Economic rebound versus imperial monopoly: Metal provenance of Early Medieval coins (9th-11th centuries) from some Italian and French mints

Chiarantini, L.,[a] Villa, I.,M.,[b] Volpi, V.,[c] Bianchi, G.,[d] Benvenuti, M.,[e] Cicali, C.,[d] Donati, A.,[c], Manca, R., [e] and Hodges, R. [d]

[a] Centro di Microscopia Elettronica e Microanalisi, Università di Firenze, Via. G. Capponi 3r, 50121, Florence, Italy.

b Centro Universitario Datazioni e Archeometria, Università di Milano Bicocca, 20126 Milano, Italy; and Institut für Geologie, Universität Bern, 3012 Bern, Switzerland.
c Dipartimento di Biotecnologie, Chimica e Fermacia, Università di Siena, Via A. Moro 2, 53100, Siena, Italy.
d Dipartimento di Scienze Storiche e dei Beni Culturali, Università di Siena, Via Roma 56, 53100, Siena, Italy.
e Dipartimento di Scienze della Terra, Università di Firenze, Via G. La Pira 4, 50121, Firenze, Italy.

Abstract

This paper represents the first systematic Pb isotope investigation of Italian Medieval coins and aims to provide new parameters for a general historical interpretation of coin production and circulation in Medieval Europe. We collected more than one hundred specimens, minted in a period between 9th - 14th centuries AD and coming mostly from archaeological sites of Tuscany. Here we report the results on the oldest group of (44) coins, dated between the end of the 9th and 11th centuries. All coins where previously characterized with handheld X-ray fluorescence (pXRF) analysis and lead isotope composition (PbIC) was performed using an MC-ICP-Mass Spectrometer. The Carolingian coins have PbIC compatible with Melle silver district; the few Carolingian coins possibly minted in Italy (Venice and Milan) are also compatible with ore districts such as Melle and Harz Mountains. Coins in the names of Italian rulers (9th-10th century) from Lucca, Pavia and other uncertain mints show PbIC compatible with Melle, Black Forest and the Harz Mountains as well. A quite similar pattern applies to coins in the names of Otto I-III and Conrad II (10th-11th century) from Lucca and Pavia mints, although they show a better overlap with the Harz Mountains. The vast majority of early medieval coins issued by the Italian mints investigated in the present paper show isotope compositions that do not match with silver (lead-copper) mines from the Colline Metallifere district of southern Tuscany, notwithstanding their exploitation in the considered period is suggested by many settlements located near mining sites.

Keywords

Lead isotopes, silver coins, Early Medieval, metal provenance, Italian mints, Tuscany, Colline Metallifere

1. Introduction

The aim of this research is to investigate mechanisms and evolution of the economic growth of central and northern Italy in the Middle Ages through the characterization of metal provenance in coins by means of Pb isotope analysis. This is the focus of the ERC-Advanced European project (nEU-Med; www.neu-med.unisi.it), from which this study has developed, and differs from previous research primarily focussed on documentary sources (Franceschi, 2017). This study has been developed from a multidisciplinary project based on archaeological findings that involves archaeologists, historians, numismatists, archaeometrists, geomorphologists, archaeobotanists, zooarchaeologists, anthropologists, chemists and computer scientists (Bianchi and Hodges, 2018; 2020). The studied period ranges from the Early Middle Ages up to the 12th century, when municipal cities gained independence and the main trade routes had been gradually recovered.

We report data from a Tuscan sample area that can be usefully compared to the results from other areas of central and northern Italy. The territory under investigation corresponds to a large portion of Western and southern Tuscany, the Colline Metallifere district (Fig. 1), which is well known from numerous research projects undertaken over the last thirty years that have focused upon archaeological and historical issues such as mining deposits and natural resources (Bianchi, 2010; Bianchi et al., 2012; Dallai and Francovich, 2005; Bianchi et al., 2013; Bianchi and Rovelli, 2018).

The Colline Metallifere district possesses important base and precious metal ore deposits that fed a long-living mining and metallurgical industry. These were certainly exploited since Copper Age (Artioli et al., 2016a) up to the 1970s for the production of copper, lead, silver and iron (Benvenuti et al., 2014).

The nEU-Med project poses economic growth as one of its main goals, so the study of silver coin minting and monetary circulation in central-northern Italy is a theme of particular relevance.

The aim of this work is to try to relate the numismatic evidence with the minting activity and the possible supply of raw metals.

Written sources about mines are often fragmentary and mostly focussed on late medieval times (mainly 11th - 12th AD); they mention only three mining districts existing on the territory of Regnum Italiae (Rovelli, 2004): Trentino (the Mt. Calisio mine), Tuscany, and later Lombardy (the Ardesio mine).

From the point of view of the numismatic sources, scholars had often argued about the rarity of Italian coin findings, the scarce ad irregular activity of mints and the rarity of hoards, especially for the

Carolingian period (Rovelli, 2012a; Coupland, 2011). It is worthwhile to remember that the Lucca mint, which during the Lombard period had a significant production of gold *tremisses*, and which lies quite near the Colline Metallifere district, declined significantly and almost ceased production between the end of 8th and the first half of 10th AD with the arrival of the Franks and the introduction of the silver *denairus* (Saccocci, 2013).

To explain the reasons of this apparent paradox it is of primary interest to trace the provenance of silver struck at Lucca during the second half of the 10th, when, during the Ottonian period, the activity of the mint was to become more regular, although the volume of its issues continued to be low (Matzke,1993).

We need to bear in mind that also the Ottonian coins found in Tuscany (as elsewhere in Italy and north of the Alps) are mainly issued by the palatine mint at Pavia (Benvenuti et al., 2018). The coins analysed in the present paper represent an exception, thanks to the many samples from National Archaeological Museum of Florence that kindly provided us with a good selection of coins minted both in Lucca and Pavia. What were the causes of this weak coin production in central Italy? What was the role of the local silver-bearing mines in ensuring coin production and when did these mining activities begin? Do we need to hypothesise the re-use of hoarded silver or the contribution of metal from non-local mines?

In order to answer some of these questions, we measured the lead isotopic composition (PbIC) of silver coins produced by northern and central Italy mints (especially Pavia and Lucca) found during the last thirty years of archaeological excavation in southern Tuscany (mainly Colline Metallifere area). As mentioned before the question is closely connected with times and methods of ore exploitation in the Colline Metallifere, especially with silver production, for which there is written and archaeological information for the period between 10th- 14th centuries but an almost total silence for the early medieval period (Bianchi, 2018). In fact, there seems to be a contradiction between this late chronology of silver exploitation, and the presence of sites in the Colline Metallifere territory (Rocca San Silvestro, Rocchette Pannocchieschi, Cugnano,) between the 8th and 10th centuries (Francovich, 1991; Grassi 2013, Bruttini et al., 2009, Bianchi et al., 2012). All these sites lie near the main Cu-Pb-Fe (Ag) ore occurrences, but no evidence of metal working before the late 10th century has been so far reported (Mascaro et al., 1995; Benvenuti et al., 2014).

We collected more than 120 specimens, minted in a period between 8th - 14th cent. AD and coming from archaeological sites of Tuscany recently investigated. An exceptional number of coins came from the key site of Vetricella (Fig.1), recently excavated, that produced 21 coins belonging to the early Medieval period (9th-11th centuries) (Rovelli, 2020). Here we report the results on the oldest group of coins, dated between the end of the 9th and 11th centuries.

It is important to bear in mind that the 44 samples analysed in the present paper (and more specifically the 21 specimens from Vetricella site) are undoubtedly unique in the panorama of archaeometric analyses of Carolingian and Italian kings' coins found in Tuscany and more general in Italy. In Tuscany, in fact, have been found just over 100 pieces of coins of this period coming from nineteen different sites; almost 60 specimens come from two or possibly three, hoards (see table A1 for details). This paper thus represents the first systematic archaeometric investigation of Italian Medieval coins, and one of the few among European coeval contexts (Hatz et al., 1991;Téreygeol et al., 2005; Sarah et al., 2008; Merkel, 2016). Its aim is providing parameters for a general historical interpretation of coin production and circulation in Medieval Europe.

2. Lead isotope analyses on medieval coins: potential, limits, and sampling strategy

Lead isotopic analysis is the most widely used archaeometric tool for tracing the provenance of metals employed for the production of artefacts. Both lead isotopic measurements of metallurgical experiments in the laboratory (e.g. smelting and cupellation of argentiferous galena from Rammelsberg mine) and of Athenian silver tetradrachms minted from Laurion silver ores confirmed that Pb does not undergo measurable isotopic fractionation by smelting or cupellation (Stos-Gale and Gale, 2009 and references therein). This means that silver produced from smelting and cupellation of lead-bearing ores will have lead isotope ratios that reflect the ore used (Brill and Shields, 1972; Stos-Gale and Gale, 2009). So far, PbIC (lead Isotope Composition) has been widely employed to investigate the provenance of ancient (mostly Roman) coins (Attanasio et al., 2001; Brill and Shields, 1972; Desaulty et al., 2011; Klein et al., 2004; Ponting et al., 2003).

The main limits of the method lie in the inevitable overlap of the PbIC fields of lead-silver ore deposits. Since the PbIC of a given deposit depends on its geological history and evolution, its isotopic composition may in some cases be unique, but it is very likely that more than one deposit, located in different parts of the world, will have a similar PbIC, such that their compositional fields overlap (Brill and Shields, 1972; Gale and Stos-Gale, 2000). This means that PbIC rarely gives a positive identification of the provenance of a given metal. An isotopic mismatch between an object (metal) and deposits clearly allows negative statements, but the overlap does not give a positive assignment, it can only suggest a number of possible sources and reliably exclude others. For this reason, the archaeological and historical evidence for silver production must also be taken into account in order to produce a positive confirmation of provenance (Baron et al., 2014). One of the advantages in this study is that the PbIC of polymetallic ores from southern Tuscany (Colline Metallifere – Campiglia Marittima) is strongly different from most other silver-rich deposits of central-western Europe (France, Germany, Czech republic, Slovakia…) and Italy (Trentino Alps), which were exploited for silver in Medieval times. Thus, if only silver from southern Tuscany had been employed for coinage in Tuscan and/or Italian mints it should be easily traceable. Otherwise the great similarity of the PbIC of the many central-western Europe metalliferous districts makes it very difficult to distinguish the provenance among them.

Further sources of ambiguity are mixing, alloying and refining, which may all impact the lead isotope composition. The small amount of lead in the silver may have become mixed during recycling (Gale and Stos-Gale, 2000) or even reflect a different source if the silver was refined through the cupellation process with imported lead, as was demonstrated by the jarosite ore and slags from Rio Tinto (Anguilano et al., 2010; Anguilano, 2012; Birch et al., 2020; Craddock, 1995, Westner et al., 2020).

A brief characterization of European mines included in our database and the age of their exploitation is summarized in Appendix B.

Very few data of Pb isotope composition of silver medieval coins are reported in literature (Guénette-Beck and Serneels, 2010). All the published samples coeval to our set of coins are included in our database for comparison (Hatz et al., 1991;Téreygeol et al., 2005; Sarah et al., 2008; Merkel, 2016).

Coins were mainly sampled from castles, monasteries, inland and coastal plain sites (Fig. 1a): the castles of Donoratico (Bianchi, 2004), Miranduolo (Valenti, 2008, Cicali, 2008); the village of San Genesio (Cantini, 2008; 2010); the monastery of S. Pietro a Monteverdi (Francovich and Bianchi, 2006); the Pieve of Pava (Campana et al., 2008); and the site of Vetricella (Marasco, 2013). Few samples came also from Abbadia San Salvatore (Cambi and Dallai, 2000).

Significant samples of Carolingian coins have been analysed thanks to a collaboration with a private collector (PV), including samples from mints in present-day France, while many coins attributed to Otto II are from the National Archaeological Museum of Florence (NAMF).

The sampled sites are summarized in figure 1a; mining districts and mints are shown (with coin issues) in figure 1b.

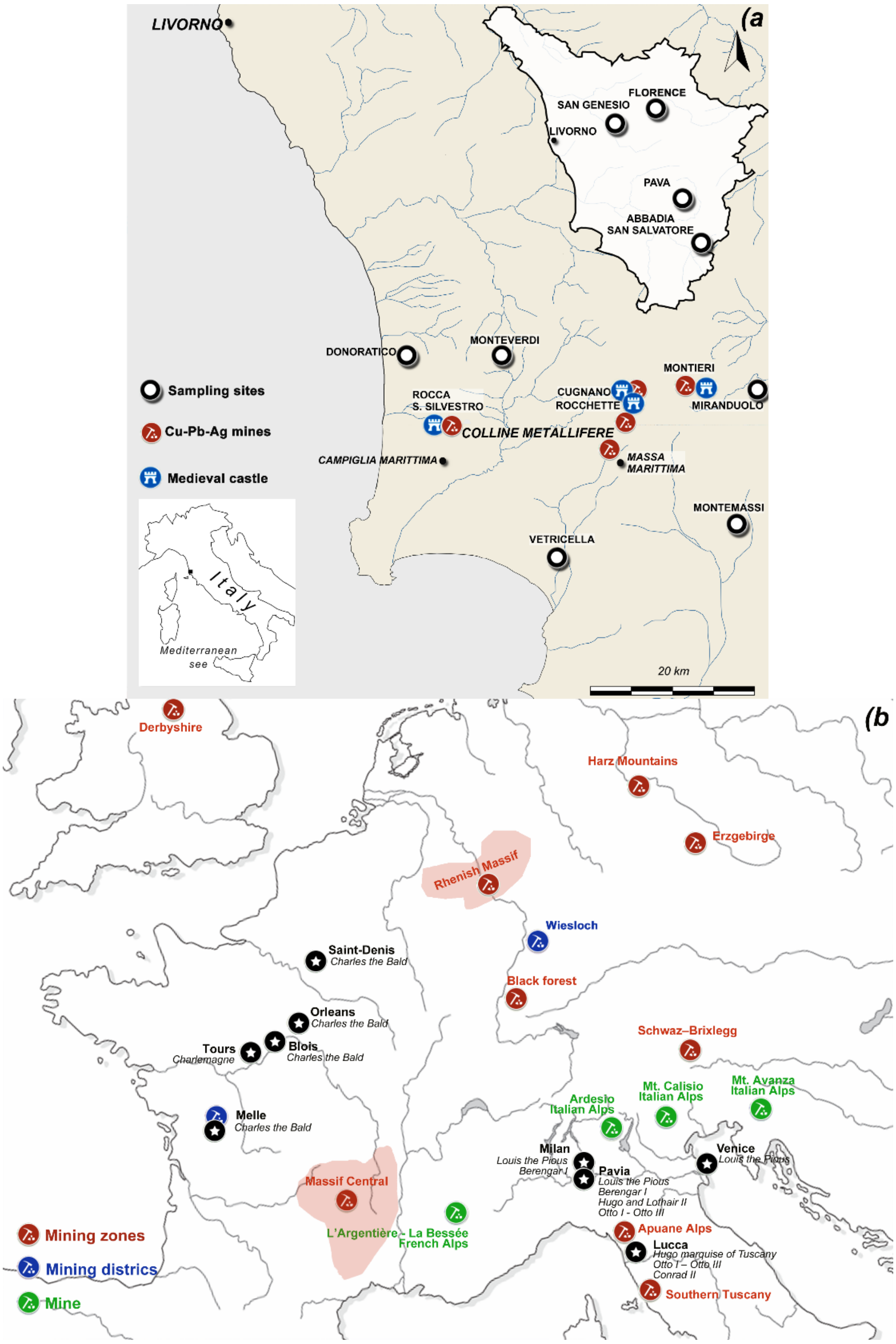

Figure 1 – a) Location of sampled sites of coins investigated in the present work; b) Location of mints with a list of investigated coin series and main mining districts included in the lead isotope database.

3. Analytical methods

Before lead isotope measurements all coins were characterized with a handheld X-ray fluorescence (pXRF) analysis to determine the major and minor elements composition. The instrument and its laboratory station were moved to Florence and Pava museums reducing any movement of the coins.

We used pXRF both to check the amount of lead in the coins to select the most suitable materials for the isotopic Pb analysis, as well as to have also a semi-quantitative chemical composition of the alloy that enabled us to create a compositional data-base of all the coins sampled, especially for those conserved and held in the museums which would not have been available for more detailed, but semi-destructive, analysis.

The instrument used is an Olympus Delta Premium Innov-X spectrometer, equipped with an X-ray tube of 40kV, 4W and 200 μA, Rh anode, a large area SDD detector for the analysis, available at the Department of Biotechnology, Chemistry and Pharmacy of the University of Siena. Six analyses for each coin (three for each side) were acquired in precious metals mode, with an acquisition time of 40 s. The position of the spot was carefully chosen through a camera built into the instrument trying to avoid the main alteration patinas.

Micro-samples (usually < 0.5 mg) were taken using a sterile scalpel from the edge of the coin without altering the inscription and weight of the coin. The sampled area is visible only for few months before silver natural re-oxidation. The samples were analysed for lead isotopes at the laboratory of the Institut für Geologie, at the University of Bern, using an MC-ICP-MS Nu Instruments™. The samples were dissolved in concentrated nitric acid. The Pb was purified with cation exchange resins, as detailed in Villa (2009). Thallium was added to samples prior to mass spectrometer analysis to correct for instrumental mass fractionation. Numerous measurements of the NIST SRM 981 international standard were carried out during analysis, to estimate the degree of analytical accuracy. The measured PbIC was indistinguishable from that reported in the literature (Rehkämper and Mezger, 2000).

4. Results and discussion

All analysed coins and their PbIC are reported in table 1.

sample identification	site/collection	name	coin denomination	authority	mint	age	Ag wt%	±2σ	Cu wt%	±2σ	Pb wt%	±2σ	$^{206}Pb/^{204}Pb$	±2σ	$^{207}Pb/^{204}Pb$	±2σ	$^{208}Pb/^{204}Pb$	±2σ
coin 1	San Genesio	32648	Dernier	Charlemagne	Tours	793/4-812	96.9	0.5	0.3	0.04	0.8	0.08	18.365	0.001	15.653	0.001	38.492	0.002
coin 2	PC	MC 300	Denaro	Louis the Pious	Milan ?	822-840	94.3	0.4	4.5	0.4	0.7	0.02	18.566	0.001	15.655	0.001	38.597	0.005
coin 3	PC	MC 805	Denaro	Louis the Pious	Venice ?	822-840	93.4	0.7	5.6	0.7	0.5	0.01	18.498	0.001	15.660	0.001	38.560	0.003
coin 4	Pava	1976 (19)	Obol	Louis the Pious	Milan?	822-840	94.5	0.4	4.0	0.4	0.7	0.03	18.493	0.003	15.660	0.003	38.568	0.007
coin 5	PC	MC 120	Denaro	Louis the Pious	Milan ?	822-840	95.0	1.8	3.6	1.3	0.6	0.02	18.496	0.003	15.650	0.003	38.457	0.008
coin 6	PC	MC 180	Dernier	Charles the Bald	Melle	840-864	98.1	0.3	1.2	0.2	0.3	0.03	18.483	0.001	15.672	0.001	38.572	0.004
coin 7	PC	MC 75	Dernier	Charles the Bald	Blois	864-877	97.6	0.1	1.2	0.1	0.2	0.08	18.487	0.001	15.669	0.001	38.574	0.004
coin 8	San Genesio	12006	Dernier	Charles the Bald	Orleans	864-877	54.5	1.0	37.0	0.9	0.8	0.03	18.477	0.001	15.660	0.001	38.518	0.002
coin 9	PC	MC 50	Dernier	Charles the Bald	St. Denis	864-877	97.0	0.2	1.5	0.1	0.4	0.08	18.492	0.002	15.665	0.002	38.573	0.005
coin 10	Pava	1265 (20)	Denaro	Berengar I	Milan	898-900 / 902-915	93.6	2.5	4.3	2.8	0.6	0.05	18.496	0.001	15.659	0.001	38.639	0.003
coin 11	Vetricella	CSN09 Q G9 US215 sf 19	Denaro	Berengar I	Pavia	898-900 / 902-915	73.4	8.0	23.0	7.8	0.4	0.09	18.401	0.001	15.651	0.001	38.548	0.004
coin 12	Vetricella	CSN09 Q G9 US215 sf 18	Denaro	Berengar I	Pavia	898-900 / 902-915	71.1	2.4	24.0	2.8	0.5	0.09	18.504	0.002	15.657	0.001	38.601	0.003
coin 13	Vetricella	CSN09 Q G8 US118 sf 52	Denaro	Berengar I	Pavia ?	898-900 / 902-915	42.0	3.3	55.5	3.5	0.3	0.04	18.501	0.001	15.659	0.001	38.604	0.003
coin 14	Vetricella	CSN11 Q G9 US190 sf 152b	Denaro	Berengar I	Pavia ?	898-900 / 902-915	47.3	6.6	48.7	6.7	1.0	0.08	18.607	0.001	15.666	0.001	38.705	0.004
coin 15	Vetricella	CSN11 Q G9 US190 sf 152a	Denaro	Berengar I	Pavia	898-900 / 902-915	48.1	3.3	48.2	3.0	0.5	0.12	18.516	0.001	15.659	0.001	38.629	0.004
coin 16	Vetricella	CSN16 Q G9 US190 sf 94	Denaro	Berengar I	Pavia ?	898-900 / 902-915	55.4	4.6	42.2	4.3	0.6	0.06	18.492	0.001	15.658	0.001	38.582	0.004
coin 17	Monteverdi	MU06 A2500 US2502	Denaro	Berengar I	Pavia ?	898-900 / 902-915	67.2	3.4	24.3	3.5	1.3	0.03	18.513	0.002	15.651	0.001	38.617	0.003
coin 18	Abbadia San Salvatore	ASS 07 US9	Denaro	Berengar I	Pavia	915-924	94.4	0.2	3.4	0.2	0.8	0.10	18.488	0.001	15.653	0.001	38.554	0.004
coin 19	Vetricella	CSN16 Q G8 US 118 sf 104	Denaro	Hugo and Lothair II	Pavia	931-947	76.5	7.3	20.8	7.3	0.9	0.07	18.502	0.002	15.653	0.002	38.608	0.005
coin 20	Vetricella	CSN09 Q G9 US194 sf 20	Denaro	Hugo and Lothair II	Pavia	931-947	95.9	1.0	1.7	1.2	0.3	0.08	18.485	0.001	15.655	0.001	38.599	0.004
coin 21	Vetricella	CSN16 Q F9 US118 sf 109	Denaro	Hugo marquise of Tuscany	Lucca	986ca - 990ca	75.2	2.4	16.7	1.4	1.1	0.04	18.451	0.001	15.647	0.001	38.527	0.004
coin 22	Donoratico	7614	Denaro	Otto I	Pavia	962-967	93.0	0.4	3.2	0.2	1.3	0.03	18.463	0.003	15.656	0.003	38.555	0.007
coin 23	Vetricella	CSN16 Q H11 US416 sf 107	Denaro	Otto I - Otto II	Pavia	962-967	76.4	4.3	20.8	4.1	0.6	0.05	18.574	0.002	15.647	0.002	38.643	0.004

coin 24	Vetricella	CSN18 QH8 US3048 SET III SF636	Denaro	Otto I - Otto II	Lucca	962-967 up to 983	97.2	0.1	0.9	0.1	0.6	0.02	18.518	0.001	15.677	0.001	38.709	0.002
coin 25	Vetricella	CSN11 Q G7 US 301 sf 153	Denaro	Otto I - Otto II	Lucca	962-967	68.8	13.0	26.9	11.9	0.2	0.03	18.595	0.002	15.673	0.001	38.750	0.004
coin 26	Vetricella	CSN09 Q E10 US207 sf 24	Denaro	Otto III	Pavia	983-1002	77.8	7.4	18.5	6.6	1.0	0.02	18.456	0.003	15.643	0.002	38.516	0.006
coin 27	Vetricella	CSN 17 US 1318 sf 235	Denaro	Otto II	Pavia	973-983	93.2	1.2	3.6	1.1	0.8	0.02	18.473	0.001	15.656	0.001	38.568	0.004
coin 28	Vetricella	CSN 17 US 1318 sf 235b	Denaro	Otto II	Pavia	973-983	92.0	0.3	3.1	0.3	0.4	0.01	18.545	0.001	15.660	0.001	38.646	0.003
coin 29	NAMF	34956	Denaro	Otto II	Lucca	973-983	94.7	0.4	3.4	0.4	0.7	0.02	18.429	0.001	15.623	0.001	38.460	0.004
coin 30	NAMF	34953	Denaro	Otto II	Lucca	973-983	91.3	2.5	6.4	1.8	0.6	0.02	18.446	0.001	15.648	0.001	38.560	0.003
coin 31	NAMF	34952	Denaro	Otto II	Lucca	973-983	85.3	1.3	10.7	1.8	0.4	0.02	18.507	0.002	15.659	0.001	38.635	0.004
coin 32	NAMF	34951	Denaro	Otto II	Lucca	973-983	91.4	1.4	7.2	1.1	0.2	0.01	18.428	0.001	15.628	0.001	38.498	0.004
coin 33	NAMF	34954	Denaro	Otto II	Lucca	973-983	79.6	6.1	15.7	6.1	0.7	0.10	18.453	0.001	15.646	0.001	38.542	0.008
coin 34	NAMF	34955	Denaro	Otto II	Lucca	973-983	89.2	3.4	8.7	3.1	0.5	0.02	18.520	0.006	15.648	0.005	38.622	0.012
coin 35	Vetricella	CSN11 US 0 sf 150	Denaro	Otto II	Pavia	973-983	88.0	3.1	7.4	2.3	0.6	0.04	18.417	0.004	15.627	0.003	38.448	0.007
coin 36	Vetricella	CSN18 QE8 US0 sf 659	Denaro	Otto III (minority)	Lucca	983-996	82.4	6.2	15.4	6.1	0.5	0.04	18.581	0.002	15.669	0.002	38.783	0.005
coin 37	Abbadia San Salvatore	ASS 07 US15	Denaro	Otto III	Pavia	983-1002	93.1	1.6	5.7	1.8	0.6	0.04	18.394	0.001	15.631	0.001	38.391	0.002
coin 38	Vetricella	CSN11 US 0 sf 151	Denaro	Conrad II	Lucca	1027-1039	87.1	9.0	10.0	8.5	1.1	0.06	18.383	0.015	15.650	0.012	38.512	0.041
coin 39	Vetricella	CSN05 Q2079	Denaro	Conrad II	Lucca	1027-1039	76.5	3.2	19.4	3.0	1.8	0.14	18.463	0.001	15.651	0.001	38.577	0.004
coin 40	Vetricella	CSN16 Q H9 US550 sf 120	Denaro	Conrad II	Lucca	1027-1039	91.9	0.2	6.5	1.1	0.4	0.05	18.372	0.001	15.630	0.002	38.387	0.006
coin 41	Vetricella	CSN18 sett. IV US 0 SF 660	Denaro	Conrad II	Lucca	1027-1039	54.8	1.2	42.7	1.2	1.0	0.20	18.481	0.001	15.657	0.001	38.615	0.003
coin 42	Miranduolo	274	Denaro	Conrad II	Lucca	1027-1039	90.1	0.3	8.0	0.3	1.0	0.05	18.393	0.001	15.646	0.001	38.494	0.004
coin 43	Miranduolo	278	Denaro	Conrad II	Lucca	1027-1039	82.2	6.6	15.7	6.8	1.3	0.07	18.641	0.003	15.682	0.002	38.820	0.005
coin 44	Pava	1289 (21)	Denaro	Conrad II	Lucca	1027-1039	89.4	1.8	8.0	1.8	1.5	0.07	18.457	0.001	15.649	0.002	38.563	0.005

Table 1 – Analysed coins, mean composition and lead isotope composition.

4.1. Carolingian coins (8th-9th centuries)

This set of coins includes samples from private and Museum collections (San Genesio, Pava). For the sake of clarity their Pb isotope analyses have been plotted in three separate diagrams and compared with compositional fields of ores from Melle, Massif Central (France); Rhenish Massif (Germany); Tuscany; Black Forest, Erzgebirge (Germany-Czech Republic); Italian Alps; Austria; Harz Mountains (Germany); northern Tuscany (Apuane Alps) and southern Tuscany (Figs. 2, 3 and 4).

The coins of this period comprise four coins of Louis the Pious (including one obol from unknown mint), and three denari presumably from Italian mints. The obol (coin 4) and the coeval denaro possibly minted at Venice (coin 3) are compatible with both Melle and Harz Mountains ores (Figs. 2 and Fig. 4).

The other two coins 2 and 5, possibly minted at Milan in the name of Louis the Pious do not fall within the Melle compositional field, but - like many other denari of Louis the Pious from the Italian mints of Venice and Pavia (cf. Sarah et al., 2008) - they fall in a broader area of the diagram with a partial overlapping with ores from the Black Forest and Harz Mountains districts.

The four Carolingian coins in the name of Charles the Bald from the mints of Melle, Blois, Orléans and Saint Denis (coins 6-9: Table 1) are clearly compatible with the Melle district. Although these coins are isotopically compatible also with other European mines like the Harz Mountains, it is highly likely that Melle is the source of silver, on the bases of Pb isotope analyses of Carolingian and most Merovingian coins from the Cabinet des Médailles de la BnF (Téreygeol et al., 2005: data reported in figure 2). Intense exploitation of Melle silver mines during the Merovingian and Carolingian empires is clearly confirmed by archaeological data (Téreygeol 2007; Téreygeol, 2013).

The dernier of Charlemagne from Tours (793/4-812), (coin 1 in Table 1), the earliest coin analysed here, does not match with Melle ores but could be isotopically compatible with Massif Central or Italian Alps/Trentino districts (Fig. 3). The provenance of the silver of this coin remains uncertain, as there is no clear evidence of exploitation for the latter mining regions during this period (see Appendix B). It is worth noting that there is only one coin of this type. Moreover, the sample could be also the result of recycling of previous or foreign silver coins or objects.

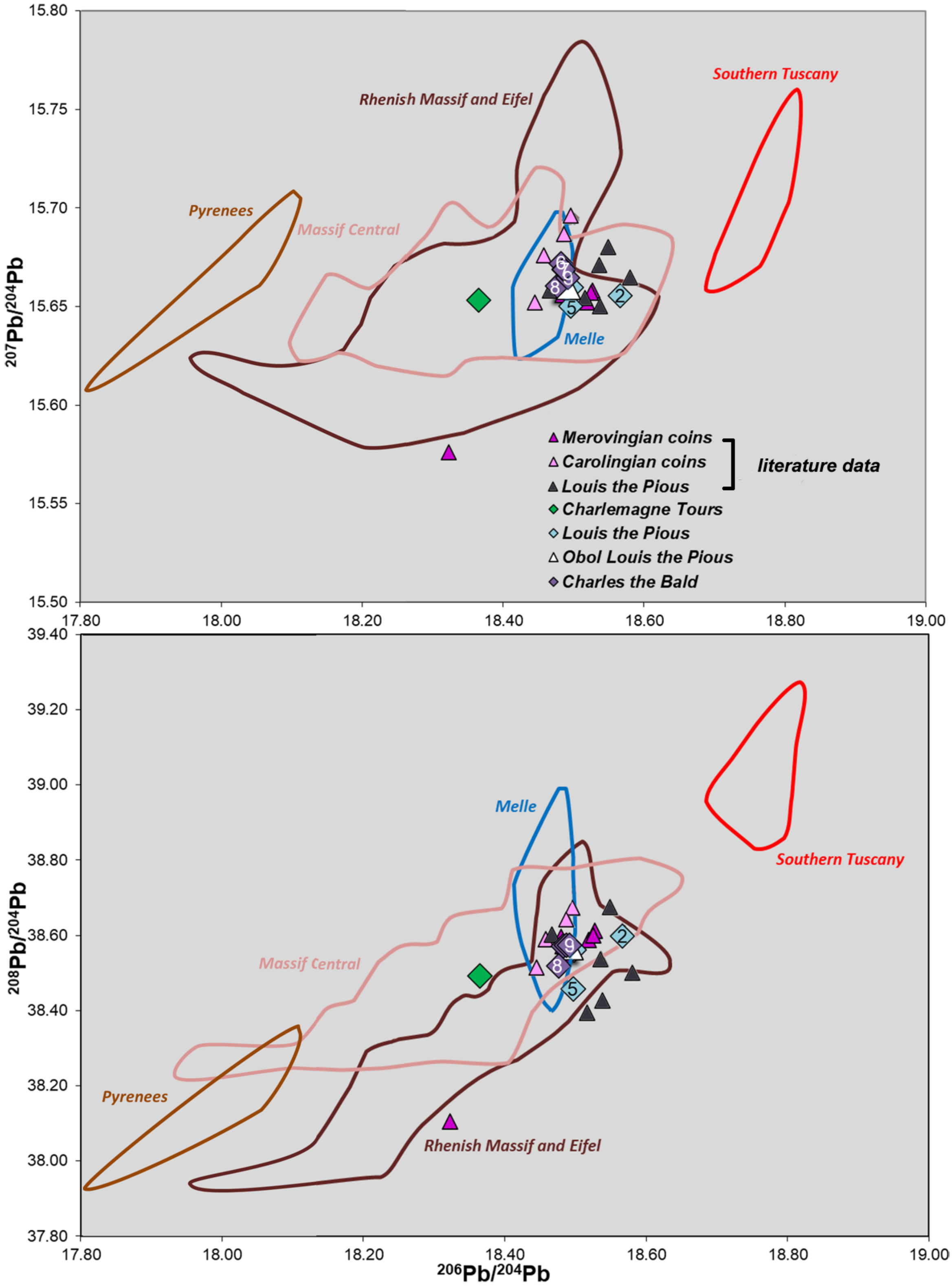

Figure 2 - $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams for Carolingian coins from the present work and from the literature, and Melle, Massif Central, Pyrenees, Rhenish Massif-Eifel, southern Tuscany ore districts. Symbols employed for coins are larger than analytical error bars, not reported in diagrams. Coloured polygons are employed for each mining district, they do not have any statistical meaning but simply enclosed all lead isotope (LI) data reported in literature as illustrated in Appendix B. Literature data of Carolingian and Merovingian coins from Téreygeolet al., 2005; Louis the Pius coins from Sarah et al., 2008.

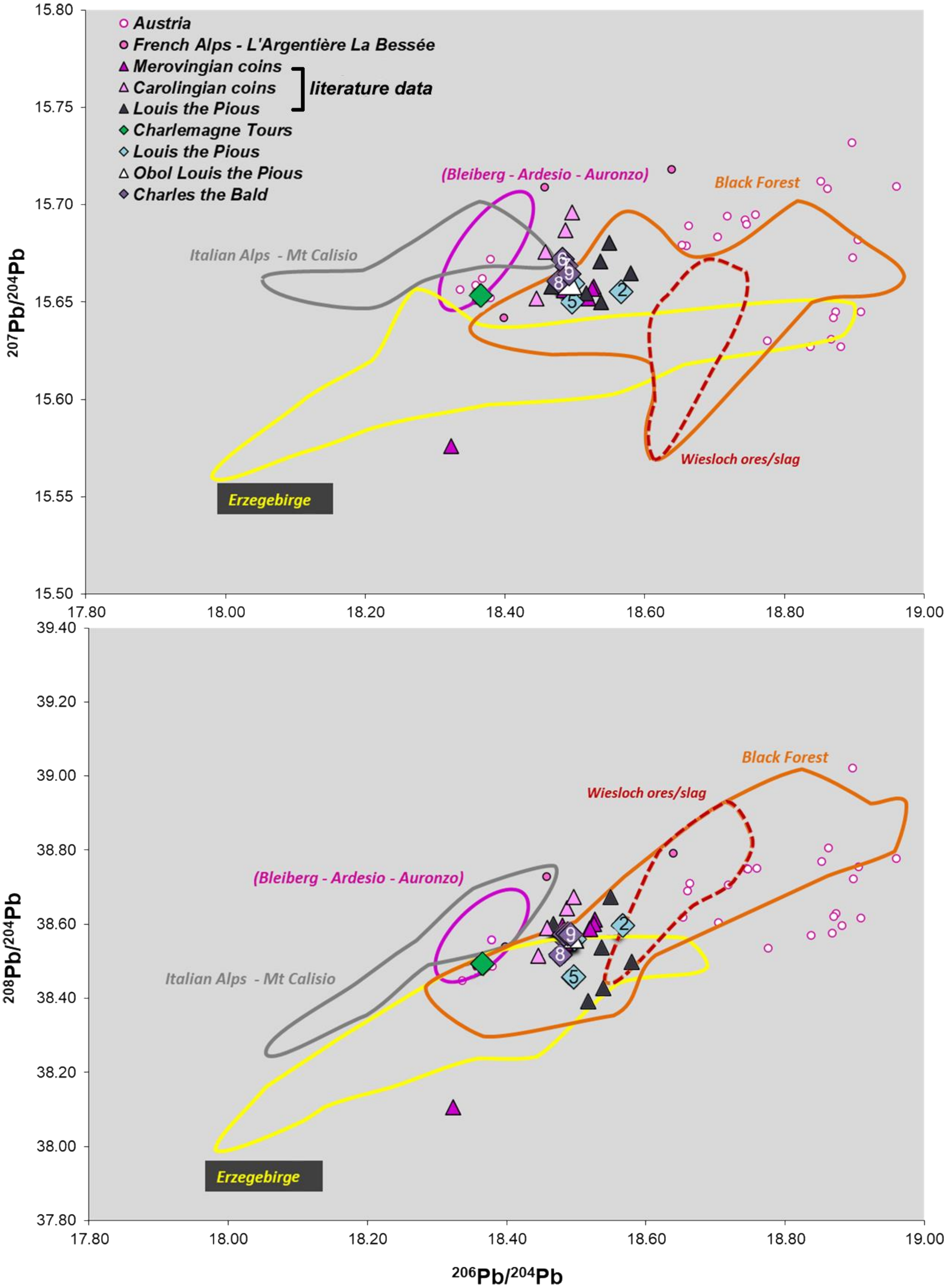

Figure 3 - ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{2046}Pb (top) and ^{208}Pb/^{204}Pb vs ^{206}Pb/^{204}Pb (bottom) diagrams for Carolingian coins and Austria, Black Forest (dashed line Wiesloch ores/slags), Erzgebirge and Italian Alps ore districts (references in Appendix B). Literature data of Carolingian and Merovingian coins from Téreygeol et al., 2005; Luis the Pius coins from Sarah et al., 2008.

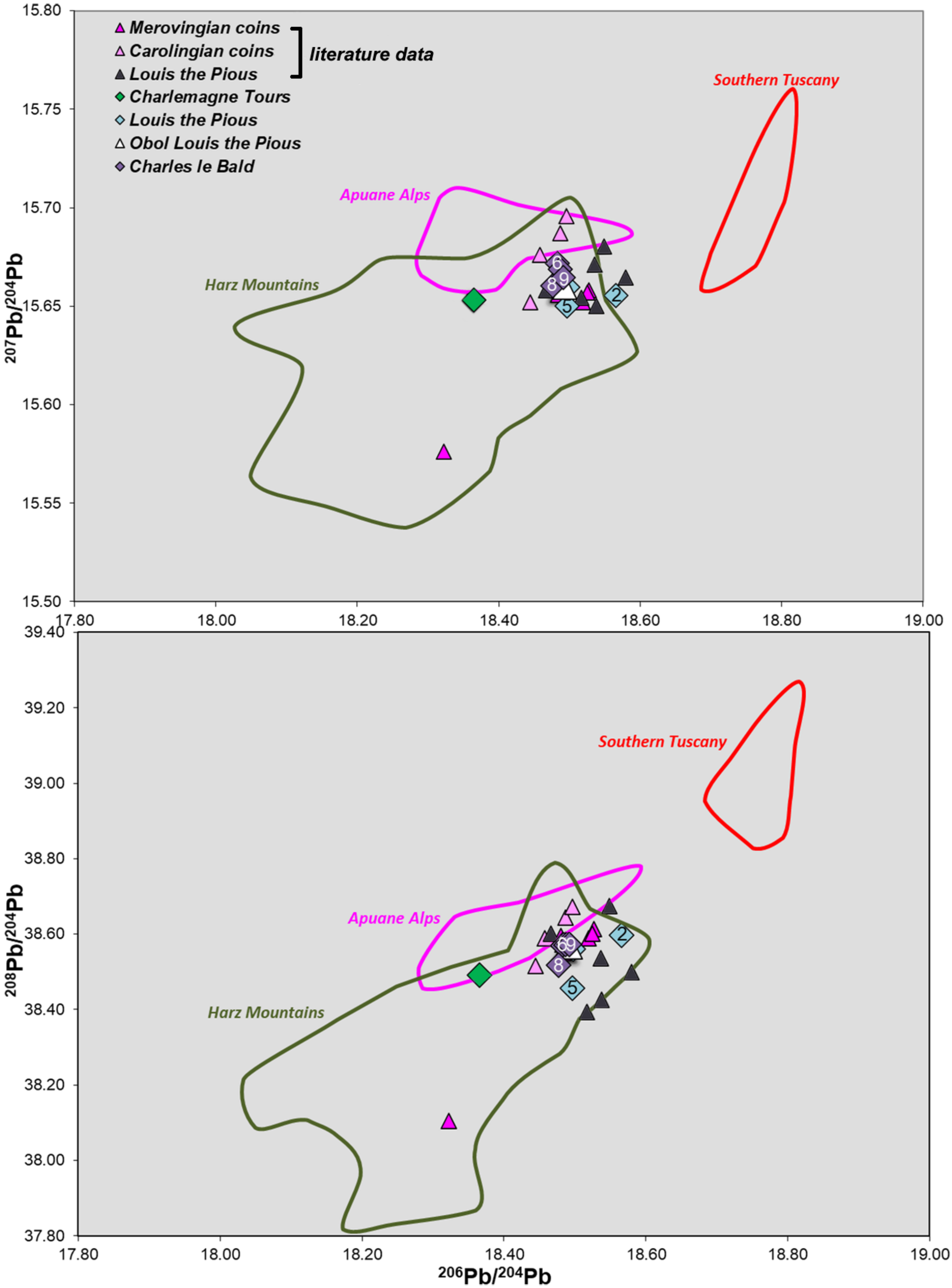

Figure 4 - ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{2046}Pb (top) and ^{208}Pb/^{204}Pb vs ^{206}Pb/^{204}Pb (bottom) diagrams for Carolingian coins, Harz Mountains, Apuane Alps and southern Tuscany ore districts (references in Appendix B). Literature data of Carolingian and Merovingian coins from Téreygeol et al., 2005; Louis the Pius coins from Sarah et al., 2008.

4.2. Coins from Italian kings and marquesses (9th-10th centuries)

This set of coins comprises nine coins attributed to Berengar I from mints of Milan and probably Pavia, (Rovelli, 2020). Most of these coins have been found at the Tuscan coastal site of Vetricella (recently excavated during the nEU-Med project) which returned 21 denari datable to the period between Berengar I and Conrad II.

The PbICs of most Berengar coins (898-900/902-915?) are quite similar (except for coins 11 and 14, see below) and closely cluster in a restricted area of the diagrams (Figs. 5-7). Their distribution only partially overlaps with the Melle field (Fig. 5) (coins 10, 16, 18), but it seems to better fit with other silver districts like the Black Forest or the Harz Mountains (Figs. 6-7).

Coin 11, on the other hand, could be isotopically compatible either with France ores of Massif Central, German ores of Black Forest and Harz Mountains, while coin 14 only with Massif Central and Black Forest.

The two rare coins of Hugo and Lothair II (931-947) from Pavia (coins 19 and 20 in Table 1) are clearly superimposed on the large group of Berengar I coins and are thus partially compatible with Melle or better with both the Black Forest and Harz Mountains districts.

The rare coin in the name of Hugo marquess of Tuscany (or Hugo the Great) minted in Lucca at the end of 10th century (coin 21 in Table1) shows a PbIC that overlaps with the Melle, the Black Forest and Harz ore districts.

Among these districts, Melle appears to decline in the 10th century; thus, a provenance from this area is probable only for coins minted up to the middle-end of this century (Téreygeol, 2013). On the other hand, a provenance from the Massif Central seems less probable for this set of coins, since exploitation of the Pb-Ag Mont-Lozère mine (southern Massif Central) should have started not earlier than the end of 10th century (Baron et al., 2006).

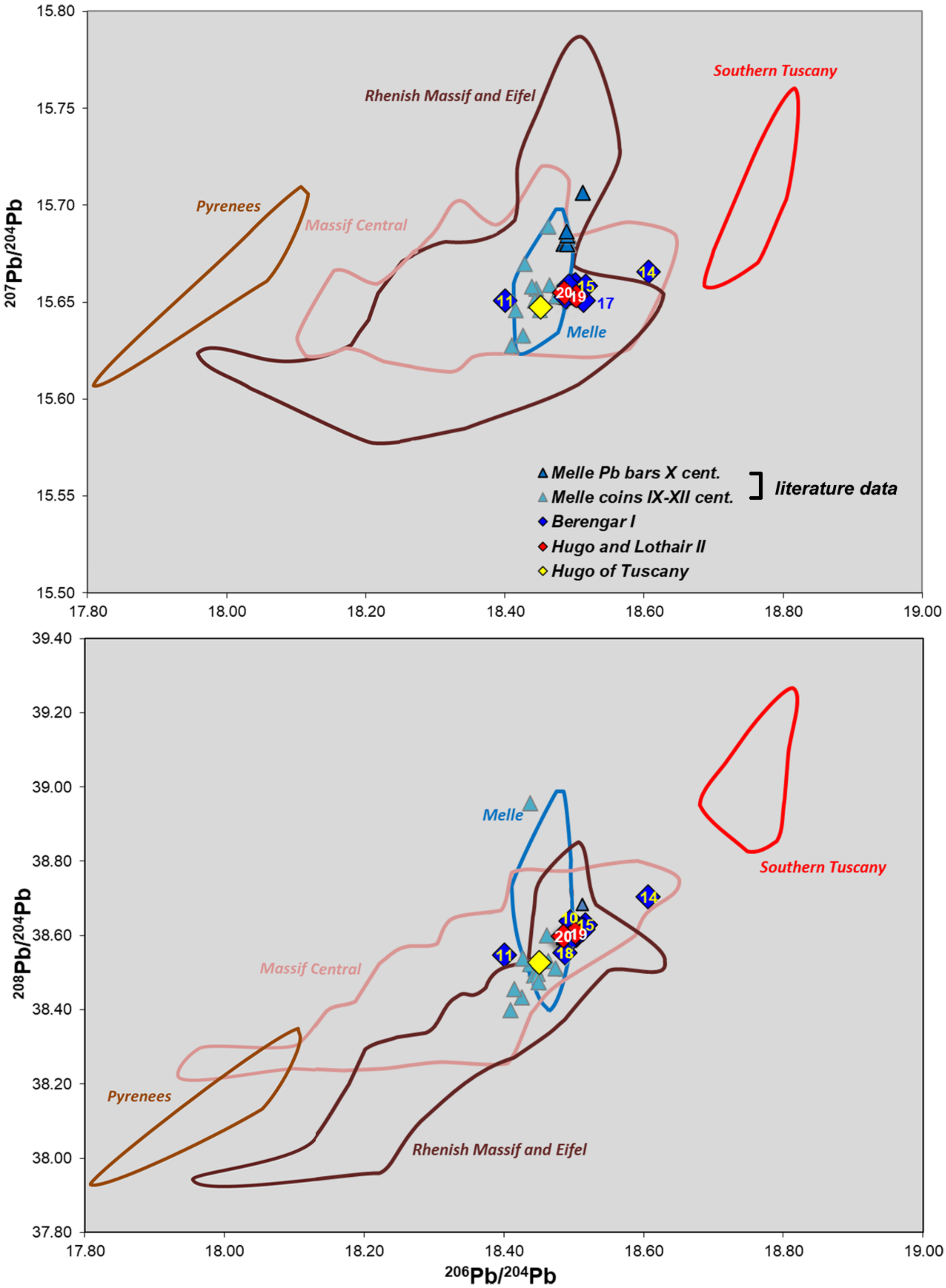

Figure 5 - $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams for coins of Italian rulers and Melle, Massif Central, Pyrenees, Rhenish Massif-Eifel, southern Tuscany ore districts (references in Appendix B). The PbIC of Melle lead bars and silver coins belonging to the 9th-12th centuries have also been reported for comparison in figure (Téreygeol et al., 2005).

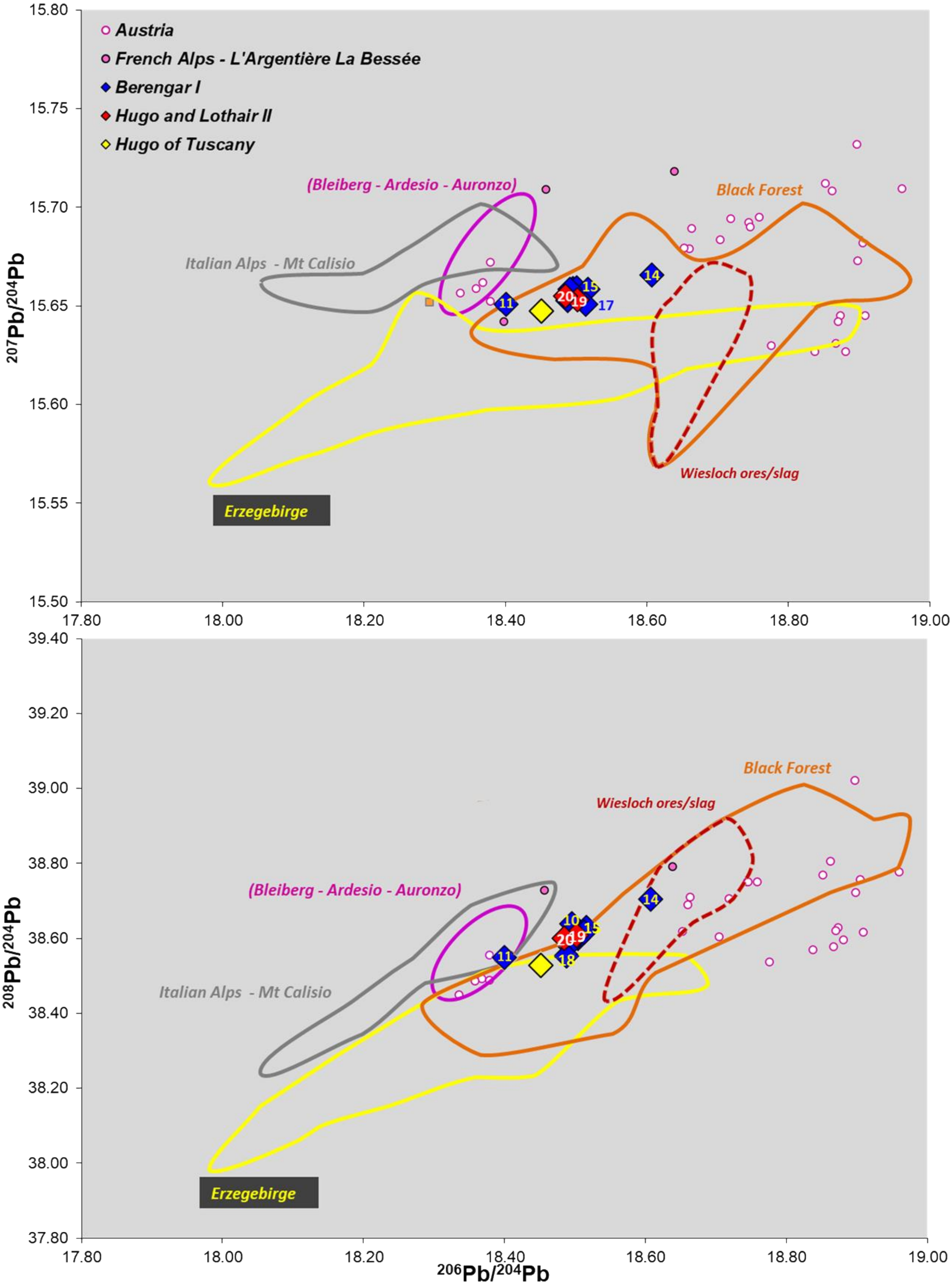

Figure 6 - ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{2046}Pb (top) and ^{208}Pb/^{204}Pb vs ^{206}Pb/^{204}Pb (bottom) diagrams for coins from Italian rulers and Austria, Black Forest, Erzgebirge, Italian Alps ore districts (references in Appendix B).

Archaeological data regarding the Black Forest mines apparently exclude a provenance of silver from this district, since there are some evidence of Roman production this region possibly resumed in the Carolingian period but the main archaeological evidence of mining remains and radiocarbon dates ranging from the late 10th to the 12th centuries (Hildebrandt, 2012; Steuer, 1993).

Differently many traces of Pb-Ag exploitation during the 9th century are concentrated in the Wiesloch region (Hildebrandt, 1993), whose PbIC is isotopically incompatible (see figure 5) (PbIC data from Ströbele et al., 2015).

A provenance from the Harz Mountains is possible, since production increased in the 9th century probably due to the organization and control of mines first by the Carolingians and later by the Ottonians (Klappauf et al., 1991).

Other mining districts sporadically exploited during 9th-10th centuries, like Spain or Anatolia (see Appendix B), are not isotopically compatible with the analysed coins.

As illustrated also for the previous Carolingian coins from Italian mints, all these coins issued by Italian rulers in the Italian mints of Pavia, Milan and Lucca show isotope composition that do not match with Italian silver mines presumably exploited in medieval times.

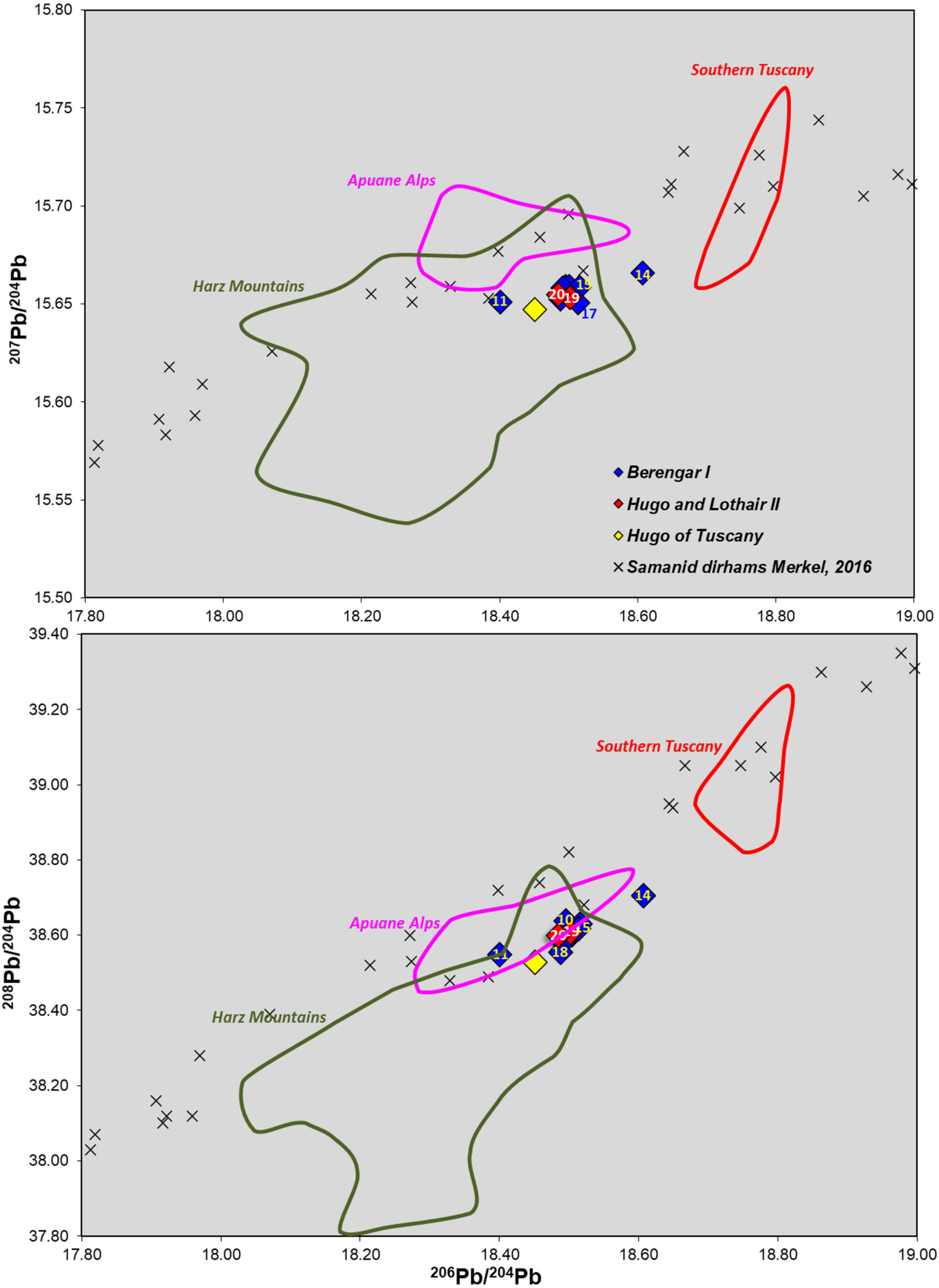

Figure 7 - $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams for coins of Italian rulers and, Harz Mountain, Apuane Alps, Samanid Dirhams (Merkel, 2016) and southern Tuscany ore districts (references in Appendix B).

4.3.Coins in the names of Otto I-III and Conrad II (10th-11th centuries)

The largest group of coins analysed so far (coins 22 to 37 in Table 1) consists of sixteen denari in the name of Otto (I-III), coined in the mints of Pavia (7 coins) and Lucca (9), datable to the period between AD 962 and 1002.

Most of the coins (except for coins 25 and 36) are concentrated in a rather narrow compositional field (Figs. 8-10), regardless of the mint which they come from. This field happens to overlap with many ore fields of central-western Europe, in particular Melle, the Black Forest and Harz Mountains, which should be considered as potential source areas.

The denari in the name of Otto are isotopically very close to two contemporary coin series (the Sachsenpfennige, 950-1000, and the Otto-Adelheid-Pfennige, 985-1040) minted by Otto I–III in Saxony, probably in Magdeburg and Goslar (white and green triangles in figure 10) in the Harz massif (cf. Merkel, 2016). Most of the latter German coins (with very few exceptions illustrated in the upper part of figure 10) have a chemical and isotopic composition compatible with the mines of northern Harz (see figure B3 in the Appendix), where there is contemporary archaeological evidence of silver production. It is thus likely that these denari were produced with metal mined from the Harz mountains (Merkel 2016). It is reasonable to suppose that coins struck in Italian mints in the same period by the same sovereigns were made from Saxon silver as well.

One possibility is that coins were produced using recycling previous coins, or using silver looted from outside the Ottonian empire. Several authors contend that at the end of 9th there was a significant change of silver routes in the north east of Europe which is indicated by the huge amounts of dirham coins (or "Kufic" silver) found in Scandinavian silver hoards and settlements (Blanchard, 2001, Kilger, 2008, Spufford, 1988). This evidence is connected with the Samanid Empire expansion between the 9th-10th centuries AD and the issuing of large quantities of silver coins. Since these dirhams coins were not generally found in coeval German and west Europe hoards it was commonly thought they could have been reused and recycled during the Ottonian dynasty (Spufford, 1988). This hypothesis is exhaustively discussed by Merkel (2016) who analysed the PbIC of many Samanid dirhams. The latter are reported also in figure 10. PbIC data evidently demonstrate that the present Ottonian coins from Italian mints are incompatible with a predominant use of recycled Samanid silver. Notably, samples from northern Afghanistan have high bismuth concentrations between 0.4 and 14 wt% (Merkel, 2016), whereas the present coin collection mostly contain < 0.4 wt% bismuth.

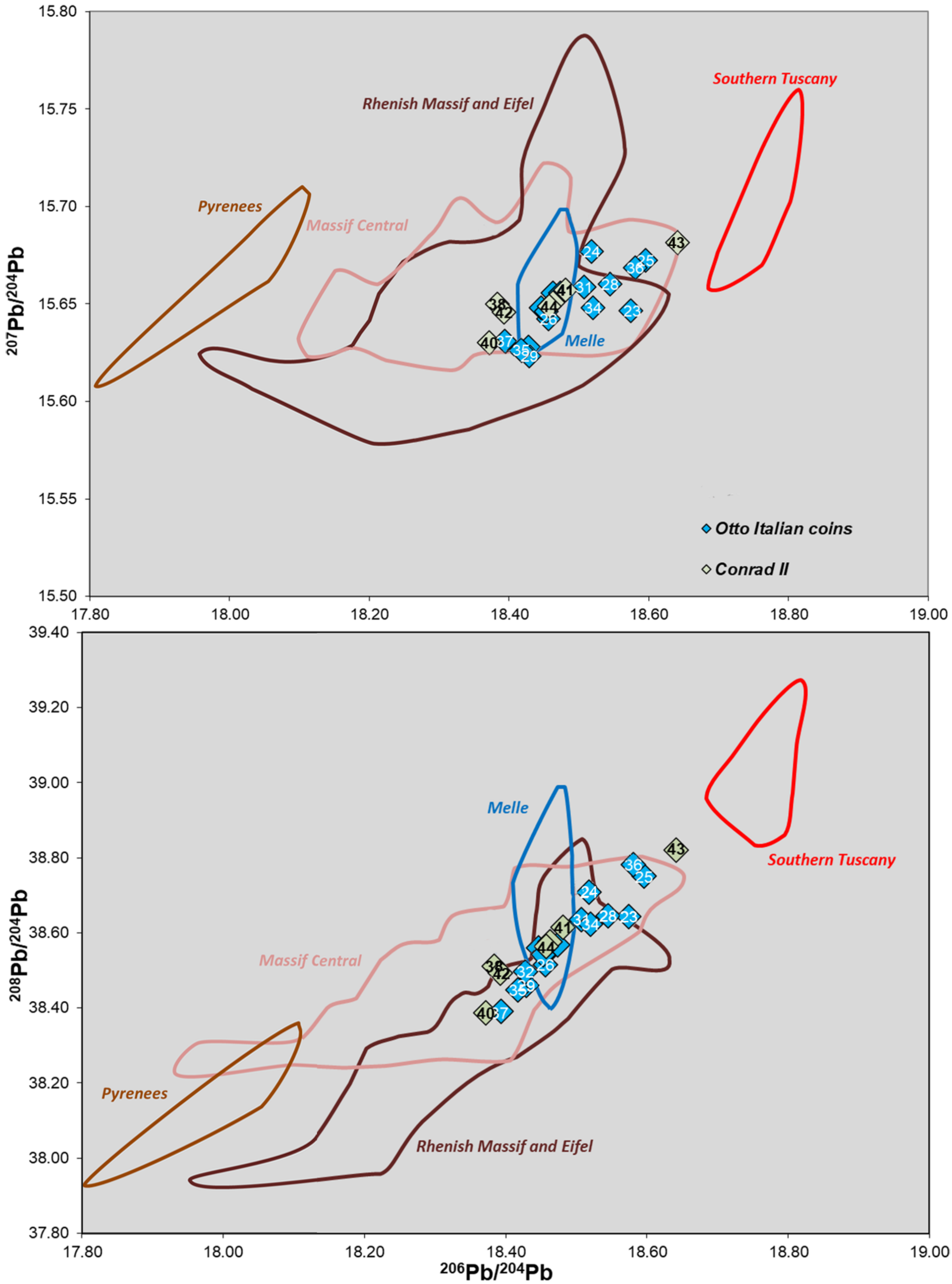

Figure 8 - $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams for Otto and Conrad II coins and Melle, Massif Central, Pyrenees, Rhenish Massif-Eifel and southern Tuscany ore districts (references in Appendix B).

The seven denari in the name of Conrad II (1026-1039), from the Lucca mint, except for coin 43, all contain characteristics plot close to the deposits in Saxony[1].

In general, most coins belonging to this group (Ottonian dynasty and Conrad II) do not appear to show clear Pb isotopic footprint referable to the Italian peninsula, neither from southern Tuscany nor from Italian Alps (Calisio, Ardesio mines). As to the latter mines, this evidence is in agreement with written sources documents attesting that these ores were exploited only from the late 11th-12th century (Menant, 1987; Ciurletti, 1997). However, at least three settlements were built in the 8th-10th centuries in the Colline Metallifere district, in close proximity to ore deposits, already known in the antiquity since the Chalcolitic (Francovich, 1991; Bruttini et al., 2009; Bianchi et al., 2012; Grassi 2013). This might suggest a recovery of mining activity already in the Early Middle Age.

A footprint possibly related to Tuscan ores is observed in three coins 25, 36, 43 (in the names Otto I, Otto III, Conrad II, respectively and possibly also coin 14 ascribed to in the name of Berengar I) with characteristics which plot neither in the main fields of European deposits nor in that of southern Tuscany. Instead their PbIC falls midway between the field of southern Tuscany and the field of the European deposits, which suggests that Tuscan silver was sporadically mixed with Saxon metal.

Evidently, if silver was mined in this period in southern Tuscany, it was scarcely employed for the production of coinage.

[1] Most of these data are hypothetically compatible also with some English ores (see Appendix B); note Tylecote's (1986) statement "Britain was mainly a silver importer at all times", PbIC of Britain ores have been not reported in diagrams (see Appendix B for details).

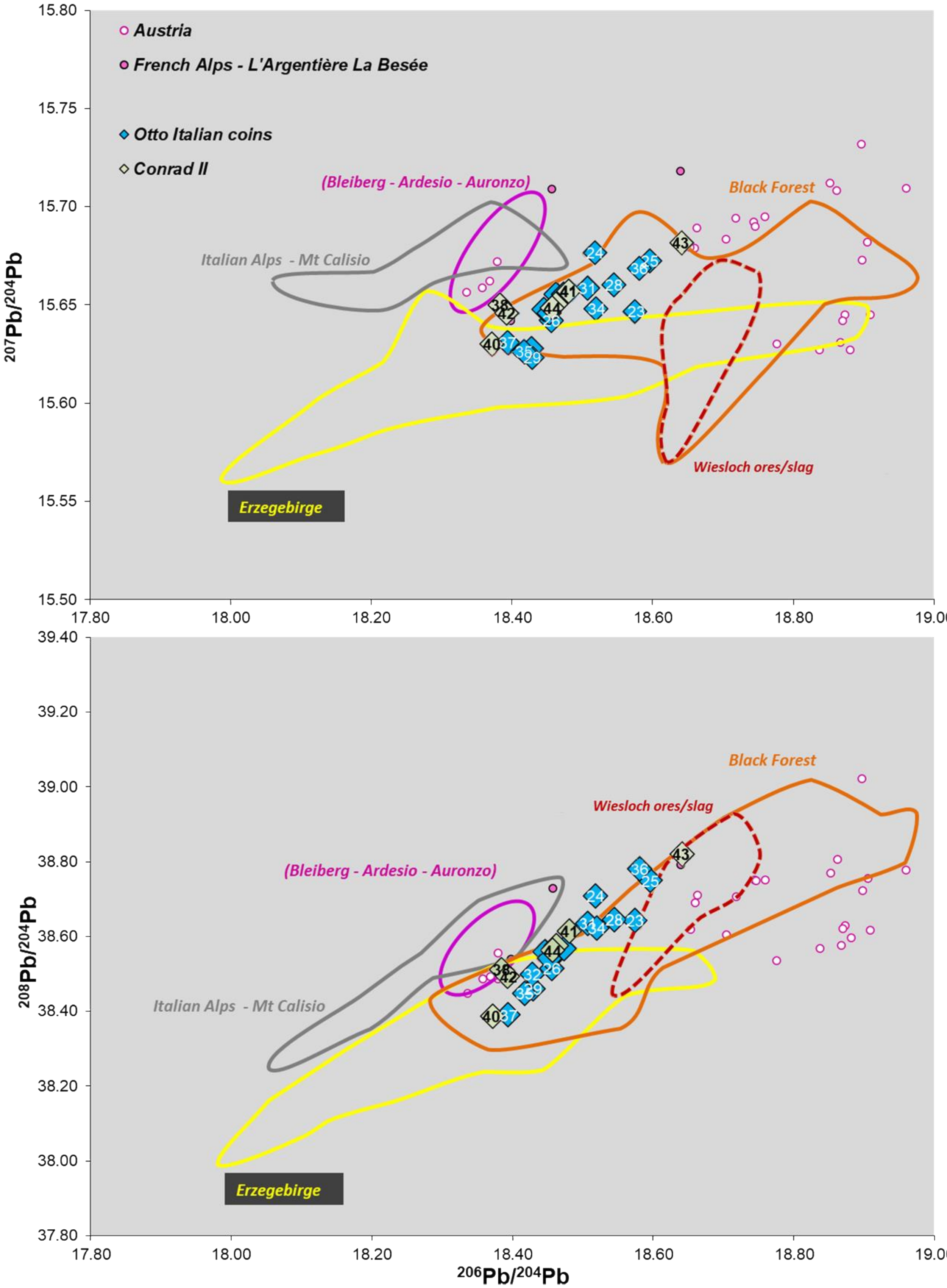

Figure 9 - ^{207}Pb/^{204}Pb vs. ^{206}Pb/^{2046}Pb (top) and ^{208}Pb/^{204}Pb vs ^{206}Pb/^{204}Pb (bottom) diagrams for Otto coins and Conrad II coins and Austria, the Black Forest, Erzgebirge, Italian Alps ore districts (references in Appendix B).

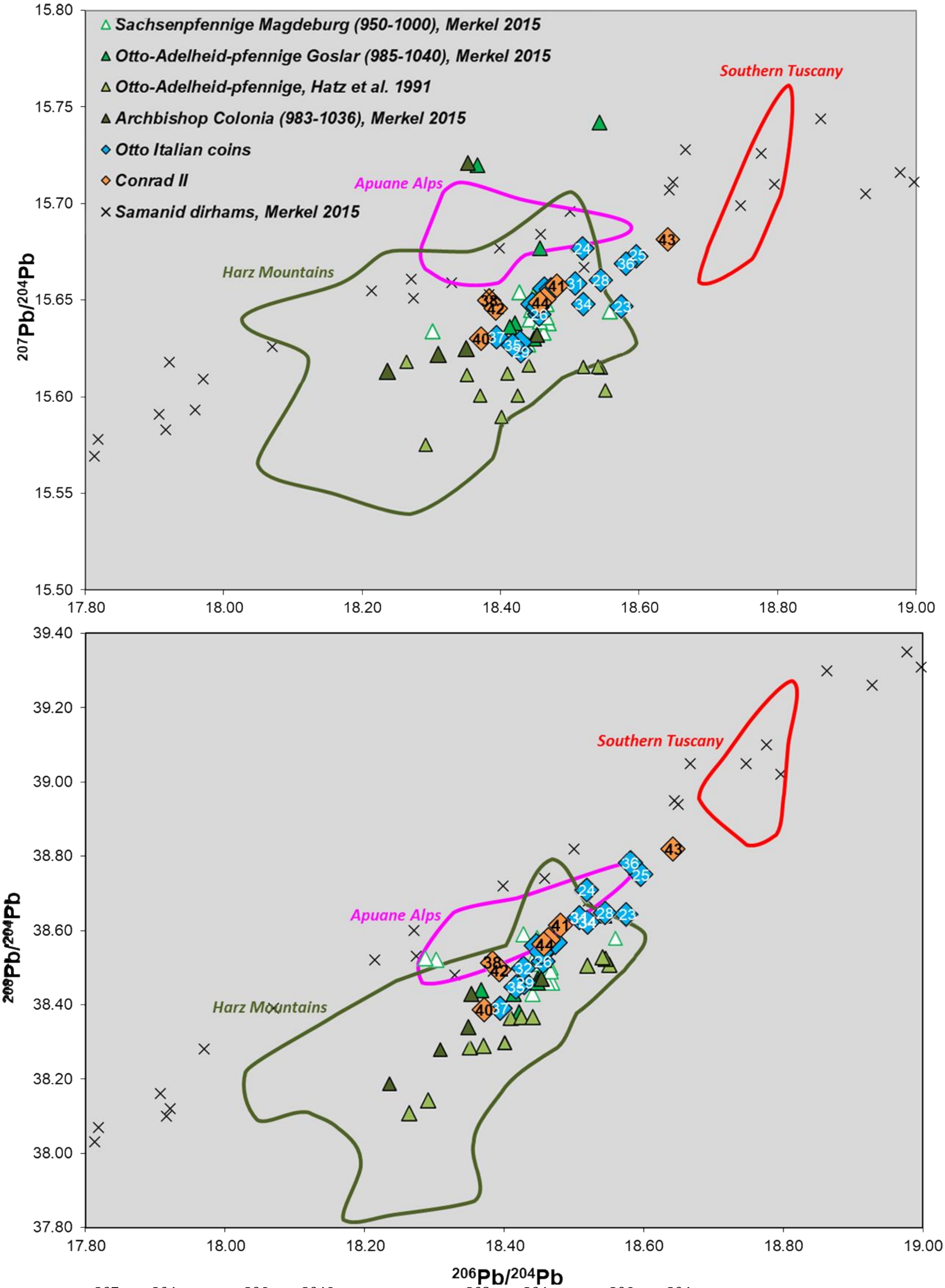

Figure 10 - $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams for Otto and Conrad II coins and Harz Mountain, Apuane Alps, and southern Tuscany ore districts (references in Appendix B). Literature data of Samanid dirhams, Sachsenpfennige, Otto-Adelheid-Pfennige and Archbishop Colonia coins from Merkel, 2016; Otto-Adelheid-Pfennige from Hatz et al., 1991

It would now appear that some lead taken from the mines of this territory was employed for local purposes (e.g., production of glazes: Fornacelli et al., 2020). It is interesting that recent Pb isotope analyses of local glazed ware found in the Donoratico castle (a coastal site very close to the Colline Metallifere district) and dated to the 9th century (Briano and Sibilia, 2018) clearly indicate two distinct sources of lead in the glaze: the Colline Metallifere district and a "foreign" source, isotopically compatible with several ore districts form central-western Europe (e.g. Melle, Harz Mountains and Rhenish Massif). Most of the glaze samples from Donoratico lie along a clear mixing line connecting southern Tuscan ores to the central-western Europe mining districts, suggesting the mixing of Pb batches of both local and "foreign" sources (Fornacelli et al., 2020). The reuse of semi products or wastes from the silver/lead production chain, for the manufacture of glasses, even coming from very distant sources, has been already mentioned in Carolingian times. As illustrated by Gratuze et al., (2014) PbIC confirms that lead slag from Melle were reused for the production of a great numbers of glass pebbles (or smoothers) that circulates in the late Carolingian times all over Europe up to Novgorod in Russia. It is then not surprising that glaze samples produced at Donoratico, could have also reemployed some lead semi-products from other European sources.

From our results it emerges between 8th and the middle of 11th century AD silver used for coinage circulating in southern Tuscany, either minted in Italy (Milan, Venice, Pavia, Lucca) or abroad (France), come from silver-bearing districts of central-western Europe. It is not clear, at this stage of the archaeological research, in which forms (ingots, row metals, coins or other forms of treasures to be recycled) silver was circulated to royal mints, but Italian mints mostly produced coins with silver from central-western Europe.

It seems, therefore, that the southern Tuscany district, and in particular the Colline Metallifere area, was not mined for silver in this period of time. It could be surmised that the extraction of silver from these ores required rather sophisticated metallurgical skill and as a result did not occur. As illustrated in Appendix B, the Colline Metallifere Cu-Pb-Fe (Ag) ores are mostly characterized by galena, chalcopyrite, sphalerite associated with variable amounts of silver-bearing minerals, mainly fahlerz (tetrahedrite-tennantite) with up to 2% silver, pyrargirite, proustite; the silver content of galena appears to be negligible (Domnori, 2013; Benvenuti et al., 2019). It is therefore possible that silver extraction from these complex ores implied a multi-step smelting process (that need to make large additions of lead in the silvery copper which leads to a very strong lengthening of the cupellation phase) so that silver recovery was not feasible and/or economically too expensive.

Otherwise, we can suppose only a very limited and sporadic extraction of silver from the Colline Metallifere district (probably from the end of 10th as suggested by coins 14, 25, 36, 43) but its employment and mixing in the mints with more abundant metal from Europe mines inevitably obliterated the PbIC signature thus limiting the archaeometric record.

5. Conclusions

Lead isotope analyses of 44 early Medieval coins found in southern Tuscany, mainly minted in the Italian mints of Pavia and Lucca, allow us to make inferences about the provenance of silver employed for coinage.

Both early (8th cent. AD) and late Carolingian coins (first half of the 9th century AD) found in southern Tuscany, including those minted in Italy (Venice and Milan), have PbIC compatible with ore deposits from central-western Europe (Melle or other Frankish silver ore districts, maybe also the Harz Mountains).

Coins in the names of Italian rulers (9th-10th century) mainly from Pavia and Lucca mints similarly point to source areas of silver compatible with Melle, Black Forest and the Harz Mountains districts. A very similar pattern applies to coins in the names of Otto I-III and Conrad II (10th-11th century) from Pavia and Lucca mints. The cluster of data points are slightly shifted in the PbIC diagrams relative to earlier coins and show a better overlap with the Harz Mountains than with Melle.

In general, the vast majority of early medieval coins (9th-11th AD) issued by the Italian mints and investigated in the present paper show isotope compositions that do not match with Italian silver-bearing ores in the Colline Metallifere, notwithstanding the making of settlements and fortifications near mining sites suggesting some exploitation occurred in this period (Bianchi, 2018).

Only four silver coins (in the names of Berengar I, Otto I, Otto III, and Conrad II) have isotopic compositions midway between the fields of central-western Europe and southern Tuscany. This could point to sporadic mixing of silver from both sources at least from the 10th century.

The analysed silver coins were minted from metal coming from mines of central-western Europe. Due to the long-distance transportation issues, it is likely that silver reached the mints in Italy as a metal and not as ore. However, it is not possible to determine in what form (raw metal, ingots, older coins or other types of metallic artifacts).

The present lead isotope analyses of coins suggest a highly centralized administration of silver used for minting during the Carolingian, especially Ottonian period and partly Salic dynasties. This hypothesis therefore introduces a scenario of considerable complexity that implies a more in-depth critical analysis of the economic relations between Italy and the heart of the Frankish and Ottonian empires, together with a discussion of the economic and management strategies of mining resources by these central powers. Addressing this type of analysis is beyond the scope of the present contribution, which focuses on the detailed presentation of the provenance analyses of the raw materials used for coins, a preliminary and essential objective of the numismatic task of the nEU-Med project. Because of their complexity, the results of these analyses will be discussed in subsequent articles with a more marked historical-economic approach.

Regarding the role of mineral resources in the Colline Metallifere, PbIC of the analysed coins does not support the significant employment of silver from the Colline Metallifere area for coinage in the imperial and royal mints. It is therefore probable that polymetallic (Cu-Pb-Fe±Ag) resources were exploited for local use only production. During the 9th century, for example, local lead sources were certainly employed for the production of Pb-rich sparse glazed ware produced at Donoratico (Fornacelli et al., 2020). A different pattern of metal procurement is exemplified by the iron objects found in the fortified costal site of Vetricella. This royal property, founded around the 8th-9th centuries AD, evolved during the 10th century as an important centre for the control and management of the territory and its productive activities. Its role is testified by the large quantity of finds and by the high number of coins that have been discovered in the site (even if the abundance of coins might also be viewed as a dispersed hoard). The metal objects, especially iron, were probably produced in the surrounding territory with local iron and stored in the fortification (Bianchi and Hodges, 2020). The polymetallic resources of the Tuscan Colline Metallifere were evidently employed for various purposes different from coinage in Early Medieval times. Further analyses of later coins from Tuscan mints, still in progress, may clarify the history of the subsequent use of Tuscan silver.

Acknowledgements

The authors are greatly thankful to all the research team members for all the scientific and logistic support during the fieldwork.

The selection of coins was made in co-operation with Alessia Rovelli (Università della Tuscia) who is also thanked for profitable discussions of results. We thank also Prof. Michael Michael McCormick (Harvard University) for providing us Carolingian coins from his private collection; Dr. Mario Iozzo Director of National Archaeological Museum of Florence (NAMF), Dr. Fiorenzo Catalli (Soprintendenza di Roma) for the selection of coins of NAMF; Dr.ssa Cristina Felici (Università di Siena) for the assistance during the analyses of coins from Pava; Prof. Federico Cantini (Università di Pisa) for coins from San Genesio site. We specially thank Prof. Zofia Stos-Gale for providing us the original PbIC data set of *Otto-Adelheid-Pfennige from Hatz et al., 1991*. Finally, our thanks go to the two anonymous referees for all their helpful suggestions and comments on the first draft of this paper.

Funding

This study has been carried out in in a project funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement n. 670792).

Declaration of interest: none

APPENDIX A

Carolingian and Italian kings' coins found in Tuscany

site	type of recovery	coin denomination	authority	mint	age	Nr. of coins	bibliography
Colle del Pionta, Arezzo	single find	*denaro*	Otto (I,II, III?)	Lucca	962-1002	1	Gianazza, 2021
Cosa, Grosseto	single find	*denaro*	Otto I Emperor	Pavia	962-973	1	Buttery, 1980
	single find	*denaro*	Otto III Emperor	Pavia	983-1002	1	
Donoratico, Livorno	single find	*denaro*	Otto I Emperor	Pavia	962-967	1	unpublished
Filattiera, Massa-Carrara	single find	*denaro*	Berengar II and Adalbert	Pavia	951-961	1	Saccocci, 2010
Galli Tassi, Lucca	hoard	*denaro*	Ugo di Arles King of Italy	Venice	926-947	2	Saccocci, 2001, 2002
		denaro	Lothair II King of Italy	Pavia	945-950	2	
		denaro	Berengar II and Adalbert	Pavia	951-961	1	
		denaro	Otto I Emperor and Otto II King	Pavia	962-967	14	
		denaro	Otto I Emperor and Otto II King	Lucca	962-983	4	
		denaro	Otto I Emperor	Magonza	962-973	1	
Gorfigliano, Lucca	single find	*denaro*	Otto III Emperor	Pavia	983-1002	1	Baldassarri, 2004
Gronda di Luscignano, Massa-Carrara	single find	*denaro*	Otto II Emperor	Pavia	947-983	1	Davite, 1988
Piazza S. Giusto, Lucca	single find	*denaro*	Otto III Emperor	Milan	983-1002	1	Saccocci, 2019
Miranduolo, Siena	single find	*denaro*	Otto I Emperor and Otto II King	Pavia	962-967	1	unpublished
	single find	*denaro*	Conrad II	Lucca	1027-1039	3	
Monteverdi Marittimo, Monastero di S. Pietro, Pisa	single find	*denaro*	Berengar I	Unspecified mint (Pavia)	898-900/902-915	1	unpublished
Pieve di Pava, Siena	single find	*obol*	Louis the Pious	Milan	822-840	1	Arslan, 2004
	single find	*denaro*	Berengar I	Milan	890-902	2	
	single find	*denaro*	Ugo di Arles King of Italy	Pavia	931-947	1	
	single find	*denaro*	Berengar I	Pavia	--------	1	
	single find	*denaro*	Conrad II	Lucca	1027-1039	2	
Pieve a Nievole, Pistoia	hoard	*denaro*	*Christus Imper*, type	Venice	1002-1027	21	Saccocci, 2003
		denaro	Henry III	Pavia	1039-1056	5	
Poggio Cavolo, Siena	single find	*denaro*	Otto I Emperor and Otto II King	Pavia	962-983	2	Vaccaro and Salvadori, 2006
Aulla, San Caprasio, Massa-Cassara	single find	*denaro*	Ugo di Arles King of Italy	Venice	926-931	1	Arslan, 2006
	single find	*denaro*	Berengar II and Adalbert	Pavia	951-961	1	
	single find	*denaro*	Otto I Emperor and Otto II King	Pavia	962-967	2	
	single find	*denaro*	Otto III Emperor	Pavia	996-1002	2	
	single find	*denaro*	Conrad II	Milano	1026-1039	1	
	single find	*denaro*	Conrad II	Lione	1032-1039	1	
San Genesio, Pisa	single find	*denaro*	Charlemagne	Tour	793-794/812	1	unpublished
	single find	*denaro*	Charles de Bald	Orleans	864-877	1	
San Pietro ad Asso, Siena	single find	*denaro*	Conrad II	Lucca	1027-1039	1	Rovelli, 2012b
San Quirico di Populonia, Monastero, Livorno	single find	*denaro*	Conrad II	Lucca	1027-1039	1	Cicali, 2016

Scarlino, Grosseto	single find	*denaro*	Otto I Emperor and Otto II King	Lucca	967-983	1	Rovelli, 1996
Verticella, Grosseto	Hoard?	*denaro*	Berengar I	Unspecified mint (Pavia)	898-900/902-915	3	Rovelli, 2020; Marasco and Cicali, 2020
		denaro	Berengar I	Pavia	898-900/902-915(?) [902-907]	3	
		denaro	Hugh of Arles and Lothar II	Pavia	931-947	1	
	single find	*denaro*	Hugh of Arles and Lothar II	Pavia	931-947	1	
	single find	*denaro*	Otto I Emperor and Otto II King	Lucca	962-967	1	
	single find	*denaro*	Otto II Emperor	Pavia	973- 983	2	
	single find	*denaro*	Otto I Emperor and Otto II King	Pavia		3	
	single find	*denaro*	Otto III (minority)	Lucca	983-996	1	
	single find	*denaro*	Otto III (?)	Pavia	983-1002 (?)	1	
	single find	*denaro*	Hugo, marquis of Tuscany	Lucca	986-c.990	1	
	single find	*denaro*	Conrad II	Lucca	1027-1039	4	
Total finds						**106**	

Table A1 – Summary of Carolingian and Italian kings' coins (9th - first half of 11th cent.) found in stratigraphic contexts and hoards of Tuscany.

APPENDIX B

Mining districts included in the PbIC database

Southern Tuscany

Metal deposits of southern Tuscany (Colline Metallifere area) are mostly characterized by Cu-Pb-Zn (Ag) vein bodies associated with late-Apenninic tectonic lineaments and emplaced by magmatic-meteoric hydrothermal fluids in the late stage of the Apenninic orogeny (Lattanzi et al., 1994). Two main areas of southern Tuscany show occurrences of silver bearing ores which could have been exploited in Medieval times: the first near Massa Marittima and the second near Campiglia Marittima. Ore district includes several Cu-Pb-Zn (Ag) ore occurrences among which the silver richest are those among Massa Marittima like Montieri, Cugnano and Rocchette castles. Following Pratellesi (1984) the mineralizations in the Montieri area occur generally as small ore veins and stockworks; main ore mineralogy includes: galena, argentian tetrahedrite, sphalerite, pyrite and chalcopyrite in a calcite-rich gangue with gypsum, fluorite and quartz. The main silver carriers are fahlerz ores (tetrahedrite-tennantite) with up to 2% silver and other minerals like pyrargirite-proustite, the presence of argentiferous galena generally mentioned in ancient papers is more probably due to small pyrargirite-proustite inclusions within galena (Domnori, 2013; Benvenuti et al., 2019)
Isotope data from: Chiarantini et al., 2018; Lattanzi et al., 1997; Stos-Gale et al., 1995.

Apuane Alps

Others silver mines in Tuscany are those located in the northern part of the region, near the Apennine Ridge, and so called Apuane Alps. Silver occurrences are mainly due to pre presence of silver bearing galena veins at Tambura mine associated with hematite ores, but exploited only in 16^{th} century (Mascaro et al., 1991), and the Pb–Ag–Zn ore deposits associated with tourmalinite (D’Orazio et al., 2016 and reference therein) of the Bottino–Gallena-Argentiera area where the first traces of silver exploitation dates back to 11^{th} century.
Isotope data from: D’Orazio et al., 2016; Lattanzi et al., 1992.

Italian Alps

Several small silver mines are mentioned scattered along the whole Italian Alps and a fully exhaustive description of all them is far behind the purpose of this paper. A general description of main copper-polymetalllic ore of Italian Alps and their lead isotope composition is provided by Artioli et al. (2016b), Giunti (2011), Nimis et al. (2012). Some of the more famous Alpine silver mines, like those of Auronzo (Veneto) have been included in the database, even if they have been exploited mostly from late Medieval or later times (www.minda.org).
Some silver occurrences that are mentioned to be possibly exploited in early Medieval times are those of Carnic Alps (Monte Avanza) firstly mentioned in 8th century AD and later deeply exploited in 13th-14th centuries under Venice Republic (Zucchini et al., 1998).
Following Rovelli (2004), written fragmentary sources mention two mining districts along Italian Alps: Ardesio mine (Lombardy) and Mt. Calisio mine (Trentino).
The Ardesio-Gorno mining district (Val Seriana) is characterized by several Zn- Pb-(Ag) and fluorite-barite ore bodies. The Gorno deposit represents one of the numerous carbonate hosted base-metal ore concentrations of the Alpine chain, also known as “Alpine-type” Zn-Pb mineralizations (Leach et al., 2003). The economically most significant deposits are those of Raibl, Salafossa, and Gorno (Italy) in the southern Alps, and Bleiberg (Austria) and Mežica-Topla (Slovenia) in the Northern Alps (Leach et al., 2003; Schroll 2005; Köppel and Schroll, 1988). The Ardesio mine was exploited between the late 12th and the mid 13th century AD (Menant, 1987). The first mention of the valley date back to a diploma dated 774, with which Charlemagne donated lands from the imperial domain located in Val Camonica, Val Seriana and Val di Scalve to the Abbey of Saint-Martin de Tours. This document is often cited but it does not contain any reference to the existence of silver veins. Charlemagne probably did not donate "the silver mines" but, more simply, the above mentioned valleys (Rovelli, 2004).
Sulphide-bearing ores of Trento area include silver-rich Pb–Zn–Cu mineralization exploited at several phases since the Middle Ages up to 1964, when the last mine of Calceranica was closed. Sulphide deposits are widespread in the area as attested by massive veins (dominated by pyrite) observed in Calceranica and the polymetallic veins (pyrite, galena, sphalerite, chalcopyrite with Bi Ag sulphides) at Erdemolo lake and Cinque Valli. Early Triassic magmatism, induced further remobilization and formation of ore deposits (galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, and barite) as observed in the Werfen formation outcropping at Mt. Calisio and Maso Furli (Lavis) (Artioli et al., 2016b, Bianchini et al., 2019, Nimis et al., 2012). The studies of Gianni Ciurletti (1997) however exclude the exploitation of the silver mines of Mont Calisio before the end of the 11th, except, some superficial and modest-scale interventions for the needs of a small local community.
Isotope data from: Artioli et al., 2016b, Giunti, 2011, Köppel and Schroll, 1988, Nimis et al., 2012.

Melle

The mines of Melle in Aquitaine were perhaps the most important silver mines during the times of Merovingian kings and Carolingian emperors. The mining of argentiferous galena began probably in the 5th century AD but a massive increase in the scale of production occurred in the late 7th century AD in association with the Merovingian Empire (Téreygeol, 2007; 2013). As a result, the coinage of Melle and of Aquitaine (8th-10th centuries AD) are found over a broad geographic area from Spain to eastern Europe (Téreygeol, 2007). The exploited ore was massive galena containing from one and five per thousand amounts of silver (Coiteux, 1982). The mineralization takes place in a karst structure with Melle as the south border. Most of galena was concentrated between 2-5 metres below the ground level. Mines were exploited as open pit mining through fire-setting. The global contents of lead and silver were thus estimated as 750,000 tons of lead and 1,400 tons of silver (Téreygeol, 2013). The abandonment of the mine at the end of the 10th century AD and absence of subsequent reworking of the deposit helped to preserve traces of medieval mining. The charcoal residue of fire setting extraction helps to reconstruct the chronology of mining through radiocarbon dating suggesting that mining was actively pursued between the last quarter of the 7th century AD until the end of the 9th century AD, and production declined in the 10th century AD partially due to the decreased wood supply (Téreygeol, 2013).
Isotope data from Téreygeol et at., 2005.

Massif Central

The French Massif Central hosts a number of lead polymetallic ores (Zn, Sb, Pb, Ag, Cu, Sn, W) of Permo-Triassic age generally associated to the emplacement of Hercynian granitoids or, in more general terms, to fluid circulations associated with the Hercynian orogeny. Many of them (Malines Mine, Les Borderies, Haut-Allier, Montagne Noire – Cevennes, Mont-Lozère) have been deeply exploited during 20th century mostly for Zn-Sb extraction and deeply investigated. Lead and polymetallic deposits of this area were mined in the pre-Roman and Roman periods between the 2nd century BC and the 1st century AD (Meier, 1995).

Medieval mining of argentiferous galena is attested by about 70 smelting sites in the in the Mont-Lozère region with radiocarbon dates ranging from the late 10th century AD to the 13th century AD (Baron et al., 2006). There is a concentration of the radiocarbon dates from the first half of the 12th century AD (Ploquin et al., 2003) and the dating of the lead-silver production might indicate that this region took over as mining operations at Melle ceased at the end of the 10th century AD. Lead-rich slag was found at 70 sites in the Mont-Lozère region dating from this period (Baron et al., 2006).They conclude from the lead isotope analysis of ore and slag from the region that galena from the mines of Montmirat and Les Bondons was the most likely ore smelted, although these mines are not the nearest to the slag heaps. It is thought that the ore was brought to the smelting sites because of the available wood supply or for political reasons (Baron et al., 2006).

Isotope data from: Brevart et al., 1982; Cassard et al., 1994; Le Guen et al., 1991; Marcoux et al., 1988; Marcoux and Bril, 1986; Marcoux and Picot, 1985.

Other France silver mines

Outside these regions other medieval mines in France are documented in the Pyrenees region with the exploitation of polymetallic or lead-silver deposits to various extents (Marcoux, 1986; Marcoux et al., 1991). In this area there is the Castel-Minier site (Aulus-les-Bains) which was one of the most important silver mines in the French kingdom during the second part of the 14th Century. The site includes both facilities related to the production of silver and iron with the beginning of the exploitation of silver deposits at the beginning of 12th century. Mining activity lasts until the 15th century. The importance of silver production and its role in the medieval economy explain why the viscount of Couserans installed the eponymous fortification. The castle is occupied and maintained as long as the mine lasts (Téreygeol, 2016). Isotope data from: Marcoux, 1986; Marcoux et al., 1991.

Another silver lead mine is that at L'Argentière-La Bessée, the largest mining districts of the French southern Alps (Ancel, 2010; Ancel et al., 2010). Medieval mining works were developed with opencast (over 2400 m^2) and underground for nearly 2 km. Manuscripts and written sources document mining between 1150 and 1250 AD and radiocarbon dates stretch this chronology from the start of the 10th to the late 13th AD (Py et al., 2014) Isotope data from: Py et al., 2014.

Rhenish Massif (Eifel, Hunsrük, Bergisches Land, Siegerland, Sauerland, Taunus)

The fold-thrust-belt of the Rhenish Massif forms a major part of the northern external zone of the Central European Variscan orogen. Fluid processes causing hydrothermal mineralization can be related to four major periods of large-scale tectonic evolution, which are: pre-orogenic extension, syn-orogenic compression, late-orogenic exhumation, and post-orogenic extension (Hein and Behr, 1994) with ages ranging from Middle and Upper Devonian to Meso-Cenozoic.

The Rhenish Massif display a number of Pb-Zn-Cu and Ag mineralization. In the region spanning from Liege to Aachen, Trier, Cologne and Dortmund there are several mines dating to the Roman period, but mining in the there is currently little evidence of Carolingian-era mining activities. The earliest evidence of mining and smelting of lead-silver ores in the Bergisches Land region, dates back to the 11th-13th century, while in the Siegerland region the first activities can be observed as early as the 9^{th-}10th centuries.

Historical records indicate that silver mining was active at least in the 12^{th} and 13^{th} centuries (the mine of Mechernich near Aachen, Lüderich, Altenberg in Siegerland, Bad Ems (Bartels and Klappauf, 2012). Many ore deposits worked by the Romans continued to be mined or were reactivated in the medieval period under the governance of the Carolingian/Ottonian/Salian sovereigns or the Archbishops of Cologne or Trier. There is evidence for mining at some localities in the Carolingian and Ottonian periods, but it is sporadic and often indirect. Some examples are: the lead-silver deposit of Lüderich (east of Cologne) with traces of Roman mining and silver production (Bode, 2008) and probably resumed the Carolingian period (9^{th} century) (Gechter, 2001); the Ramsbeck mine where there are evidences that medieval lead-copper-silver mining began in the 10^{th}-11^{th} century AD, though the first historical mention of the mine is only in the 14^{th} century (Strassburger, 2007); and many others Pb-Ag ore occurrences (see Merkel, 2016 for further details).
Isotope data from: Durali-Mueller et al., 2007, Large and Schaeffer, 1983, Krahn and Baumann,1996; Lehmann, 2011, Wagner and Schneider, 2002.

Harz Mountains
There are two main ore mineralizations in the Harz Mountains: Rammelsberg, which is characterized by banded fine-grained intergrowth of pyrite, chalcopyrite, galena, sphalerite, and fahlore (tetrahedrite), and the Upper Harz, which is characterized by hydrothermal veins with large crystal growths of galena, sphalerite, pyrite, chalcopyrite and fahlore (Asmus, 2012). The two deposits formed under very different geologic conditions and ages. The Rammelsberg deposit formed in the Carboniferous during the Variscan orogeny, while those in the Upper Harz are distinctly younger and formed during the post-Variscan Triassic era. Both types of deposits host silver ores, but the Upper Harz deposits are on average richer and can be easier beneficiated since characterized by pockets of mineralization and veins containing high-grade silver ore can be found (argentiferous galena – tetrahedrite) (Asmus, 2012; Stedingk, 2012).

Mining in the Harz Mountains probably occurred since the 3^{rd} century AD (Klappauf, 1989). Copper, lead, and silver were produced in the following centuries with an increase in production in the 9^{th} century probably due to the organization and control of mines first by the Carolingians and later under the Ottonians (Klappauf et al., 1991). The first historical mentions of silver mining come from the History of the Saxons by Widukind von Corvey in 968 stating that “veins of silver were opened in the land of the Saxons”. In the same manner Thietmar of Merseburg in the early 11^{th} century wrote that under the reign of Otto the Great (936-973 AD), “the first silver mine was established in the land of the Saxons” (Steuer, 2004). Silver mining in the Harz have often been associated with the Rammelsberg deposit, which is however primarily a copper deposit while ore deposits of the Upper Harz and western Harz were probably more important for medieval silver production (Klappauf, 2011; Klappauf et al., 2008).
Also the archaeological evidence in the Upper Harz indicates that Cu-Pb and silver were already produced in the 9^{th} century (Alper, 2003) and the sharp increase of silver mining in the 10^{th} century may have been a result of the combined efforts of Ottonian emperors and ecclesiastic administration in Magdeburg.
In the settlement of Badenhausen were found remains of smelting and cupellation dating to the 9^{th} - 10^{th} century (Brockner et al., 1989; Klappauf, 1993).
Isotope data from: Hatz et al., 1991; Lehmann, 2011; Lévèque and Haack, 1993.

Erzgebirge
Most of the base metal deposits in the Erzgebirge are hydrothermal polymetallic (Pb-Zn-Cu-Ag-Sn-Co) sulphide-vein mineralizations (Baumann et al., 2000; Niederschlag et al., 2003). The Saxonian Erzgebirge is famous for its rich silver deposits, which were mined in the High and Late Middle Ages. The first historical mentions of silver ore at Freiberg date to around 1168 AD (Schwabenicky, 2011), a time when the development of mining laws started a period of intensive colonization in the region

(Asrih, 2013). Archaeological evidence of silver metallurgy is attested in the Erzgebirge in the 13th and 14th centuries AD (Eckstein et al., 1994).
Mining of silver in Slovakian Erzgebirge may have begun in the Early Middle Ages when the gold-silver ore deposits in the region of Banská Štiavnica were particularly important. Silver mining in this region may have had its roots in the 10th century AD as mentioned in the Nestor Chronicles written in 969 AD. In the Middle Ages Banská Štiavnica region may have produced silver with a high gold content (up to 1 %) (Zámora et al., 2008) and the historical accounts suggest that silver was produced in quantities large enough for export, at least into the Danube-Dnieper river systems.
Isotope data from: Niederschlag et al., 2003

Black Forest and Odenwald

In southwestern Germany there are more than 1000 hydrothermal mineralizations of Permian to Cenozoic age most of which occur in the Black Forest area which is part of the European Variscan fold belt. The mineralizations are typically classified as hydrothermal vein-type deposits (Pfaff et al., 2009, Staude et al., 2009), strata bound mineralizations of sedimentary origin (Hofmann, 1979; 1989), and carbonate-hosted, strata bound Mississippi Valley-type deposits (Pfaff et al., 2010).
In the Black Forest a document issued by Konrad II in 1028 AD mentions the silver mines south of Freiburg, donating the mines and the mineral deposit to the bishop's church in Basel. There is evidence of Roman lead and silver production in the area near Sulzburg, and mining was possibly resumed in the Carolingian period but archaeological evidence for production has been radiocarbon dated from the late 10th to the 12th centuries AD (Hildebrandt, 2012; Steuer, 1993).

At Wiesloch in the Odenwald, a number of mines, ore-beneficiation sites, and smelting sites have been discovered dating to the 9th and 10th century AD (Hildebrandt, 1993; 2012). The Mississippi-Valley-Type lead-zinc-silver deposit of Wiesloch was exploited by the Romans. In the past it was thought that the medieval production focused on the extraction of lead and zinc sulphides (Hildebrandt, 1993; 2012), but more recent research indicates that lead-zinc deposits containing calamine were probably more important for silver production, since a notable silver content up to 5000 ppm is found in sphalerite and other zinc minerals (Kötz et al., 2009). The slags from Wiesloch are thought to have been produced during the smelting of argentiferous calamine and galena (Ströbele et al., 2010).
Isotope data from: Hatz et al., 1991; Ströbele et al, 2012; 2015.

Austria

Several silver rich ore deposits occur in Austria, among them the large copper deposits in the Schwaz–Brixlegg area in the Inn Valley (Gstrein, 1979). They contained predominantly argentiferous tetrahedrite, which formed the basis of enormous wealth in the 14th and 15th centuries AD producing about 3000 metric tons of silver and about 250000 metric tons of copper (Hanneberg and Schuster, 1994).
The mineralizations in the Schwaz–Brixlegg area occur in different geological complexes: the Triassic limestones are partly mineralized with copper, lead and zinc ores, with minor cobalt and silver minerals, while the fahlore composition in the Palaeozoic gneiss and the Schwazer dolomite (lower Devonian) is predominantly arsenical tetrahedrite and in the Triassic limestone it is mainly tennantite. The primary ore of the deposits between Schwaz and Brixlegg is almost exclusively arsenical tetrahedrite with significant concentrations of Zn, Hg, Fe and Ag. In decomposed fahlores, Ag and Hg are enriched. This mineral paragenesis is characteristic of the so-called Grauwackenzone of the northern Alps (Höppner et al., 2005).
Other precious metal-bearing ore districts occur the eastern Tauern window south of Salzburg: the Au-quartz veins in the Badgastein-Sonnblick area (Feitzinger and Paar, 1991); the As±Au±Ag deposits around Rotgülden (Weidinger and Lang, 1991); and the Au district of Schellgaden near the eastern margin (Göd, 1981). These deposits played an important part in the historical and cultural

development of the region. Mining of gold and silver-bearing lodes up to an elevation of more than 3000 m, started probably in pre-Roman times and flourished between the 15th and the 18th century. Isotope data from: Höppner et al., 2005; Horner et al., 1997, Schroll et. al., 2006.

England and Ireland

Following Tylecote (1986) "Britain was mainly a silver importer at all times". There is limited evidence suggesting that some newly mined silver came from English sources from the 10th century onwards but it was not until the early part of the 12th century that firm evidence is available (Claughton and Rondelez, 2013). Some documentation of silver production is reported from the mines of Alston, Cumberland between 1100-1307 AD, while much more evidence of Pb production was concentrated in Derbyshire and the Mendips (Tylecote, 1986), where silver production in 9th century is still uncertain (Blanchard, 2001). The only known documentary evidence for silver production in England before the 12th century is to be found in Domesday Book, which was compiled from a survey made in 1086. The five Derbyshire manors of Darley, Matlock, Wirksworth, Ashbourne, and Parwich were recorded providing an annual payment of 40 pounds of pure silver in 1066. The resources of the manors included lead works or mines (plumbiariae), which may well have been the source of the 40 pounds of silver. During the 12th century the main focus of silver production in the Pennines moved from Derbyshire in the south to the northern Pennine ore field, which covers parts of Cumberland, Northumberland, and Durham. The English Crown controlled the dispersed collection of workings known as the 'mine of Carlisle', which were actually around Alston about 35 miles to the east of Carlisle, where the mining operation here probably began in the 1120 (Allen, 2011). Once the silver-bearing deposits in the North Pennines had been worked out in the late 12th century, England had to rely on continental European resources until new mines were opened up in Devon at the end of the 13th century (Claughton and Rondelez, 2013).
Ross Island in Ireland is mentioned as a Cu-Pb-Zn-Ag deposits exploited since Bonze Age with evidence also of early medieval workings (Ixer and Budd, 1998). Copper matte found in slags dated to the 9th century contains some silver; however, it is unknown if silver was indeed produced at Ross Island (Meyerdirks et al., 2004), and in what amounts.
Isotope data from: Rohl, 1996.

Other mining districts exploited in Early Medieval Times

Silver is well known to have been produced in Iberia during Phoenician and Roman times, but not after the Barbaric Invasions. Following Blanchard (2001) silver production resumed during the 9th-10th centuries in the Roman mines at Carthagena and Mazarrón.
Some evidence of Pb-Ag exploitation in Anatolia during the Byzantine Empire since the 7th century AD came from the famous deposit of Tralles, near Magnesia in SW Anatolia (present-day Gümüşköy; Meier, 1995), and small workings of silver mines after the 8th cent. are testified in the region (Matschke, 2002).

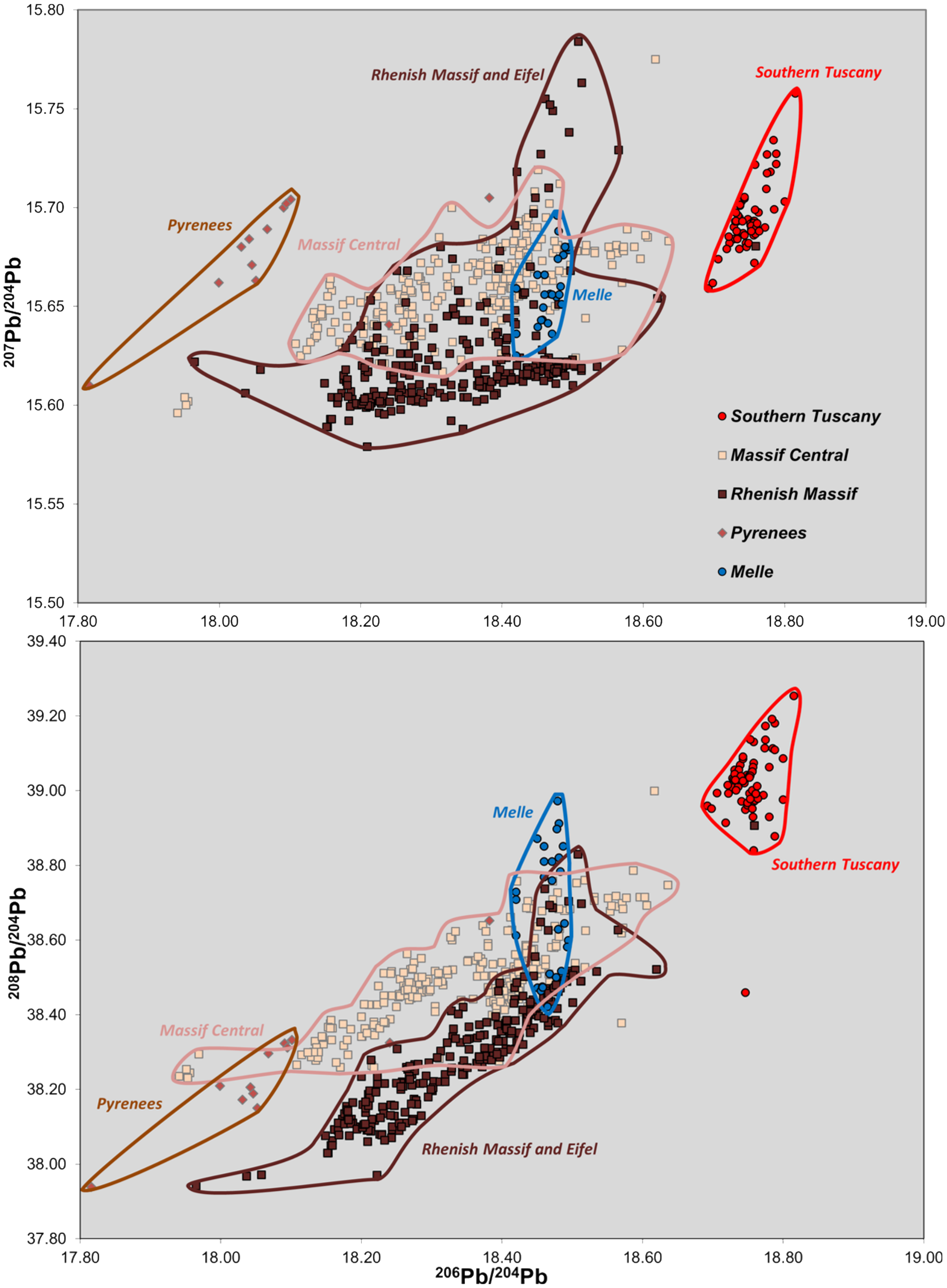

Figure B1 - $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams displaying Melle, Massif Central, Pyrenees, Rhenish Massif-Eifel and southern Tuscany ore districts. Coloured polygons enclosed all LI data from literature as reported in Appendix B.

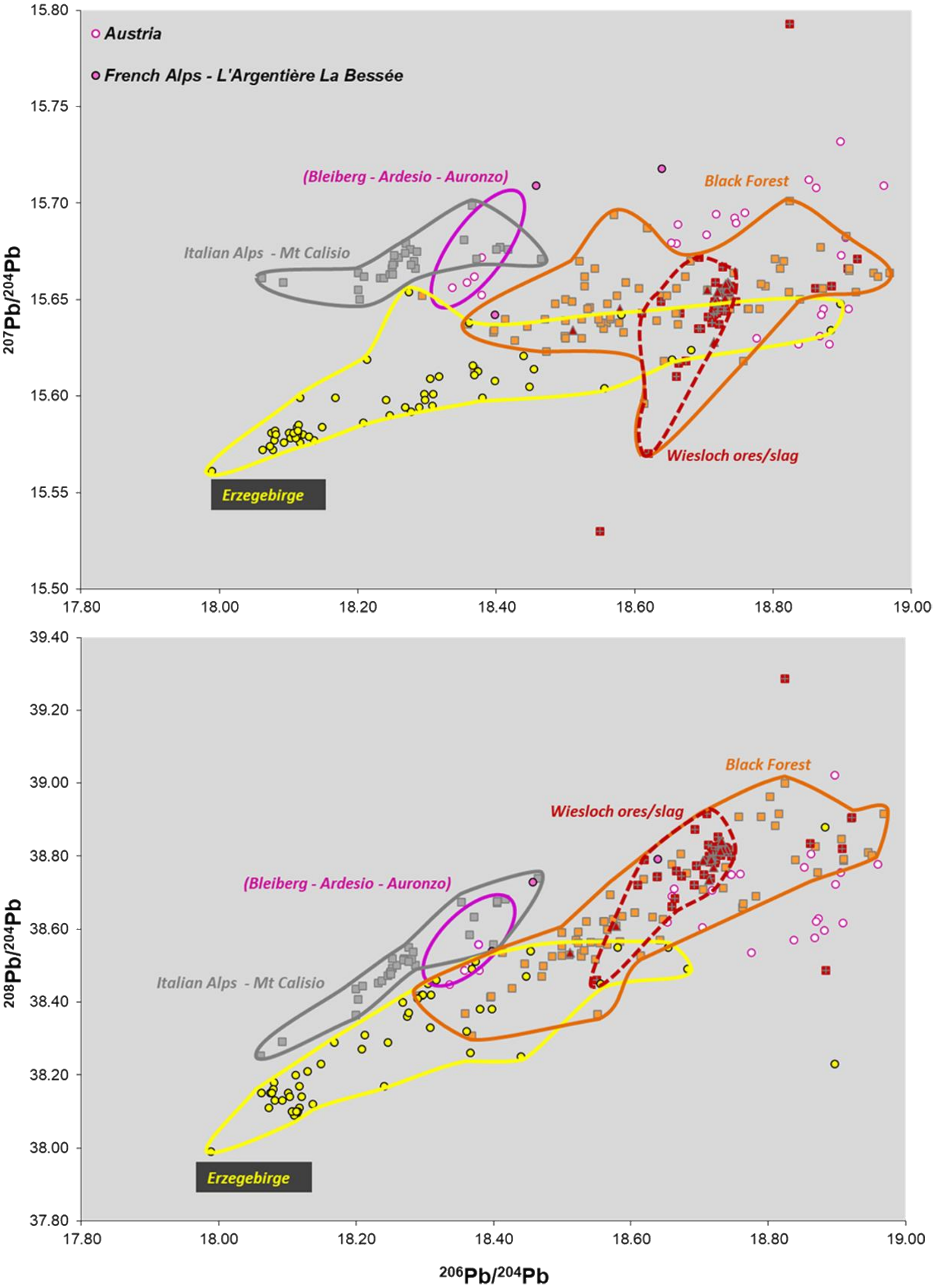

Figure B2 - *^{207}Pb/^{204}Pb vs. ^{206}Pb/^{2046}Pb (top) and ^{208}Pb/^{204}Pb vs ^{206}Pb/^{204}Pb (bottom) Austria, Black Forest, Erzgebirge and Italian Alps ore districts. Coloured polygons enclosed all LI data from literature as reported in Appendix B.*

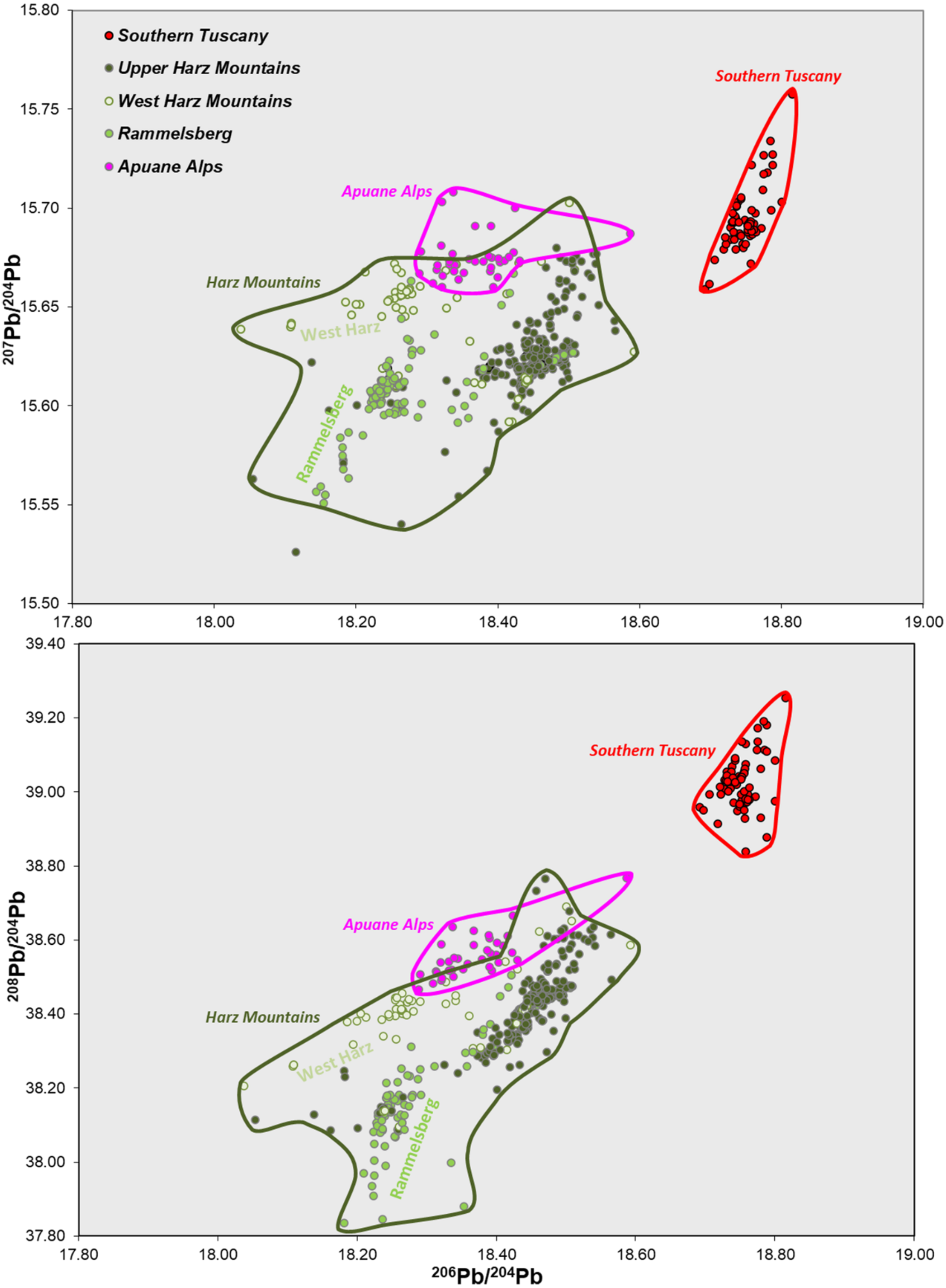

Figure B3 - *$^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{2046}Pb$ (top) and $^{208}Pb/^{204}Pb$ vs $^{206}Pb/^{204}Pb$ (bottom) diagrams displaying Harz Mountain, Apuane Alps and southern Tuscany ore districts. Coloured polygons enclosed all LI data from literature as reported in Appendix B.*

References

Allen, M. 2011. Silver production and the money supply in England andWales, 1086–c.1500. Economic History Review, 64, 1, 114–131.

Alper, G., 2003. Johanneser Kurhaus. Ein mittelalterlicher Blei-Silbergewinnungsplatz bei Clausthal Zellerfeld im Oberharz. Materialhefte zur Ur- und Frühgeschichte Niedersachsens 32, Rahden Westphalia.

Ancel, B., 2010. Les anciennes mines métalliques des Alpes du Sud: bilan diachronique. Archéologie de l'espace montagnard: confrontation d'expériences européennes, Archéologie de la montagne européenne, Actes de la table ronde internationale de Gap, 29, 293-300.

Ancel, B., Py, V., Kammenthaler, E., Leleu, V., Marconnet, C., 2010. Une mine de plomb argentifère dans un environnement montagnard. La mine médiévale du Fournel à L'Argentière-la-Bessée (Hautes-Alpes). ArcheoSciences 34, 203-220.

Anguilano, L., Rehren, T., Müller, W., Rothenberg, B., 2010. The importance of lead in the silver production at Riotinto (Spain). ArcheoSciences 34, 269-276.

Anguilano, L., 2012. Roman lead silver smelting at Rio Tinto: the case study of Corta Lago. PhD thesis, University College London. https://discovery.ucl.ac.uk/id/eprint/1348305/1/1348305.pdf (accessed 21 July 2020).

Arslan, E.A.,2004. Saggio di repertorio dei ritrovamenti di moneta vandala, altomedievale (489-1002), bizantina e islamica in Italia peninsulare e insulare, con Corsica, Canton Ticino, Istria croata, on line edition from 2002 to 2004 (last edition 1/12/2004), http://www.muenzgeschichte.ch/downloads/Repertorio_AltoMedievale.pdf.

Arslan, E., A., 2006. S. Caprasio di Aulla. Le monete, in AA.VV., Indagini archeologiche nella chiesa dell'abbazia altomedievale di San Caprasio ad Aulla (MS), Archeologia Medievale XXXIII, 167-221.

Artioli, G., Angelini, I., Addis, A., Canovaro, C., Chiarantini, L., Benvenuti, M., 2016a. Ceramiche tecniche, scorie, minerali e metalli: interpretazione del processo metallurgico, in: Fedeli, L., Galiberti, A. (Eds.), Metalli e metallurghi della preistoria: l'insediamento eneolitico di San Carlo-Cava Solvay, Tagete Edizioni, Pontedera, pp. 68–81.

Artioli, G., Angelini, I., Nimis, P., Villa, I.M., 2016b. A lead-isotope database of copper ores from the Southeastern Alps: A tool for the investigation of prehistoric copper metallurgy. Journal of Archaeol. Sci. 75, 27-39.

Asmus, B., 2012. Medieval copper smelting in the Harz Mountains, Germany. Montanregion Harz, Band 10, Bergbau-Museum, Bochum.

Asrih, L., 2013. Analysis of the Medieval Development of Mining Laws and Settlements in the Saxon Ore Mountains, Metalla 20(2), 28-29.

Attanasio, D., Bultrini, G., Ingo, G.M., 2001. The Possibility of Provenancing a Series of Bronze Punic Coins Found at Tharros (Western Sardinia) using the Literature Lead Isotope Database, Archaeometry 43(4), 529–47.
Baldassarri, M., 2004. I reperti numismatici, in Quiros Castillo, J.A. (Ed.), Archeologia e storia di un castello apuano: Gorfigliano dal medioevo all'età moderna, Firenze, 146-148.
Baron, S., Carignan, J., Laurent, S., Ploquin, A., 2006. Medieval lead making on Mont-Lozère Massif (Cévennes-France): Tracing ore sources using Pb isotopes, Appl. Geochem. 21(2), 241–52.
Baron, S., Tămaş, C. G., Le Carlier, C., 2014. How mineralogy and geochemistry can improve the significance of Pb isotopes in metal provenance studies, Archaeometry 56(4), 665–80.
Bartels, C., Klappauf, L., 2012. Der Aufschwung des Bergbaus in der Zeit der Karolinger und Ottonen, die mittelalterliche Blüte und der Abschwung bis zur Mitte des 14. Jahrhunderts, in: Bartels, C., Slotta, R. (Eds.), Geschichte des deutschen Bergbaus: Band 1, Der alteuropäische Bergbau. Von den Anfängen bis zur Mitte des 18. Jahrhunderts, Münster, 111-238.
Baumann, L., Kuschka, E., Seifert, Th., 2000. Lagerstätten des Erzgebirges, Enke im Thieme Verlag, Stuttgart.
Benvenuti, M., Bianchi, G., Bruttini, J., Buonincontri, M., Chiarantini, L., Dallai, L., Di Pasquale, G., Donati, A., Grassi, F., Pescini, V., 2014. Studying the Colline Metallifere mining area in Tuscany: an interdisciplinary approach, in: Silvertant, J. (Ed.), Research and preservation of ancient mining areas, IES Yearbook 2014, pp. 274-287.
Benvenuti, M., Chiarantini, L., Cicali, C., Donati, A., Rovelli, A., Villa, I., Volpi, V., 2018. Metals and coinage in Medieval Tuscany: the Colline Metallifere, in: Bianchi, G., Hodges, R. (Eds.), The nEU-Med project: Vetricella an early medieval royal property on Tuscany’s Mediterranean, All’Insegna del Giglio, Florence, pp. 135-146.
Benvenuti, M., Chiarantini, L., Cicali, C., Villa, I. M., Volpi, V., 2019. La produzione d’argento nel distretto minerario di Montieri-Massa Marittima (Colline Metallifere, Toscana meridionale). Alcune considerazioni su dati recenti, in: Larousse, N. M., Bailly-Maitre, M.C., Bianchi, G., (Eds.), Les métaux précieux en Méditerranée médiévale Exploitations, transformations, circulations, Presses Universitaires de Provence, pp. 41-51.
Bianchi, G., 2004. Castello di Donoratico. I risultati delle prime campagne di scavo (2000-2002), All’Insegna del Giglio, Firenze.
Bianchi, G., 2010. Dominare e gestire un territorio. Ascesa e sviluppo delle ‘signorie forti’ nella Maremma toscana del Centro Nord tra X e metà XII secolo, Archeologia Medievale, XXXVII, pp. 93-104.

Bianchi, G., 2018. Public powers, private powers and the exploitation of metals for coinage. The case of medievale Tuscany, in: Balzaretti, R., Barrow, J., Skinner, P. (Eds), Italy and Early Medieval Europe. Papers for Chris Wickham, Oxford University Press, Oxford, pp. 384-401.

Bianchi, G., Bruttini, J., Grassi, F., 2012. Lo scavo della Canonica di San Niccolò a Montieri (GR), Notiziario della Soprintendenza per i Beni Archeologici della Toscana, 8, pp. 564-567.

Bianchi, G., Bruttini, J., Dallai, L., Grassi, F., 2013. Nuovi dati dalla ricerca archeologica per la ricostruzione del paesaggio storico delle Colline Metallifere massetane, in: Galeotti, G., Paperini, M. (Eds.), Città e territorio. Conoscenza, tutela e valorizzazione dei paesaggi culturali, Debatte, Livorno, pp. 81-85.

Bianchi, G., Hodges, R., 2018. Origins of a new economic union (7th-12th centuries). Preliminary results of the nEU-Med project: October 2015-March 2017, All’Insegna del Giglio, Firenze.

Bianchi, G., Rovelli, A., 2018. Production minière et production monétaire en Toscane au Moyen Âge (VIII^{e}-XII^{e} siècle): un long chemin, in: Bompaire, M., Sarah, G. (Eds), Mine, metal, monnaie, Melle. Les voies de la quantification de l’histoire monétaire du haut Moyen Âge, Droz, Genève, pp. 111-139.

Bianchi, G., Hodges, R. , 2020. nEU-Med project: Vetricella, an Early Medieval royal property on Tuscany’s Mediterranean, All’Insegna del Giglio, Firenze.

Bianchini, G., Natali, C., Ferretti, P., Casagrande, L., Conedera, M., Marchina, C., 2019. Trace-Element Distribution on Sulfide Mineralization in Trento Province, NE Italy. Minerals 9, 736.

Birch, T., Westner, K. J., Kemmers, F., Klein, S., Höfer, H. E., Seitz, H. M., 2020. Retracing Magna Graecia's silver: coupling lead isotopes with a multi-standard trace element procedure. Archaeometry 62(1), 81-108.

Blanchard, I., 2001. Mining and Minting in the Middle Ages, Vol. 1, Asiatic Supremacy, 425-1125, Franz Steiner Verlag, Stuttgart.

Bode, M., 2008. Archäometallurgische Untersuchungen zur Blei-Silbergewinnung im Germanien der frühen römischen Kaiserzeit, PhD Thesis, Westfälische Wilhelms Universität Münster. http://d-nb.info/992682231/34 Accessed 24 July 2020.

Brevart, O., Dupré, B., Allegre, C.J., 1982. Metallogenic provinces and the remobilization process studied by lead isotopes; lead-zinc ore deposits from the southern Massif Central, France, Econ. Geol. 77(3), 564-575.

Briano, A., Sibilia, E., 2018, Progetto nEU-Med. Nuove analisi archeologiche e archeometriche sulla ceramica a vetrina sparsa dal castello di Donoratico (LI): i risultati della Termoluminescenza, Archeologia Medievale, XLV, 357-365.

Brill, R.H., Shields, W R., 1972. Lead Isotopes in Ancient Coins, Methods of Chem. and Metallurg. Investig. of Ancient Coinage 269(8), 272-303.

Brockner, W., Kolb, H.E., Heimbruch, G., 1989. Eine Silberraffinierhütte des frühen Mittelalters in Badenhausen am Harz. Nachrichten aus Niedersachsen Urgeschichte 58, 193-206.

Bruttini, J., Fichera, G., Grassi, F., 2009. Un insediamento a vocazione mineraria nella Toscana medievale: il caso di Cugnano nelle Colline Metallifere, The Journal of Fasti Online 179, 1-10.

Buttery, T., V., 1980. Cosa: the coins. Memoirs of the American Academy in Rome, 34, 1-65.

Cambi, F., Dallai, L., 2000. Archeologia di un monastero: gli scavi a San Salvatore al monte Amiata, Archeologia Medievale, XXVII, 193-210.

Campana, S., Felici, C., Marasco, L., 2008. La vita di una Chiesa dalla fase paleocristiana a quella basso medievale. Scavo archeologico della pieve e del cimitero di Pavia (fine V-inizio XIII secolo), in: Campana, S., Felici, C., Francovich, R., Gabbrielli, F., (Eds), Chiese e insediamenti nei secoli di formazione dei paesaggi medievali della Toscana (V-X secolo), Atti del Seminario (San Giovanni d'Asso-Montisi, 10-11 novembre 2006), All'Insegna del Giglio, Firenze, pp.24-35.

Cantini, F., 2008. La Chiesa e il borgo di San Genesio: primi risultati dello scavo di una grande pieve della Toscana altomedievale (campagne di scavo 2001-2007), in: Campana, S., Felici, C., Francovich, R., Gabbrielli, F. (Eds.), Chiese e insediamenti nei secoli di formazione dei paesaggi medievali della Toscana (V-X secolo), Atti del Seminario (San Giovanni d'Asso-Montisi, 10-11 novembre 2006), All'Insegna del Giglio, Firenze, pp. 65-94.

Cantini, F., 2010, Vicus Wallari-borgo San Genesio. Il contributo dell'archeologia alla ricostruzione della storia di un central place della valle dell'Arno, in: Cantini, F., Salvestrini, F. (Eds.), Vico Wallari – San Genesio. Ricerca storica e indagini archeologiche su una comunità del Medio Valdarno inferiore fra alto e pieno medioevo, Firenze University Press, Firenze, pp. 81-123.

Cassard, D., Chabod, J. C., Marcoux, E., Bourgine, B., & Castaing, C., 1994. Mise en place et origine des minéralisations du gisement filonien à Zn, Ge, Ag, (Pb, Cd) de Noailhac-Saint-Salvy (Tarn, France). Chronique de la recherche minière 514, 3-37.

Chiarantini, L., Benvenuti, M., Costagliola, P., Dini, A., Firmati, M., Guideri, S., Villa, I.M., 2018. Copper metallurgy in ancient Etruria (southern Tuscany, Italy) at the Bronze-Iron Age transition: a lead isotope provenance study, Journal of Archaeol. Sci. Rep. 19, 11-23.

Cicali, C., 2008. I reperti monetali di Miranduolo. Prime indicazioni sulle tipologie e sugli aspetti circolatori, in: Valenti, M. (Ed.), Miranduolo in Alta Val di Merse (Chiusdino – SI), All'Insegna del Giglio, Firenze, pp. 403-414.

Cicali, C., 2016. I reperti numismatici, in Bianchi, G., Gelichi, S. (Eds.), Un monastero sul mare. Ricerche archeologiche a San Quirico di Populonia (Piombino, LI), Firenze, 277-282.

Ciurletti, G., 1997. Le miniere d'argento del Monte Calisio: già note e coltivate prima del Medioevo?, in: Brigo, L., Tizzoni, M. (Eds.), II Monte Calisio e l'argento nelle Alpi dall'Antichità al XVIII secolo. Giacimenti, storia e rapporti con la tradizione mineraria mitteleuropea. Atti del Convegno europeo, 12-14 ottobre 1995, Trento, p. 69-78.

Claughton, P., Rondelez, P., 2013. Early silver mining in Westren Europe: an irish perspective. Journal of the Mining Heritage Trust of Ireland, 13, 1-8.

Coiteux, S., 1982. Le métallotecte de Melle (Deux-Sèvres) contexte sédimentaire et minéralisation, unpublished PhD Thesis, Université de Poitiers, 1982.

Coupland, S., 2011. Riders, traders, worshippers and settlers: the continental prospective, in: Graham-Campbell, J., Sindbæk, S.M., Williams, G., (Eds.), Silver economies, monetisation and society in Scandinavia AD 800-1100, Aarhus University Press, Aarhus pp.113-131.

Craddock, P., 1995. Early Metal Mining and Production, Edinburgh University Press, Edinburgh.

Dallai, L., Francovich, R., 2005. Archeologia di miniera ed insediamenti minerari delle Colline Metallifere grossetane nel Medioevo, in: Cataldi, R., Ciardi, M. (Eds.), Il calore della terra, ETS, Pisa, pp. 126-142.

Davite, C., 1988. Scavi e ricognizioni nel sito rurale tardo antico di Gronda (Luscignano, Massa Carrara), Archeologia Medievale, 15, 397-40.

D'Orazio, M., Biagioni, C., Dini, A., Vezzoni, S., 2016. Thallium-rich pyrite ores from the Apuan Alps, Tuscany, Italy: constraints for their origin and environmental concerns, Mineralium Deposita, 52, 687–707.

Desaulty, A.M., Telouk, P., Albalat, E., Albarède, F., 2011. Isotopic Ag – Cu – Pb record of silver circulation through 16th – 18th century Spain, PNAS 108(22), 9002-7.

Domnori, M., 2013. Le mineralizzazioni a Pb-Cu-Ag del territorio di Massa Marittima-Montieri-Monterotondo Marittimo (provincia di Grosseto): aspetti giacimentologici e studio delle inclusioni fluide, MSc Thesis, Università degli Studi di Firenze.

Durali-Mueller, S., Brey, G. P., Wigg-Wolf, D., Lahaye, Y., 2007. Roman lead mining in Germany: its origin and development through time deduced from lead isotope provenance studies. J. of Archaeol. Sci. 34(10), 1555-1567.

Eckstein, K., Rehren, T. H. H., Hauptmann, A., 1994. Hochmittelalterliches Montanwesen im sächsischen Erzgebirge und seinem Vorland. Die Gewinnung von Blei und Silber. Der Anschnitt 46, 122-132.

Feitzinger, G., Paar, W.H., 1991. Gangförmige Gold-Silber-Vererzungen in der Sonnblickgruppe (Hohe Tauern, Kärnten). Archiv für Lagerstättenforschung der Geologischen Bundesanstalt 13, 17-50.

Fornacelli, C., Briano, A., Chiarantini, L., Bianchi, G., Benvenuti, M., Giamello, M., Kang, J.S., Villa, I.M., Talarico, M., Hodges, R. 2020. Archaeometric provenance constraints for Early

Medieval sparse glazed pottery from Donoratico (Livorno, Italy), Archaeometry, DOI: 10.1111/arcm.12633.

Franceschi, F., 2017. Introduzione, in: La crescita economica dell'Occidente medievale. Un tema storico non ancora esaurito, Viella, Roma, pp.1-24.

Francovich, R., 1991. *Rocca San Silvestro*, Leonardo-De Luca, Roma.

Francovich, R., Bianchi, G., 2006. Prime indagini archeologiche in un monastero della Tuscia altomedievale: S. Pietro in Palazzuolo a Monteverdi Marittimo (PI), in: Francovich, R., Valenti, M. (Eds.), IV Congresso Nazionale di Archeologia Medievale, All'Insegna del Giglio, Firenze, pp. 346-352.

Gale, N.H., Stos-Gale, Z., 2000. Lead isotope analyses applied to provenance studies, Chemic. Analysis 1(155), 503–84.

Gechter, M., 2001. Ein Überblick über den Forschungsstand zur Montanarchäologie im Bergischen Land, in: Pohl, E., Recker, U., Theume, C. (Eds.), Archäologisches Zellwerk. Beiträge zur Kulturgeschichte in Europa und Asien, Rahden Westphalia, 39-45.

Gianazza, L., 2021. Repertorio dei ritrovamenti monetari. Italia (medievale e moderno), edition 15/2021 (last version 24/03/2021), https://www.sibrium.org/Materiali/index.htm.

Giunti, I., 2011. Geochemical and isotopic tracers in copper deposits and ancient artifacts: a database for provenance, PhD thesis, University of Padova.

Göd, R., 1981. Ein Beitrag zur Petrographie und Geologie des Bergbaureviers Schellgaden. Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich 27, 189-200.

Grassi, F., 2013. L'insediamento medievale nelle Colline Metallifere (Toscana, Italia): il sito minerario di Rocchette Pannocchieschi dall'VIII al XIV secolo, BAR International Series 2532, Oxford.

Gratuze, B., Guerrot, C., Foy, D., Bayley, J., Arles, A., Téreygeol, F., 2014. Melle : mise en évidence de l'utilisation des scories vitreuses issues de la chaîne opératoire de production de l'argent comme matière première de l'industrie verrière, in Téreygeol F. (Ed.), Du monde franc aux califats omeyyade et abbasside : extraction et produits des mines d'argent de Melle et de Jabali. Begleitband zur Ausstellung « Silberpfade zwischen Orient und Okzident » im Deutschen Bergbau-Museum Bochum, 2014, pp. 211-230

Gstrein, P., 1979. Neuerkenntnisse über die Genese der Fahlerzlagerstätte Schwaz (Tirol), Mineralium Deposita 14, 185–94.

Guénette-Beck, B., Serneels, V., 2010. About the Interpretation of Lead Isotope Analyses in Archaeology. ArchéoSciences 1, 289-297.

Hanneberg, A., Schuster, H., 1994. Die Geschichte des Bergbaus in Schwaz und Brixlegg, Mineralienmagazin Lapis, 19(7/8), 13-21.

Hatz, G., Hatz, V., Zwicker, U., Gale, N.H., Stos-Gale, Z.A.,1991. Otto-Adelheid-Pfennige - Untersuchungen zu Munzen des 10./11. Jahrhunderts.' Commentationes de Nummis Saeculorum IX-XI. In Suecia Repertis. Nova Series 7. The Royal Swedish Academy of Letters, History and Antiquities. 59-146.Hein, U.F., Behr, H.J., 1994. Zur Entwicklung von Fluidsystemen im Verlauf der Deformationsgeschichte des Rhenoherzynikums, Göttinger Arb. Geol. Paläontol. Sonderbd. 1, 191–193.

Hildebrandt, L.H., 1993. Zum mittelalterlichen Blei-Zink-Silber-Bergbau südlich von Heidelberg, in: Steuer, H., Zimmermann, U. (Eds.), Montanarchäologie in Europa. Berichte zum Internationalen Kolloquium "Frühe Erzgewinnung und Verhüttung in Europa", J. Thorbecke Verlag, Sigmaringen, 255-265.

Hildebrandt, L.H. 2012, Blei-Silber-Bergbau im Reich der Salierzeit, Mitteilungen des historischen Vereins der Pfalz, 110, 293-300.

Hofmann, B., 1979. Blei-, Zink-, Kupfer- und Arsenvererzungen im Wellengebirge (unterer Muschelkalk, Trias) am südöstlichen und östlichen Schwarzwaldrand, Mitt. Natur. Ges. Schaffhausen, 31, 157-196.

Hofmann, B., 1989. Erzmineralien in paläozoischen, mesozoischen und tertiären Sedimenten der Nordschweiz und Südwestdeutschands, Schweiz. Mineral. Petrogr. Mitt. 69, 345-357.

Höppner, B., Bartelheim, M., Huijsmans, M., Krauss, R., Martinek, K.P., Pernicka. E., Schwab, R., 2005. Prehistoric copper production in the Inn Valley (Austria) and the earliest copper in Central Europe, Archaeometry 47(2), 293-315.

Horner, J., Neubauer, F., Paar, W.H., Hansmann, W., Koeppel, V., Robl, K., 1997. Structure, mineralogy, and Pb isotopic composition of the As-Au-Ag deposit Rotgülden, Eastern Alps (Austria): significance for formation of epigenetic ore deposits within metamorphic domes. Mineralium deposita 32(6), 555-568.

Ixer, R. A., Budd, P., 1998. The mineralogy of Bronze Age copper ores from the British Isles: implications for the composition of early metalwork. Oxford Journal of Archaeology 17(1), 15-41.

Klappauf, L., 1989. Auswirkung der Grabungen im frühmittelalterlichen Herrensitz Düna bei Osterode am Harz auf die Montanforschung im Harz. Nachrichten aus Niedersachsen, Urgeschichte 58, 171-184.

Klappauf, L., Linke, F.A., Brockner, W., Heimbruch, G., Koerfer, S., 1991. Early Mining and Smelting in the Harz Region, in: Pernicka, E., Wagner, G.A. (Eds.), Archaometry '90, Birkhäuser Verlag, Basel, 77-86.

Klappauf, L., 1993. Zur Archäologie des Harzes im frühen Mittelalter: Eine Skizze zu Forschungsstand und Aussagemöglichkeiten, in: Brandt, M., Eggebrecht, A. (Eds.), Bernward von Hildesheim und das Zeitalter der Ottonen 1, Hildesheim, 249-257.

Klappauf, L., Bartels, C., Linke, F. A., Asmus, B., 2008. Das Montanwesen am Rammelsberg und im Westharz. Historische und archäologische Quellen zum '12.'und '13.'Jahrhundert, in: Brandt, M. (Ed.), Bild und Bestie. Hildesheimer Bronzen der Stauferzeit, Schnell & Steiner, Hildesheim, 65–76.

Klappauf, L., 2011. Montanarchäologie im Westharz, in: Smolnik, R. (Ed.), Aufbruch unter Tage. Stand und Aufgaben der montanarchäologischen Forschung in Sachsen. Arbeits- und Forschungsberichte zur Sächsischen Bodendenkmalpflege, Beiheft 22, Dresden, 169-178.

Klein, S., Lahaye, Y., Brey, G.P., von Kaenel, H.M., 2004. The early roman imperial AES coinage II: Tracing the copper sources by analysis of lead and copper isotopes — Copper coins of Augustus and Tiberius, Archaeometry 46(3), 469–80.

Kilger, C., 2008. Kaupang from Afar: aspects of the interpretation of Dirham fins in northern and eastern europe between the Late 8th and Early 10th Centuries, in Skre, D. (Ed.), Means of exchange. Dealing with silver in the viking age.Kaupang excavation project, Publication series, volume 2, Oslo 2008, 199-252.

Köppel, V., Schroll, E, 1988. Pb-isotope evidence for the origin of lead in strata-bound Pb-Zn deposits in Triassic carbonates of the Eastern and Southern Alps. Mineralium Deposita 23(2), 96-103.

Kötz, S., Pfaff, K., Ströbele, F., Jehn, J., Hildebrandt, L.H., Lorenz, S., Matzke, M., Pernicka, E., Markl, G., 2009. Römischer bis neuzeitlicher Bergbau in Wiesloch (Baden) aus lagerstättenkundlicher, historischer und archäologischer Sicht. Ein interdisziplinäres Forschungsprojekt an der Universität Tübingen, in: Oeggl, K., Prast, M. (Eds.), Die Geschichte des Bergbaus in Tirol und seinen angrenzenden Gebieten. Proceedings zum 3. Milestone-Meeting des SFB-HiMAT, Innsbruck, 165-174.

Krahn, L, Baumann, A., 1996. Lead isotope systematics of epigenetic lead-zinc mineralization in the western part of the Rheinisches Schiefergebirge. Mineralium Deposita 31, 225-237.

Large, D., Schaeffer, R., Höhndorf, A., 1983. Lead isotope data from selected galena occurrences in the North Eifel and North Sauerland, Germany. Mineralium Deposita, 18(2), 235-243.

Lattanzi, P., Hansmann, W., Koeppel, V., & Costagliola, P. 1992. Source of metals in metamorphic ore-forming processes in the Apuane Alps (NW Tuscany, Italy): constraints by Pb-isotope data. Mineral. and Petrol. 45(3-4), 217-229.

Lattanzi, P., Benvenuti, M., Costagliola, P., Tanelli, G., 1994. An overview on recent research on the metallogeny of Tuscany, with special reference to Apuane Alps, Memorie della societa geologica Italiana 48, 605-617.

Lattanzi, P., Benvenuti, M., Gale, N.H., Hansmann, W., Koeppel, V., Stos Gale, Z., 1997. Pb-isotope data on ore deposits of Southern Tuscany. Plinius 18, 123-124.

Le Guen, M., Orgeval, J. J., Lancelot, J., 1991. Lead isotope behaviour in a polyphased Pb-Zn ore deposit: Les Malines (Cévennes, France). Mineralium Deposita 26(3), 180-188.

Leach, D. L., Bechstädt, T., Boni, M., Zeeh, S., 2003. Triassic-hosted Mississippi Valley-type zinc-lead ores of Poland, Austria, Slovenia, and Italy, in: Ashton, J., Boland, M., Cruise, M., Earls, G., Fusciardi, L., Kelly, J., Stanley, G., Andrew, C., (Eds), Europe's Major Base Metal Deposits, Irish Association of Economic Geologists, pp 169–213.

Lehmann, R., 2011. Archäometallurgie von mittelalterlichen deutschen Silberbarren und Münzen, PhD Thesis, Leibniz Universität, Hannover. www.repo.uni-hannover.de/handle/123456789/7735.

Lévèque, J., Haack, U., 1993. Pb isotopes of hydrothermal ores in the Harz, in: Möller, P., Lüders, V. (Eds.), Formation of Hydrothermal Vein Deposits: A Case Study of the Pb-Zn, Barite and Fluorite Deposits of the Harz Mountains. Mineral Deposits 30, 197-210.

Marasco, L., 2013. La Castellina di Scarlino e le fortificazioni di terra nelle pianure costiere della Maremma Settentrionale, Archeologia Medievale XXXIX, 57-69.

Marasco, L., Cicali, C., 2020. The medieval coins from Vetricella (Scarlino, Grosseto): the stratigraphic cntext, in Bianchi, G., Hodges, R., (Eds.),nEU-Med project: Vetricella, an Early Medieval royal property 774 on Tuscany's Mediterranean, All'Insegna del Giglio, Firenze, 99-104.

Marcoux, E., Picot, P., 1985. Les minéralisations de Pontgibaud (Puy-de-Dôme): une approche par la géochimie isotopique du blomb et les paragenèses, Chron. Rech. Min. 481, 27-38.

Marcoux, E., 1986. Isotopes du plomb et paragenèses métalliques, traceurs de l'histoire des gîtes minéraux. Illustration des concepts de source, d'héritage et de régionalisme dans les gîtes français, PhD Thesis, Université de Clermont-Ferrand II.

Marcoux, E., Bril, H., 1986. Heritage et sources des metaux d'apres la geochimie isotopique du plomb. Mineralium deposita 21(1), 35-43.

Marcoux, E., Moëlo, Y., Picot, P., Baubron, J. C., 1988. Evolution minéralogique et isotopique (Pb) du filon sulfuré complexe des Borderies (Massif Central Français)- implications métallogéniques. Mineralium Deposita 23(1), 58-70.

Marcoux, E., Joubert, M., Lescuyer, J. L., 1991. Origine des minéralisations stratiformes de la bordure du Canigou (Pyrénées-orientales, France): apport de la géochimie isotopique du plomb. Comptes rendus de l'Académie des sciences. Série 2, 312(3), 281-287.

Mascaro, I., Guideri, S., Benvenuti, M., 1991. Inventario del patrimonio minerario e mineralogico in Toscana, Giunta regionale Toscana, Firenze.

Mascaro, I., Benvenuti, M., Tanelli, G., 1995. Mineralogy applied to Archeometallurgy: an investigation of medieval slags from Rocca San Silvestro (Campiglia M.ma, Tuscany). Sci. Technol. Cult. Herit. 4(1), 87-98.

Matschke, K.P., 2002. Mining, in: Laiou, A.E. (Ed.), The Economic History of Byzantium: Vol. 1, From the Seventh through the Fifteenth Century, Dumbarton Oaks, Washington D.C., 115-120.

Matzke, M., 1993. Vom Ottolinus zum Grossus: Münzprägung in der Toskana vom10. Bis zum 13. Jahrhundert, Schweizerische Numismatische Rundschau, 71, 135-199.

Meier, S.W., 1995. Blei in der Antike: Bergbau, Verhüttung, Fernhandel, PhD Thesis, Universität Zürich.

Menant, F., 1987. Pour une histoire médiévale de l'entreprise minière en Lombardie, Annales E.S.C. 4, 779-796.

Merkel, S.W., 2016. Silver mining in central Europe: Silver and the Silver Economy at Hedeby, Montanhistorische Zeitschrift DER ANSCHNITT, 33, 216.

Meyerdirks, U., Rehren, T., Harvey, A., 2004. Reconstructing the early medieval copper smelting at Ross Island. In: O’Brien, W. (Ed.), Ross Island: Mining, Metal and Society in Early Ireland, Bronze Age Studies 6, National University of Ireland, Galway, 651-664.

Niederschlag, E., Pernicka, E., Seifert, T., Bartelheim, M., 2003. The determination of lead isotope ratios by multiple collector ICP-MS: A case study of Early Bronze Age artefacts and their possible relation with ore deposits of the Erzgebirge, Archaeometry 45(1), 61-100.

Nimis, P., Omenetto, P., Giunti, I., Artioli, G., Angelini, I., 2012. Lead isotope systematics in hydrothermal sulphide deposits from the central-eastern Southalpine (northern Italy). Eur. J. of Mineral. 24(1), 23-37.

Pfaff, K., Wagner, T., Markl, G., 2009. Fluid mixing recorded by mineral assemblage and mineral chemistry in a Mississippi Valley-type Pb–Zn–Ag deposit in Wiesloch, SW Germany. J. Geochem. Explor. 1(101), 81.

Pfaff, K., Hildebrandt, L. H., Leach, D. L., Jacob, D. E., Markl, G., 2010. Formation of the Wiesloch Mississippi Valley-type Zn-Pb-Ag deposit in the extensional setting of the Upper Rhinegraben, SW Germany. Mineralium Deposita 45(7), 647-666.

Ploquin, A., Allée, P., Bailly-Maître, M. C., Baron, S., de Beaulieu, J. L., Carignan, J., Laurent, S., Le Carlier de Veslud, C., Lavoie, M., Pulido, M., 2003. Medieval Lead Smelting on the Mont Lozère, Southern France, Archaeometallurgy in Europe 1, Milan, 635-644.

Ponting, M., Evans, J. A., & Pashley, V., 2003. Fingerprinting of Roman mints using laser-ablation MC–ICP–MS lead isotope analysis. Archaeometry 45(4), 591-597.

Pratellesi, G., 1984. Studio giacimentologico delle mineralizzazioni argentifere della zona di Massa Marittima -Montieri, MSc Thesis, Università degli Studi di Firenze, 1984.

Py, V., Véron, A., Edouard, J. L., De Beaulieu, J. L., Ancel, B., Segard, M., Durand, A, Leveau, P., 2014. Interdisciplinary characterisation and environmental imprints of mining and forestry in the upper Durance valley (France) during the Holocene, Quaternary International 353, 74-97.

Rehkämper, M., Mezger, K., 2000. Investigation of matrix effects for Pb isotope ratio measurements by multiple collector ICPMS: Verification and application of optimised analytical protocols. J. Anal. Atom. Spectrom. 15, 1451–1460.

Rohl, B. M., 1996. Lead isotope data from the Isotrace Laboratory, Oxford: archaeometry data base 2, galena from Britain and Ireland, Archaeometry 38(1), 165-180.

Rovelli, A. 1996. Le monete del castello di Scarlino. Materiali per lo studio della circolazione monetaria nella Toscana meridionale, Annali dell'Istituto Italiano di Numismatica, 43, Roma, 225-254.

Rovelli, A., 2004. Mines et monnaies au haut Moyen Âge. Les sources de l'Italie carolingienne. Bull. de la société française de Numismatique 59(4), 58-64.

Rovelli, A., 2012a. Coinage and Coin Use in Medieval Italy, Variorum Collected Studies Series CS1023, Ashgate, Farnham.

Rovelli, A., 2012b. Le monete, in Hobart, M., Campana, S., Hodges, R. (Eds.) Monasteri contesi nella Tuscia Longobarda: il caso di San Pietro ad Asso, Montalcino (SI), Archeologia Medievale, 31, 175-213.

Rovelli, A., 2020. The coins from the excavations of Vetricella (Scarlino, Grosseto). Notes on the Pavese issues of Berengar I, in: Bianchi, G., Hodges, R. (Eds.), nEU-Med project: Vetricella, an Early Medieval royal property on Tuscany's Mediterranean, All'Insegna del Giglio, Firenze, 89-97.

Saccocci, A., 2001-02. Il ripostiglio dall'area "Galli Tassi" di Lucca e la cronologia delle emissioni pavesi e lucchesi di X secolo, "BdN" 36-39 (2001-02), 167-204.

Saccocci, A., 2003. Il ripostiglio di monete, in Ciampoltrini, G. and Pieri, E. (Eds.), Archeologia a Pieve a Nievole dalla baselica sita loco Neure alla pieve romanica, 83.

Saccocci, A., 2010. Le monete medievali, in Giannichedda, E. (Ed.), Filattiera-Sorano: Gli insediamenti sul dosso della pieve e altre ricerche, Firenze, 149-150.

Saccocci, A., 2013. Rinvenimenti monetali della Tuscia dell'alto medioevo: i flussi (secc. XI-V), in Alberti, C., Baldassarri, M., (Eds.), Monete antiche. Usi e flussi monetari in Valdera e nella Toscana nord-occidentale dall'età romana al Medioevo, Quaderni Rete Museale Valdera 4, 21-34.

Saccocci, A., 2019. Le monete, in Cantini, F. (Ed.), "Costruire lo sviluppo". La crescita di città e campagna tra espansione urbana e nuove fondazioni (XII-prima metà XIII secolo), 15-19.

Sarah, G., Bompaire, M., McCormick, M., Rovelli, A., Guerrot, C., 2008. Analyses élémentaires demonnaies de Charlemagne et Louis le Pieux du Cabinet des Médailles: l'Italie carolingienne et Venise, Revuenumismatique 6(164), 355-406.

Schroll, E., 2005. Alpine type Pb-Zn-deposits (APT) hosted by Triassic carbonates, in: Mao, J., Bierlein, F.P. (Eds.), Mineral deposit research: meeting the global challenge, Springer, Berlin, 175-178.

Schroll, E., Köppel, V., Cerny, I., 2006. Pb and Sr isotope and geochemical data from the Pb–Zn deposit Bleiberg (Austria): constraints on the age of mineralization. Mineral. and Petrol. 86(1), 129-156.

Schwabenicky, W., 2011. Mittelalterlicher Silberbergbau in Sachsen: Forschungsstand - Probleme – Fragestellungen, in: Smolnik, R. (Ed.), Aufbruch unter Tage: Stand und Aufgaben der montanarchäologischen Forschung in Sachsen, Dresden, 7-36.

Spufford, P., 1988. Money and ist use in medieval Europe, Cambridge University Press, Cambridge.

Staude, S., Bons, P. D., Markl, G., 2009. Hydrothermal vein formation by extension-driven dewatering of the middle crust: An example from SW Germany. Earth and Planet. Sci. Lett. 286(3-4), 387-395.

Stedingk K., 2012, Die Grunder Lagerstätte im Oberharzer Gang- gebiet, in: Lampe, W., Langefeld, O. (Eds.), „Arsch ab!“ Zum Kolloquium 20 Jahre Stilllegung Erzbergwerk Grund, Bad Grund, Clausthal-Zellerfeld, 9-48.

Steuer, H., 1993, Bergbau auf Silber und Kupfer im Mittelalter, in: Steuer, H., Zimmermann, U. (Eds.), Alter Bergbau in Deutschland, Hamburg, 75-91.

Steuer, H., 2004. Münzprägung, Silberströme und Bergbau um das Jahr 1000 in Europa – wirtschaftlicher Aufbruch und technische Innovation, in: Hubel, A., Schneidmüller, B. (Eds.), Aufbruch ins zweite Jahrtausend: Innovation und Kontinuität in der Mitte des Mittelalters, Ostfildern, 117-149.

Stos-Gale, Z.A., Gale, N.H., Houghton, J., Speakman, R., 1995. Lead Isotopes from Isotrace Laboratory, Oxford: Archaeometry database 1, ores from western Mediterranean, Archaeometry 37(2), 407-415.

Stos-Gale, Z.A., Gale, N.H., 2009. Metal provenancing using isotopes and the Oxford archaeological lead isotope database (OXALID), Archaeol. and Anthropol. Sci., 1(3), 195–213.

Strassburger, M., 2007. Archäologie und Geschichte des Ramsbecker Bergbaus bis 1854, Der Anschnitt 59(6), 182-190.

Ströbele, F., Wenzel, T., Kronz, A., Hildebrandt, L.H., Markl, G., 2010. Mineralogical and geochemical characterization of high-medieval lead–silver smelting slags from Wiesloch near

Heidelberg (Germany) - an approach to process reconstruction. Archaeol. and Anthropol. Sci. 2(3), 191-215.

Ströbele, F., Staude, S., Pfaff, K., Premo, W.R., Hildebrandt, L.H., Baumann, A., Pernicka, E., Markl, G., 2012. Pb isotope constraints on fluid flow and mineralization processes in SW Germany. Neues Jahrbuch für Mineralogie-Abhandlungen, J. of Mineral. and Geochem. 189(3), 287-309.

Ströbele, F., Hildebrandt, L.H., Baumann, A., Pernicka, E., Markl, G., 2015. Pb isotope data of Roman and medieval objects from Wiesloch near Heidelberg, Germany, Archaeol. and Anthropol. Sci. 7(4), 465–72.

Téreygeol, F., Hoelzl, S., Horn, P., 2005. Journée archéologique de Melle, Le monnayage de Melle au haut Moyen Age: état de la recherche, Association des archéologues de Poitou-Charentes, Bulletin de liaison et d'infomation 34, 49-56.

Téreygeol, F., 2007. Production and circulation of silver and secondary products (lead and glass) from Frankish royal silver mines at Melle (eighth to tenth century), in: Henning, J. (Ed.), Post-Roman Towns, Trade and Settlement in Europe and Byzantium: The heirs of the Roman West, W. De Gruyter, Berlin, 123-134.

Téreygeol, F., 2013. How to quantify medieval silver production at Melle, Metalla 18(1), 5-15.

Téreygeol, F., 2016. L'apogée de la mouline: Castel-Minier au XVIe siècle, Colloque Les chemins du fer en Belledonne, 105-112.

Tylecote, R.F., 1986. The Prehistory of Metallurgy in the British Isles, The Institute of Metals, London.

Vaccaro, E., Salvadori, H., 2006, Prime analisi sui reperti ceramici e numismatici di X secolo dal villaggio medievale di Poggio cavolo (GR), in Francovic, R., Valenti, M., (Eds.), IV Congresso Nazionale di Archeologia Medievale, Firenze, 480-484.

Valenti, M. (Ed.), 2008. Miranduolo in Alta a Val di Merse (Chiusdino - SI), All'Insegna del Giglio, Firenze.

Villa, I.M., 2009. Lead isotopic measurements in archeological objects, Archaeol. and Anthropol. Sci. 1(3), 149–53.

Wagner, T., Schneider, J., 2002. Lead isotope systematics of vein-type antimony mineralization, Rheinisches Schiefergebirge, Germany: A case history of complex reaction and remobilization processes, Mineralium Deposita 37(2), 185–97.

Weidinger, J., Lang, M., 1991. Der As-Au-Ag-Bergbau Rotgülden im Lungau. Archiv für Lagerstättenforschung der Geologischen Bundesanstalt 13, 233-247.

Westner, K. J., Birch, T., Kemmers, F., Klein, S., Höfer, H. E., Seitz, H. M., 2020. ROME'S Rise to Power. Geochemical Analysis of Silver Coinage from the Western Mediterranean (Fourth to Second Centuries BCE). Archaeometry 62(3), 577-592.

Zámora, P., Vozár, J., Turčan, T., 2008. History of Mining in Slovakia, Kosiče.

Zucchini, R., 1998. Miniere e mineralizzazioni nella provincia di Udine, Edizione del Museo Friulano di Storia Naturale, 40, Udine.