HOW TO QUANTIFY MEDIEVAL SILVER PRODUCTION AT MELLE?

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The question of quantification of the production of ancient silver mines is essential for the economic history. Usually, if a quantification of production can be proposed, it is based on written sources, and is therefore limited to the accuracy, authenticity and frame of reference of the used source. How is it possible to make the balance between an often static quantitative date and the frequently multi-year chronological series obtainable thanks to archaeological research? The field of archaeometry, when focused on the origin of materials, helps to restore commercial networks but remains incapable to characterize the intensity of flows. But if only archaeological sources would be available, the problem would in no way be easier. Fieldwork obviously brings to light the systems of production, the used structures and allows chronological fine-tuning with regard to the written sources. Naturally, silver, the final and desired product, is not there anymore. Worse, the slags connected to its production very often disappear through reworking, obliterating the possibility of quantification as it is known within the framework of iron production. Then there is the mine, a original place where the desired wealth could be found. To go forward this way, we must work on preserved mining networks, and it is better if there is no later exploitation. The site of Melle presents several advantages which help pave the way to an attempt of quantification of its production. The mine is partially accessible and has remained undisturbed since the abandonment of mining activities around 1000 AD. The presence of a mint which produced a coinage bearing the name of Melle facilitates the work of connecting the ore to the finished object. Finally, the chemical signature of the ore allows the integration of the archaeological data and the numismatics with those resulting from the analysis (Téreygeol, *et al.*, 2005). To quantify the production of Melle, first the importance of the mine and the nature of the exploited ore must be emphasized. The knowledge of the system of production of the ore to the silver provides useful information towards this purpose. It is only at this stage that we can work towards an assessment of silver production. Then, to combine the production chain with the knowledge of the environmental conditions a a long-term chronological sequence of silver production can be proposed.

Geological studies undertaken at Melle since the second half of the 20th century allow us to say, without too much risk, that the exploited ore was galena containing slight amounts of silver (Coiteux, 1982). This silver content in regard to the lead ranges between one and five per thousand. There is nothing other than galena as ore. Excluding the specific questions relative to geology, the example of Melle appears rather simple from the point of view of the mineralization: a rare case of exclusive exploitation of argentiferous galena.

The Melle deposit distribution is well known through the study led by the BRGM in the second half of the 20th century. The mineralization takes place in a karst. It is contained in a quadrangle of ten by ten kilometres and covers this space 47 km^2, with Melle as the south border (fig. 01) (Coiteux, 1982, fig. 48). Geologist performed core drillings at diverse points of the deposit. It gives an image of the vertical distribution of galena in this karst layer. The mineralized part of this secondary formation is between zero and six meters, directly under the blue marls of Toarcien. Its concentration was considered meter per meter beginning with the of the top of the layer (Lougnon, 1959, p.11). In the first meter, we find 1.6 % of the lead's total content. Between meters two and five, two thirds of mineralized layer thickness is where the main part of galena is concentrated (96.3 %). The last meter represents only 2.1 % of the total lead content. The deposit in itself is a horizontal stratum, with a very light slope (around 1 %). The goal of this geologic research was to try to estimate the economic potential of reopening this deposit. The global contents of lead and silver were thus defined: 750,000 tons of lead and 1,400 tons of silver. Thanks to geological research, we know that the mineralized zones developed in long and narrow bands from fifty to hundred meters wide, which in parts, can converge. The content of galena is estimated between 1 and 2 %, but this method of calculation is useless because it is based on the mod-

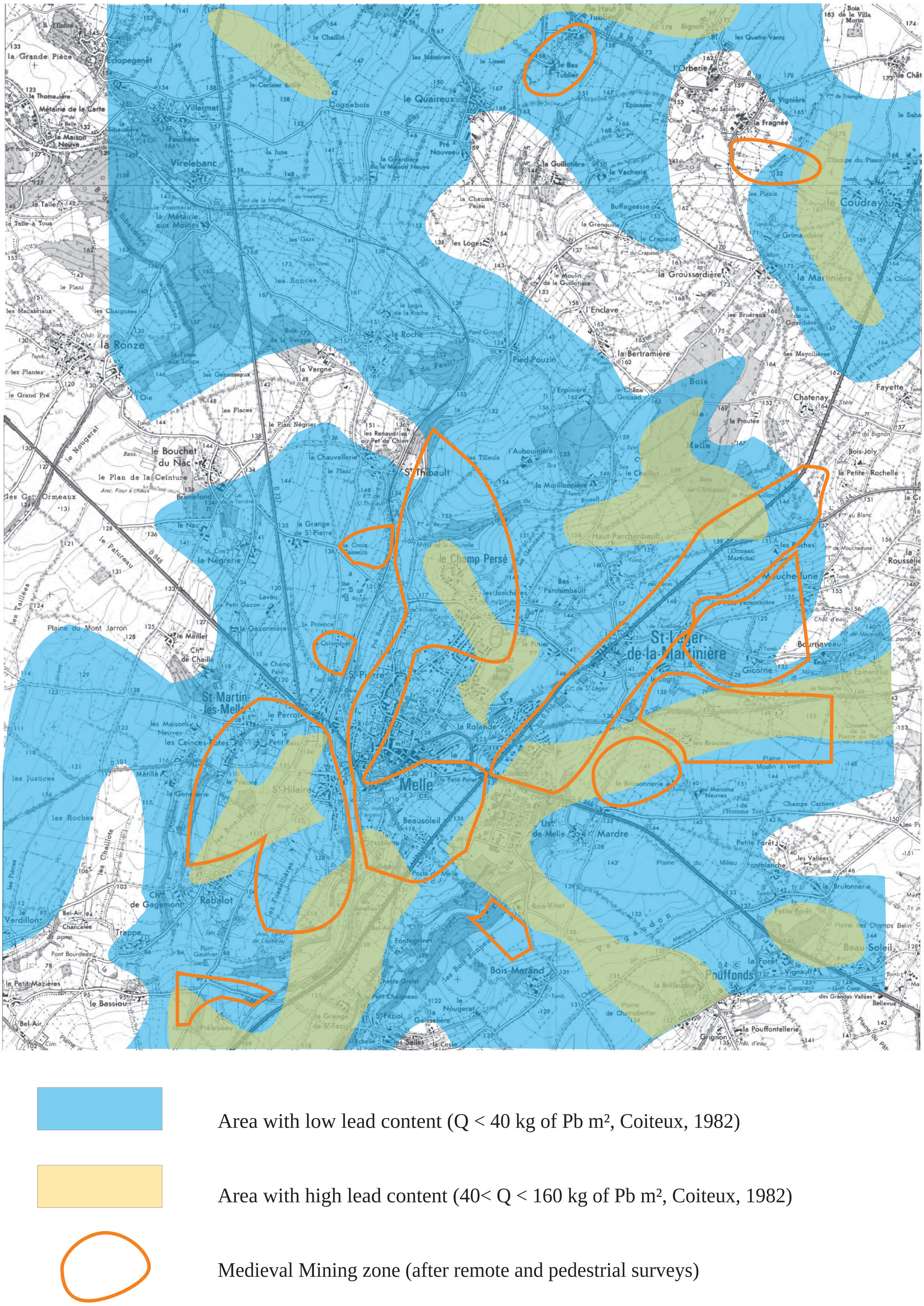

Fig. 1: Map with deposit lead content and old mining areas.

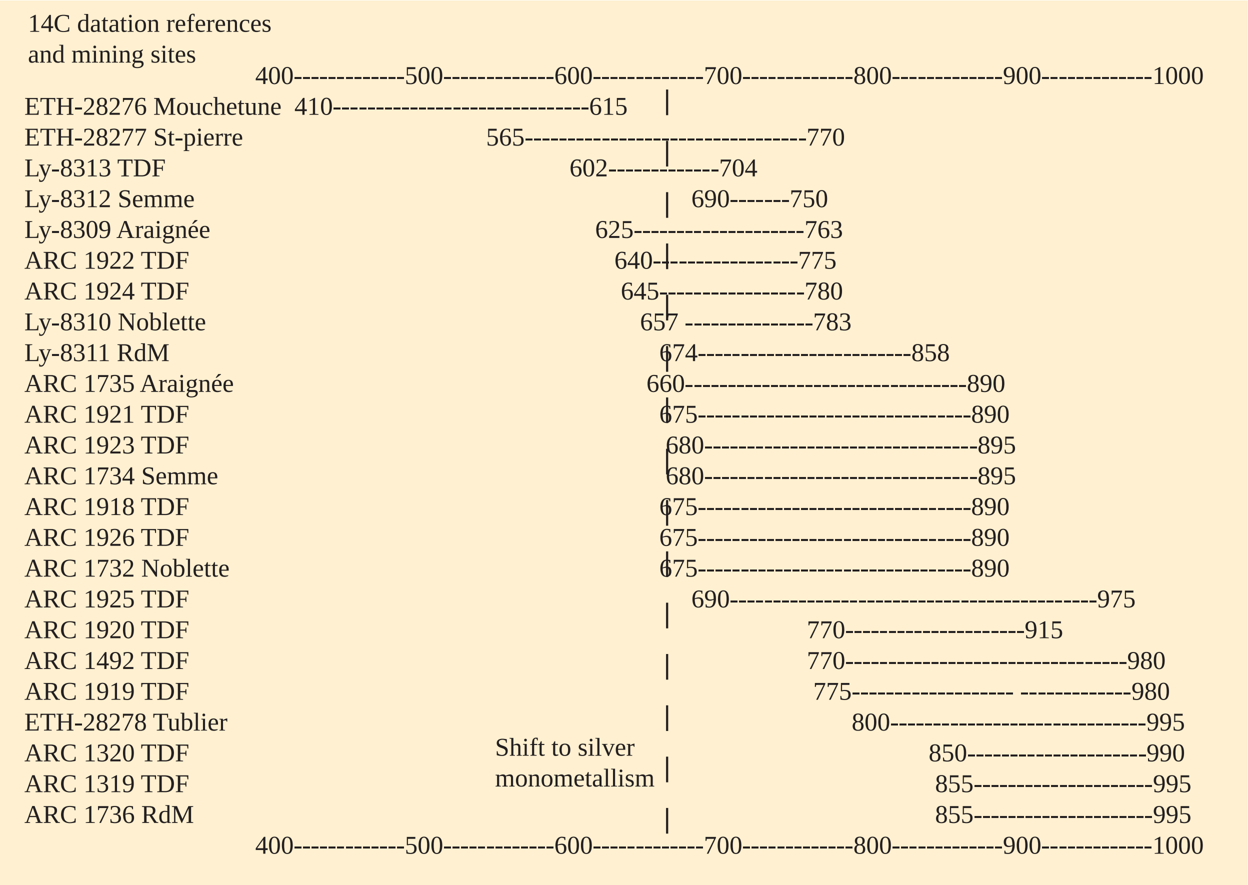

Fig. 2: Radiocarbon datations at Melle.

ern methods of exploitation: open pit mining. The ancient mining technique was vein mining through fire-setting. Experimental fire settings give a rate of lead concentration certainly more representative of that obtained by the Carolingian miners. In the mining network of Noblette, experimental fire-setting yielded galena that is not lower than 5 % mass. In this way, Melle presents a rare potential for an attempt of quantification of its production. The chronology was established by radiocarbon dating and cross-referencing with numismatic data. Mining works were spread out over a maximum of six centuries (fig. 02). The starting point is in the 5th century AD and the abandonment takes place in the 10th century (Téreygeol, 2007). The whole process is present: from the mine to the mint (Téreygeol, 2002). Every stage can be the object of an estimation of the produced quantities and an average production per period can be proposed.

Of course, the first step of production takes place inside the mine. The archaeological survey was undertaken using both aerial imaging and ground proofing which allowed the whole field to be covered. We were able to propose an estimation of the extent of mining works. The field extends over 47 km^2, but the exploited zones cover only 7 km^2. This figure is obtained by defining an area which includes the remains of mining activity on the surface, mainly consisting of heaps and mining shaft heads. Shafts mark the minimal extension of networks widely dependent on these openings to ensure the ventilation essential for setting fire. The traces of mining on the surface are considered as a minimum estimate. In parallel, the survey of a mining network shows that the mineralization was mainly the first five meters of the deposit's thickness. Thus, 97.9 % of the available galena was accessible through mining. The abrupt variation of ore concentration in the same mining zone is a reality, and it is revealed by the nature of the mining network which varies from one to five meters in height (fig. 03). To propose an extracted volume, it seems appropriate to consider the not the maximum of five meters of rock, but only two meters (Lougnon, 1957, p.11). Like the surface, it seems preferable to tend towards a lower estimation. From here it is not much work to obtain an extracted volume of rock which would amount to fourteen million cubic meters. By considering a 2.7 density of the surrounding limestone, the extracted mass would be around 38,000,000 tons. This figure concerns 600 years of exploitation. Reduced to an annual production, it represents a mass of 63,000 tons. At this stage, it is only about the rock. How does this relate to the mass of ore? The 5% content obtained by experiment lets

Fig. 3: An example (Loubeau) of length changing on Melle mining networks.

to believe that the miners would unearth 3,150 tons of galena a year with 87 % mass of lead. The available lead in 3,150 tons of galena amounts to 2,750 tons. The dressing step which follows the extraction entails inevitably a part of loss of potential ore, but these quantities seems unimportant with regard to our studies on dressing units excavated at Melle (Téreygeol, 2003). It should become incorporated without any trouble into our margins of error. On the other hand, the extractive metallurgy is a large lead consumer: a part is trapped in the slag and part disappears into the fumes. In the end, a low yield, around 12.5 %, does not appear as so irrational (Téreygeol and Happ, 2000). The annual average production of argentiferous lead would be around 340 tons. This loss has no consequence on the silver process because the precious metal stays entirely in the metallic lead resulting from the reduction. The silver content varies within deposit. It is rarely lower than 1‰ mass and does not exceed 5‰ mass. The experimental refining of Melle's lead, and also the silver concentrations determined elemental analysis of archaeological ore sampless show an average silver content around 1.5‰ mass. In the absence of silver loss in the metallurgical process, an annual silver production of 4.1 tons can be proposed. Melle is exceptional for the longevity of the mining works (fig. 04). There is hardly any but one, the district of Sainte-Marie-aux-Mines, which has a longer duration (10th -18th century). But we have no quantification of the production and its activity is cyclic (Fluck, 2000). Potosi could also be mentioned, but the story of this silver mine exploited at least during the 14th century is ongoing even today. Actually, the combination of the duration of activity with the availability of potential resources is ideal which make Melle an exemplary mining site. However, one element escapes us. Without archives, we cannot perceive mining cycles or discontinuities of exploitation. Melle's example is already particular by the total absence of reworking after the abandonment of the exploitation in the 10th century. It is not very probable from a structural or cyclical basis that the extraction was made without the famous mining "booms" which give rhythm to the life of every exploitation.

The geological studies of Melle give an available resource of 1,400 tons of silver remaining. Our own estimations end in a mass extracted from 2,460 tons of precious metal, while less than 15 % of the surface of the deposit show the obvious traces of medieval exploitation. The map of lead content helps to clear

Site	Datation	Yearly prod.	Tot. Prod.	Type	Source	Référence
Melle	V-X	4,1 t	2460 t	Mining district	Archaeology	
Goslar	936-973	400 kg	14,8 t	Mining district	Archives	Blanchard, 2001, p.566.
Argentière	XII	nc	1,8 t	Mine	Archaeology	Py, 2009, p.52.
Carlisle	1125-1225	3,5 à 5 t	278 t	Mining district	Archives	Blanchard, 2001, p.610.
Durham	1165	16,5 t	nc	Mining district	Archives	Blanchard, 2001, p.609.
Brandes	1236	174 kg	nc	Mining district	Archives	Bailly-Maître, 1994, p,103.
Kuttenberg	1250-1412	1,5 à 6,5 t	nc	Mining district	Archives	Blanchard, 2005, p.929.
Orzals	1267-1268	145 kg	290 kg	Mine	Archives	Collectif, 1997, p.32.
Freiberg	1297	0,42 à 0,63 t	nc	Mining district	Archives	Blanchard, 2005, p.929.
Castel-Minier	1320-1340	1,2 t	24 t	Mining district	Archives	Leroy, 1974, p.117.
Bere Ferrers	1441-1451	150 kg	1,5 t	Mine	Archives	Blanchard, 2005, p.1701.
Pampailly	1455-1457	175 kg	528 kg	Mine	Archives	Benoit, 1997 p. 85.
Mts du Lyonnais	1455-1457	23 kg	69,5 kg	Mining district	Archives	Benoit, 1997 p. 24.
Kuttenberg	1526-1535	1,3 t	13 t	Mining district	Archives	Breuer , 1974, p.115.
Val de Lièpvre	1551-1574	1,2 t	29 t	Mining district	Archives	Grandemange, 1991, p.40.
Potosi	1580	163 t	nc	Mine	Archives	Bakewell, 1997, p.75.

Fig. 4.: some silver production on medieval and modern silver mines.

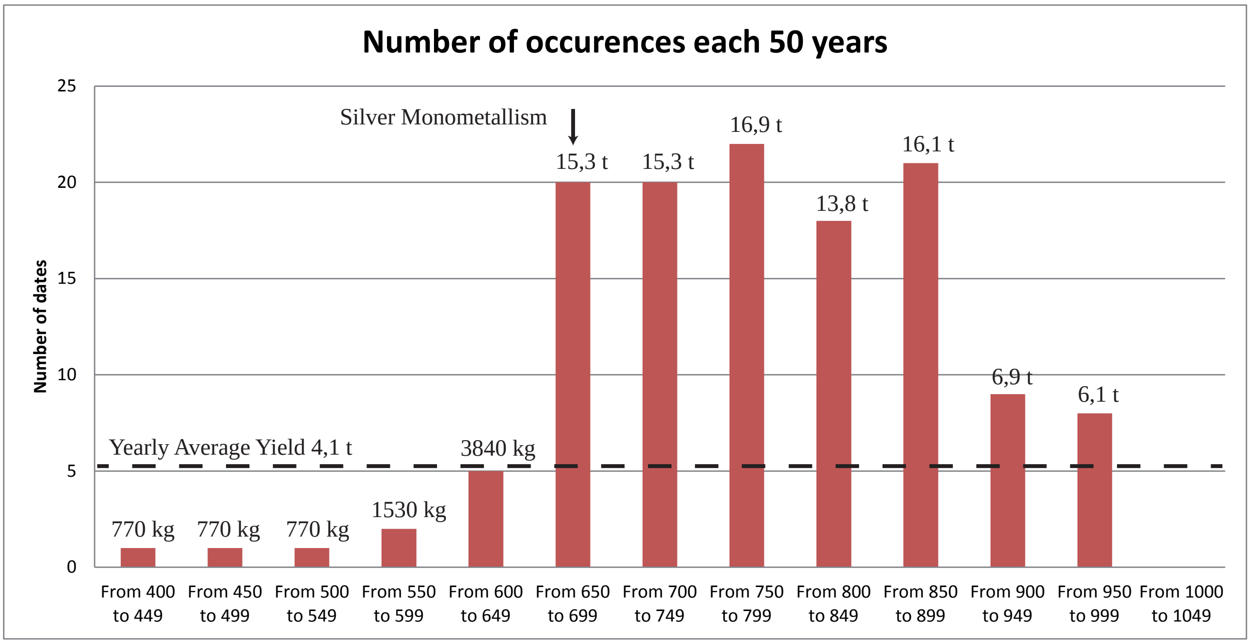

Fig. 5: Histogram of radiocarbon datation at Melle crossing with yearly silver production (each 50 y.).

up this point because there is a strong correlation between zones with the highest lead content in the deposit and those which were successfully exploited: no zone with high lead content was ignored.

When the average annual production is held constant, it is around 4.1 tons, Melle's mining district gives the possibility that the mint was able to produce two million denarii a year. It is naturally an volume which reflects no real time production. An integration of the data obtained by radiocarbon dating and the number of their occurrances by half century refines this datum and offers another image of the Melle's production (fig. 05). The concurrence of the introduction of silver coinage and the increase of the frequency of dates was already shown (Téreygeol, 2010). This development is expressed here in the quantity of silver. During Merovingian times, the production of silver is truly existent at Melle, and silver is already used to produce coins (Clairand and Téreygeol, 2009). It would remain limited around a ton of pure silver a year. Little in regard to what appears for the following period, but the place of silver coinage in Merovingian economy would agree well enough with this interpretation. If the link established between dates and production quantity enables us to see the rough increase of the production, it still represents a simple estimation. Besides the numismatics, the environmental study, without inevitably validating this hypothesis, strengthens this hypothesis (fig. 06). The anthracological data resulting from three archaeological sites

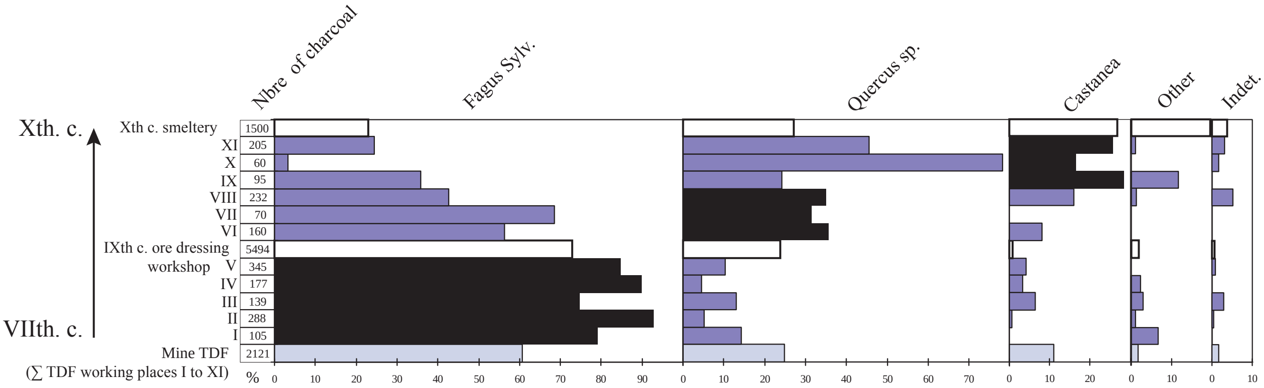

Fig. 6: Anthracological spectrum of TDF mining network with relative chronology compared to surface sites.

(a mine, a dressing plant and a foundry) enable not only the definition of the fuel supply strategy, but also the characterization the forest cover (Téreygeol and Dubois, 2003). From the beginning of the exploitation until the 9th century, the beech is the most used wood for the extraction. In this century, a transition is as clear as day light: Oak becomes the majority. In the 10th century, the situation has changed further with the massive arrival and consumption of the sweet chestnut tree. If the consumption of the wood for these metallurgical activities reflects the compound of forests, it is a classic situation of progression of a beech grove towards an oak grove making way for degraded spaces afforested in sweet chestnut tree. Well-known on the west side of France, this progression ends usually not before the 11th century of the Middles Ages (Gone and Lespez, 2006). At Melle, it is finished before 1000 AD. If the early advancement of agricultural pressure is not apparent elsewhere, then the silver production could in this specific case explain the speed of this change. In contrast to equally dense populations, the overconsumption of wood is probably connected to its use in both extraction from the mine and in metallurgy We have to understand why the transition has this rough character beginning and finishing between the 9th and the 10th century. The indistinctness of the radiocarbon dating does not enable a finer reading. On the other hand, the numismatic studies led on the Carolingian coinage highlights clearly the importance of the Melle production within the Empire and the increase of Melle's production in the second half of the 9th century. Moreover when the edict of Pîtres was drafted, it gave evidence of Melle's importance in the Carolingian economy. It is possible to demonstrate an active will to increase the production of Melle's coinage between the years 850 and 900. This increase of the monetary production also would have required an increase in the mining and also the wood consumption. The latter would have caused an ecological imbalance precipitating this advanced progression and driving it to the end of the extraction. In the end, our statistic image of the importance of the silver production at Melle until the end of the 9th century seems to agree with the evolution of the environment.

With 4.1 tons of extracted silver each year, Melle is truly a major centre of production of white metal in the Carolingian Empire. The assertion according to which the Melle' silver production had no impact on the monetary volume in circulation during Carolingian period is a view that in need of revision, especially because no other Carolingian mining districts of such size have been identified. The data acquired by radiocarbon dating enlighten the close link between metal production and currency, in particular during the passage to a silver monometallism economic system which is concurrent with the extension of the mining network at Melle. For the end of the history of this district's exploitation, it is the environmental approach which gives us the most information. It shows the impact of the mining activity on the surrounding forests. To confirm this model of production, these data, which already incorporates archaeological, environmental and experimental information, would benefit by being compared to archaeometric information on the chemical composition of coins. Today it is possible to define the area of influence of Melle precisely. Compared with the trade of lead smoother produced at Melle, it already appears as very wide (Gratuze *et al.*, 2003). Finally, if a potential quantity of silver can be proposed, the mass of Carolingian lead launched on the market remains difficult to determine. The continuation of experimental work should bring some answers, but already it seems that the payment of a tax of 8,000 pounds every two years in the abbey of Saint-Denis reported in Gesta Dagoberti did not prove difficult for the miners.

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