoniac in vinegar (Pomaro Gabriella. *I Ricettari*...: 162-163 and 167).

than welding "because it uses twice as much gold", but also more durable. The recipe recommends warming the piece and putting it into a bowl with some gilding water, "but not for too long if you don't want it to crumble away"; after taking it out and cleaning it, it must be put into another vase with the mercury, "and you will make sure to stir it until the mercury sits in and the surface is made to look like silver"; following this, it must be put into the fire "where the mercury will be consumed and the golden colour will remain". Finally, after cooling down, the piece is polished[81]. Benvenuto Cellini's work includes a similar recipe for gilding with mercury amalgam; the starting point is a set of gold leaf fragments hammered into the thickness of writing paper, cut into small pieces, mixed with the mercury inside a previously warmed, new crucible —in the "usual" proportion, one part of gold to eight parts of mercury— and left to simmer until the gold is molten and mixed with the mercury. Once the mixture is perfectly even the crucible must be taken off the fire and the amalgam poured into a container with clean water. Meanwhile, the object to be decorated must be perfectly polished. Afterwards, the alloy is applied with a brush or some other instrument, and the object set upon a heat source to volatilise the mercury[82].

Numerous European recipes refer to this method, very popular during the Middle Ages, and detail the use of gilding waters and the most efficient mineral fluxes. Recipe number 133 in the Manuscript of Lucca, for example, recommends mixing gold leaf and mercury and administering heat to volatilise the mercury while the gold remains fixed to the surface, specifying that this method is also valid for gilding iron, provided that the base is previously treated with alum, vitriol, a pinch of salt and vinegar. The same treatise includes another recipe which suggests the preliminary treatment of iron objects with a mixture of vitriol, alum and tragacanth. This mixture had to be diluted in water and boiled for an hour before being applied to the surface to be gilded. After rinsing, the gold leaf could be applied and polished. Similar recipes can be found in other mansucripts in the Fondo Palatino, for example Pal. 869, which also indicates the preparation of concoctions (by using vitriol, alum, salt, salammoniac, tartar, etc. all diluted in vinegar or wine) to bath the iron object before the application of the amalgam and heating; once the process is finished, the document recommends polishing the finished object with hare fur. Finally, Isabella Cortese's *Secreti*, published in the 16th century, includes a similar recipe for gilding iron: the gilding water is prepared with alum, tartar, verdigris and salt; the iron object, previously warmed, must then be submerged in it for a short while, following with the application of the gold and mercury amalgam. Finally, the object is put on the fire until the mercury volatilises leaving the gold on the surface[83].

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81. BNE. ms. 2019, f. 62r; cited in: Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 141.

82. Cellini, Benvenuto. *Tratados de orfebrería escultura, dibujo y arquitectura*, ed. Fernando Checa. Barcelona: Akal, 1989: 140-142.

83. Caffaro, Adriano. *Scrivere in oro*...: 149 and 103; BNCF. ms. Pal. 869, f. 95r, one ounce of vitriol, one of alum, half of salt, all boiled in white wine; also, common salt, tartar, rock alum, salammoniac and Roman vitriol (Pomaro, Gabriella. *I Ricettari*...: 162-163); book II, Chap. 59, *To gild iron* (The Secrets of Lady Isabella Cortese, which will contain things mineral, medicines, *arteficiose*, and alchemy, and many of

3.4. On wood, bone and fabric

The application of gilded decoration on wood, mostly for the ornamentation of free standing sculptures or altar pieces, was not significantly different from a technical point of view, because wood also required preliminary treatment. In fact, the technique is very similar to the application of *sisa* on parchment, the most common raw materials being gypsum and bol, along with binders and softeners.

One of the techniques found in the recipe books of the time is the so called "water based gilding". This is a simple procedure, involving the preparation of a base with a mixture of gypsum and animal glue, upon which several coats of ground bole —diluted in parchment glue or egg white— were applied, before polishing with a cloth and wetting stlightly to provide a brighter shine. The gold leaf was applied while the base was still humid and with the aid of a glue. Once dried, the gold leaf could be polished with agate, haematite or animal tooth[84]. These recipes appear in numerous texts from all over Europe, including Audemar, who mentiones the use of layers of gypsum mixed with glue and egg white; or Cennini's *The Craftman's Handbook*, which details the sealing of the surface of the wood with parchment glue, followed by the application of three successive coats of coarse gypsum, fine gypsum and bole, in that order[85]. The regulations of Cordoban painters published in 1493 explain this procedure in detail with reference to the gilding of altar pieces, indicating that before the gold is applied the *emprimadura* —a coat of gypsum scraped with iron knives rather than with sandpaper, just as with parchment— needs to be laid out. The final step, after applying the gold leaf, was polishing[86].

The second technique is known as "oil based gilding" and, although similar to the previous one, since it is also based on the application of a foundation for the gold, it differs in the ingredients used for the preparation of this kind of *sisa*. The main ingredients in this case were a mixture of glue and egg white or flax oil. This was not as popular as the water-based technique because it did not allow the leaf to be polished (whithout the support of a gypsum or a bole base, the gold would tear). For this reason, extra mordants such as crushed garlic, minium, ochre and verdigris,

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the art of perfumery, belonging to every great lady; with other beautiful secrets added, Venice: Giouanni Bariletto, 1565: 53); cited in: Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 160-163.

84. This was the most popular technique because the different coats of gypsum and bole favoured the fixing and polishing of the gold and, therefore, ensured a significantly better final result. This explains the popularity of the method among the writers of the time (Theophilus, Cennini). On the key features of the method see, among many others: López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 274-281; González-Alonso, Enriqueta. *Tratado del dorado*...: 156; Matteini, Mauro. *La Química en la restauración: los materiales del arte pictórico*...: 139; López, Eva; Dalmau, Consuelo. "Materiales y técnicas de dorado a través de las antiguas fuentes documentales". *PH. Boletín del Instituto Andaluz del Patrimonio Histórico*, 61 (2007): 110-129; Martínez, Sofía. "El dorado: técnicas, procedimientos y materiales". *Ars Longa: Cuadernos de Arte*, 11 (2002): 139-140.

85. López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 258-267.

86. Córdoba, Ricardo. *La industria medieval de Córdoba*...: 332-333; the use of knives to eliminate the excess gypsum is also mentioned by Cennini, chapter 115, *The Craftman's Handbook* (González-Alonso, Enriqueta. *Tratado del dorado*...: 146; Gañán, Constantino. *Técnicas y evolución de la imaginería polícroma en Sevilla*. Seville: Universidad de Sevilla, 1999: 150-156).

were added to give the leaf extra stability, while varnishes were also applied as a substitute for the polish (orpiment, alum, saffron, bile, sugar, gum, pine resin)[87]. One of the recipes in ms. 2019, Biblioteca Nacional de España, describes the process of gilding wooden figures by the application of gold paint or varnish in two steps: first, the piece must be treated with several coats of *emprimadura* (the first with a soft glue, the second with flax oil and the third with a mixture of black paint and minio), combining binders with softeners; the second step is the application of the golden paint[88].

The joint participation of goldbeaters and painters in the application of this technique seems to be the normal practice in this period. We can see an example of this in the contract signed in July 1494 by Manuel Ruiz, a goldbeater from the parish of Santa María la Blanca, in Seville; Juan de Robledo, a painter from the parish of San Vicente; and Antonio Núñez, a painter from the parish of San Román, after the latter had commissioned Pedro de Trujillo, another painter in the parish of Santiago, to carry out several works —including five mouldings in polished gold, twenty golden battens, fourteen beam-ends in polished gold, a number of miniature battlements for an organ and a number of top decorations for the box of said organ— for the church of Santa Clara in the village of Moguer[89].

With regard to the application of golden decoration on bone, the procedure involved the preparation by distillation of a kind of "gilding water", into which the bone was introduced for a certain time to achieve the desired colour. There are two known recipes for this process in Castile, both in ms. II/1393, Biblioteca del Palacio Real, and describing an identical process: a mixture of quicklime and strong vinegar is distilled through a still, and the gold leaf put inside ("and the strength of the concoction will dissolve it"). The bone is then submerged in this compound for six or seven days, after which it will come out "as though it was pure gold"[90].

Finally, the recipe books also give us some indication as to the techniques used for gilding textile fabrics. These tecniques are essentially equivalent to the water-based and oil-based techniques used in gilding wood, both concerning raw materials and procedure. Although the known Castilian technical handbooks do not include this technique, the rules published in Córdoba in 1493 to regulate the work of painters mention a water-based gilding technique in two steps. In the first, the canvas is

87. López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 281-291; López, Eva; Dalmau, Consuelo. "Materiales y técnicas de dorado a través de las antiguas fuentes documentales...": 110-129; Martínez, Sofía. "El dorado: técnicas, procedimientos y materiales...": 138; Maltese, Carlos. *Las técnicas artísticas*. Madrid: Cátedra, 2006: 65-67.

88. BNE. ms. 2019, *Para dar color de bronce a figuras*, f. 46; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 136. The Manuscript of Lucca includes a similar recipe, number 108, recommending the use of almond gum, macerated in water for a day, mixed with gum, and heated on a soft fire (Caffaro, Adriano. *Scrivere in oro*...: 135); the *Mappae Clavicula*, on the other hand, merely suggests the application of one coat of saffron and egg as the base for the gold (López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 259).

89. AHPS. PNSe, Leg. 2154, f. 684r (21st July 1494).

90. BPR. ms. II/1393, *Para hazer un hueso color de oro* y *Para color de puro oro*, f. 4r and 9v; cit. Criado, Teresa. *Tratados y recetarios de técnica industrial*...: 167.

treated with an *emprimadura* made with gypsum, binders and softeners, including a first coat of wheatpaste, parchment glue or cow tail glue mixed with honey —the presence of the latter, according to the regulations, "makes the base soft and helps the figures not to crack when the fabric is bent"— and a second coat of gound gypsum diluted in warm water and wheatpaste. Once this base was dry the gilding could be applied in the form of gold leaf or paint[91].

On the other hand, some European texts mention a second technique more akin to oil-based gilding on wood. For example, Theophilus, in Chapter 30, Book I, explains how to apply paint imitating gold on a base of saffron: "take the saffron used to dye silk, mix with undiluted egg white, and leave it overnight". Heraclius points out that the fabrics are to be submerged in parchment glue diluted in hot water, stretched out and rubbed with a glass before the application of the gold leaf. The *Mappae Clavicula* refers to the use of flax oil as an adhesive on fabrics which have previously been treated with a mordant made with almond gum, gum and saffron. Audemar mixes gum Arabic, gypsum and egg white, and the Manuscript of Lucca proposes a similar procedure in its recipe 108, in which it recommends the mixture of egg white and saffron, with the addition of flax and gum if desired[92].

4. Conclusion

The application of golden decoration on various objects and surfaces was a highly significant artisanal and artistic activity in Europe and the Iberian Peninsula during the late Middle Ages. These techniques not only served illuminators, painters, sculptors and other artists producing works of art (miniatures, paintings, sculptures, altar pieces and canvases), but also artisans engaged in the manufacture of everyday objects, goldbeaters preparing gold, silver and oropel leaf, gilders applying the leaf to swords, basins and other items, and leather, metal and wood workers in their various productions. The possibility of making a humble object shine as though it was made of gold explains the popularity and assiduity of these techniques in medieval society.

This popularity explains the abundance of references to these techniques, both in archive (contracts recording transactions with gilded items, for example) and technical documents (guild rules and professional regulations, recipe books and technical treatises) preserved today in manuscript form in multiple libraries throughout Europe, but especially in Spain and Italy. Until very recently it was only possible to approach these techniques with European texts (*Compositiones Lucenses*, *Mappae Clavicula*, Heraclius and Audemar, and the more detailed late medieval technical treatises: Theophilus, Cennini, Cellini, the manuscripts of Lucca

91. Córdoba, Ricardo. *La industria medieval de Córdoba*...: 334.

92. López, Eva; Dalmau Consuelo. "La técnica del dorado sobre soportes diversos a través de fuentes literarias antiguas". *Pátina*, 15 (2008): 75-84; López, Eva. *Estudio de los materiales y procedimientos del dorado*...: 308-311; Caffaro, Adriano. *Scrivere in oro*...: 135.

and Bologna, etc.), but the recent find and study of Castilian manuscripts (such as mss. H490, Faculty of Medicine, Montpellier, 2019 and 9226, Biblioteca Nacional de España, and II/1393, Biblioteca del Palacio Real de Madrid) and the growing knowledge of the major 16th and 17th century Spanish handbooks (Arfe, Fernández del Castillo, Barba) has corroborated that these techniques were also known and implemented in the Iberian Peninsula. The evidence yielded by these sources has also provided additional information on gold refining and on the use of *cimiento real*, mercury amalgams, sulphur, antimony and acid; on the reduction of gold to a fine sheet —gold leaf— or dust; on the production of its various imitations; and, finally, on the techniques used for its application on a wide variety of materials, most particularly parchment, leather, metal and wood.

The evidence is equally valuable in confirming the importance of gilding techniques in the 15th and 16th centuries, as shown by a wide variety of art works produced during those centuries and which have been a major subject of study for art historians for decades. Their interest for scholars engaged in the scientific analysis of the materials employed is, however, more recent, but no less relevant. The frequent mention to these objects in the written record —in the shape of inventories, property lists, contracts, etc.— also shows their extensive impact on late medieval everyday life.

5. Appendix 1. Original and printed sources

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