Supplementary Information for

Exploring the ancient chemistry of mercury

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Supplementary Information Text

Manual grinding of cinnabar with copper

The amount of reagents used for the cold extractions of mercury was based on volume: a spatula spoon was employed to measure the quantity of the reagents (Fig. S1). The extraction was also repeated, taking the stoichiometry of the reaction into account, i.e. a molar ratio of 1:2 HgS:Cu in the extraction with copper.

It is worth noting that the HgCu amalgam is well-established, but in all our replications we observed the presence of drops of mercury, although we do not exclude the possible formation of amorphous HgCu.

Hot extraction of mercury from cinnabar with iron

A spoonful of synthetic HgS and iron powder were inserted into a round flask and heated with a Bunsen burner for 10 minutes (Fig. S8 and S9). During the procedure, no formation of residual black power (metacinnabar) on the glassware was observed; on the other hand, droplets of mercury condensed on the flask's wall and could be collected.

The procedure was then repeated with mineral cinnabar instead of synthetic HgS, in which condition droplets of mercury could also be found in the residual powder (Fig. S11).

Hot extraction of mercury from cinnabar with sodium carbonate

Inside an alumina crucible, one spoonful each of mineral cinnabar (sample C4) and sodium carbonate were added. The reaction mixture was then heated with a Bunsen burner. After 10 minutes, the reaction stopped: mercury droplets had condensed on the alumina lid and could be recovered (Fig. S16).

The hot extraction was then repeated using the heating mantle to attain a milder condition. One gram of synthetic cinnabar was added to each reaction flask: one gram of sodium carbonate was inserted in only one of the two flasks. With the heating mantle (300 °C), the flasks were simultaneously reaction-heated for 48 hours. In the flask containing HgS and sodium carbonate (Na_2CO_3), the cinnabar was consumed (Fig. S19); in the one containing only cinnabar, at the end of the 48 hours, HgS was still present, as confirmed by the XRPD analysis (Fig. S22 and S23).

The same experiment was then repeated by substituting synthetic HgS with cinnabar ore (sample C1). The X-ray analysis of the residual powder after 48 hours exhibited the same result as that discussed above: in the flask where cinnabar ore reacted with atmospheric oxygen, HgS remained present in the residual powder (Fig. S24 and S25); where the cinnabar also reacted with the Na_2CO_3, the extraction was complete (Fig. S26 and S27).

Hot extraction of mercury from cinnabar with sodium carbonate in water

A crucible containing one gram of synthetic HgS, one gram of sodium carbonate and water was heated with a heating mantle (300 °C). After 4 hours, the residual powder within the crucible constituted metacinnabar (which at room temperature and over time reverts to cinnabar; Fig. S28, C) and Na_2CO_3, which did not react. The extracted mercury condensed on the lid (Fig. S28, D), from which it could be recovered.

Hot extraction of mercury from cinnabar with sodium carbonate in flaxseed oil

A crucible containing one gram of synthetic HgS, one gram of Na_2CO_3 and flaxseed oil was heated by means of a heating mantle (300 °C). After two hours of heating, some drops of mercury could be observed on the lid and the residual powder inside the crucible had become burnt (Fig. S29, B and C). For that reason, the extraction was repeated at a lower temperature in order to avoid oil burning. Nevertheless, when the heating mantle was set to 100 °C, no mercury accumulated on the lid (Fig. S30).

Hot extraction of mercury from cinnabar with sodium carbonate in vinegar

One gram each of synthetic HgS and Na_2CO_3 were added to the reaction flask; a few millilitres of vinegar were then added to the powder. Using a heating mantle (300 °C), the reaction mixture was heated for 72 hours: HgS, as confirmed by X-ray analysis, was consumed and mercury condensed on the glass lid (Fig. S31 and S32).

Hot extraction of mercury from cinnabar with calcium carbonate and calcium oxide

For this experiment, 500 mg of synthetic HgS and 215 mg of calcium carbonate ($CaCO_3$) were added to the reaction flask. The reaction mixture was then heated with a heating mantle (at 300 °C) for 72 hours; Hg was extracted and condensed on the lid, but HgS was not consumed, as confirmed by X-ray analysis (Fig. S34). Indeed, in the residual powder, $CaCO_3$ that had not been depleted could also be identified. The amount of Hg extract could be relayed to the atmospheric oxygen reacting with HgS, but not the $CaCO_3$.

If the hot extraction was repeated by heating HgS (500 mg) in the presence of calcium oxide (CaO, 120 mg), the result, as expected, differed: all of the cinnabar was consumed and calcium sulphate ($CaSO_4$) was present as product of this reaction (see figures S35 and S36).

Given the nature of *nitron oil*, the powder was likely dissolved in a liquid – in the case of $CaCO_3$, the dissolution in water did not change its chemical nature; however, when CaO was dissolved in either vinegar or water, calcium hydroxide ($Ca(OH)_2$, traditionally called slaked lime) forms, which was no longer active in the extraction.

Hot extraction of mercury under vacuum

The reaction flask containing synthetic HgS was heated with a Bunsen burner under vacuum. After 10 minutes, all of the cinnabar had been sublimated and condensed into metacinnabar on the glassware (Fig. S37, B and C). No formation of Hg was detected, which was ascribable to the absence of air oxygen.

The same experiment was repeated but with Na_2CO_3 added to the HgS (excess of Na_2CO_3), heating the reaction mixture with both a Bunsen burner and heating mantle under vacuum. When the heating source was a Bunsen burner, the reaction stopped after 10 minutes; Hg drops appeared on the neck of the flask (Fig. S38, C). The extraction proved that Na_2CO_3 serves as the oxygen source in the reaction, as in that condition air oxygen is not present.

When the reaction mixture was mildly heated (300 °C), the reaction was stopped after eight hours: metallic mercury condensed on the glassware and could be recovered (Fig. S42, B).

In both vacuum extractions (with a Bunsen burner and heating mantle), when the HgS reacted with the Na_2CO_3, it was fully consumed. However, if the amount of Na_2CO_3 was equimolar to the HgS, at the end of the reaction, HgS could be found in the residual powder (Fig. S44 and S45).

Sources: Ancient recipes on the extraction of mercury

1) Theophrastus, *On Stones*, VII.60 (fourth century BCE)
Edition and translation: D. E. Eichholz, *Theophrastus, De lapidibus. Edited with Introduction, Translation and Commentary* (Oxford: Clarendon Press, 1965), p. 81.

ποιεῖται (*scil.* χυτὸν ἄργυρον) δὲ ὅταν <κιννάβαρι> τριφῇ μετ' ὄξους ἐν ἀγγείῳ χαλκῷ καὶ δοίδυκι χαλκῷ.
‘(quicksilver) is made by grinding cinnabar with vinegar in a copper mortar with a copper pestle’.

2) Syriac version of three recipes by Zosimus of Panopolis (third–fourth century CE)
Source: Cambridge University Library, MS Mm 6.29 (fifteenth century CE), fol. 60v2–5 (first and second recipes); fol. 61r7–13 (third recipe).
Edition and translation by Matteo Martelli.

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ܒܠܟܐ. ܒܕܡܟܐ ܕܗ̇ܘܐ ܒܗܘܪ ܓܗ̇ ܡܚܝܠܬܐ. ܘܢܒܠܠ ܒܗ̇ ܒܓܪܐ ܕܒܡܪܐ ܕܒܬܡܪܐ
ܣܕܢܪܛܘܣ ܗܬ̈ܝܟܐ ܬܠܬܐ ܘܫܚܘܩ ܢܘܬ̈ܚܡ ܩ̈ܠܝܠܐ. ܗܕܐ ܗܒܠ ܣܕܢܪܛܘܣ
ܡܬܓܪܐ ܐܦ ܐܠܟܣܝܢܐ.

‘(Another) recipe: take a lead mortar and pestle; put cinnabar in it and grind it with water until quicksilver is produced.
(Another) recipe: other people take vinegar and grind (cinnabar) in the sun.
(Another) recipe: take a lead vessel as it has been said, where you should grind cinnabar with vinegar at the rising of the dog constellation (Syrius), so that the mixture is proportioned. Then mix the juice of the plant called *sidēritis*, three *kotulai*, with it, and grind these (ingredients) for many days. This plant that is now called *sidēritis* was also called *elxinē*’.

3) Two Syriac recipes (the dating is uncertain)
Edition: M. Berthelot, R. Duval, *La chimie au Moyen-Âge,* vol 2: *L’alchimie syriaque* (Paris: Imprimerie nationale, 1893), p. 47. Translation by Matteo Martelli.

ܦܘ̄ ܣܒ ܡܕܘܟܬܐ ܕܟܝܘܢ ܘܐܪܡܐ ܒܗ̇ ܩܢܒܪܝܣ. ܘܫܚܘܩ ܒܡ̈ܝܐ ܒܕܘܟܐ ܬܘܒ ܕܒ̇ܟ
ܟܝܘܢ. ܥܕ ܗܘ̇ܐ ܙܝܘܓ ✣
ܦܘ̄ ܐܪܡܐ ܚܠܐ ܘܫܚܘܩ ܒܫܡܫ̄.

‘(Another) recipe: take a lead mortar and put cinnabar in it; then, grind it in water with a pestle comprised of lead, until quicksilver is produced.
(Another) recipe: add vinegar and grind (cinnabar) in the sun’.

4) Zosimus of Panopolis, *Chapters to Eusebia* (third–fourth century CE)
Edition: M. Berthelot, C.-É. Ruelle, *Collection des anciens alchimistes grecs*, 3 vols (Paris: G. Steinheil, 1888), vol. 2, p. 172. The Greek text has been revised on the basis of the earliest Byzantine manuscripts; translation by Matteo Martelli.

ἔγωγε νομίζω βέλτιον εἶναι κιννάβαριν συλλειοῦν […]. Καὶ γὰρ οἰκονομούμενα ἐν τῷ ἡλίῳ τὰ εἴδη ὕδατι ἢ ὄξει νεφέλην ἀποτίκτουσιν· καὶ τοῦτο διὰ πείρας ἐπιστάμεθα. Καὶ πᾶσαι αἱ γραφαὶ καὶ Χίμης καὶ ἡ Μαρία φησίν· θυΐα μολιβδίνη καὶ δοίδυξ μολίβδινος· κιννάβαριν ὄξει λείου ἐν ἡλίῳ ἕως γένηται νεφέλη. Ὁμοίως καὶ ἐπὶ κασσιτέρου πάλιν τὸ αὐτό.
‘I think that it is better to grind cinnabar […]. In fact, different substances produce quicksilver (lit. cloud) when they are processed with water or vinegar in the sun. And we know this from experience. And every book as well as Chymes and Maria say: “Lead mortar and lead pestle. Grind cinnabar with vinegar in the sun until quicksilver (lit. cloud) is produced”. They do the same with tin (mortars and pestles)’.

5) Syriac translation of another recipe by Zosimus of Panopolis (third–fourth century CE)
Source: Cambridge University Library, MS Mm 6.29 (fifteenth century CE), fol. 59v12–17.
Edition and translation by Matteo Martelli.

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ܕܛܦܝܐ ܡܢ ܠܥܠ ܒܐܣܦܘܓܐ ܥܕܡܐ ܕܟܠܗ ܡܫܬܠܡ ܘܢܦܩ. ܘܐܪܡܝܗܝ، ܒܟܘܪܐ ܕܠܝܬ
ܠܗ ܟܣܝܐ. ܘܟܣܝܗ̇ ܒܐܚܪܬܐ. ܘܣܝܡ ܥܠ ܢܘܪܐ ܕܢܣܘܪܬܐ. ܘܡܫܟܚ ܐܢܬ ܠܥܠ ܐܝܟ
ܥܢܢܐ.

‘Another (recipe). (Take) copper scrapings and grind (cinnabar) with water. Little by little you will collect the mercury (lit. cloud) that floats on the surface with a sponge, until all (the ingredients) have been exhausted and consumed. Then put (what is left) in a vessel without a lid; you will cover it with another vessel and place this vessel on a fire of sawdust. You will find mercury in the upper (vessel)’.

6) Syriac version of another recipe by Zosimus of Panopolis (third–fourth century CE).
Source: Cambridge University Library, MS Mm 6.29 (fifteenth century CE), fol. 59v20–60r.
Edition and translation by Matteo Martelli.

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ܕܐܡܝܪ ܡܢ ܠܥܠ ܥܠ ܐܦܪܘܕܝܛ ܐܘ ܐܝܟ ܕܐܡܝܪ ܠܗ ܠܦܝܒܝܟܝܘܣ ܘܗܘܐ

‘Another (recipe). Take pure leaves of iron and make use of a mortar. Make scrapings as it is explained above (in the section) on copper (leaves) or as it is explained by Pebichius, and (mercury) is produced’.

7) Vitruvius, *On Architecture*, VII.8,1-4 (first century BCE)
Edition: F. Krohn, *Vitruvii De architectura libri decem* (Leipzig: Teubner, 1912), p. 163.
Translation: I. D. Rowland, M. J. Dewar, *Vitruvius, Ten Books on Architecture* (Cambridge: Cambridge University Press, 1999), p. 93.

Cum id foditur, ex plagis ferramentorum crebras emittit lacrimas argenti vivi, quae a fossoribus statim colliguntur. hae glaebae, cum collectae sunt, in officina propter umoris plenitatem coiciuntur in fornacem, ut interarescant, et is qui ex his ab ignis vapore fumus suscitatur, cum resedit in solum furni, invenitur esse argentum vivum. exemptis glaebis guttae eae, quae residebunt, propter brevitates non possunt colligi, sed in vas aquae converruntur et ibi inter se congruunt et una confunduntur.
‘When it is extracted, under the blows of iron tools it sheds copious tears of quicksilver, which is immediately gathered by the miners. When these clods of ore have been collected, because of their saturation with moisture they are cast into a kiln at the foundry in order to dry them out, and the smoke that is driven out of them by the heat of the fire, once it settles again along the floor of the kiln, will be found to consist of quicksilver. Once the clods have been removed, the droplets that have settled out cannot be gathered because they are so small, but they are swept into a tub of water and there they merge with one another and are finally poured together into a single mass’.

8) Pliny the Elder, *Natural History*, XXXIII.123 (first century CE)
Edition and translation: H. Rackham, *Pliny, Natural History, with an English Translation in Ten Volumes. Volume IX. Libri XXXIII-XXXV* (Cambridge, MA – London: Loeb, 1961), pp. 92-93.

(minium) patinis fictilibus impositum ferrea concha, calice coopertum, argilla superinlita, dein sub patinis accenso follibus continuis igni atque ita calici sudore deterso, qui fit argenti colore et aquae liquore. Idem guttis dividi facilis et lubrico umore compluere,
‘It (i.e., cinnabar) is put in an iron shell in flat earthenware pans, ad covered with a convex lid smeared on with clay, and then a fire is lit under the pans and kept constantly burning by means of bellows, and so the surface moisture (with the colour of silver and fluidity of water) which forms on the lid is wiped off it. This moisture is also easily divided into drops and rains down freely with slippery fluidity’.

9) Alchemical papyrus, *The Leyden Papyrus* (*P.Leid.X*), fol. 16 (third century CE).
Edition and translation by Matteo Martelli.

θέντες γὰρ ἐπὶ λοπάδος κεραμεᾶς κόγχον σιδηροῦν ἔχοντα κιννάβαρι, περικαθάπτουσιν ἄμβικα περιαλείψαντες πηλῷ, εἶθ’ ὑποκαίουσιν ἄνθραξιν· ἡ γὰρ προσίζουσα τῷ ἄμβικι αἰθάλη ἀποψηχθεῖσα ὑδράργυρος γίνεται.
‘They put an iron shell containing cinnabar in an earthenware vessel and enclose it with a convex lid smeared on with clay; then they light a fire upon (the vessel) with charcoal. The vapour that settles on the lid, when wiped off, is mercury’ (passage taken from Dioscorides, *On Medical Substances*, V.95).

10) Byzantine anonymous alchemist (eighth–ninth century CE) reporting a recipe by Pseudo-Democritus (first century CE)
Edition: M. Berthelot, C.-É Ruelle, *Collection des anciens alchimistes grecs*, 3 vols (Paris: G. Steinheil, 1888), vol. 2, p. 123. The Greek text has been revised on the basis of the earliest Byzantine manuscripts; translation by Matteo Martelli.

Οὗτος οὖν ὁ ἀγαθώτατος φιλόσοφος· Τίς δὲ οὐκ οἶδεν ὅτι ἡ αἰθάλη τῆς κινναβάρεως ὑδράργυρός ἐστι, δι’ ἧς καὶ συντέθειται; Διὸ καὶ εἴ τις ἐλλείωσας αὐτὴν τὴν κιννάβαριν νιτρελαίῳ, ἀναφυράσας

καὶ περικλείσας ἐν ἄγγεσιν διπλοῖς, ὑποκαύσας φωσὶν ἀλήκτοις, πᾶσαν αἰθάλην λήψεται ἐγκεκαθημένην [*lege* ἐγκαθημένην?] είς τά σώματα.
‘This very famous philosopher (i.e., Pseudo-Democritus) said: Who does not know that the vapour of cinnabar is the mercury of which it is composed? Therefore, if anyone grinds cinnabar with oil of natron, mixes them together, puts them in the double vessels and lights a persistent fire, he will collect the entire vapour that was sitting in the bodies (of cinnabar)’.

11) Byzantine anonymous recipe (the dating is uncertain)
Edition: Berthelot, M., Ruelle, C.-É. *Collection des anciens alchimistes grecs*, 3 vols (Paris: G. Steinheil, 1888), vol. 2, 38. Translation by Matteo Martelli.

Περὶ κινναβάρεως. Δεῖ γινώσκειν ὅτι ἡ ἀνάκαμψις τῆς κινναβάρεως διὰ νιτρελαίου γίνεται, καὶ οὕτως χωνεύεται μετὰ πυρᾶς λεπτῆς, ὡς ἐπινοεῖς.
‘On cinnabar. You must know that the transformation of cinnabar happens by means of the oil of natron: in this way cinnabar is melted by a light fire, as you know’.

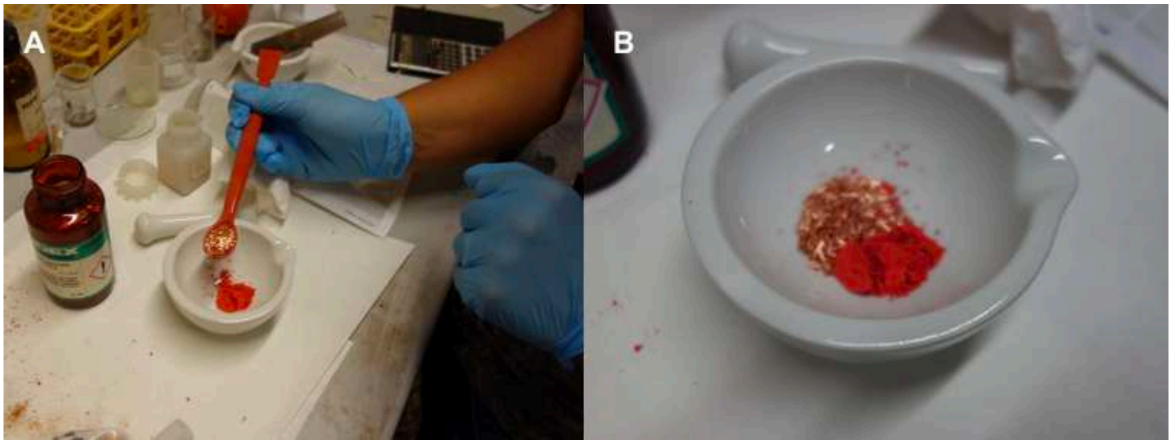

Fig. S1. Reagents for cold extraction of mercury. Addition of a spatula spoon with small pieces of copper in a mortar containing synthetic mercury sulphide powder.

Fig. S2. Cold extraction of mercury with copper. (**A** and **B**) Reaction mixture containing synthetic mercury sulphide, small pieces of copper and acetic acid (6%) after two hours of grinding. At the end of the reaction, the amalgam HgCu formed on the copper pieces (**C**).

Fig. S3. Cold extraction of mercury in bronze mortar. Bronze mortar before (**A**) and after (**B**) the reaction performed by grinding the synthetic mercury sulphide powder in the presence of acetic acid (6%) exploiting the copper in the metal alloy: at the bottom of the mortar and on the pestle, the HgCu amalgam is present.

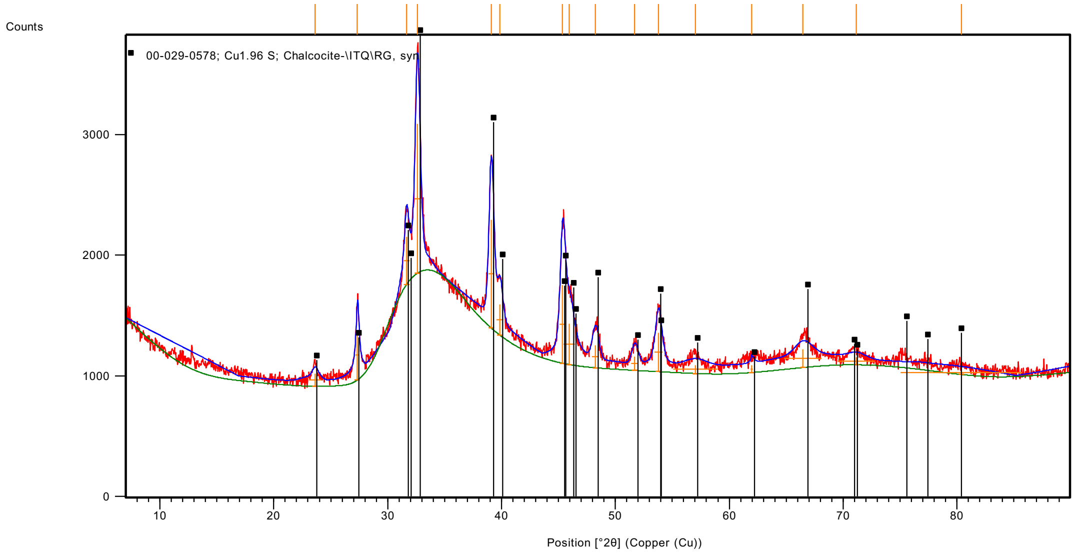

Fig. S4. Ball milling of cinnabar with copper. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide and copper powder in the presence of acetic acid (reaction mixture ground with a ball mill for four hours at 25 Hz). Phase identification was performed using the *PDF 2 Release 2004* database.

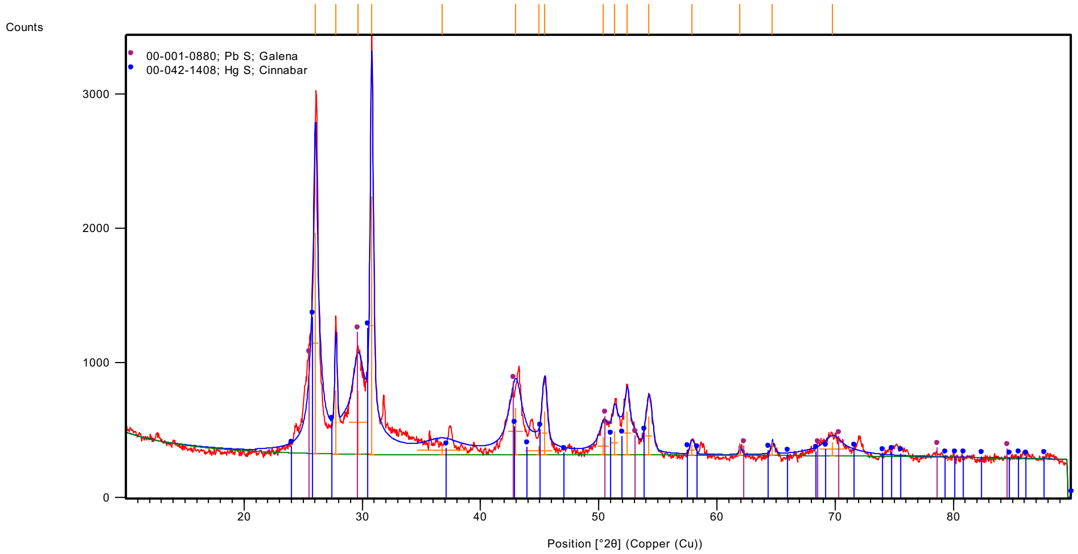

Fig. S5. Ball milling of cinnabar with lead. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide and the lead airgun pellet in the presence of acetic acid (the reaction mixture was ground with a ball mill for four hours at 25 Hz). Phase identification was performed using the *PDF 2 Release 2004 database.*

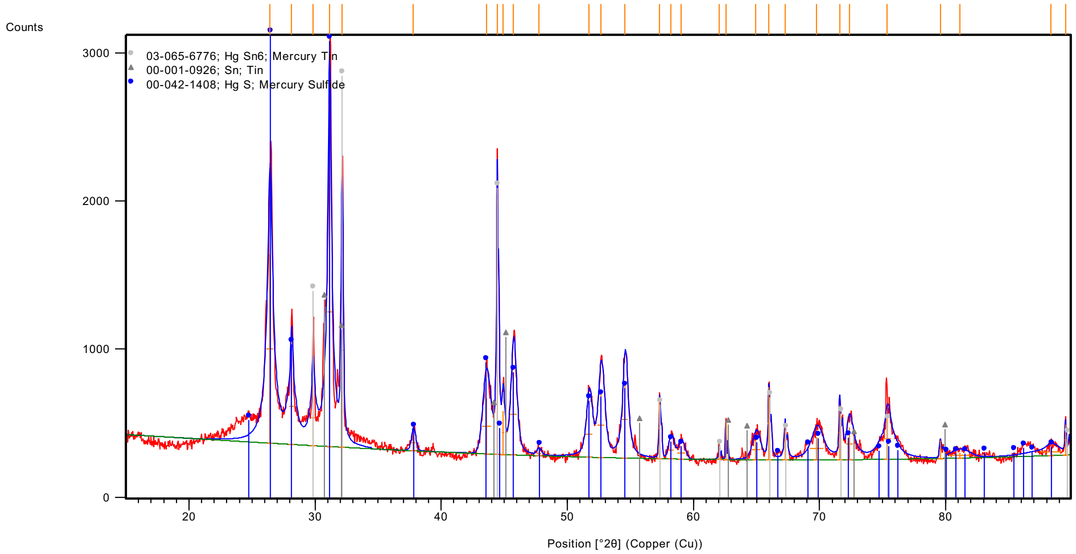

Fig. S6. Ball milling cinnabar with tin. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide and tin powder in the presence of acetic acid (the reaction mixture was ground with a ball mill for four hours at 25 Hz). Phase identification was performed using the *PDF 2 Release 2004 database.*

Fig. S7. Amalgam of mercury and tin. Residual products inside the mortar where the cold extraction of Hg was performed by grinding synthetic mercury sulphide together with tin powder: the presence of the HgSn amalgam was evident.

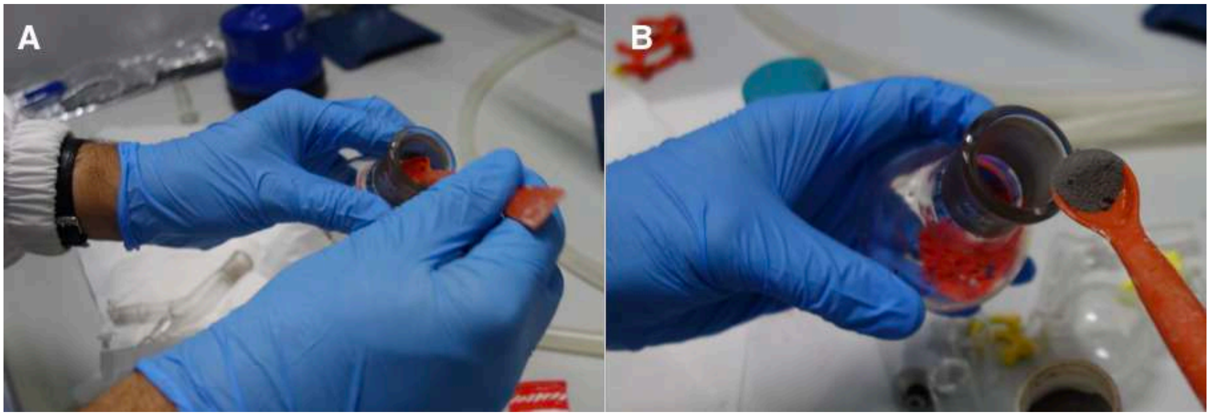

Fig. S8. Hot extraction of mercury with iron powder. (**A**) Addition of HgS and (**B**) iron powder to the reaction flask for hot extraction of mercury.

Fig. S9. Hot extraction of mercury with iron powder. (**A**) Reaction flask at the end of the reaction and (**B**) enlarged image of it; (**C**) residual powder and droplets of mercury collected at the end of the reaction.

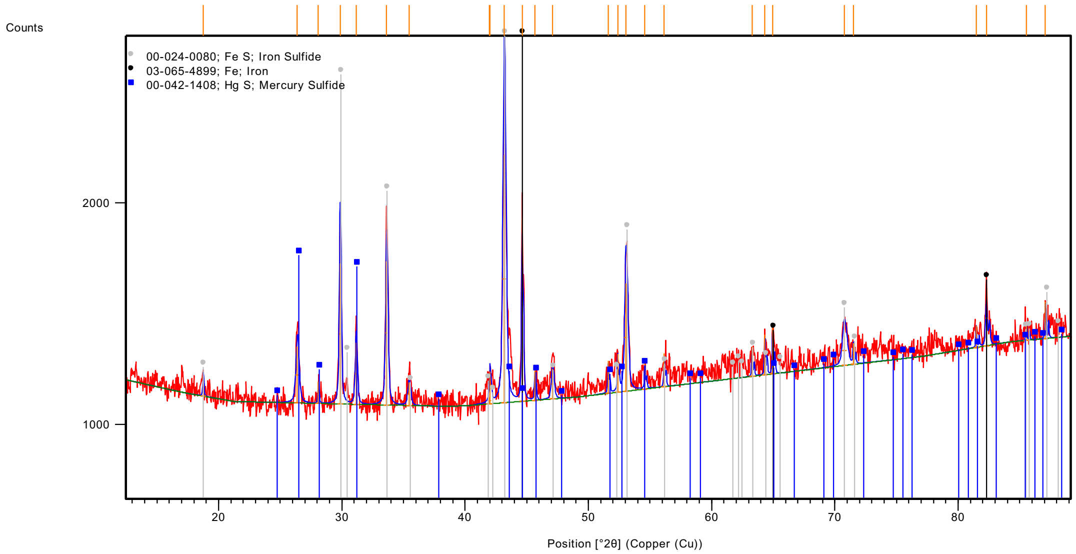

Fig. S10. Hot extraction of mercury with iron powder. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide and iron powder; the reaction mixture was heated with a Bunsen burner for 10 minutes. Phase identification was performed using the *PDF 2 Release 2004 database.*

Fig. S11. Hot extraction of mercury with iron powder. Residual powder recovered and the end of the reaction between the mineral cinnabar and iron powder after heating with a Bunsen burner.

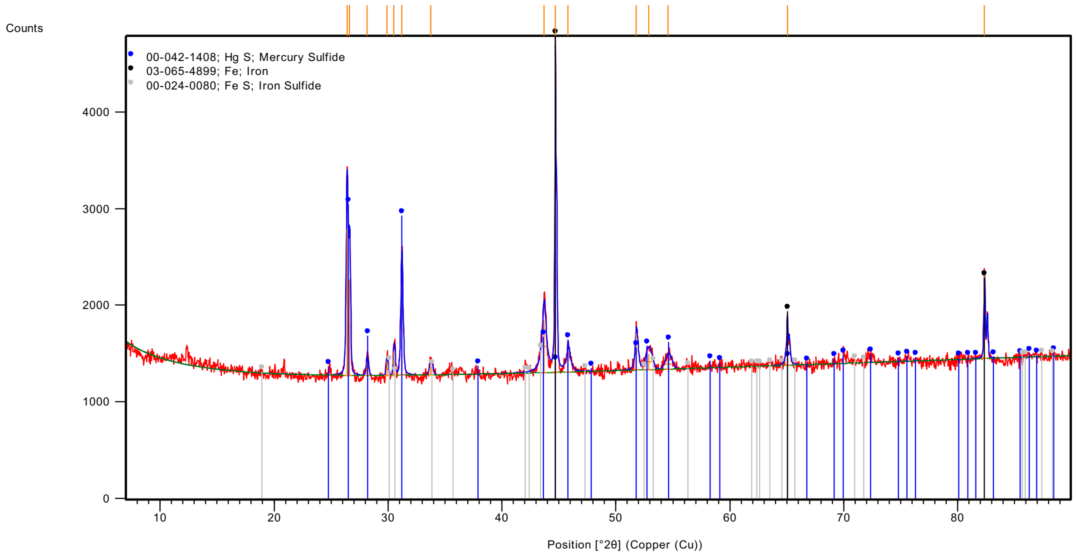

Fig. S12. Hot extraction of mercury with iron powder. XRPD pattern of the residual powder obtained from the reaction of the cinnabar ore (sample C5) and iron powder; the reaction mixture was heated with a Bunsen burner for 10 minutes. Phase identification was performed using the *PDF 2 Release 2004 database.*

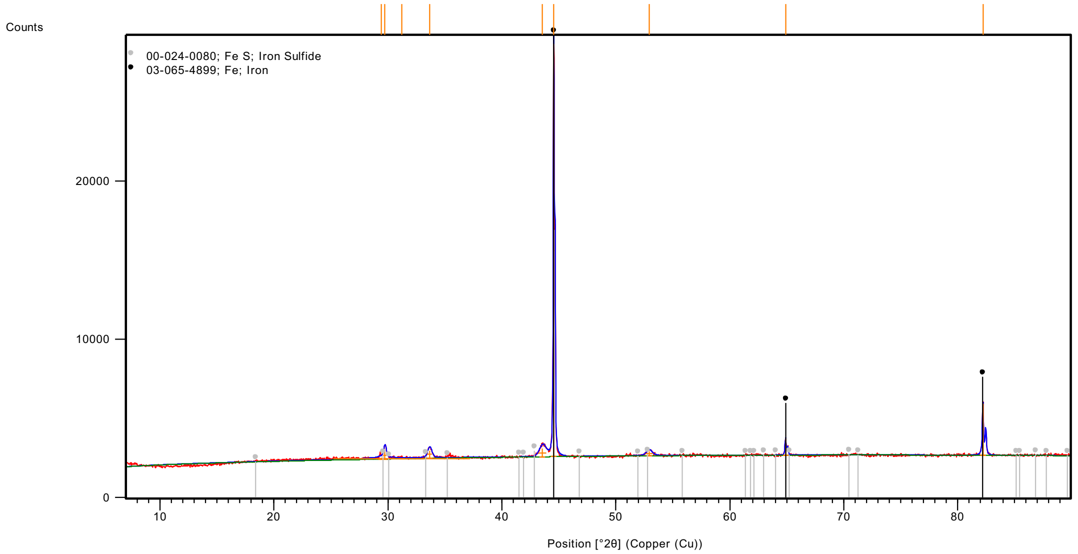

Fig. S13. Hot extraction of mercury with iron plate. XRPD pattern of the iron plate at the end of the reaction with cinnabar ore (sample C4); the reaction mixture was heated with a Bunsen burner for 10 minutes. Phase identification was performed using the *PDF 2 Release 2004 database.*

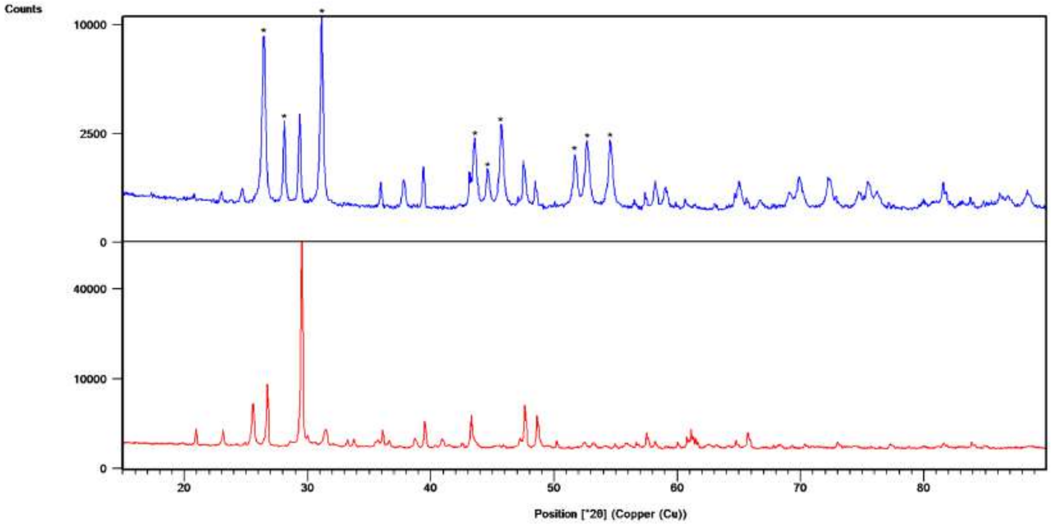

Fig. S14. Hot extraction of mercury with iron plate. Comparison between the XRPD of the cinnabar ore (sample C4, blue solid line) and the residual powder obtained from the reaction of the cinnabar ore (sample C4) and iron plate (red solid line); the reaction mixture was heated with a Bunsen burner. The asterisks in the blue XRPD diffractogram indicate the peaks assigned to the cinnabar.

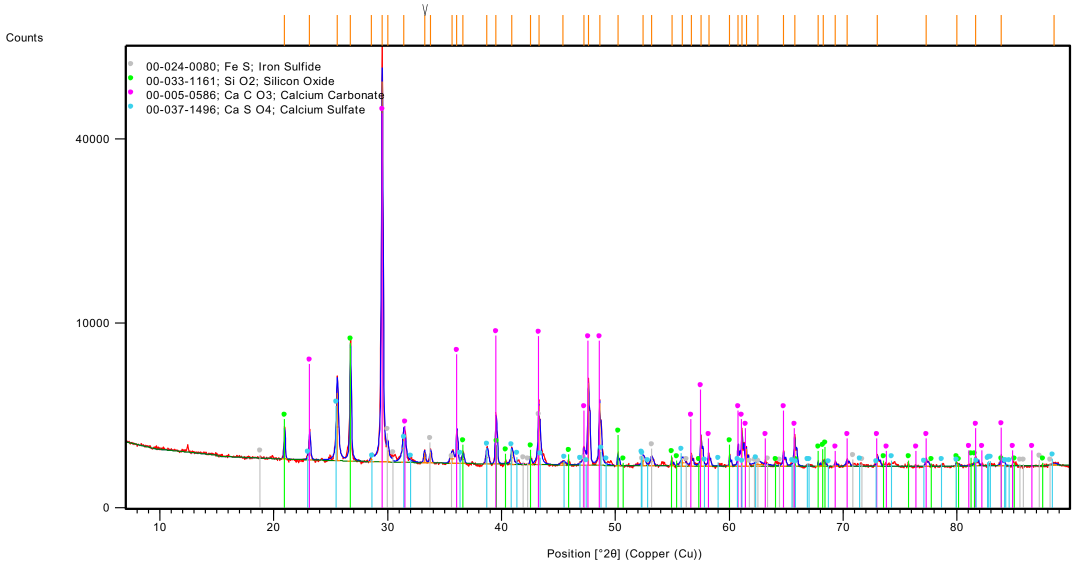

Fig. S15. Hot extraction of mercury with iron plate. XRPD pattern of the residual powder obtained from the reaction of cinnabar ore (sample C4) and iron plate; the reaction mixture was heated with a Bunsen burner for 10 minutes. Phase identification was performed using the *PDF 2 Release 2004 database.* Calcium sulphate ($CaSO_4$) was obtained as the product of hot extraction due to the mercury sulphide reaction with calcium oxide (CaO): indeed, CaO is obtained via the thermal decomposition of calcium carbonate ($CaCO_3$) present in sample C4 (see the XRPD diffractogram in Fig. S47).

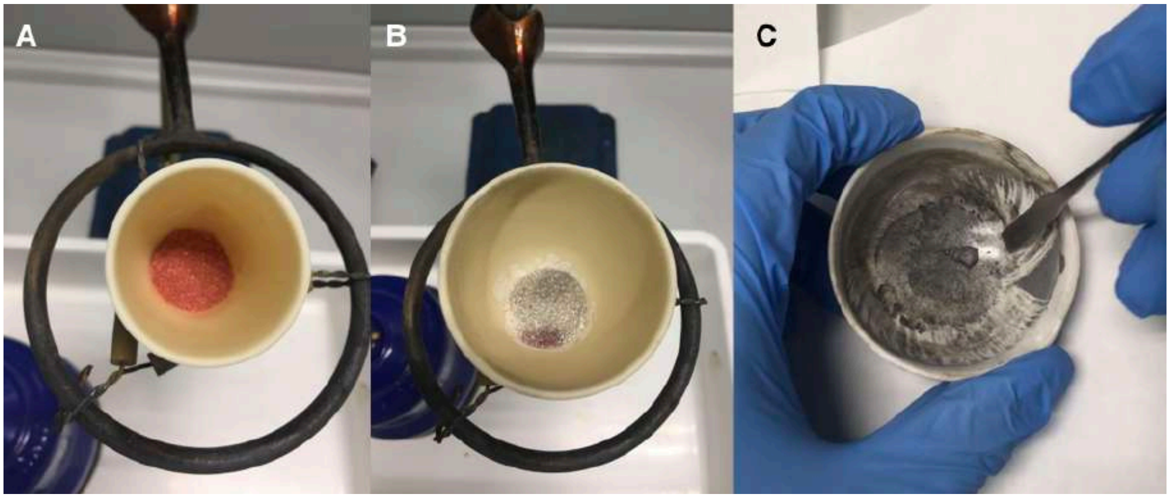

Fig. S16. Hot extraction of mercury with sodium carbonate. Reaction vessel (**A**) before and (**B**) at the end of the reaction; (**C**) droplets of mercury were visible on the alumina lid.

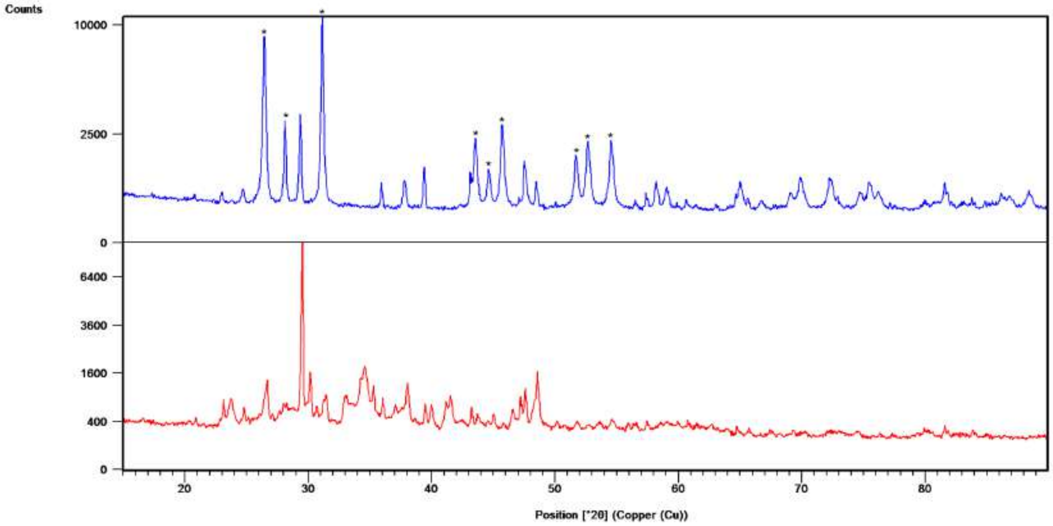

Fig. S17. Hot extraction of mercury with sodium carbonate. Comparison between the XRPD of the cinnabar ore (sample C4, blue solid line) and the residual powder obtained from the reaction of cinnabar ore (sample C4) and sodium carbonate (red solid line); the reaction mixture was heated with a Bunsen burner for 10 minutes. The asterisks in the blue XRPD diffractogram indicate the peaks assigned to the cinnabar.

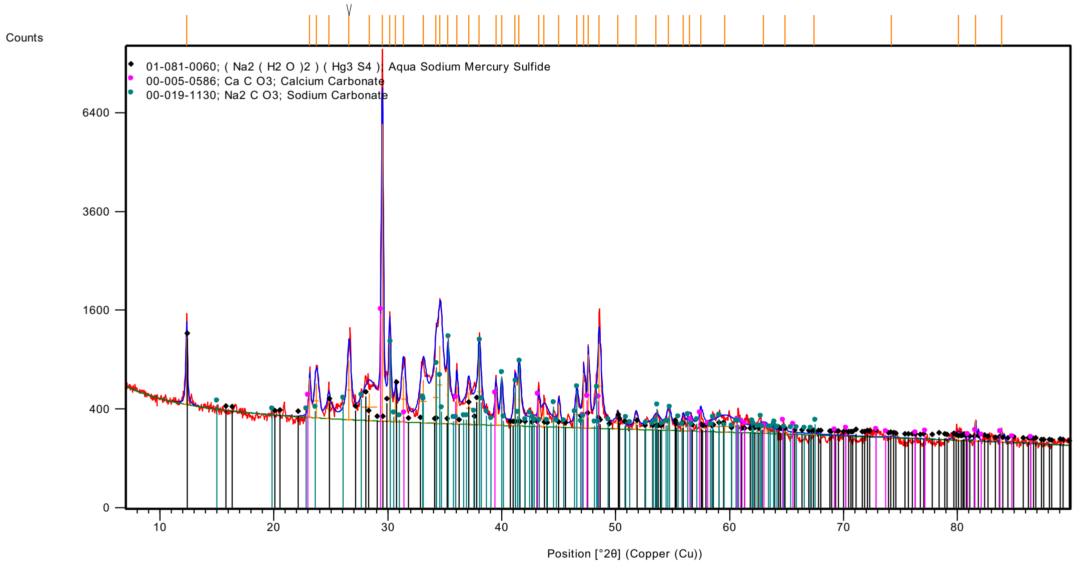

Fig. S18. Hot extraction of mercury with sodium carbonate. XRPD pattern of the residual powder obtained from the reaction of the cinnabar ore (sample C4) and sodium carbonate; the reaction mixture was heated with a Bunsen burner for 10 minutes. Phase identification was performed using the *PDF 2 Release 2004 database.*

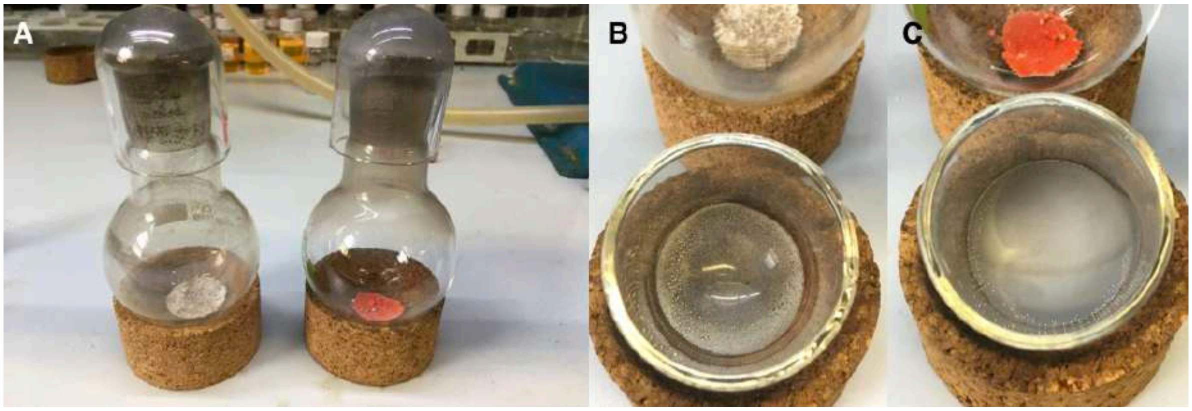

Fig. S19. Hot extraction of mercury with sodium carbonate and with atmospheric oxygen. (**A**) Reaction flasks containing synthetic mercury sulphide and sodium carbonate (left) and only synthetic mercury sulphide (right) after 48 hours of heating (300 °C) with enlarged images of the corresponding lids where drops of mercury were visible (**B** and **C**).

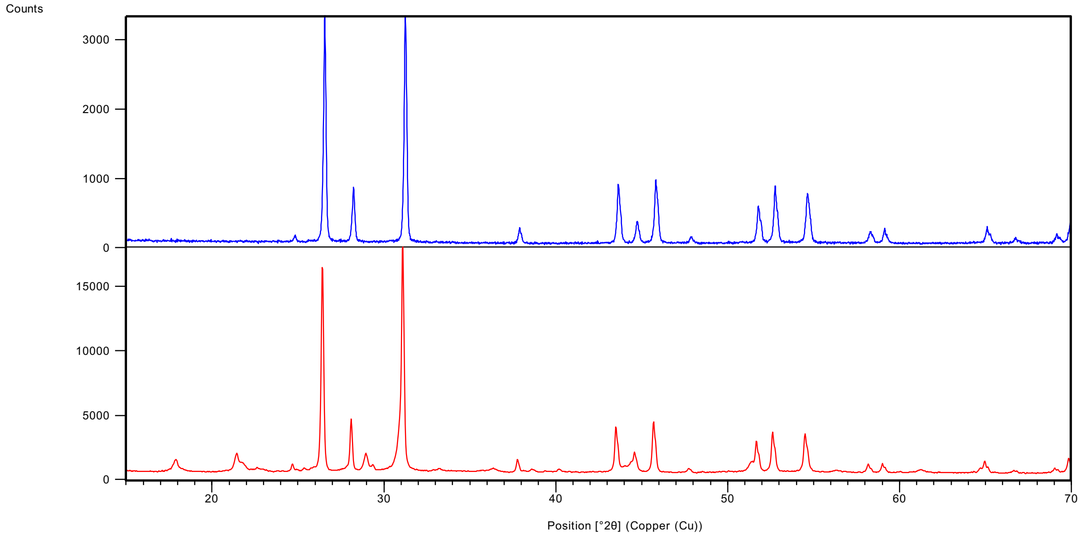

Fig. S20. Hot extraction of mercury with atmospheric oxygen. Comparison between the XRPD of the synthetic mercury sulphide (blue solid line) and the residual powder obtained from the reaction of synthetic mercury sulphide with atmospheric oxygen (red solid line); the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours.

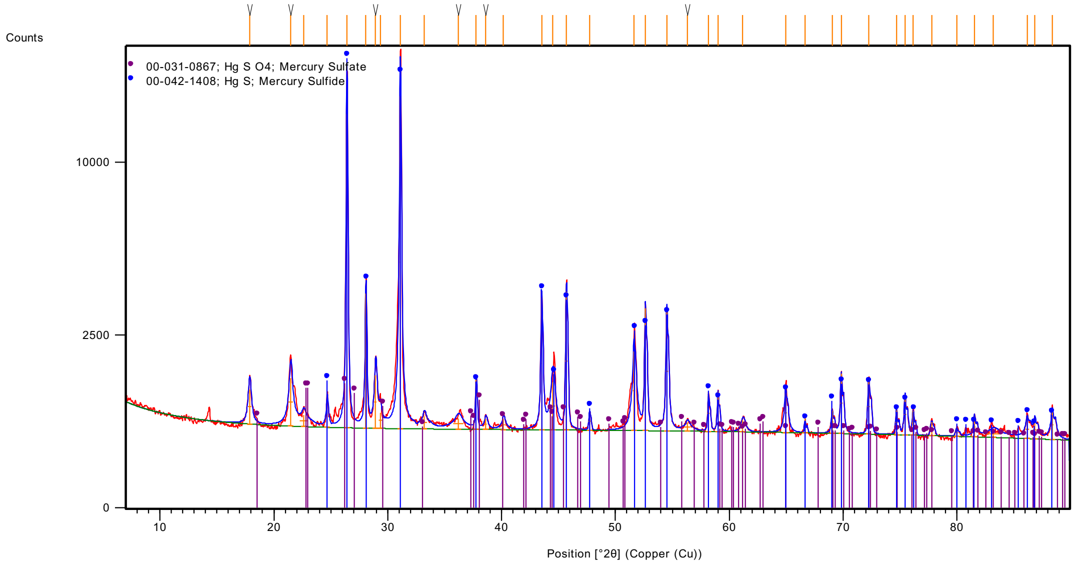

Fig. S21. Hot extraction of mercury with atmospheric oxygen. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide with atmospheric oxygen; the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

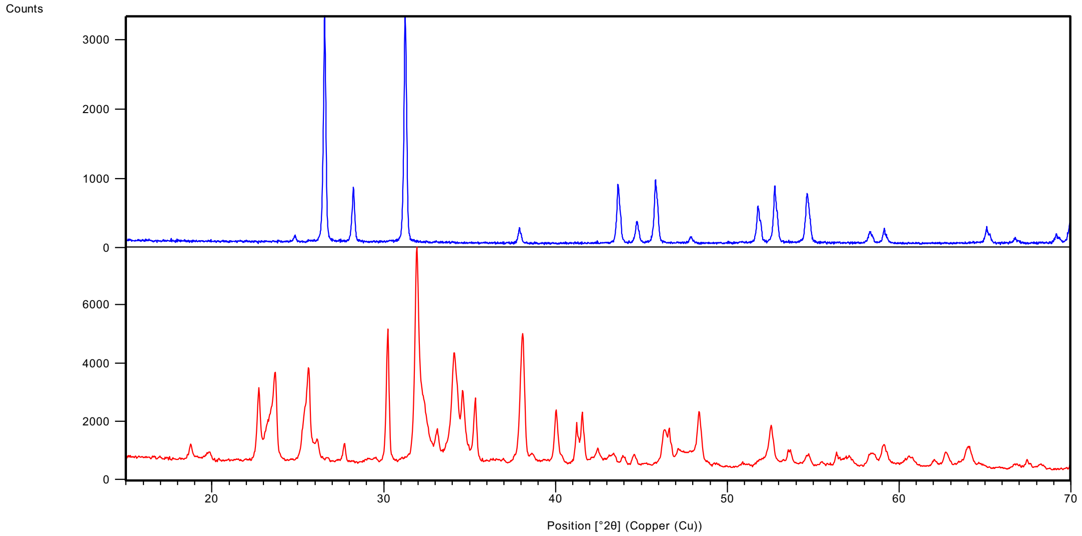

Fig. S22. Hot extraction of mercury with sodium carbonate. Comparison between the XRPD of the synthetic mercury sulphide (blue solid line) and the residual powder obtained from the reaction of synthetic mercury sulphide with sodium carbonate (red solid line); the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours.

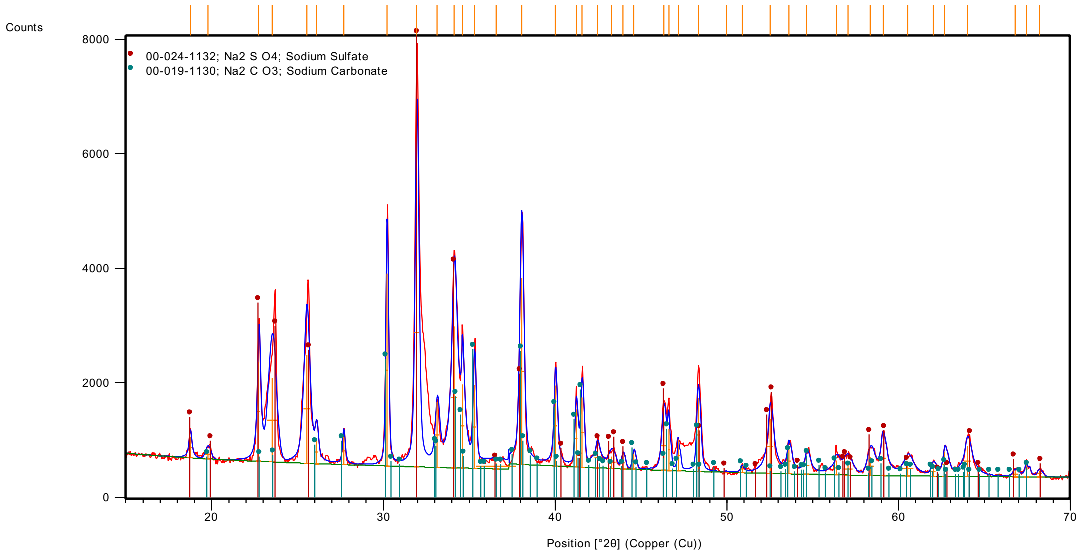

Fig. S23. Hot extraction of mercury with sodium carbonate. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide with sodium carbonate; the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

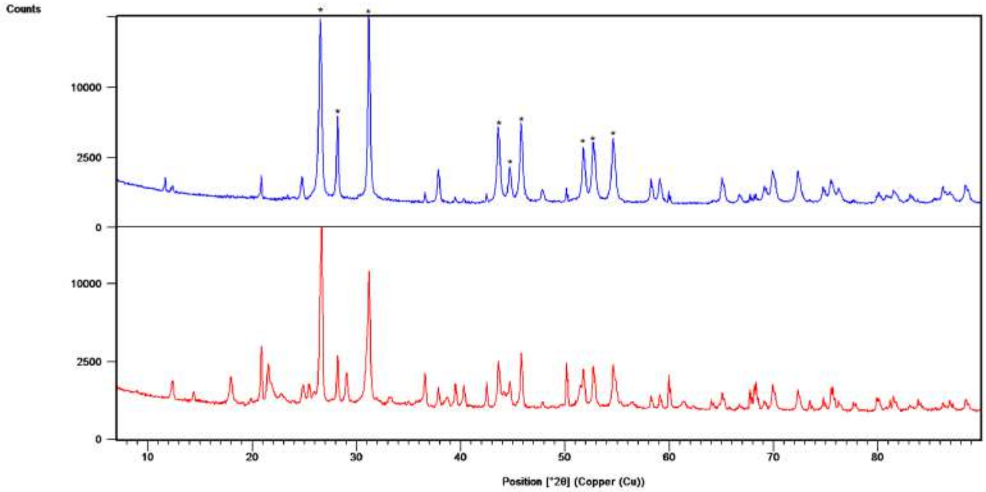

Fig. S14. Hot extraction of mercury with atmospheric oxygen. Comparison between the XRPD of the cinnabar ore (sample C1, blue solid line) and the residual powder obtained from the reaction thereof (sample C1**)** with atmospheric oxygen (red solid line); the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours. The asterisks in the blue XRPD diffractogram indicate the peaks assigned to the cinnabar.

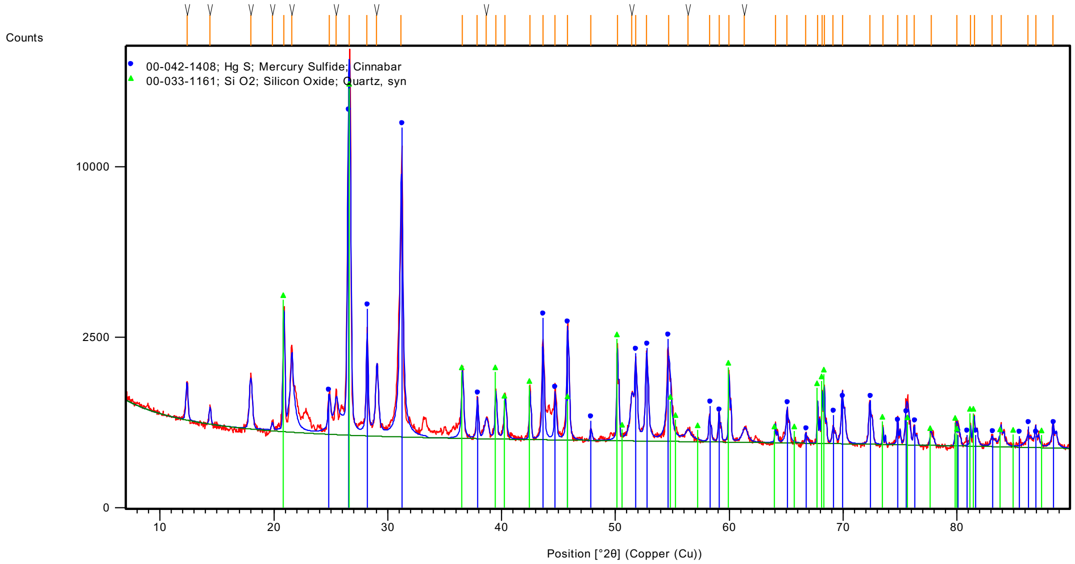

Fig. S25. Hot extraction of mercury with atmospheric oxygen. XRPD pattern of the residual powder obtained from the reaction of the cinnabar ore (sample C1) with atmospheric oxygen; the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

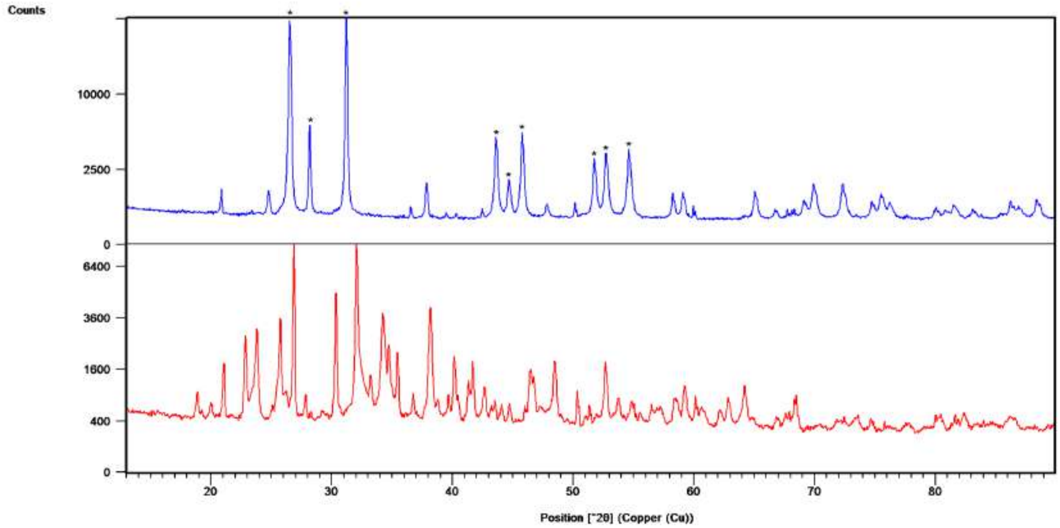

Fig. S26. Hot extraction of mercury with sodium carbonate. Comparison between the XRPD of the cinnabar ore (sample C1, blue solid line) and the residual powder obtained from the reaction of the cinnabar ore (sample C1) with sodium carbonate (red solid line); the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours. The asterisks in the blue XRPD diffractogram represent the peaks assigned to the cinnabar.

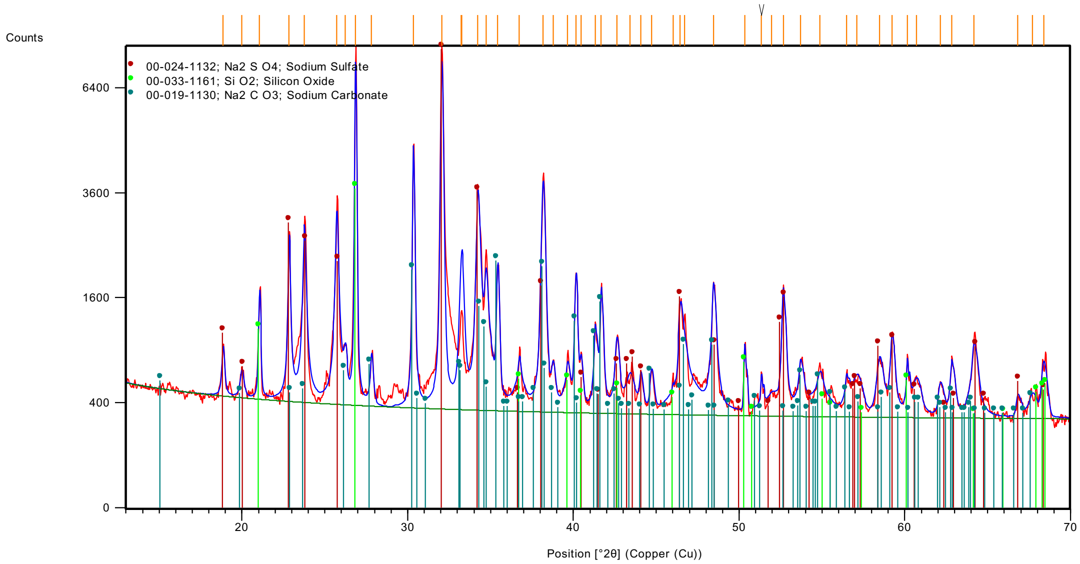

Fig. S27. Hot extraction of mercury with sodium carbonate. XRPD pattern of the residual powder obtained from the reaction of the cinnabar ore (sample C1) with sodium carbonate; the reaction mixture was then heated with a mantle (at 300 °C) for 48 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

Fig. S28. Hot extraction of mercury with sodium carbonate in presence of water. Experimental setup used for the hot extraction of Hg from synthetic mercury sulphide in the presence of water and sodium carbonate (**A**) before and (**B**) after 4 hours of heating; (**C**) residual powder inside the crucible at the end of the reaction; and (**D**) enlargement of the lid with condensed Hg.

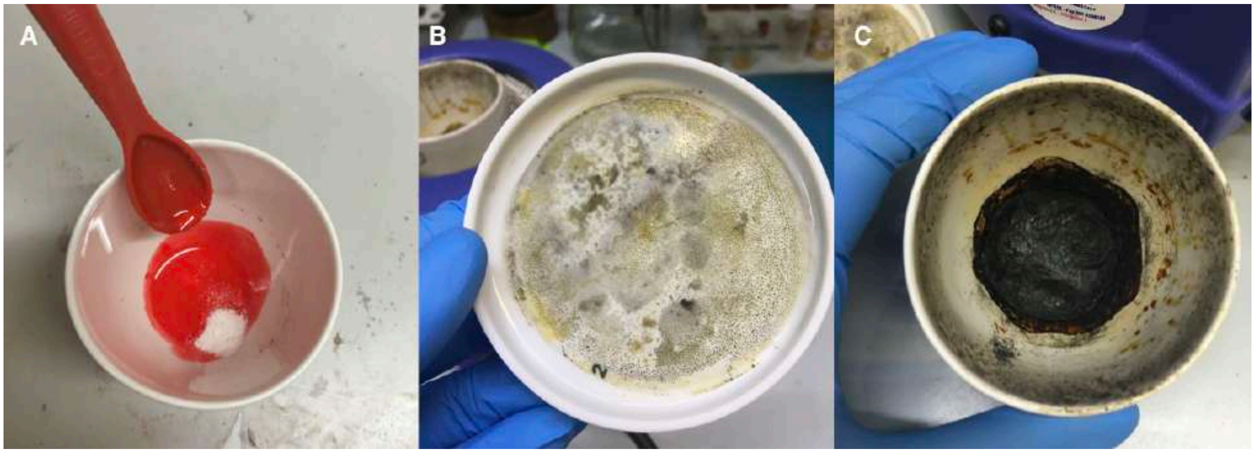

Fig. S29. Hot extraction of mercury with sodium carbonate in presence of flaxseed oil. (**A**) Reaction vessel with synthetic mercury sulphide, flaxseed oil and sodium carbonate; (**B**) the lid and (**C**) the crucible at the end of the reaction. The heating mantle was set to 300 °C.

Fig. S30. Hot extraction of mercury with sodium carbonate in presence of flaxseed oil. Crucible and lid at the end of the reaction. The heating mantle was set to 100 °C.

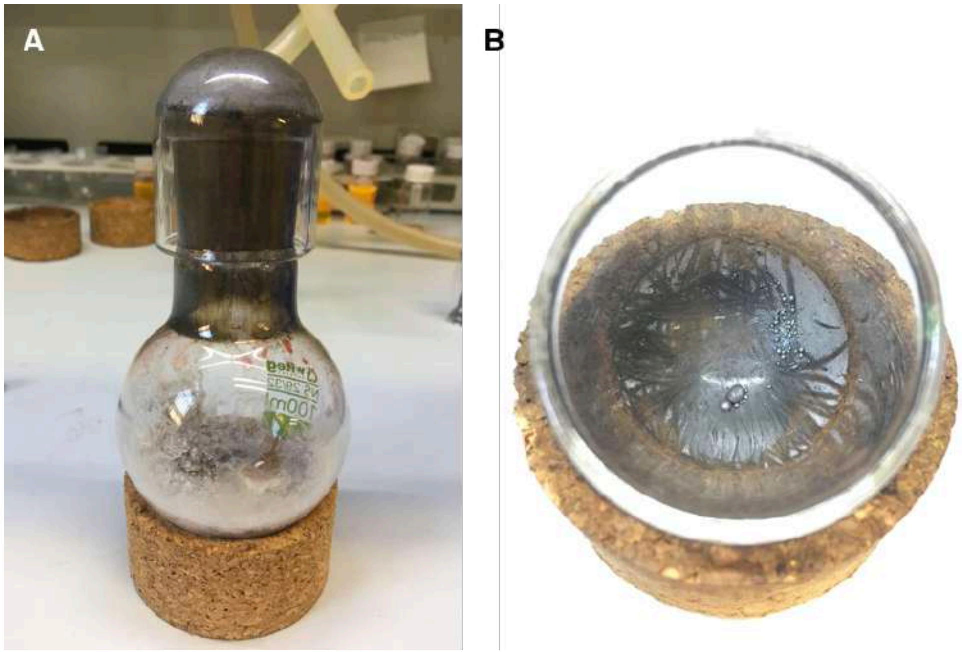

Fig. S31. Hot extraction of mercury with sodium carbonate in presence of vinegar. (**A**) Reaction flask containing synthetic mercury sulphide, sodium carbonate and vinegar after 72 hours of heating (300°C); (**B**) droplets of mercury were visible on the lid.

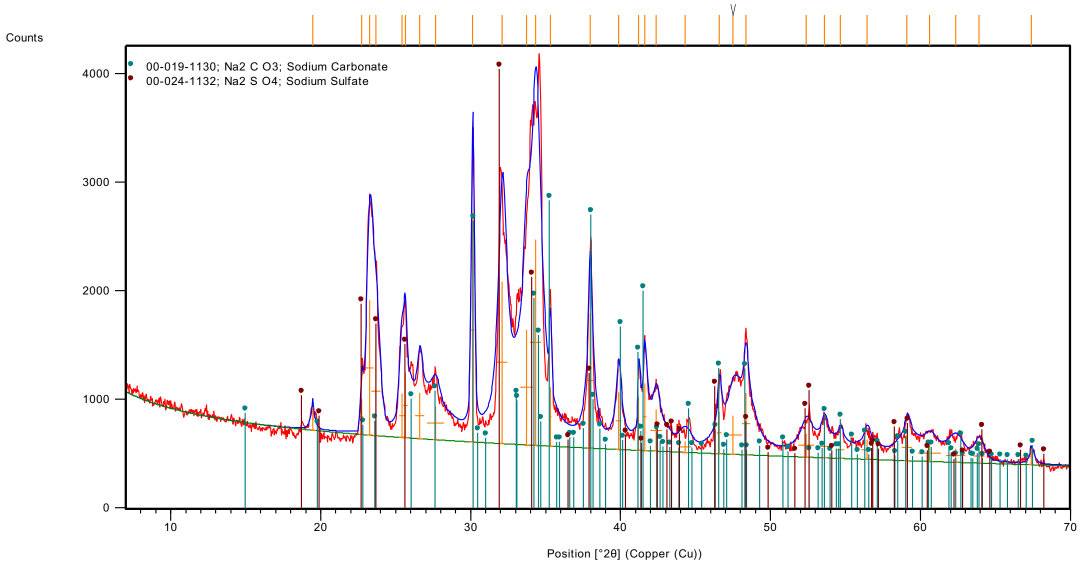

Fig. S32. Hot extraction of mercury with sodium carbonate in presence of vinegar. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide with sodium carbonate dispersed in vinegar; the reaction mixture was heated with a mantle (at 300 °C) for 72 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

Fig. S33. Hot extraction of mercury from cinnabar with calcium carbonate and calcium oxide. Reaction flasks containing synthetic mercury sulphide and calcium oxide (left); synthetic mercury sulphide and calcium carbonate after 48 hours of heating at 300 °C (right).

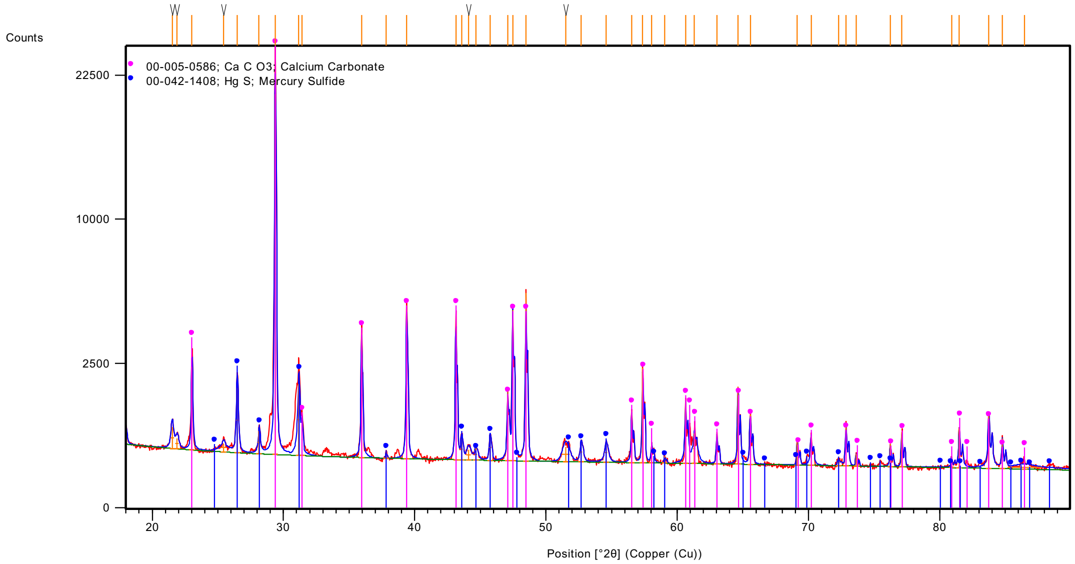

Fig. S34. Hot extraction of mercury from cinnabar with calcium carbonate. XRPD pattern of the residual powder obtained from the reaction of synthetic mercury sulphide with calcium carbonate; the reaction mixture was heated with a mantle (at 300 °C) for 48 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

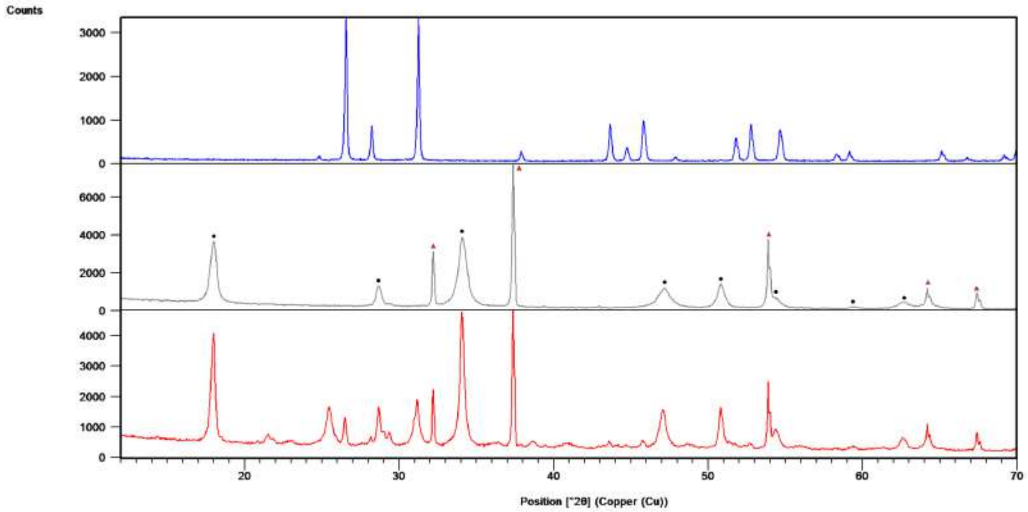

Fig. S35. Hot extraction of mercury from cinnabar with calcium carbonate and calcium oxide. Comparison between the XRPD of the synthetic mercury sulphide (blue solid line) and the calcium oxide (CaO) used for the hot extraction, which is a mixture of CaO and calcium hydroxide Ca(OH)$_2$ (marked by the grey solid line, with the red triangles indicating the peaks assigned to the CaO and the black dots representing the peaks assigned to Ca(OH)$_2$) and the residual powder obtained from the reaction of the synthetic mercury sulphide with the mixture CaO–Ca(OH)$_2$ (red solid line); the reaction mixture was heated with a mantle (at 300 °C) for 48 hours.

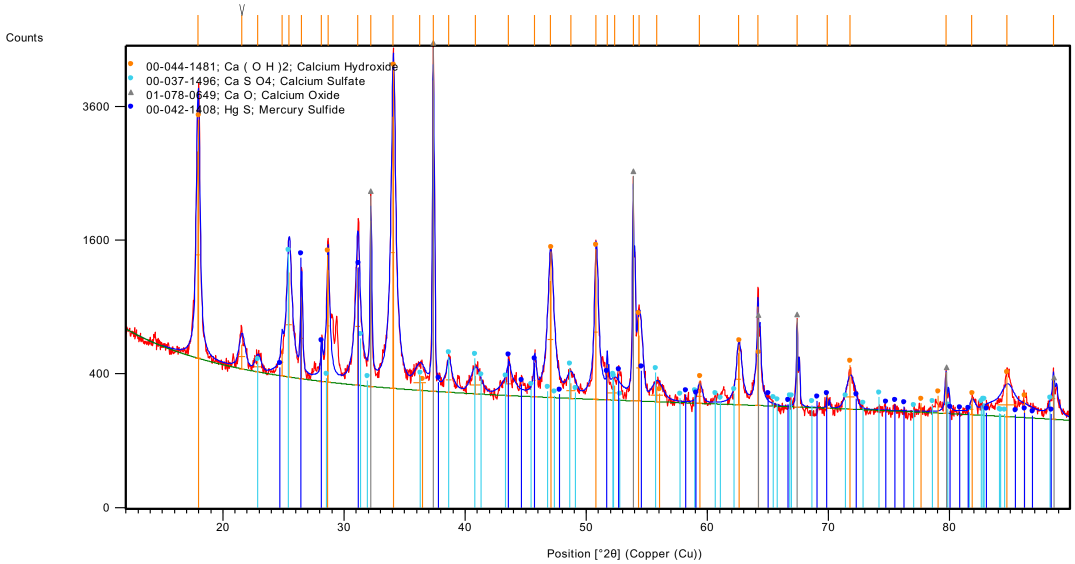

Fig. S36. Hot extraction of mercury from cinnabar with calcium carbonate and calcium oxide. XRPD pattern of the residual powder obtained from the reaction of the synthetic mercury sulphide with the mixture calcium oxide-calcium hydroxide; the reaction mixture was heated with a mantle (at 300 °C) for 48 hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

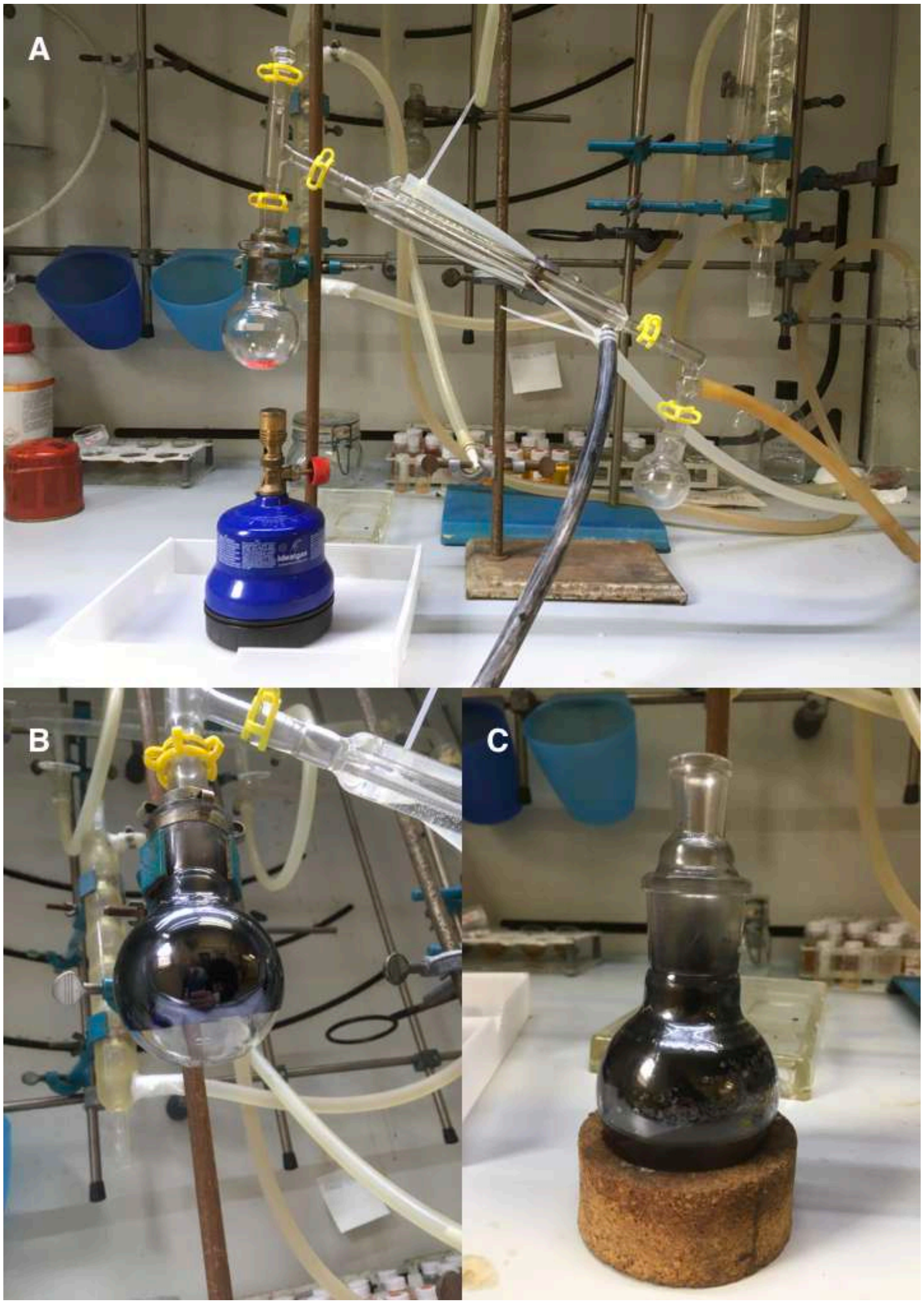

Fig. S37. Hot extraction of mercury under vacuum. (**A**) Experimental setup for the hot extraction of mercury from synthetic mercury sulphide under vacuum. (**B** and **C**) Reaction flask at the end of the reaction.

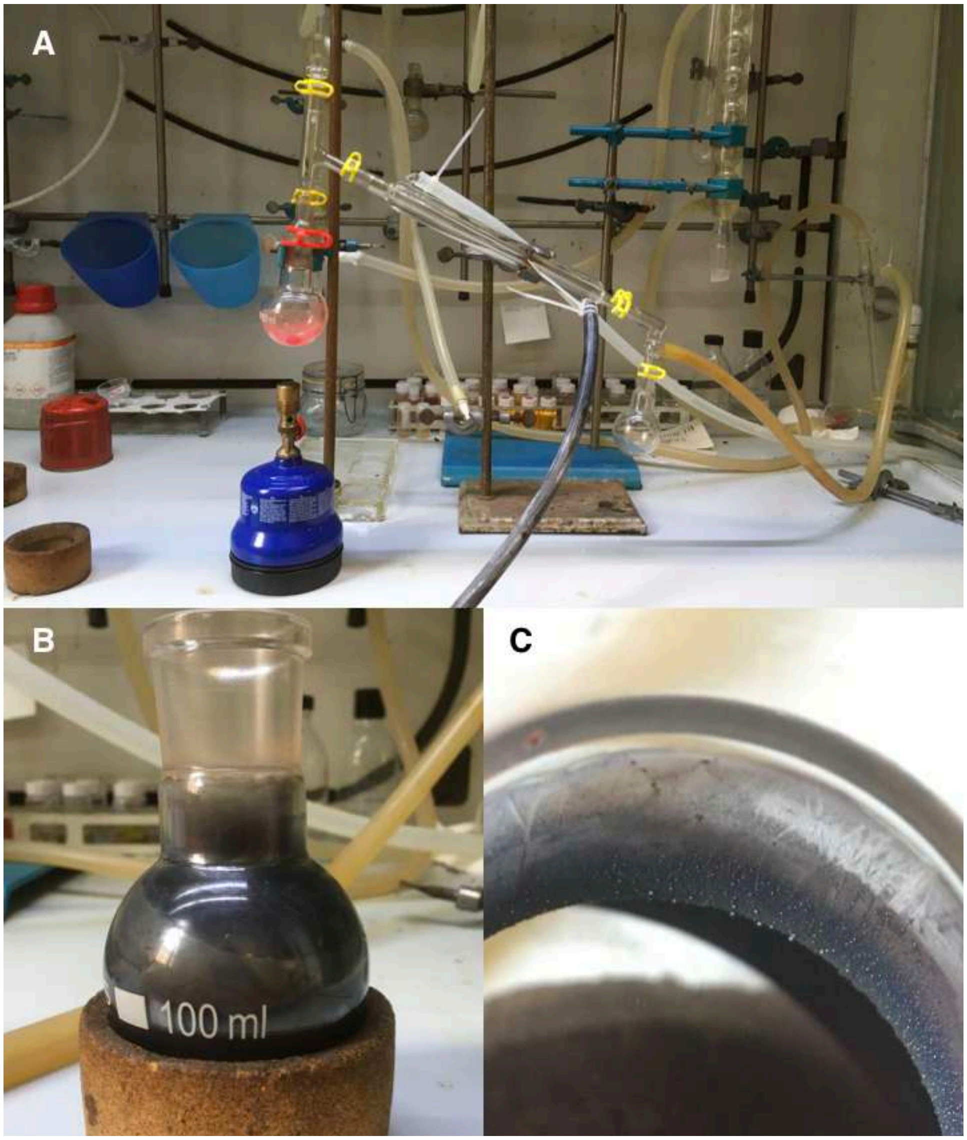

Fig. S38. Hot extraction of mercury in presence of sodium carbonate under vacuum. (**A**) Experimental setup for the hot extraction of mercury from synthetic mercury sulphide in the presence of sodium carbonate under vacuum. (**B**) Reaction flask at the end of the reaction; (**C**) enlargement of the reaction flask with mercury droplets on the flask's neck.

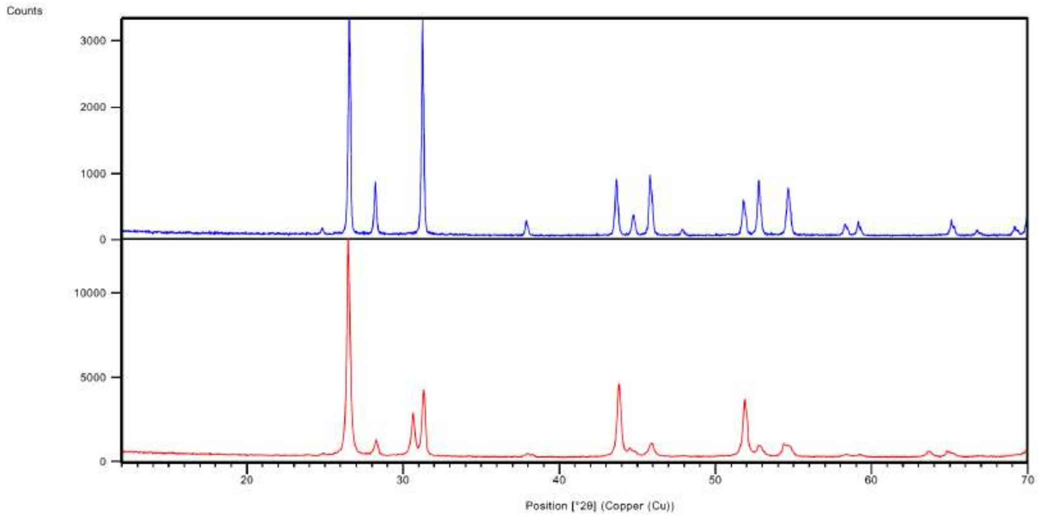

Fig. S39. Hot extraction of mercury under vacuum. Comparison between the XRPD of the synthetic mercury sulphide (blue solid line) and the residual powder obtained by heating the mercury sulphide under vacuum with a Bunsen burner for 10 minutes (red solid line).

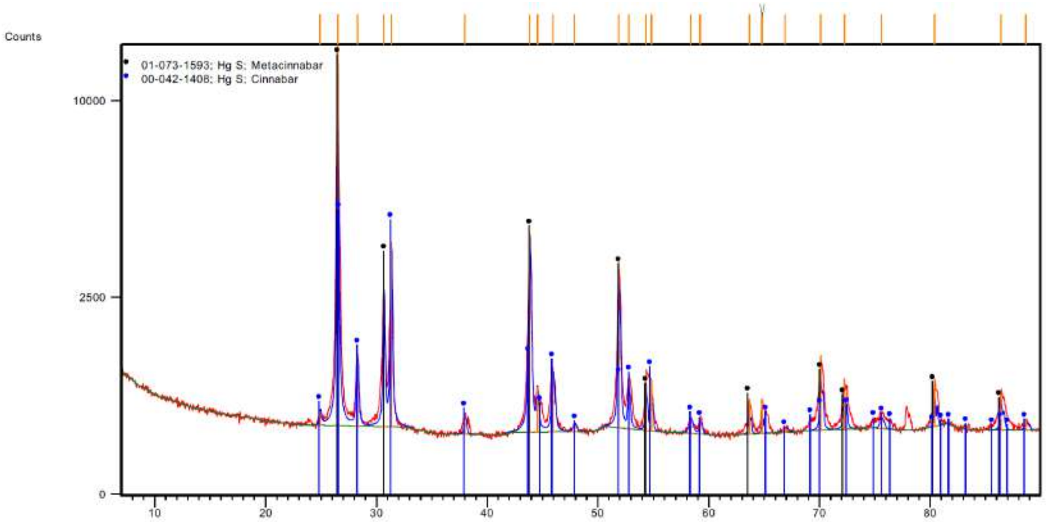

Fig. S40. Hot extraction of mercury under vacuum. XRPD pattern of the residual powder obtained by heating with a Bunsen burner (for 10 minutes) mercury sulphide under vacuum. Phase identification was performed using the *PDF 2 Release 2004 database.*

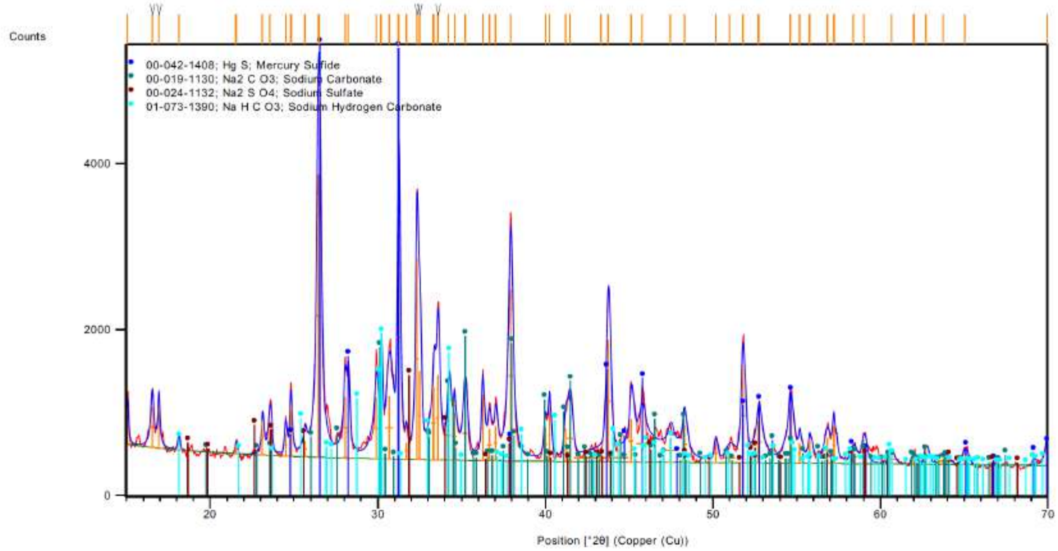

Fig. S41. Hot extraction of mercury in presence of sodium carbonate under vacuum. XRPD pattern of the residual powder obtained from the reaction of the synthetic mercury sulphide with the sodium carbonate under vacuum; the reaction mixture was heated with a Bunsen burner for 10 minutes. Phase identification was performed using the *PDF 2 Release 2004 database.*

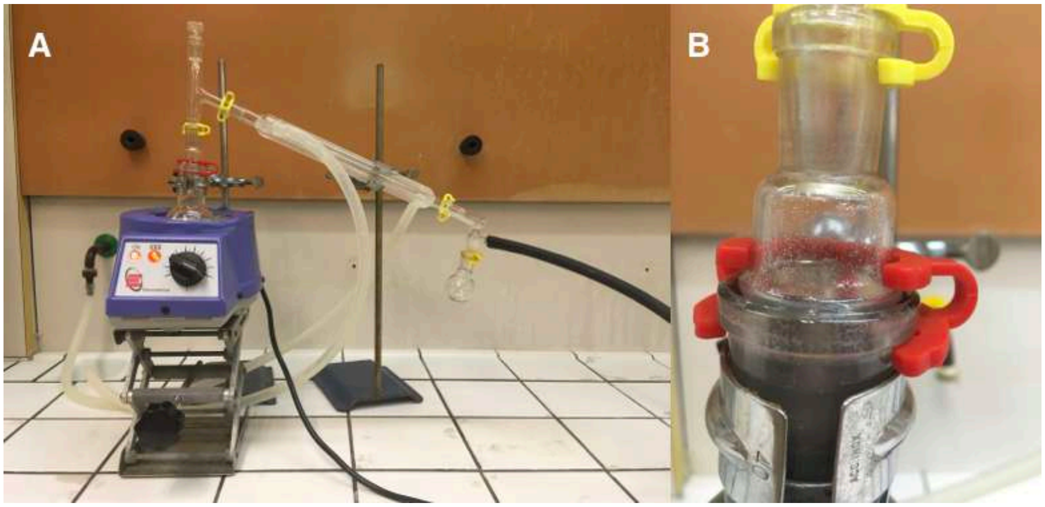

Fig. S42. Hot extraction of mercury in presence of sodium carbonate under vacuum. (**A**) Experimental setup for the hot extraction of mercury from the synthetic mercury sulphide in the presence of an excess of sodium carbonate under vacuum; (**B**) enlargement of the reaction flask at the end of the reaction (eight hours), with mercury droplets having condensed on the flask's neck.

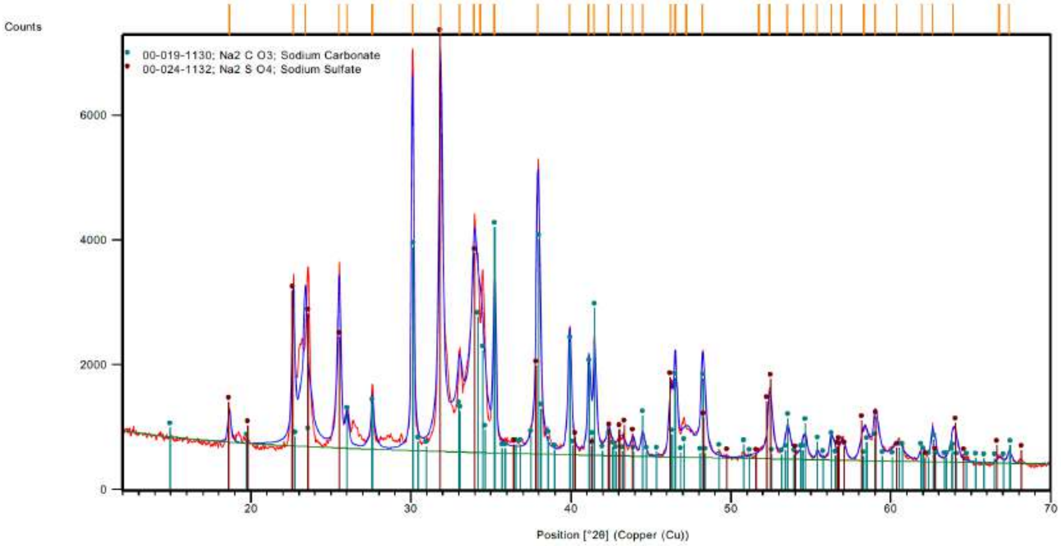

Fig. S43. Hot extraction of mercury in presence of sodium carbonate under vacuum. XRPD pattern of the residual powder obtained from the reaction of the synthetic mercury sulphide (HgS) with the sodium carbonate (Na_2CO_3), ratio: 1:2, HgS:Na_2CO_3, under vacuum; the reaction mixture was heated with a heating mantle (at 300 °C) for eight hours. Phase identification was performed using the *PDF 2 Release 2004 database.*

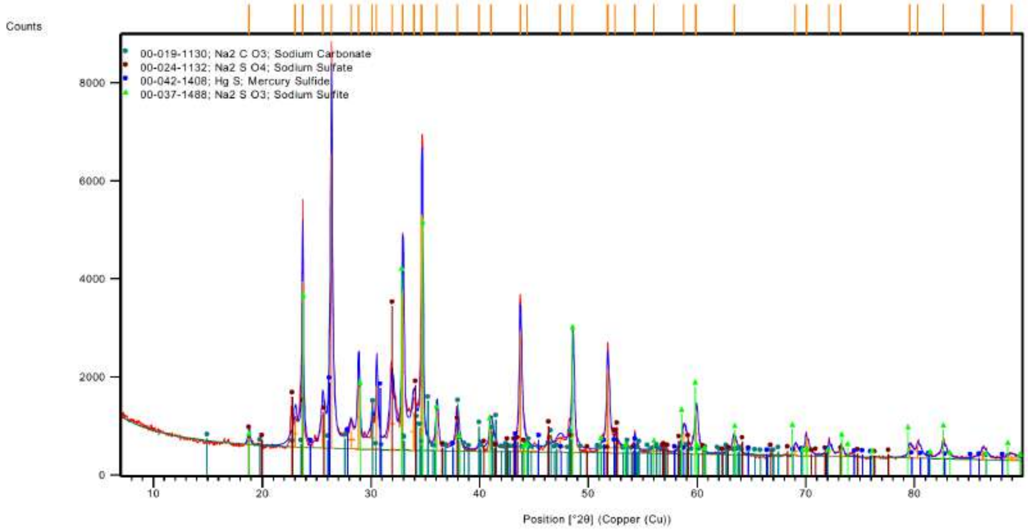

Fig. S44. Hot extraction of mercury in presence of sodium carbonate under vacuum. XRPD pattern of the residual powder obtained from the reaction of the synthetic mercury sulphide (HgS) with the sodium carbonate (Na_2CO_3), ratio: 1:1, HgS:Na_2CO_3, under vacuum; the reaction mixture was heated with a heating mantle (at 300 °C) for eight hours. Phase identification was performed using the *PDF 2 Release 2004* database.

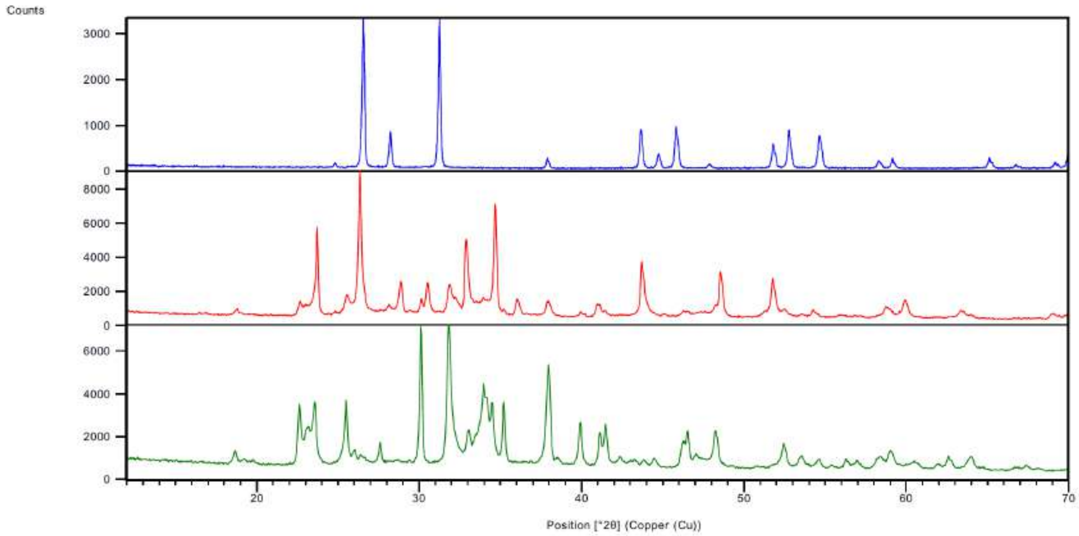

Fig. S45. Hot extraction of mercury in presence of sodium carbonate under vacuum. Comparison between the XRPD of the synthetic mercury sulphide (blue solid line) and the residual powder obtained from the reaction of the synthetic mercury sulphide and sodium carbonate in ratio 1:1 (red solid line) and ratio 1:2 (green solid line).

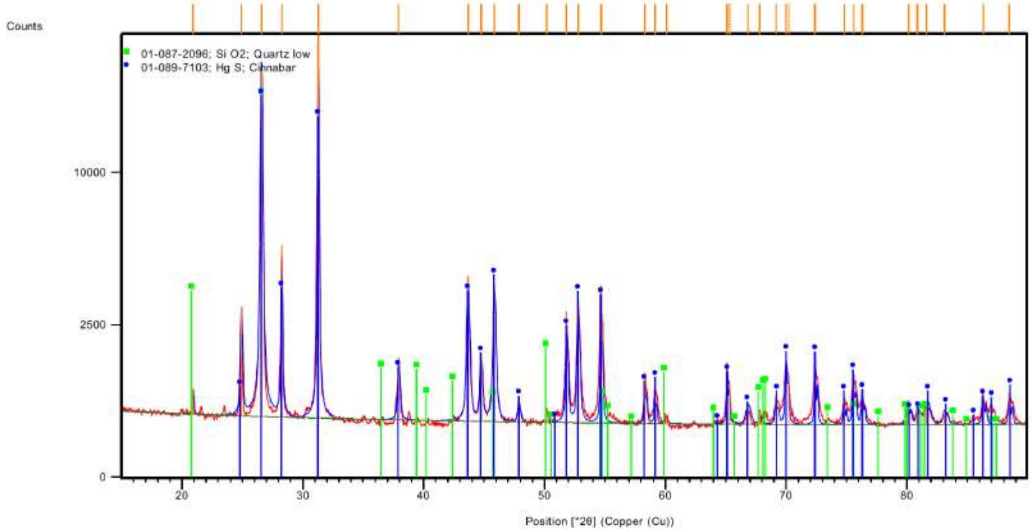

Fig. S46. Cinnabar ore sample C1. XRPD pattern of cinnabar ore sample C1. Phase identification was performed using the *PDF 2 Release 2004 database.*

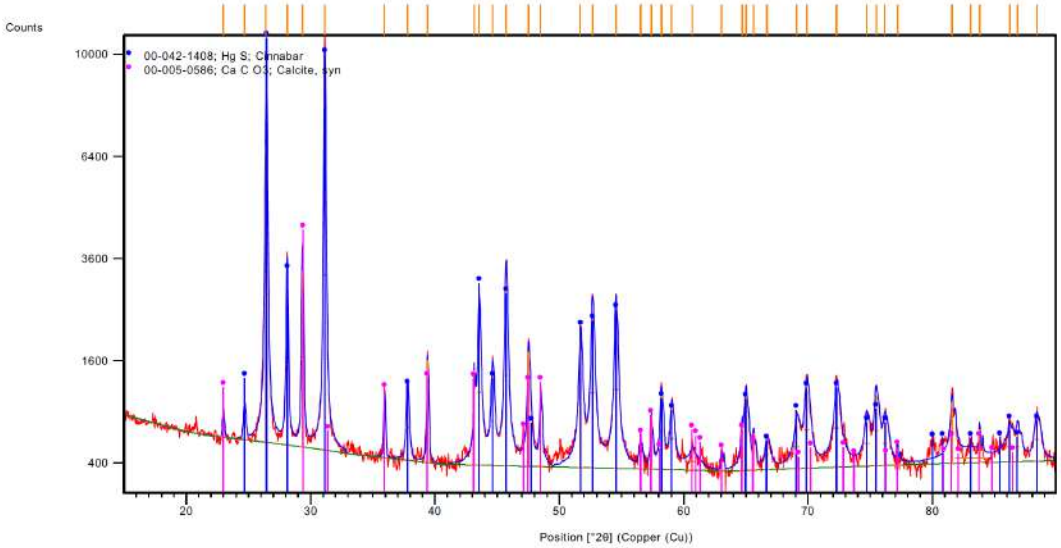

Fig. S47. Cinnabar ore sample C4. XRPD pattern of cinnabar ore sample C4. Phase identification was performed using the *PDF 2 Release 2004 database.*

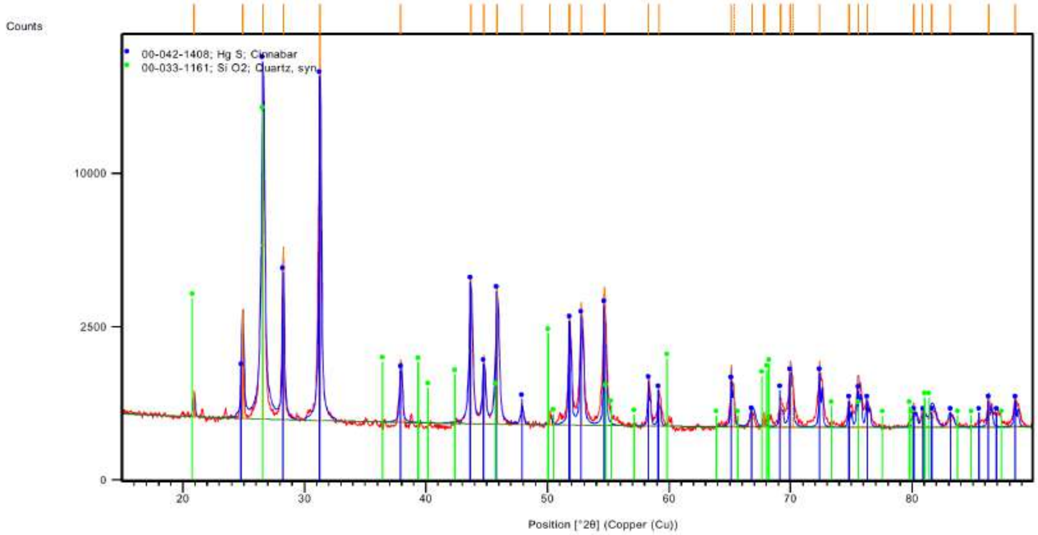

Fig. S48. Cinnabar ore sample C5. XRPD pattern of cinnabar ore sample C5. Phase identification was performed using the *PDF 2 Release 2004 database.*