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# Writing in Gold and Silver. Byzantine Ink Recipes from MS Bononiensis 1808*

Giacomo Montanari, Eugenio Villa

**Abstract** The article examines six hitherto unpublished Byzantine recipes for the production of gold and silver inks preserved in MS 1808 of the University Library of Bologna. The study of these recipes raises a number of problems of interpretation regarding the substances and procedures involved, which we seek to resolve by taking into account the philological and linguistic aspects as well as the chemical and technological ones.

**Keywords** History of Science; Inks; Replication; Pigments

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# Writing in Gold and Silver. Byzantine Ink Recipes from MS Bononiensis 1808*

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**Abstract** L'articolo prende in esame sei ricette bizantine finora inedite per la produzione di inchiostri d'oro e d'argento contenute nel codice 1808 della Biblioteca Universitaria di Bologna. Lo studio di queste ricette fa emergere alcuni problemi interpretativi circa le sostanze e le procedure utilizzate, i quali si tenta di risolvere tenendo conto tanto degli aspetti filologico-linguistici, quanto di quelli chimici e tecnologici.

**Parole chiave** Storia della scienza; Inchiostri; Repliche; Pigmenti

Giacomo Montanari è assegnista di ricerca per il progetto FARE *AlchemEast in the West: Graeco-Arabic Alchemy in Western Europe* (PI Prof. Matteo Martelli, ID R18W-2STNE2) presso l'Università di Bologna; la sua attività di ricerca è incentrata sullo studio di pratiche scientifico-tecnologiche di interesse storico, in modo particolare attraverso repliche sperimentali supportate dai sui studi pregressi nel campo della Chimica e delle Scienze Farmaceutiche.

Eugenio Villa si è laureato in lettere classiche presso l'Università di Udine e ha conseguito il dottorato di ricerca in scienze dell'antichità presso la Scuola Normale Superiore di Pisa e l'École Pratique des Hautes Études di Parigi. Dal 2022 al 2024 è stato assegnista ricerca per il progetto FARE *The Western AlchemEast: Graeco-Arabic Alchemy in Early Modern Europe* presso l'Università di Bologna. Attualmente è assegnista di ricerca per il progetto PRIN 2022 *Reception and Transmission of Greek Texts from Byzantium to the Renaissance: Towards a Repertorium of the Greek Scribes in the Italian Libraries* presso l'Università di Udine.

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During Late Antiquity and the Middle Ages, both in the Byzantine world and in the West, most of the processes involved in book production were carried out by craftsmen, from the making of the writing materials to the copying of texts and the binding of the actual books. The knowledge and skills required to carry out these operations were almost exclusively passed on orally, from master to apprentice, from teacher to pupil. It is therefore not surprising that manuals and collections of recipes with instructions on book production technique are exceedingly rare, especially in the Byzantine world, where book production has historically been a much less organised and structured industry than in the West. For this reason, the few ancient and medieval collections that have come down to us – such as the Leiden Papyrus X or the *Mappae Clavicula* – play a fundamental role in palaeography, codicology, and the history of technical sciences. While these key texts have rightly been studied in depth, however, especially from a technical and chemical point of view[1], many other recipes and sets of instructions have been neglected, some because they are preserved in late manuscripts and are therefore considered to be later developments of the more ancient collections, others simply because they are unedited and unknown. The latter is particularly the case when it comes to ink production. Indeed, since copyists themselves prepared their own inks, it is not uncommon to find recipes written down extempora-

* This paper was written within the research project FARE *The Western AlchemEast: Graeco-Arabic Alchemy in Early Modern Europe*. We would like to thank Lucia Maini, Marianna Marchini, and Matteo Martelli for their advice and guidance, Eduardo A. Escobar for his help in proofreading the paper, and the anonymous reviewers for their insightful remarks.

[1] Particularly noteworthy is V. Trost, *Gold- und Silbertinten. Technologische Untersuchungen zur abendländischen Chrysographie und Argyrographie von der Spätantike bis zum hohen Mittelalter*, Wiesbaden 1991.

neously in notebooks or in the guard-sheets of a manuscript, but these types of sources are rarely accounted for in catalogues. An important step forward in this regard was made a dozen years ago by Peter Schreiner and Doris Oltrogge, who published and commented on eighty Byzantine recipes for ink and dye production from various late Byzantine manuscripts[2].

The present paper aims to contribute to this field of research by examining six recipes to produce gold and silver inks known only from Codex 1808 of the Bologna University Library[3]. Moreover, a number of these recipes have also been replicated in a modern laboratory, to gain a better understanding of their content and to suggest an interpretation for some of the more obscure indications. The paper is composed in two parts: the first part, written by Eugenio Villa, is devoted to the philological questions raised by these recipes and to how they relate to ancient and medieval texts on the same subjects; the second part, written by Giacomo Montanari, consists of some notes related to the experimental replication of these recipes[4]. Despite this division, we would like to emphasise that this has been a joint effort and that the results presented here have only been possible by combining our different expertise.

[2] P. Schreiner, D. Oltrogge, *Byzantinische Tinten-, Tuschen- und Farbrezepte*, Wien 2011. For an overview of the studies that preceded this book see pp. 16-7.

[3] The recipes are listed in C.O. Zuretti, *Catalogue des manuscrits alchimiques grecs*, vol. II: *Les manuscrits italiens*, Bruxelles 1927, pp. 143-4 and G. Pausillo, *Un nuovo catalogo dei manoscritti alchemici greci delle biblioteche italiane*, Tesi di Dottorato, Bologna 2022, pp. 45-6. Both scholars mistakenly merge recipes [4] and [5] into a single one, giving the incipit of [4] and the explicit of [5]. Recipes [1] and [2] have been recently edited in M. Martelli, *Late Byzantine Alchemical Recipe Books. Metallurgy, Pharmacology, and Cuisine*, in P. Bouras-Vallianatos, D. Stathakopoulos (edd.), *Drugs in the Medieval Mediterranean. Transmission and Circulation of Pharmacological Knowledge*, Cambridge 2023, pp. 336-65, at 347.

[4] The chemical issues are discussed in more detail in G. Montanari, E. Villa, L. Maini, *Scrivere in Oro e Argento*, in *Rendiconti - Accademia Nazionale delle Scienze detta dei XL. Memorie di Scienze Fisiche e Naturali*, 141, pp. 213-219, Roma 2023, part of ISBN 978-88-98075-55-3

## *Part 1*

### 1.1 *The manuscript*

MS Bononiensis 1808[5] is a paper codex of 332 folios dating from the second half of the 14th century. It was copied, almost in its entirety, by a single anonymous hand[6] and it contains extracts from a wide range of scientific texts, the majority of which is medical in nature. At fol. 310r a different hand wrote the following *ex-libris*: «Νικηφόρος Δούκας ὁ Μαλάκης». Spyridon Lambros proposed to identify the owner with Nikephoros Doukas Palaiologos Malakes, a physician in emperor Manuel II Palaiologos' retinue during his military campaign in the Peloponnese in 1415[7]. This identification was later accepted by Ioannes Polemis and Giuseppe De Gregorio[8], and may now be definitively proven by an additional, previously unnoticed *ex-libris* on fol. 332v: «Νικηφόρος Δούκας ὁ Μαλάκης ὁ δούλος τοῦ κρατεοῦ καὶ ἁγίου ἡμῶν αὐφθέντου καὶ βασι[λέως]» (sic omnia). It is likely that the *ex-libris* also recorded the emperor's name before the pages were trimmed. The extant Greek-style binding is made with uncovered wooden boards, so it is not possible to say when it was made, though certainly after Nikephoros came into possession of the manuscript. The paper appears to be of Western manufacture, with no discernible watermark. The manuscript's provenance prior to its arrival at the University Library of Bologna is unknown.

[5] Pausillo, *Un nuovo catalogo*, n. 3, pp. 44-52; G. De Gregorio, *Un'aggiunta su copisti greci del secolo XIV: a proposito di Giovanni Duca Malace, collaboratore di Giorgio Galesiota nell'*Athen. EBE 2, «Νέα Ῥώμη», 16, 2019, pp. 161-275, at 252-3; Zuretti, *Catalogue*, n. 3, pp. 143-4; A. Olivieri, *Codices Graeci Bononienses*, «SIFC», 3, 1895, pp. 387-466, at 389-96. The manuscript is digitized at the following link https://historica.unibo.it/handle/20.500.14008/79659.

[6] De Gregorio, *Un'aggiunta*, n. 5, p. 252 n. 210 argues that the scribe's handwriting shows «spiccati caratteri provinciali», though without further elaboration on the matter.

[7] S. Lambros, *Λακεδαιμόνιοι βιβλιογράφοι καὶ κτήτορες κωδίκων κατὰ τοὺς μέσους αἰῶνας καὶ ἐπὶ Τουρκοκρατίας*, «Νέος Ἑλληνομνήμων», 4, 1907, pp. 152-87, 303-57, at 181-2. Cf. *PLP* 16454; A. Cataldi Palau, *Mazaris, Giorgio Baiophoros e il monastero di Prodromo Petra*, «Νέα Ῥώμη» 7, 2010, pp. 367-97, at 370 n. 15.

[8] De Gregorio, *Un'aggiunta*, n. 5, pp. 252-3; I. Polemis, *The Doukai. A Contribution to Byzantine Prosopography*, London 1968, pp. 141-2.

1.2. *Critical edition and translation*[9]

Recipe [1]: Bonon. 1808, fol. 46v lines 1-4

Ἀργυρογραφίας ἐπιστήμη· λαβὼν ῥίνισμα ἀργύρου τρίψον μετὰ ὑδραργύρου εἰς θυίαν ψήφινον καὶ μίξας κόμμι ἀρκοῦν γράφε.

Transl.: Knowledge of silver ink. Take filings of silver, grind them with mercury in a marble mortar; mix it with enough gum Arabic and write.

Recipe [2]: Bonon. 1808, fol. 46v lines 4-6

Ἀργυρογραφίας ἐπιστήμη· τοῦ μολύβδου τὸ ἀπόκαυμα λαβὼν, ᾠοῦ τὸ λεπτὸν βρέξας καὶ τρίψας γράφε.

λεπτὸν cod.] λευκὸν fort. recte Martelli

Transl.: Knowledge of the silver ink. Take a burnt part of lead, soak it in egg white, mix it and write.

Recipe [3]: Bonon. 1808, fol. 54v lines 1-6

Περὶ χρυσογραφίας σκευασία· λαβὼν ἀρσενικοῦ νομίσματα τρία καὶ Ἰνδανίκου σιδήρου ῥινίσματος ὀγγίας τὸ ἥμισυ καὶ ἐνώσας ἔμβαλε ἐν βουτίῳ ὀστρακίνῳ σὺν ὄξει· καὶ καύσας αὐτὰ χῦσον καὶ λείωσον. Εἶθ' οὕτως λάβον χάλξ πυρροῦ ὀγγίαν μίαν καὶ ἀρσενικοῦ νόμισμα ἕν καὶ μόλυβδον νομίσματα τρία καύσας πάλιν κάμνε.

εἶθ' cod.] ἤ fort. corrigendum
πυρροῦ ego] τυροῦ cod.

Transl.: Preparation of the gold ink. Take three ounces of orpiment and one ounce of Indian iron filings, mix them and put them in a ceramic crucible with vinegar. Fire, then pour and grind. After that, add one ounce of yellowish calx, one ounce of orpiment and three pounds of lead. Fire again and wrought.

[9] I have tacitly corrected the few phonetic or palaeographic errors made by the scribe, while retaining spellings, accents, and grammatical constructions attested in other Byzantine texts recorded in the *TLG* or in D. Holton *et al.*, *Cambridge Grammar of Medieval and Early Modern Greek*, Cambridge 2019.

Recipe [4]: Bonon. 1808, fol. 54v ll. 7-10

<X>ρυσογραφίας ἐπιστήμη· λαβὼν ἀρσενικοῦ ὀγγίαν μίαν καὶ ῥινίσματος χάλξ πυρροῦ ὀγγίαν μίαν, ταῦτα ἑνώσας μετ᾽ ὄξους ἕψει ἐν βουτίῳ ὀστρακίνῳ ἐπ᾽ ἀνθράκων καὶ γράφε.

ὀγγίαν μίαν...ὀγγίαν μίαν cod.] ὀγγίαν μίαν...ὀγγίας τρεῖς aut νόμισμα ἕν...ὀγγίαν μίαν fort. corrigendum
χάλξ ego] χάρξ cod.
πυρροῦ ego] πυροῦ cod.

Transl.: Knowledge of the gold ink. Take one ounce of orpiment and one ounce of filings of yellowish calx. Put them with vinegar in a ceramic crucible on charcoal, boil it down and write.

Recipe [5]: Bonon. 1808, fol. 54v lines 10-14

Χρυσογραφίας σκευασία· λαβὼν ῥινίσματα ἠλέκτρου καὶ κασσιτέρου ῥινίσματα καὶ ἀρσενικοῦ καὶ θείου ἀπύρου καὶ μολύβδου καθαροῦ ἀνὰ νόμισμα ἕν, ταῦτα ἑνώσας ἐν ὀστρακίνῳ βουτίῳ σὺν ὄξει καῦσον καὶ κάμνε.

Transl.: Preparation of the gold ink. Take filings of electrum, filings of tin, orpiment, unburned sulphur, pure lead, one pound each; put them in a ceramic crucible with vinegar, fire and wrought.

Recipe [6]: Bonon. 1808, fol. 62v lines 2-16

Σκευασία τῆς χρυσογραμμίας· ὀφείλῃς λαβεῖν χρυσάφιν μάλαγμα καὶ λεπτύνας αὐτὸ καλῶς, βάλον εἰς τὸ χωνείον καὶ καθίσας τοῦτο ἐπ᾽ ἄνω τῶν ἀνθράκων καὶ ἀναλύσας βάλον ὕδωρ ἀργύρου. Μετὰ δὲ τὸ καταβαλεῖν ὁ ὑδράργυρος, τὸν χρυσὸν ἔκβαλον τὸ χωνείον καὶ βάλον αὐτὸ εἰς ἄγγος μετὰ ὕδατος. Καὶ μετὰ τὸ ψυχρανθῆναι τὸν χρυσὸν μετὰ τοῦ ὑδραργύρου, βάλον αὐτὸν εἰς βέβρανον χάρτην καὶ ἐκθλίψας αὐτὸν καλῶς, ἐξερχέται ὁ ὑδράργυρος. Καὶ τὸ ἐναπολειφθὲν ἐντὸς τοῦ χάρτου θὲς ἐπ᾽ ἄνω εἰς Ῥωμαῖον μαρμάρον καὶ τρίψον καλῶς μετὰ τῆς χρυσοτεάφης. Εἶτα σύναξον ἀκριβῶς καὶ βάλον αὐτὸ πάλιν εἰς τὸ χωνείον καὶ θὲς αὐτὸ ἐπὶ τῆς ἀνθρακιᾶς καὶ ἂς μείνῃ ἐκεῖσε ὥραν ἱκανὴν ἕως οὐ φέρει θεωρίαν ὄχρας. Καὶ ἐκβαλὼν σακέλισον αὐτὸ καλῶς καὶ γραφε μετὰ κμιδίου.

ὁ ὑδράργυρος cod.] τὸν ὑδράργυρον fort. corrigendum
ἄγγος Martelli] ἄγκος cod.
κμιδίου cod.] κομίδιου fort. corrigendum

Transl.: Preparation of the gold ink. Take a mass of gold, make it very thin, put it in a crucible and place the crucible over charcoal. When [*scilicet* the gold] has melted, add mercury. After having added the mercury, take the gold out of the crucible and throw it in a recipient with some water. When the gold and mercury have cooled, put them in a piece of parchment and squeeze them well: the mercury will come out. Put what remains in the parchment on Roman marble and crush it well with gold-coloured sulphur. Collect it carefully, put it back in the crucible and put it on hot embers; leave it for a while until it turns yellow ochre. Take it, sieve it carefully and write with gum Arabic.

1.3. *Commentary*

The main obstacle concerning the use of gold and silver in the production of inks was their high malleability, which makes it difficult to obtain by neat grinding a homogeneous powder that can be mixed with gum Arabic (or similar) and spread on the page. Two methods were devised to pulverise gold and silver, both of which are already found in the earliest recipe collections and technical treatises. The first method is to mix them with mercury to make an amalgam and then apply heat to sublimate the mercury. The second method involves beating gold or silver into leaves, grind them with salt, orpiment (arsenic trisulphide), or honey, and, where appropriate, to wash them in water. To avoid all this – and to keep costs down, especially in the production of gold ink – other substances, both organic and inorganic, were used. The main substitutes for gold were orpiment, sulphur, and celandine; for silver, lead, tin, and blue vitriol (copper sulphate)[10]. In one recipe for silver ink found in the Leiden Papyrus X and in the *Mappae Clavicula* we find an ingredient called litharge (gr. λιθάργυρος, lat. *lithargyrus* or *spuma argenti*)[11], which is supposed to be a lead oxide[12]. However, while it would seem to make sense as a substitute for gold[13], since its colour ranges from pale yellow to dark orange, it does not seem to fit into the recipes for silver ink. Dioscorides distinguishes two

[10] Trost, *Gold- und Silbertinten*, n. 1, pp. 32-5.

[11] In Greek ἀφροσέληνος is semantically identical to *spuma argenti*, but it refers to selenite (calcium sulfate), not to litharge. This is odd and should be investigated further.

[12] P.Leid. 77; *Mappae Clavicula* LXXII ed. Baroni, Pizzigoni, Travaglio (= 81 ed. Smith, Hawthorne). The recipe of the *Mappae Clavicula* is unequivocally a translation of the one from the Leiden Papyrus.

[13] Litharge is indeed listed as ingredient in a recipe for gold gilding by Moses of

types of litharge, a yellow one called χρυσῖτις, that probably correspond to what we call litharge also nowadays, and a bluish-violet one called ἀργυρῖτις, that has not been identified yet[14]. It is possible that the recipes for silver inks referred to the latter type, which, as will be explained in more detail in part 2, could be a mixture of lead oxides and lead obtained by a process similar to that used to make actual litharge.

The six ink recipes found in MS Bononiensis 1808 are scattered throughout an untitled collection of instructions and recipes of various kinds from known and unknown sources (fols. 42r-63v). We find, for example, a range of procedural instructions on subjects as diverse as: the removal of leeches (Aetius of Amida, fol. 44v); eliminating dandruff (Dioscorides, fol. 47r); unedited instructions on catching oysters (fol. 55r) and on how to calm epileptic seizures (fol. 61v). All these texts seem to have been copied at the same time, so it is highly unlikely that the copyist of the Bononiensis was also the author of the collection, which could, therefore, be much older. The clumsy mistakes made by the scribe point in the same direction, suggesting that they did not always understand the meaning of what they were reading. The ink recipes are divided into three blocks: the first, which in the manuscript is preceded by the title περὶ ἀργυρογραφίας, contains two recipes for the production of silver inks (recipes [1] and [2])[15]; the second, without a title, contains three recipes for the production of gold inks (recipes [3], [4] and [5]); the last, without a title, contains five recipes for the production of inks and dyes[16], among which one for gold ink (recipe [6]). This grouping of the recipes may be an indication that they have been

Alexandria. See M. Berthelot, C.É. Ruelle (edd.), *Collection des anciens alchimistes grecs*, vol. 2, Paris 1888, p. 298.

[14] Dsc. 5.87.2: «Καλεῖται δὲ ἡ μὲν [*scilicet* λιθάργυρος] ξανθὴ καὶ στίλβουσα χρυσῖτις, ἥτις ἐστὶ κρεῖττων, ἡ δὲ πελιὰ ἀργυρῖτις». Plin. *NH* 33.106 is probably dependent on Dioscorides, but interprets the two terms differently: «Optima quam chrysitim vocant, sequens quam argyritim. […] Chrysitis ex vena ipsa fit, argyritis ex argento». See also P. Leid. 34: «Ἄλλη [*scilicet* χρυσογραφία]. Λιθαργύρου χρυσίτιδος μέρος α', στυπτηρίας μέρη β'». Trost, *Gold- und Silbertinten*, n. 1, p. 287 suggests identifying ἀργυρῖτις with what we now call massicot (yellow lead oxide) and χρυσῖτις with litharge (red lead oxide). The interpretation is unconvincing, especially the first part, as it seems exaggerated to describe massicot as «silberglanzende».

[15] On these two recipes see also Martelli, *Late Byzantine*, n. 3, pp. 347-8.

[16] Two are recipes for lacquer and were edited in L. Benedetti, *Ricette bizantine del XII secolo per tinture e inchiostri*, «Aevum», 88, 2014, pp. 443-54, at 452-4.

taken from a few different sources. Although each recipe has parallels in already known texts or collections, none of them has an identical counterpart. It cannot be ruled out with certainty that the sources could date back to the first centuries A. D., but some linguistic clues seem to indicate a later origin. For instance, χρυσογραμμία (recipe [6]), which according to Basile Atsalos is a synonym for χρυσογραφία, and χρυσοτεάφη (recipe [6]) are only attested in middle and late Byzantine texts[17]. Again in recipe [6] we find the word μάλαγμα with the clear meaning of 'gold' or 'gold mass', which is only attested in Byzantine period[18]. In addition, it may be possible to detect an influence from the medieval world, which would also be consistent with, and support the hypothesis that, the manuscript was produced in the Morea, considering that the region had been almost entirely under Western rule since the Fourth Crusade in 1204. I refer to χάλξ (recipes [3] and [4]), which we believe is to be understood as a loanword from the Latin *calx*, rather than an incorrect form for χαλκός, which is also supported by our replications as described in part 2, and to ἐπιστήμη (recipes [1], [2] and [4]), which seems used in an odd way, unless we think of its Latin equivalent *scientia*.

Recipe [1] appears to be fairly simple, as the only ingredients are mercury and silver, and no special procedure is required. However, this apparent simplicity belies a fundamental issue. As mentioned above, gold and silver were pulverised by forming an amalgam with mercury and then heating it to evaporate the mercury. The recipe seems to describe exactly this procedure, but it omits the heating step, without which one cannot obtain a silver powder. Many similar recipes from other sources omit the heating step[19], which is even more curious when we deal with recipes for gold inks, since gold-mercury amalgam retains almost none of the colour of gold. For this reason, scholars tend to suggest that heating is implied,

[17] See, respectively, B. Atsalos, *Termes byzantins relatifs à la décoration des manuscrits grecs*, in G. Prato (ed.), *I manoscritti greci tra riflessione e dibattito. Atti del V Colloquio Internazionale di Paleografia Greca (Cremona, 4-10 ottobre 1998)*, vol. 2, Firenze 2000, pp. 445-511, at 493-4; Schreiner, Oltrogge, *Byzantinische*, n. 2, pp. 46, 58. Schreiner and Oltrogge maintain that χρυσοτεάφη refers to a particularly bright yellow sulphur and translate it *Goldschwefel*, which is confusing since in German the word is already used to refer to kermesite (i.e. antimony oxysulfide).

[18] Cf. *LBG* s. v. μάλαγμα.

[19] E.g.: P.Leid. 33; P.Leid. 69; *Mappae Clavicula* XLIII ed. Baroni, Pizzigoni, Travaglio (= 39 ed. Smith, Hawthorne)

but this is difficult to maintain in more complex and detailed recipes[20]. In silver ink recipes, it is possible that the mercury was not removed in order to obtain an ink that was less expensive but still fairly silver in colour. An identical recipe, albeit not *verbatim*, is found in the medieval recipe collection usually referred to as *Compositiones ad tingenda musiva* preserved in MS Lucensis 490[21]:

Lucensis 490, fol. 230r lines 26-29 (n° 153 Caffaro)
Argirorantisia. Argentum mundum commisce cum argento vibo et deinde tolle ipsum argentum et teres donec fiat pulvis et commisce. Tum compositionem daufira et dispone, ubi volueris.

Similarly, also recipe [2], although pithy and apparently simple, raises an interesting question. The main ingredient is called τὸ ἀπόκαυμα τοῦ μολύβδου, an otherwise unattested and somewhat obscure phrase. The word ἀπόκαυμα is found almost exclusively in medical or lexicographical texts, where it is used to refer to chilblains, blisters, and firebrands, none of which seem appropriate in relation to lead. According to *LSJ*, ἀποκαίω, whose general meaning is 'burn off', translates as 'calcine' in the chapter on chalcopyrite in Dioscorides' *De materia medica*. Albert Neuburger and William Rostocker argue that the process that Dioscorides describes in the passage is actually roasting[22]. In any case, it is most likely that τὸ ἀπόκαυμα τοῦ μολύβδου refers either to some form of roasted lead or to a byproduct of lead or lead ores processing. Unfortunately, as in the case of ἀργυρῖτις, ancient sources are often vague when it comes to lead and its derivatives, and no study has been carried out to identify these substances. The most compelling parallels are ἀργυρῖτις and a substance called 'burnt lead' (gr. κεκαυμένος μολύβδος, lat. *plumbum exustum*), which is frequently mentioned in ancient and medieval medical and alchemical texts[23]. The latter is particularly promising as the colour of roasted lead is

[20] Schreiner, Oltrogge, *Byzantinische*, n. 2, p. 108; A. Caffaro, *Scrivere in oro: ricettari medievali d'arte e artigianato (secoli IX-XI). Codici di Lucca e Ivrea*, Napoli 2003, p. 111 n. 155; Trost, *Gold- und Silbertinten*, n. 1, p. 59.

[21] Caffaro, *Scrivere*, n. 20, pp. 1-24;

[22] W. Rostocker, *Some Experiments in Prehistoric Copper Smelting*, «Paléorient», 3, 1975-1977, pp. 311-5; A. Neuburger, *The Technical Arts and Sciences of the Ancients*, trad. H. L. Brose, London 1930, p. 14.

[23] E.g.: Gal. 12.233; Albertus Magnus *In mineralium* VIII; Celius Aurelianus *De morbis*

consistent with the colour we would expect from silver ink (this point will be expanded further in part 2)[24]. Finally, it cannot be ruled out that the ingredient mentioned in the recipe is rather to be identified with a substance called σποδός or σποδίον, probably an impure form of zinc oxide that is produced in zinc-lead ores processing[25], or with another one called σκωρία μολύβδου (lat. *scoria plumbi* or *stercus plumbi* or *recrementum plumbi*), which is supposedly lead dross[26].

Recipes [3] and [4] are clearly related as they are copied one after the other and are very similar, in that they are both gold ink recipes that list only substitutes. The main problem they pose is the identification of the ingredient called χάλξ πυρρός. First and foremost, it should be noted that the phrase χάλξ πυρρός does not actually appear in either recipe: recipe [3] reads χάλξ τυροῦ and recipe [4] χάρξ πυροῦ. The similarity between the two phrases cannot be coincidental and their differences may easily be explained as phonetical errors, so we may infer that they were originally identical. Between τυροῦ (possibly to be interpreted as a corruption for τύρου, from Tyre) and πυρρός (yellowish-red), considering the subject of these recipes, it seems clearly preferable to take πυρρός as the correct reading. Similarly, although both χάλξ and χάρξ are *athesaurismata*, the former is unequivocally more likely to be the correct reading. Indeed, while we have not found any possible interpretation for χάρξ, χάλξ could be understood as a loanword from the Latin *calx* or as an error or deformation of χαλκός (copper). The identification with χαλκός is particularly tempting given that the expression χαλκὸς πυρρός (red copper) is attested in an alchemical treatise ascribed to Moses[27] and in a medical text attributed to the Byzantine physician Demetrius Pepagomenus[28]. In addition, the Latin equivalent *cuper ruber* is attested in two recipes in Theophilus' *De diver-*

*acutis et chronicis* 2.37. It should be noted that the latter is a translation from Soranus of Ephesus' *Gynaeciorum libri iv*.

[24] Cf. Dsc. 5.81.4-5.

[25] Cf. Dsc. 5.75

[26] Dsc. 5.82; Plin. *NH* 34.171. Cf. W. G. Spencer (ed.), *Celsus. On Medicine*, vol. 2, Cambridge, MA 1938, p. xlviii.

[27] Berthelot, Ruelle (edd.), *Collection*, n. 13, pp. 301, 310. The title of the treatise is Εὐποία καὶ εὐτυχία τοῦ κτισαμένου καὶ ἐπιτυχία καμάτου καὶ μακροχρονία βίου.

[28] R. Hercher (ed.), *Demetrii Pepagomeni Cynosophium*, Leipzig 1866, p. 399 (chapter 87).

*sis artibus*[29]. However, as will be explained in more detail in part 2, the interpretation of the ingredient as copper is problematic because copper forms verdigris (green or bluish copper salts of acetic acid) when heated with vinegar, the use of which is prescribed in both recipes. Instead, if we interpret the word as a loanword from the Latin *calx*, it would be possible to identify the substance either with some kind of vitriol (copper or iron sulphates), compounds usually called χάλκανθος in ancient texts and καλακάνθιν or βεντριόλο in Byzantine recipes, or with a substance derived from the calcination of a vitriol. This hypothesis is consistent with the laboratory tests carried out by Giacomo Montanari and it is perhaps corroborated by a passage from Hipprocrates' *De morbis popularibus*, where it is prescribed to heat vitriol until it turns red[30].

Recipe [3] poses two additional issues. The first concerns the identification of the so-called Indian iron (Ἰνδάνικος σίδηρος), which could be iron of very high quality imported from India, steel produced in Damascus, or an alloy of iron and arsenic or manganese[31]. The second issue concerns the addition of orpiment in both steps of the recipe, a redundancy that is rather odd from a technical perspective, so it is possible that the second part of the recipe was actually an alternative recipe. From a textual perspective, however, it is quite normative to find alchemical texts which often overcomplicate recipes for the sake of codifying more elaborated and, by extension, authoritative procedures. An economical way to separate the two operations into different recipes would be to emend εἶθ' with ἢ (transl.: 'or in this way etc.'). However, this solution is not at all satisfactory, since, if we were to accept it, we would also have to disregard the presence of the adverb πάλιν in the text. It could be argued that one of the two mentions of orpiment is an error due to confusion between two different alchemical signs; for example, the symbol for orpiment and that for untouched sulphur (θεῖον ἄθικτον) are quite similar. For my part, I believe that the simplest solution is that it is a case of redundancy.

[29] C.R. Dodwell (ed.), *Theophilus. The Various Arts*, London-Edinburgh-Paris-Melbourne-Toronto-New York 1961, pp. 83 (book three, recipe XXXI), 89 (book three, recipe XXXVII).

[30] Hp. *Epid*. 2.6.22 (V 136 ed. Littrè = W. E. Smith (ed.), *Hippocrates. Epidemics 2, 4-7*, Cambridge, MA 1994, p. 86): «χαλκοῦ ἄνθος, καύσας ἔστ' ἂν πυρρὸν ᾖ».

[31] R. Halleux, *Sur la fabrication de l'acier dans l'Antiquité et au Moyen Âge*, «Comptes rendus des séances de l'Académie des Inscriptions et Belles-Lettres», 151, 2007, pp. 1301-1319. Cf. *LBG* s. v. Ἰνδανικός.

Recipe [5] is the only known ink recipe that lists electrum as an ingredient. This makes the recipe odd, since it is unclear why someone would use electrum (i. e. a gold-silver alloy) instead of gold to make gold ink. It can hardly be interpreted as a way of obtaining a cheaper gold ink, since there are many cheaper and more effective substances that can be mixed with gold instead of silver. One possible solution is that the recipe was designed for those who could get their hands on electrum more easily than gold. The few documents we have on the mining and trading of precious metals between the late Roman Period and the middle Byzantine Period show that most mines were either state-owned or had to give priority to the various Imperial mints for the purchase of the mined metals and that electrum mines were few and concentrated in the western part of Lydia[32]. The Byzantine Empire has always needed large quantities of precious metals for coinage, and over the centuries the emperors often had no choice but to debase their gold coin, the nomisma, especially as Arabs and Slavs gained power over the regions where most of the mines were located[33]. In particular, from the 11th century onwards, coins made of artificial electrum begun to appear alongside, or even replace, gold coins[34]. Despite the lack of sources indicating how scribes procured the materials needed to make inks, we may surmise that in provincial areas where gold and silver were scarce coins themselves were used as a reasonable source of precious metals. Taking these points into account, we might interpret the recipe as the product of the middle or late Byzantine Period, when pure gold was harder to source.

Recipe [6] is the longest of those included in the Bononiensis. This is mainly because it prescribes the use of both amalgamation and mechanical grinding to pulverise gold, while most ink recipes that use actual gold call either for one or the other method. There are no similar recipes in the Leiden Papyrus X and the earliest known examples that have this feature are included in Latin collections: a recipe in the *Mappae Clavicula*[35], another in MS Lucensis 490 (early 9th century)[36], another in MS Epore-

[32] T.I. Afanas'eva, S. A. Ivanov, *Unexpected Evidence concerning Gold Mining in Early Byzantium*, «GRBS», 53, 2013, pp. 138-144; S. Vryonis, *The Question of Byzantine Mines*, «Speculum», 37, 1962, pp. 1-17.

[33] P. Grierson, *Byzantine Coinage*, Washington, D. C. 1999, pp. 6-17.

[34] P. Grierson, *Byzantine Coins*, London-Berkeley-Los Angeles 1982, p. 14, *passim*.

[35] *Mappae Clavicula* LV ed. Baroni, Pizzigoni, Travaglio (= 60 ed. Smith, Hawthorne).

[36] Caffaro, *Scrivere*, n. 20, pp. 150-1 (title: *De tertia crisocrafia*).

diensis 54 (early 11th century)[37], and another in Theophilus' *De diversis artibus* (12th century)[38]. Of the recipes edited by Schreiner and Oltrogge, eight prescribe to use both methods, but the authors fail to acknowledge this, claiming instead that there is only one[39]. Together with the linguistic peculiarities mentioned above, the fact that recipes of this kind are only found in medieval and late Byzantine manuscripts is further proof that recipe [6] cannot be much older than the manuscript that preserves it. Moreover, it is the only one, apart from recipe [1], for which fairly close parallels can be traced. The same steps and in the same order are found in the following recipe from the Eporediensis 54:

Eporediensis 54, fol. 118r
Si aurum ad scribendum teritur, tam diu a malleatoribus incude flagelletur quo usque a mulieribus contexi possit. Ipsaque tenuis lamula forpicibus secetur minutissimis particulis tuncque cuius sit ponderis noscatur. Iusta hoc septiplicetur vivum argentum misceaturque auro ac longo tempore nitida scutella digitis perfricetur, sicque simul nocte una morentur. Mane autem, facto positum, luteo cacabo super calidas prunas tam diu malleolo fricetur donec argentum [*scilicet* vivum] evanescat calore simul et fumo aurumque durescat, nec adeo durescat ut nimis siccetur, nec adeo liquefiat ut non in aliquo indurescat. Sicque nitida[m] proiciatur in aqua. Inde vero abstractum, linteo volutetur ut aqua careat. Tunc bina illa confectio auri et argenti [*scilicet* vivi] simul pondus noscatur ac sulphur decemplicetur ut cum eo misceatur; et sic super purpureum lapidem mallo plano perfricetur donec fere dimidia dies ibi mittatur. Haec talis tritura eodem cacabo et prunae calide revertatur et tunc subtili et veroso misceatur cultelbo donec cu-

[37] For the recipes in these manuscripts see P. Travaglio, *Ut auro scribatur*, in S. Baroni (ed.), *Oro, argento e porpora. Prescrizioni e procedimenti nella letteratura tecnica medievale*, Trento 2012, pp. 69-86; Caffaro, *Scrivere*, n. 20, pp. 198-201; L. Bona Quaglia, S. Tira, *Prescrizione "ut auro scribatur" di un codice piemontese dell'undicesimo secolo*, in P. Antoniotti, L. Cetturi (edd.), *Atti del I° convegno di storia della chimica*, Torino 1985, pp. 24-32.

[38] C.R. Dodwell (ed.), *Theophilus. The Various Arts*, London-Edinburgh-Paris-Melbourne-Toronto-New York 1961, pp. 86-87 (book three, recipe XXXV).

[39] Schreiner, Oltrogge, *Byzantinische*, n. 2, pp. 107-110. The reference numbers of the recipes that prescribe both methods are: 37, 40, 41, 42, 43, 44, 45, and 46. They are preserved in the Escorialensis Φ III 7 (13th century), in the Vaticanus Palatinus gr. 243 (mid-14th century), in the Vaticanus gr. 914 (early 15th century), in the Angelicanus gr. 17 (mid-15th century), and in the Parisinus gr. 2327 (1478).

ratur argentum [*scilicet* vivum] et sulphur ac flama evanescant tenui et fumo. His ita peractis pulvis ille auri nitida proitiatur in aqua et ita diligentissime non tam decies quam si opus sit tricies pura et mutata abluatur lympha.

Almost the same procedure is found in a recipe in the Vaticanus gr. 914, the only difference being that the Vaticanus does not prescribe to put the substance in a cloth and squeeze it to let the mercury or the water flow out[40]:

Vaticanus gr. 914, fol. 1v lines 20-29
Εἰ βούλῃ γράψειν μετὰ μαλάγματος ποίησον οὕτως· λαβὼν μάλαγμα λείωσον μετὰ ὑδραργύρου καθὼς ποιεῖ ὁ χρυσοχόος. Εἶθ᾽ οὕτως ἔκβαλον καὶ πλῦνον καλῶς καὶ πάλιν πλῦνον. Εἶτα βαλὼν αὐτὸ εἰς χωνίον καινούργιον, βαλὼν καὶ τεάφην, θὲς ἐπάνω τοῦ πυρός.῎Εστω δὲ ἡ τεάφη διπλῆ ὑπὲρ τὸν ὑδράργυρον. ῎Εστω δὲ ἐπάνω τοῦ πυρὸς ἄχρις ἂν καῇ ὁ ὑδράργυρος. Εἶτα ἐκβαλὼν αὐτὸ πάλιν πλῦνον καλῶς καὶ θὲς αὐτὸ εἰς μάρμαρον πορφυροῦν καὶ ἄρχου καὶ τρίβετο. Βαλὼν δὲ ὀλίγον ἅλας πάλιν τρίψον καὶ πάλιν βαλὼν ἕτερον ὀλίγον ἅλας τρίψον ἄχρις ἂν γένηται καθὼς ἡ ὤχρα κίτρινον. Εἶτα συνάξας βάλε εἰς ἄγγος καὶ εἰ θέλεις γράψειν λείωσον κομμίδιν ἀλεξανδρεωτικὸν καὶ ἑνώσας μετὰ κινναβάρεως γράψον μετ᾽ ἐκείνου, καὶ ὅταν στεγνώσῃ καλῶς, ἔχε σαρδονύχιν καὶ θὲς ἐπάνω βλατὶν εἰς τὰ γράμματα μεταξωτὸν καὶ στίλβωσον αὐτό, εἰ δὲ οὐκ ἔνι σαρδονύχιν, μετὰ ὀδόντος κυνός.

It should be noted that the use of a cloth or parchment sheet to remove excess mercury or water is rarely mentioned in ink recipes, and never in ancient texts[41].

[40] Schreiner, Oltrogge, *Byzantinische*, n. 2, p. 60. Cf. F. Noussia, *Ανέκδοτο κείμενο περί σκευασίας μελανιού, κινναβάρεως, βαρζίου, καταστατού και κόλλησης χαρτιού*, in N. Tsironi (ed.), *Το βιβλίο στο Βυζάντιο. Βυζαντινή και Μεταβυζαντινή Βιβλιοδεσία. Πρακτικά Διεθνούς Συνεδρίου (Αθήνα, 13-16 Οκτωβρίου 2005)*, Athens 2008, pp. 43-62.

[41] Schreiner, Oltrogge, *Byzantinische*, n. 2, p. 57 (recipe 41); *Mappae Clavicula* LX ed. Baroni, Pizzigoni, Travaglio (= 55 ed. Smith, Hawthorne); *Mappae Clavicula* CX ed. Baroni, Pizzigoni, Travaglio (= 107-A ed. Smith, Hawthorne).

*Part 2*

2.1 *Experimental replications*

As discussed in part 1, two expressions used to refer to ingredients in the recipes of the Bononiensis are rather obscure, namely: τὸ ἀπόκαυμα τοῦ μολύβδου (recipe [2]) and χάλξ πυρρός (recipes [3] and [4]). Because the historical sources, including technological texts and linguistic data, do not aid in providing clear indications as to the identification of these two substances, we employed experimental replications to gain a better understanding of the ingredients that may have been used.

Regarding τὸ ἀπόκαυμα τοῦ μολύβδου (recipe [2]), as discussed in part 1, the most likely scenario is that it is some form of roasted lead. In theory, when lead is heated to high temperatures in the presence of oxygen, a lead oxide should be formed. Pure lead oxides are yellow (β-PbO, massicot), red (α-PbO, litharge, or $Pb_3O_4$, minium), or dark brown ($PbO_2$, plattnerite). The former three present colours that are not suitable for silver inks; with regards to the latter (plattnerite) it is difficult to produce in pre-modern conditions. Moreover, $PbO_2$ is chemically unstable and it easily decomposes to $Pb_3O_4$ or to PbO if heated in air. However, by roasting metallic lead for several hours in a muffle oven at 700°C, we found that it oxidises to form a mixture of massicot, litharge, and metallic lead, which has a grey colour with a metallic sheen (due to the presence of metallic lead). The ink produced by dispersing this substance in egg white is indeed silver in colour and can be easily used with both a stylus or a brush.

Regarding recipes [3] and [4], the interpretation of χάλξ as χαλκός is not supported by laboratory evidence. When we replicated recipe [4] using copper powder and observed that, when boiled in vinegar, it forms copper acetate (verdigris); the outcome, a bluish-green colour, is clearly incompatible with a gold ink recipe. In contrast, if χάλξ is interpreted as a loanword from the Latin *calx*, we could argue that the substance is an oxide, as many inorganic salts (such as sulphates or carbonates) decompose to the respective gaseous anhydride (sulphur trioxide or carbon dioxide) and metallic oxide with calcination. In addition, when calcined in air, the copper and iron ions oxidise readily to their highest available oxidation state, so Fe (II) becomes Fe (III) and Cu (I) becomes Cu (II). The production of $Cu_2O$, which would be red, by calcination of copper(I) sulphate or carbonate is somewhat difficult as it tends to produce copper (II) oxide instead, which is black. Conversely, it is quite easy to make red iron (III) oxide ($Fe_2O_3$, hematite) or yellow iron (II) and iron (III) hydroxysulphate

($Fe^{II}Fe^{III}SO_4(OH)$) from iron (II) sulphate ($FeSO_4{\cdot}7H_2O$, melanterite)[42]. We produced the two compounds and replicated recipe [4] with both. On the one hand, using hematite, which we believe to be the most likely option, results in a red-brownish pigment with a 1:1 ratio of orpiment to hematite and a yellow-reddish pigment with a 1:3 ratio of orpiment to hematite, so a possible solution could be to emend the text by replacing either ῥινίσματος χάλξ πυρροῦ ὀγγίαν μίαν with ῥινίσματος χάλξ πυρροῦ ὀγγίας τρεῖς or ἀρσενικοῦ ὀγγίαν μίαν with ἀρσενικοῦ νόμισμα ἕν. On the other hand, the use of yellow iron sulphate gives a yellow pigment even with a 1:1 ratio of orpiment to yellow iron sulphate. Finally, it should be noted that we have excluded the possibility that χάλξ πυρρός refers to a lead oxide of suitable colour, since these compounds were widely known under other names.

[42] This topic is further discussed in G. Montanari, M. Marchini, M. Martelli, L. Maini, *Artificial Vitriols*, «RSC Advances», 2024, 14, pp. 21538-21543.