ARE PLATINUM AND PALLADIUM RELEVANT TRACERS FOR ANCIENT GOLD COINS? ARCHAEOMETALLURGICAL AND ARCHAEOMETRIC DATA TO STUDY AN ANTIQUE NUMISMATIC PROBLEM

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Abstract

Archaeometallurgical experiments were carried out at the platform of Melle (France) to study how the trace elements of gold, in particular platinum and palladium behave when gold is melted, cupelled and then cemented. Our tests proved that platinum and palladium are reliable tracers of ancient gold. They can therefore shed light on the provenance of the gold coined by Caesar in Rome around 46-44 BC. Did he indeed melt down the Celtic gold gained from his conquest of Gaul in 51 BC as suggested by textual sources? To give a first insight into this tricky problem LA-ICP-MS was performed on some Late Celtic coins and some of Caesar's coins in order to compare especially their platinum and palladium contents, and in fact our first results support this hypothesis.

Key Words: gold; trace elements; platinum; palladium; cementation; cupellation; LA-ICP-MS; Late Celtic coins; Caesar.

Resumen

Experimentos arqueometalúrgicos realizados en la plataforma de Melle (Francia) han permitido estudiar cómo reaccionan los elementos traza del oro (sobre todo el platino y el paladio) durante los procesos de refundición, copelación y cementación de este mismo metal. Las pruebas indican que el platino y el paladio constituyen unos indicadores seguros para la trazabilidad del oro antiguo. Por lo tanto, resulta pertinente utilizar dichos elementos para examinar una cuestión muy debatida en los estudios numismáticos: ¿refundió Julio César el oro de Galia (conquistada en el año 51 a.C.) para sus propias acuñaciones de oro, como lo sugieren las fuentes literarias? Para establecer un primer enfoque global en torno a este espinoso asunto, hemos analizado monedas célticas tardías y monedas de Julio César gracias al sistema LA-ICP-MS, con en fin de comparar detalladamente sus contenidos en platino y en paladio.

Palabras Clave: oro; elementos traza; platino; paladio; cementación; copelación; LA-ICP-MS; monedas célticas tardías; Cesar

INTRODUCTION

Platinum and palladium are impurities of ancient gold that are usually drawn on for provenance studies (Blet-Lemarquand *et al.* 2014a). For instance, they can be used to distinguish between different stocks of precious metals if their contents scaled to the gold concentrations are significantly different. At the same time, they can also help to confirm that gold coins were melted down to manufacture other coins if the contents of both groups of coins are consistent. Their role as gold tracers is based on the assumption that platinum and palladium do not separate from

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gold in the course of the ancient metallurgical treatments such as smelting, melting, cupellation or cementation, because these elements are highly unreactive and have high melting points.

In fact, there has not been any systematic study to determine how the trace elements of gold behave during metallurgical processes but studies are available that reports experiments on the melting of gold ores or metal gold spiked with some trace elements in oxidising or reducing atmospheres (Raub 1995; Hauptmann *et al.* 1995; see a brief report in Ehser 2011). Nor has there been any study exploring how trace elements behave during cupellation of gold based alloys. The behaviour of certain elements, how ever, may be generalised from the different works carried out on the cupellation of silver alloys (McKerrell and Stevenson 1972; Pernicka and Bachmann 1983; L'Héritier *et al.* 2015). Unfortunately, no platinum elements were examined in these articles. Cementation experiments typically focus on the efficiency of the process for major elements and neglect the minor and trace elements (Wunderlich *et al.* 2014; Geçkinli *et al.* 2000; review in Craddock 2000c). The present paper presents new analytical and experimental data for the role of platinum and palladium as valuable gold tracers.

In addition, we explore the question of provenance of the gold minted by Caesar after he conquered Celtic Gaul in the middle of the first century BC.[1] Written sources report that he seized large quantities of precious metals during his campaigns. The validity of these sources can be tested by comparing the composition of Caesar's gold coins with that of the Late Celtic Gaul gold coins. As Late Celtic gold coins are made of gold based ternary alloys, Romans would have had to melt down and purify the Celtic alloys in order to mint their high purity gold coinage. This is why our archaeometallurgical experiments included several steps, especially cupellation and cementation, in order to replicate the *chaîne opératoire* that the Romans would have probably followed. Some first results of these archaeometallurgical experiments were published in 2014 in a paper which lays the foundations for the present study (Blet-Lemarquand *et al.* 2014b).

[1] This study lies within the framework of researches devoted to the provenance of Augustean gold (Suspène et al. 2011; Blet-Lemarquand et al. 2015) and of the earliest gold coins struck in Gaul (current researches led by S. Nieto-Pelletier).

ARCHAEOMETALLURGICAL EXPERIMENTS AND LABORATORY ANALYSES OF THE EXPERIMENTAL ARTEFACTS

The archaeometallurgical treatments were conceived to resemble the melting down of Late Celtic gold coins and the refining of their gold.[2] The first step was to manufacture a gold-silver-copper alloy having the same major element composition as the gold coins struck by the Celtic tribe of the Arverni in the middle of the first century BC (Tab. 4) and that contains substantial amounts of platinum and palladium. The ternary alloy was then cupelled in order to eliminate copper and other base metals from the alloy. The gold-silver alloy obtained after cupellation was laminated and finally cemented to separate gold from silver.[3] Cementation alone should be sufficient to part gold from silver and copper. For this, the gold based alloy needs to be beaten into thin foils to expose the maximum surface area. As it is easier to beat a gold-silver alloy than a gold based ternary alloy a two stage process consisting of cupellation and then cementation was preferred.

A 19th-century French gold coin[4] was selected for the experiments because previous LA-ICP-MS analysis showed it contained about 1,400 ppm platinum and 340 ppm palladium (Tab. 1).[5] This 6.40 g coin was melted down with 3.12 g of pure silver and 2.07 g of pure copper to manufacture a ternary alloy of about 50 % gold, 30 % silver and 20 % copper (Fig. 1A).

The first purification process was cupellation that requires that lead is added in the right proportions to the ternary alloy. A block of lead coming from a medieval site was selected because previous LA-ICP-MS analysis showed that this lead would not contaminate our samples with platinum or palladium. For the gold-silver-copper alloy to be cupelled successfully, it requires about 10 times its weight of lead to be added to the melt as advised in published tables (Hervé, 1839: 26). Four buttons were cast that were then

[2] Descriptions of the ancient gold refining methods can be found in Halleux 1985 and Craddock 2000b.

[3] The amalgamation process was not taken into account because it is not attested for Antiquity (Craddock 2000a). It was used to separate gold from platinum in Colombia during the 18th century (Morrisson *et al.* 1999: 125). Hence this method certainly modifies the platinum and palladium fingerprints of gold.

[4] Louis XVIII, 20 francs, 1816, bare head.

[5] Information about the LA-ICP-MS analysis of ancient gold coins can be found in Dussubieux and van Zelst 2004; for the depth profile mode developed for this method see Gratuze et al. 2004, Blet-Lemarquand *et al.* 2009 and Blet-Lemarquand et al. forthcoming (for gold coins) and Sarah et al. 2007 (for silver coins).

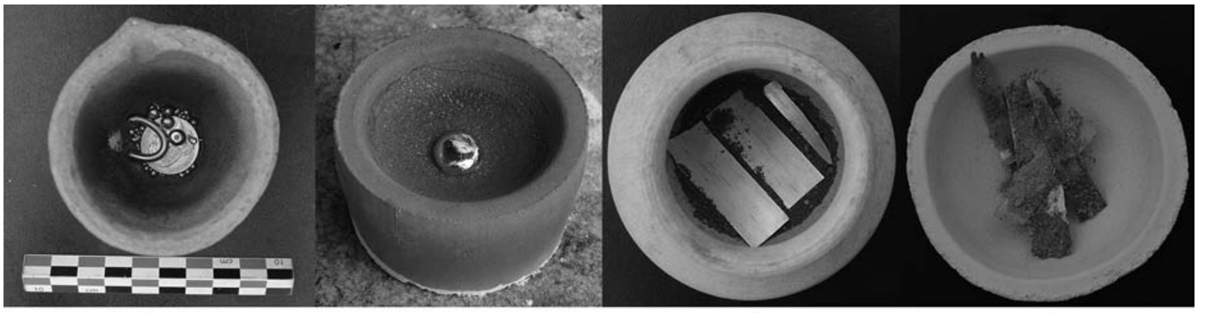

Fig. **1**. *The different steps of the archaeometallurgical experiments (from Blet-Lemarquand* **et al.** *2014). From left to right, A: manufacture of the gold-silver-copper alloy; B: gold-silver alloy button obtained after cupellation; C: laminated foils made of gold-silver alloy in the cementation pot before cementation takes place; D: foils after cementation.*

put into cupels made from bone ashes. The cupellations were carried out in a muffle furnace under a blast of air with temperatures varying between 950 °C and 1000 °C and four white gold buttons were obtained (Fig. 1B). The process was interrupted in the course of one of the operations because the temperature had dropped. Lead was added to the button and cupellation resumed in a new cupel.

The cementation experiments were inspired by Theophilus' recipes dating back to the 12th century AD (Hawthorne and Smith 2014) as well as by the archaeological finds from Sardis. The excavations of the workshop of Sardis provide the first archaeological evidence of the cementation of gold no later than the middle of the 6th century BC (Ramage and Craddock 2000). The four white gold buttons obtained after cupellation were accordingly laminated to a 50 micrometre thickness.[6] About 10 cycles of metal rolling and annealing were necessary to achieve this thickness. Common salt was used as active agent in the cement.[7] Twice as much ground brick was added to play the role of inert carrier even though the use of brick is not certain in Antiquity.[8] The gold foils were put alternatively with the cement in the parting vessel —a cooking pot— and the mixture was dampened with vinegar (Fig. 1C). The pot was covered with a lid, which was in fact a scorifier that had been turn over and drilled to add a temperature sensor. The process took place in an open furnace fed by charcoal that covered the cementation pot entirely and the temperature was regulated through an adjustable electric blower. In a second cementation experiment the pot was sealed with a lute[9] as recommended by Theophilus in his treatise (Hawthorne and Smith 2014: 109) in order to prevent the acid vapours from escaping. In fact, this lute broke in the course of the cementation. In both experiments the temperatures were maintained below the melting point of the gold-silver alloy foils of approximately 1035 °C. The first cementation lasted eight hours with temperatures maintained between 650 °C and 700 °C and the second one was lengthened to 12 hours and the temperatures were raised to 700 °C-800 °C.

The cementation experiments kept the foils intact and enhanced their golden colour. The foils obtained from the first cementation had sometimes remains of cement adhering to their surface (Fig. 1D) whereas the ones coming from the second experiment were much cleaner.

The gold based alloys were sampled at every step of the purification process in order to study their microstructure by SEM and their composition using LA-ICP-MS and SEM-EDX. The aims were to check that the metallurgical treatments were efficient and to investigate the trace element composition. The LA-ICP-MS analyses were performed using the time resolved mode that enables to reconstruct depth profiles from the surface to the interior of the object, the laser ablation being made at one spot (see for instance Fig. 4B showing a surface depletion in silver thus an enrichment in gold in a cemented foil). The calculation of the concentrations only considers the signals detected when the interior of the experimental sample is reached by the laser. The obtained results are summarized in Tab. 1.

[6] The gold foils excavated in Sardis which were subjected to cementation were obviously hammered and not laminated but for the sake of convenience we preferred to laminate our samples.

[7] A review of the different recipes for cements was established by Halleux (1983).

[8] Craddock 2000d: 204.

[9] The lute was made of a mixture of clay and horse dung.

		Au (wt%)	Ag (wt%)	Cu (wt%)	Fe (ppm)	Zn (ppm)	As (ppm)	Pd (ppm)	Sn (ppm)	Sb (ppm)	Pt (ppm)	Pb (ppm)	Bi (ppm)	Pt/Au	Pd/Au
(1) Gold coin		90.2	5.4	3.8	2,668	119	48	343	163	60	1,362	181	15	1,510	380
(2) Au-Ag-Cu alloy	1	50.2	30.3	19.4	<50	0.7	1	172	6	3	741	9	6	1,476	343
(3) Foils made from the cupelled alloy (interior)	3a	63.5	34.6	1.4	<50	0.1	0.01	243	4	0.2	1,047	1,646	0.2	1,649	382
	3b	64.3	35.1	0.12	<50	0.03	0.2	230	3	0.1	977	3,766	0.4	1,521	359
	3c	62.8	35.3	1.5	<50	0.3	0.04	224	6	0.2	985	2,382	0.2	1,568	357
	3d	62.2	35.4	1.7	<50	0.1	0.1	225	5	0.1	994	4,788	0.8	1,598	361
	AVG	63.2	35.1	1.2		0.1	0.07	230	5	0.1	1,001	3,145	0.4	1,584	365
	SD	0.9	0.4	0.7		0.1	0.06	9	1	0.1	32	1,404	0.3	54	12
(6) Cemented foils experiment no. 1 (interior)	6.1.b	66.0	33.0	0.8	278	13	61	233	79	230	934	168	2	1,415	353
	6.1.c	63.5	36.1	0.2	311	9	46	244	112	140	1,045	182	3	1,646	384
	6.2.a	64.2	34.9	0.8	366	7	57	242	74	189	1,047	65	3	1,631	377
	6.3.a	63.4	35.2	1.2	155	2	56	237	51	117	1,016	298	3	1,604	373
	6.4.a	62.8	35.6	1.3	294	5	63	220	72	134	923	307	4	1,470	350
	AVG	64.0	35.0	0.8	281	7	56	235	77	162	993	204	3.1	1,553	367
	SD	1.2	1.2	0.5	78	4	7	10	22	46	60	101	0.4	104	15
(7) Cemented foil experiment no. 2 (interior)	7.1	68.2	29.7	1.7	44	15	729	247	137	626	1,018	319	1.1	1,493	362

TAB. **1**. *Elemental composition of the coin and of the alloys obtained by archaeometallurgical experiments (LA-ICP-MS analysis). Each content is the average of the concentrations calculated for 3 to 6 micro sampling. Contents in weight % (Au, Ag, Cu) or weight ppm (other elements). AVG: average, SD: standard deviation.*

The cupellation proved to be efficient because copper was to a great extend eliminated from the alloy: its content was reduced from 19.4 % to about 1.6 % or even lowered to 0.1 % (Tab. 1) in the sample which was subjected to a two stage cupellation (see above).

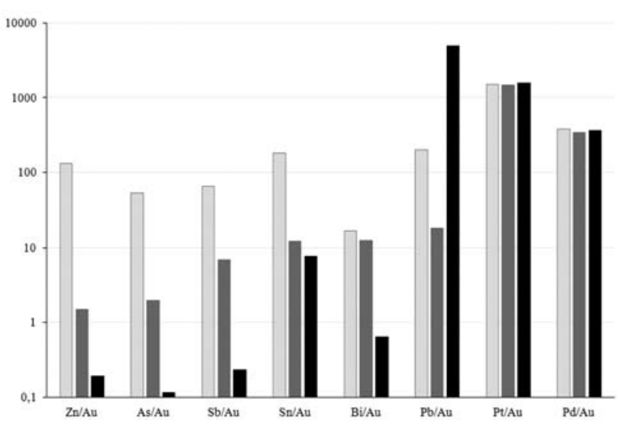

FIG. **2**. *Behaviour of the trace elements during melting and cupellation.*

The contents of the trace elements were divided by the gold concentration for each sample in order to determine how they behaved relative to gold (Fig. 2). The ratios of most of the trace elements were reduced by a factor of 10 to 100 (Zn, As, Sb, Sn, Pb, Fe) when the gold was melted down (comparison between gold coin and Au-Ag-Cu alloy on Fig. 2A) and these parameters were still lowered during the cupellation (comparison between Au-Ag-Cu alloy and cemented alloy on Fig. 2). In contrast, the Pt/Au and Pd/Au ratios remained unchanged between the gold coin and the cupelled alloy (Fig. 2B). It can be noticed that the cupellation left some lead (0.2 to 0.5 %) in the alloy (Tab. 1). It can be concluded that most of the trace elements were separated from the gold during melting and cupellation whereas platinum and palladium remained with adhered to gold in the course of both operations.

The cementation led to the partial elimination of silver as can be seen in several ways. The foils look more golden once they were cemented. At high magnification using a scanning electron microscope their surfaces reveal characteristics of cementation: porosities which result from the parting process (they extend along the grain boundaries and the triple points), and deposits of silver chloride formed from the attack of the silver (Fig. 3).[10] The surface of the cemented samples is also depleted in silver compared to the foils that have not been cemented: a minimum of 8-10 % silver was obtained for the foils from the first cementation and the content of sil-

[10] See Craddock 2000c: 181 for explanations on the chemistry of the salt cementation process.

ver is around 5 % for the sample from the second experiment (SEM-EDX analysis). However the cross-section of a foil led us to think that the first cementation did not consistently reach the core of the foil (Fig. 4A). In fact, the depth profile analysis of the cemented foils clearly established that the surface is enriched in gold while the composition of the core remained unchanged (Fig. 4B and Tab. 1). The second cementation was more efficient than the first in that a depletion of silver was achieved also inside the foil (decrease of 5 % see Tab. 1). It seems that the cementation had an effect on the composition of some minor elements in the interior of foils. Lead contents were lowered by a factor of ten and at the same time the binary alloys were enriched in some trace elements (Sb, As, Zn, Sn, Bi), probably as a result of contaminations from the cement (Tab. 1).

The Pt/Au and Pd/Au ratios remained the same after the two cementation experiments (Tab. 1). However, we cannot strictly deduce from these analyses carried out inside the foils that cementation has no effect on these parameters because the enrichment of gold inside the foils was at best slight. But the depth profile analyses undemiably showed that the Pt/Au and Pd/Au ratios are constant from the cemented surface to the interior of the foil (Fig. 4b). Thus, cementation has no effect to these ratios.

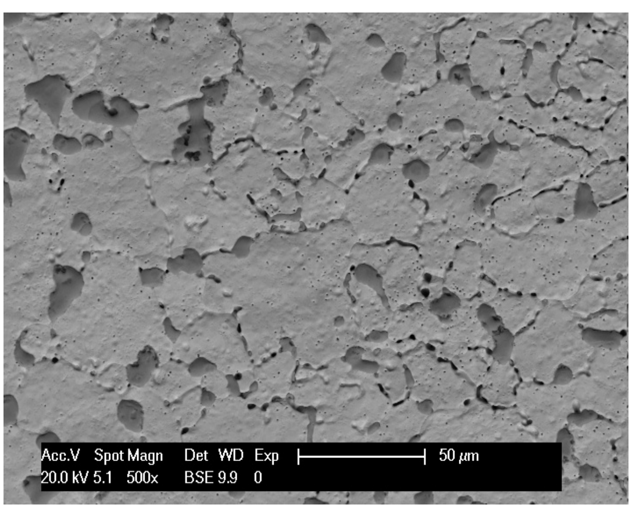

FIG. **3**. *Cemented foil after the second experiment. SEM image obtained with back scattering electron detector. Surface of the Au-Ag alloy with remains of silver chloride.*

Our archaeometallurgical experiments firmly established that platinum and palladium can be relevant tracers to track a gold bullion. Consequently, platinum and palladium contents can confirm whether or not ancient gold coins were melted down and used as bullions to strike new specimen. It should be noted that most of the other element are of less reliable when trying to trace the life cycle of gold coins.

PROVENANCE OF THE GOLD COINS MINTED BY CAESAR BETWEEN 46 AND 44 BC IN ROME

During the Roman Republic, gold had only been coined in times of emergency (like the Hannibalic War or the First Civil War, Burnett 2004: 49). Caesar is actually the first Roman minting authority who regularly produced gold coins from 46-44 BC at his own mint located somewhere in Rome (Woytek 2003: 263-271). It is thought that Caesar melted down the huge quantities of gold that he had seized during his campaigns in Gaul (see Suetonius)[11] and the precious metal he took from the state's treasury in 49 BC. Pliny the Elder reported that Caesar looted in the *aerarium* not only 30 million *sestertii* or coins but also 15,000 ingots of gold and 30,000 ingots of silver (see Pliny).[12]

Several scholars have already discussed the impact of the arrival of great quantities of precious metals on the Roman economy (Castelin 1977, Nash 1987: 34 or van Heesch 2005). This paper contributes new information to this discussion in the form of analytical data of Ceasar's gold coins in comparison with Late Celtic coins. In so doing, we do not claim to solve this mystery once and for all, but rather offer an important piece of new evidence about the economic ramifications of Caesar's conquests. For this purpose, 15 gold coins *(aurei)* minted by Caesar and believed to be representative of Caesarian coins (particularly the Hirtius issue) were selected for analyses (Tab. 2 and Fig. 5).

The composition of the gold circulating in Gaul at the time of Caesar's campaign can be gleaned on the one hand from the composition of Late Celtic coins and on the other hand from Celtic gold objects. Unfortunately, the trace element compositions of the latter are still unknown. The advantage of coins over object is that they were manufactured in large quantities and that consequently the composition of one single specimen is expected to represent the mean composition of a set of them belonging to the same series.

The Celtic coins selected for our study possibly date back to the 1st century BC (Aubin *et al.* 2011; Barrandon *et al.* 1994; Nieto-Pelletier *et al.* 2011) and are attributed to different tribes:

[11] Suetonius, *Vie de Jules César*, LIV, 2.

[12] Pliny, *Naturalis Historia*, XXXIII, 17. Unfortunately, as pointed out by Crawford, «We have no idea how large theses bars of gold and silver taken from the *aerarium* were» (Crawford 1974: 639).

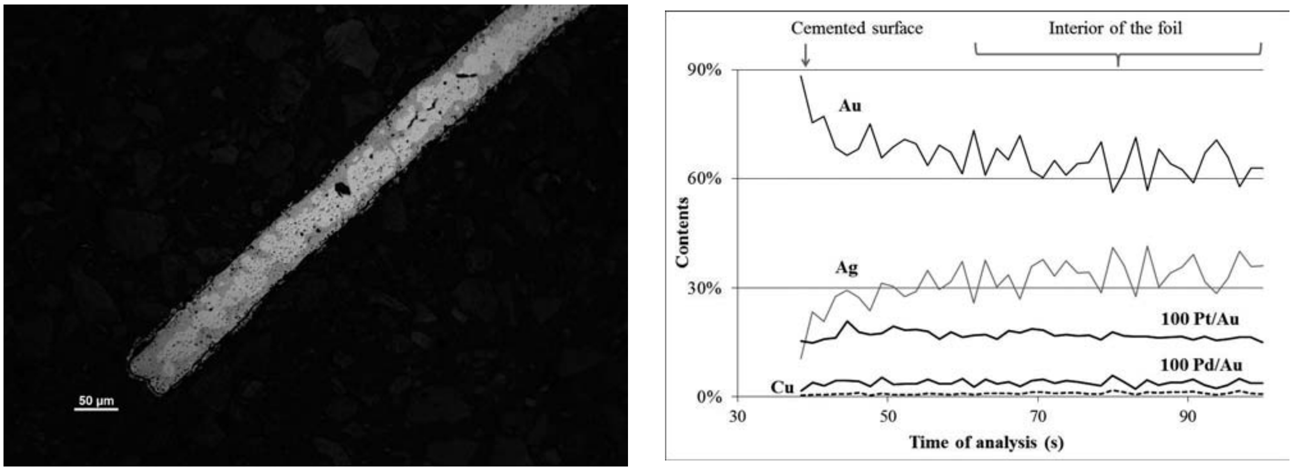

Fig. **4**. *Cemented foils after the first experiment, left to right. 4A: Cross-section of 6.2.a observed using a binocular lens; 4B: Depth profile analysis of 6.1.b (LA-ICP-MS analysis).*

Cenomani, Arverni and Osismii (Tab. 3 and Fig. 5). The concentrations of more than 50 coins analysed using LA-ICP-MS were gathered for our study. The protocol of analysis of the coins resembles that applied to the gold foils and uses the depth profile mode to determine the composition beyond the surface that may be enriched in gold as a result of silver and copper depletion[13] and that may be «contaminated» in other elements. The laser diameter was lowered to 80 micrometres so as the craters left on the coin can not be seen with the naked eyes. Three different micro-samplings were carried out on each coin and the calculated contents are the results of the means.

Fig. **5**. *Pictures of some of the coins analysed for this study. 1. Osismii; Caesar's aurei: 2.* **RRC** *466/1 (A. Hirtius); 3.* **RRC** *475/1b (L. Plancus); 4* **RRC** *481/1 (COS QVINC). Sources: IRAMAT-CEB A. Arles and G. Sarah (Celtic coin) and gallica.bnf.fr (Roman coins).*

The three series of Late Celtic coins are made of different gold-silver-copper alloys with gold contents ranging from about 50 % to 20 % depending on the issuing authorities (Tab. 4). In contrast, the Caesar's aurei were struck from purified gold that contains about 99.4 % gold (Tab. 4). If Caesar has indeed reused the highly debased Late Celtic coins to mint his coinage, purification processes must have necessarily been carried out to eliminate copper and silver probably by cupellation and cementation. One could wonder if it was worthwhile to purify such highly debased gold. The parting vessels discovered in Roman archaeological contexts in Britain give weight to the hypothesis of the recycling of the Iron Age precious metal by the Romans (Bayley 2009: 430).[14]

As we have demonstrated, it is relevant to compare Pt/Au and Pd/Au ratios to discuss the provenance of gold (see above). The contents of platinum and palladium are normalized to gold and plotted on a binary graph for the Late Celtic and the Caesar's coins (Fig. 6). Most of the Late Celtic coins fall into an ellipse characterised by Pt/Au ratios ranging from 20 and 100, Pd/Au ratios between 8 and 40 and Pt/Pd ratios around 2.5. The two Arvernian gold coins have higher Pt and Pd contents in relation to Au but their Pt/Pd ratios are close to those of the other Late Celtic coins. It would be necessary to increase the analytical data on the Late Celtic coins especially the Arverni coins to confirm these trends.

[13] Three patterns of depth heterogeneities were obtained for the Celtic coins from the hoard of Laniscat, see Blet-Lemarquand et al. forthcoming.

[14] For instance, J. Bayley identified parting crucibles among archaeological remains found in Chichester (Britain), a Roman settlement from immediately after the Claudian conquest of Britain in AD 43 (Bayley 2009). This site which hosted the 2nd Legion for up to two years is located near Selsey, an oppidum of the Atrebatic kingdom, where large quantities of coins and fragments of gold have been found (Bayley 2009: 430). Previous analysis established that these late Iron Age gold coins were made from ternary alloys containing around 40-50 % gold. Bayley concludes that «the late Iron Age precious metal was requisitioned in the period following the Claudian conquest and [...] (purified) so it could be subsumed into the precious metal pool the Romans had in circulation.» We are indebted to J. Bayley for directing our attention to these researches.

Type No.	Issue	Dating	Mint	Specimen known	Number of obverse dies	Number of reverse dies	Number of analysed coins
RRC 466	A. Hirtius	Early 46 BC	Rome	143	[100]	[100]	7
RRC 475	L. Plancus	Early 45 BC	Rome	78	[50]	[50]	6
RRC 481	Caesar	Between 1 January and 15 February 44 BC	Rome	31	[20]	[20]	2

TAB. 2. *Types of the Caesar's gold coins selected for LA-ICP-MS analysis. All these coins are kept at the Bibliothèque nationale de France (BnF), département des Monnaies, médailles et antiques.* RRC = *Crawford 1974. The dating of coins, the number of specimen known and of dies were quoted from* Roman Republican Coinage *(Crawford 1974: 93-4; 888).*[15]

Minting authority (area)	Hoard	Number of analysed coins
Cenomani (Maine in the modern 'départment' of Sarthe)	Les Sablons	14
Arverni (Auvergne area)	/	2
Osismii (Armorica)	Laniscat	35

TAB. 3. *Late Celtic gold coins selected for LA-ICP-MS analysis. These coins are kept at the BnF or at the Musée archéologique du Mans (hoard of Les Sablons) or at the Direction Régionale des Affaires Culturelles de Bretagne, Service Régional de l'Archéologie (hoard of Laniscat).*

Minting authorities	Number of analysed coins	Au (wt%)		Ag (wt%)		Cu (wt%)	
		AVG	SD	AVG	SD	AVG	SD
Cenomani	14	51.9	1.6	33.8	1.3	14.1	1.2
Arverni	2	43.5	0.01	32.3	4.2	24.1	4.1
Osismii	35	16.8	2.1	14.8	4.2	67.9	4.9
Caesar	15	99.4	0.2	0.27	0.11	0.031	0.011

TAB. 4. *Contents of gold, silver, and copper determined for the Late Celtic coins and for the Caesar's coins. Average (AVG) and standard deviation (SD). For the results of late Celtic coins, see Aubin et al. 2011 (Cenomani); Nieto-Pelletier 2013 (Arverni) and Nieto-Pelletier et al. 2011 (Osismii). Caesar's gold: unpublished results.*

The 15 Roman coins show various Pt and Pd fingerprints stretching from low values which match the Cenomani and Osismii gold compositions to higher contents which are more consistent with the trend of the two Arvernian coins. However, three Caesar's coins seem to deviate from the Late Celtic gold because they have a lower Pt/Pd ratio of 1.3 (grey dotted line): they belong to the Plancus issue (*RRC* 475) or have COS QVINC on their reverse (*RRC* 481). This progression in the composition of the gold minted by Caesar is consistent with the dating of coins and could let us to think that Caesar also used – from 45 onwards – other supplies than the gold recovered from the Celtic coins.[16]

In summary, the Hirtius issue, which represents the bulk of the gold minted by Caesar in Rome, appears to be consistent with the Late Celtic gold coins when the Pt and Pd contents are compared. At first sight, the hypothesis of recycling of the Late Celtic gold coinage by Caesar to mint his Roman coins cannot be ruled out however, as expected, other sources of gold were also used. The study is still ongoing and further analyses are planned in the framework of a next research program to complete a diachronic overview of the gold coined in the Western part of

[15] The actual numbers of coins of these types are most likely more numerous than the numbers quoted in Crawford 1974 because other specimens were found since. One should also keep in mind that the assessment of the numbers of dies are very arbitrary and only indicate that the Hirtius issue was really very common whereas the Plancus and especially the Caesar issues were much less widespread.

[16] It is known from the literary sources that Caesar stole precious metal from the state's treasury in 49 BC (see Pliny the Elder). But we do not know where this gold accumulated in the *aerarium* came from. Gold previously sent by Caesar to Rome during 58 and 49? More ancient Celtic gold? Gold coming from outside? This question remains open.

the Mediterranean basin between the end of the 4th century BC and the 1st century AD[17]. This data will give us arguments to hypothesize which other gold supplies could be available for Caesar.

CONCLUSION

Archaeometallurgical experiments provided firm evidence that the Pt/Au and Pd/Au ratios remain unchanged when the gold based alloy is melted down, cupelled and then cemented. We were not able to demonstrate that cementation keeps these ratios consistent, but given the moderate temperature of the cementation process we expect this to be the case as platinum and palladium do not react with the cement at such low temperatures. Hence, platinum and palladium can serve as relevant tracers to study the provenance of gold. All other trace elements of gold, in contrast, do not survive the melting and refining of gold.

This property of platinum and palladium was applied to explore the provenance of the numerous gold coins minted by Caesar in Rome around 46-44 BC. The elemental composition of Caesar's gold coins were accordingly compared to some Late Celtic coins and at first sight their platinum and palladium chemical fingerprints partially match each other. The analytical results are consistent with the written sources. These are however preliminary results which need to be confirmed and qualified by further analyses especially on Late Celtic coins and on Celtic jewels within the framework of future research programs.

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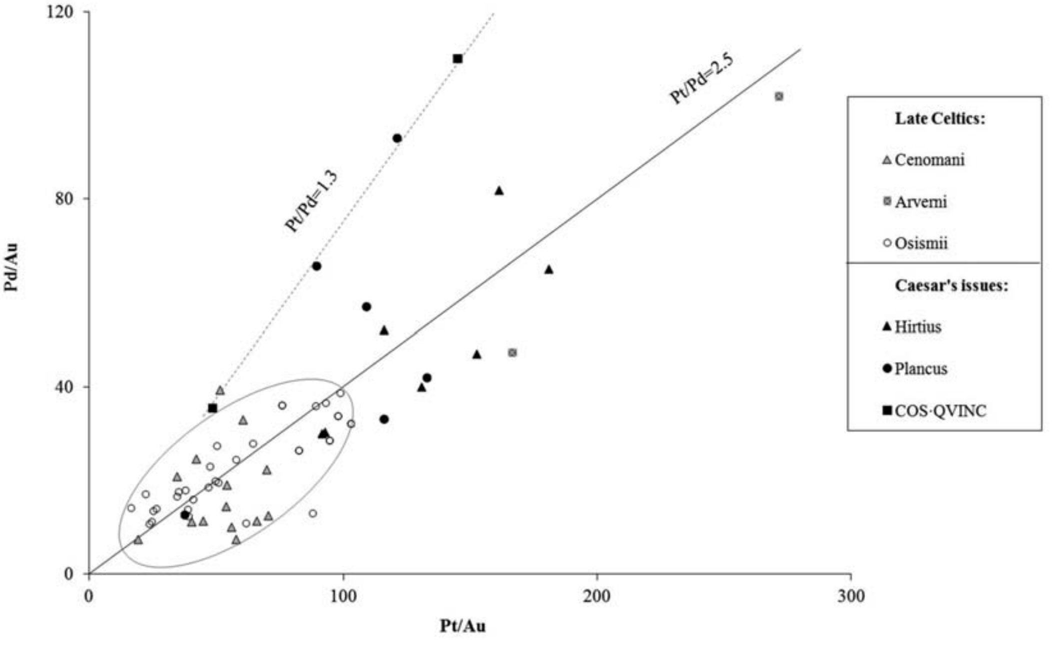

Fig. 6. *Scatterplot of the ratios of palladium and platinum to gold for the Late Celtic coins compared with the Caesar's coins (LA-ICP-MS analysis). Cenomani's results: Aubin et al. 2011; Arverni's and Osismii's gold: unpublished results. Caesar's gold: unpublished results.*[18]

[17] APR IA 2016-7 "AUREUS. À la naissance du monnayage d'or romain : étude et caractérisation de l'or monnayé en Occident de la fin de la période hellénistique au premier siècle de notre ère" (directed by A. Suspène) founded by the Région Centre-Val de Loire.

[18] The uncertainties on these ratios are mainly due to variations in the Pt and Pd contents at the scale of the micro-sampling. In fact the relative standard deviation is around 30 % for the three ablations carried out on the Caesar's coins. Despite these high fluctuations the Pt/Pd ratio remains steady for each coin. This has already been noticed for other antique gold coins (Blet-Lemarquand et al. forthcoming).

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