Ore grinding in the Middle Ages: the example of Brandes-en-Oisans (Isère, France)

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Introduction

Across the millennia, mills have played the role of ‘power transformers’ for multiple purposes: milling and grinding food, of course (grain, olives, etc.), and for activities unrelated to food such as tanning and metallurgy as well.

The silver coins that fed most of the economy of the west in the Middle Ages were produced by means of a long process in which mills were used to grind ore extracted from the mines. The activity was carried out on large industrial sites like the Argenteria de brandis. Brandes-en-Oisans (fig. 1) was a mining community, a part of the Dauphiné Principality, fully devoted to the extraction and treatment of several argentiferous lead veins between the 12th and 14th centuries (Bailly-Maître and Dupraz 1994.). The site, which comprised a village with some 80 dwellings, fortifications, a parish church and large industrial areas, has been excavated by the CNRS since 1977. So far, it has revealed more than 206 millstones, plus fragments and chips, the remains of the ore mills that operated on the plateau at that time as links in a large chain of mineralurgical operations. The ore leaving the galleries was trapped in gangue consisting mainly of barite and quartz. A process was required to separate the precious metal from this waste rock and several methods were implemented, such as crushing, decrepitation and grinding. While crushing was done manually and decrepitation was done by fire, grinding was mechanised by water-mills. However, instead of pouring grain onto the millstones, the miners cast ore and gangue onto them and recovered a powder that was then treated in washing and decantation basins to collect even the smallest gram of silver.

Very few documents describe this activity and this is no doubt the reason for which the mills were only acknowledged as a result of the excavation of several mining sites. Archaeologists have addressed the subject, first separately (Benoit 1997; Domergue *et al*. 1997, 48-61; Bailly-Maître 2002, 224) and then collectively to summarise acquired knowledge and set the foundations for future research in an article published in 1997 for the Aix-en-Provence symposium (Benoit *et al*. 1997, 62-69).

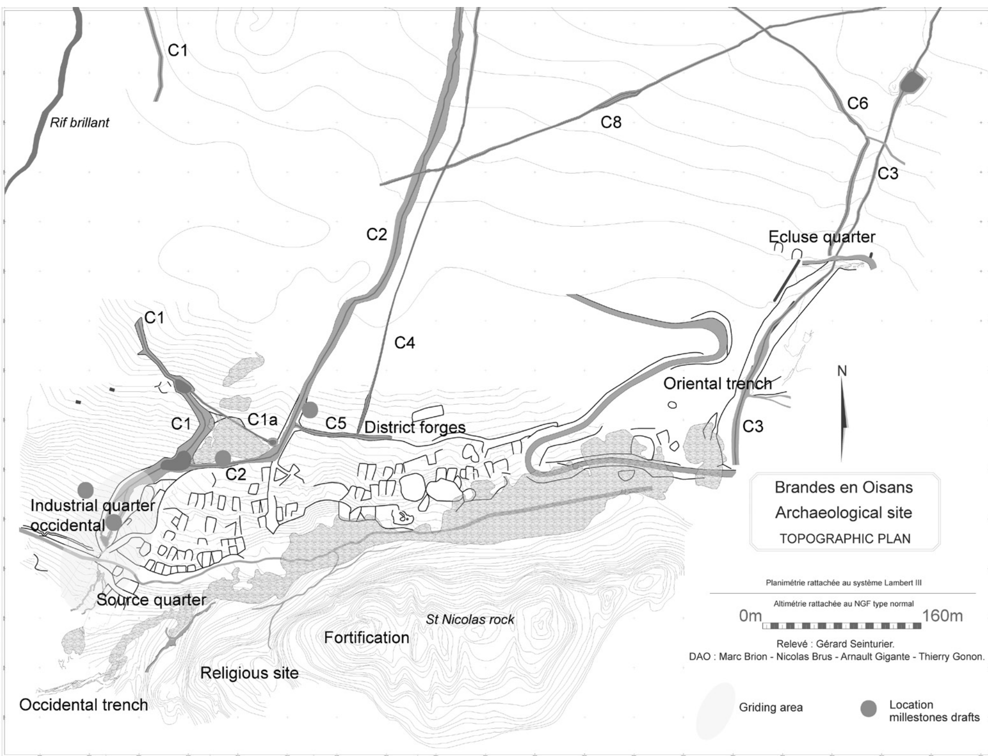


Figure 1. Brandes-en Oisans.

Figure 2. Millstone Grit B106.

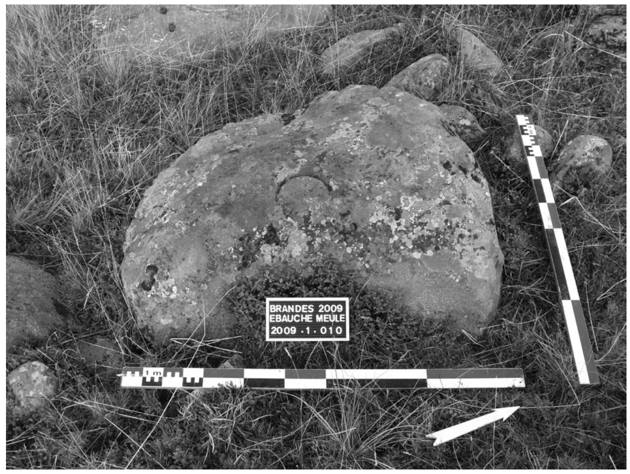


Figure 3. Rough-out 2009-1-009.

This study starts with three main themes. The first one will focus on the production of millstones, their extraction and shaping, as shown by fragments that still show traces of cutting, and also by the rough-outs found on the plateau. The second theme will then evoke the 'memory' of grinding, in particular by analysing traces of wear on the grinding surfaces of millstones. The third theme consists of establishing the context in which the millstones were used in the mills, proposing interpretation schemes based on elements noted by observing the millstones and also through the contribution of other types of sources.

From quarry to millstone

1.1 Millstone grit in Brandes-en-Oisans

The Brandes plateau, composed of various outcrops and innumerable blocks, was worked to supply the millstones required for the mills on the site. The miners used the millstone grit over and over since it provided them with stones they could extract on location, without the difficulty and cost of transporting stones weighing several hundreds of kilos. Rather than working rocky massifs, however, they preferred to extract their millstones from blocks dispersed across the plateau. These blocks were the remains of glaciers or had crashed down from the slopes of the surrounding summits and many of them were indeed the right size for shaping millstones (Figs. 2 and 3).

The millstone grit quarries of Brandes are highly representative of 'village millstone grits' for local production, situated as close as possible to the mills (Belmont 2006, 77). Ore mills are no different from grain mills in this respect. Our vision is not optimal though, since few blocks of this sort have been preserved. They were probably fully whittled down by extraction and the few minute scraps created by cutting are most likely to have been dispersed or reused.

Whatever the case may be, whether the millstone grits were obtained locally or further away, this practice is not an archaism, as it might be presumed in view of the period of the operations and use (13th century AD), and given that the industry was destined to expand and become specialised. As regards the grain mills of the neighbouring community of Huez, for example, millstones continued to be extracted in this manner over the centuries that followed, up to the 19th century (AD 38, 7 S 1/1, 1809 survey on mills in France. Cited by Alain Belmont, Atlas des meulières de France et d'Europe, 2006, http://meuliere.ishlyon.cnrs.fr/index.htm). There are several reasons for this. First of all, it would appear that the financial investment was much too high for the intended use. But, considering the fact that the Huez inhabitants remained faithful to this type of quarry for wheat mills for at least 600 years, it is important to turn our attention to the quality of the stone.

1.2. Rocks

The quality of the millstone rocks cannot be emphasized too strongly. It has now been established that this point was of key importance (Belmont 2006, 89-113.). Certainly, the millstones used to grind ore did not necessarily meet the same requirements as grain millstones, but the elements that break away from them, as small as they may be, nevertheless add pollution to an ore that is supposed to be in the enrichment phase. Millstone wear is another factor to be considered. The faster the millstone wears out, the faster it needs to be changed.

The millstones from Brandes are shaped from two main types of clast (Fig. 4): 56.4% conglomerate and 33% sandstone. Added to this are a few gneiss and granite inclusions (4.3%), but they remain marginal. These are indeed the rocks that form the blocks scattered across the plateau, apart from the gneiss and granite which come from the rocky massifs (This classification was carried out by Stéphane Rouméjon (Université Joseph Fourrier, Grenoble I) to whom we are deeply grateful).

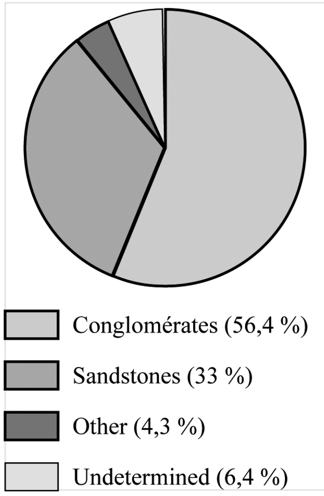


Figure 4. Distribution of types of rocks.

Is there a constant to be detected in the rocks chosen by the miners? Nothing is less certain. Resistance tests can provide part of the answer, provided that a comparative approach is used. In 2005, Yves Orengo, of the Laboratoire Interdisciplinaire de Recherche Impliquant la Géologie et la Mécanique (LIRIGM) of the Université Joseph Fourier (Grenoble I) conducted tests on three samples from the millstone grit B 106 excavation that took place during the 2004 campaign. The samples are a siliceous micro-conglomerate. The results are summarised in the table below (Fig. 5):

Sample	Density (t/m3)	Compression strength (MPa)	Static modulus (GPa)	Tensile strength (MPa)	Deere-Miller
BRANDES 1	2.693	136	44.8	13.3	BM
BRANDES 2	2.693	156	39.5	10.5	BM
BRANDES 3	2.692	111	40	9.8	CM-BM

Figure 5. Results of analyses carried out in 2005 by Yves Orengo (UJF, Grenoble I).

For each of the samples analysed, the compression strength (col. 3) is greater than 110 mega Pascal. On a scale used for the tests carried out on a number of European millstone grits (Fabre *et al*. 2006, 91-97.), the Brandes samples are situated beside the silex of La Ferté-sous-Jouarre (80 MPa) or Corfélix (240 MPa) in the Brie region (France). Hence, this is a high quality rock. Moreover, this rock was used equally for both ore and grain. This dual usage is visible on three grain millstones made from the same conglomerate and used for the Brandes miners' food. Caution is advisable however as regards the characteristics of these millstones. We do not know exactly which qualities were required for the rocks intended to grind ore. Other mining works, for their part, such as those in Pampailly (Rhône - France) (Benoit 1997, 70.), or Castel Minier (Ariège - France) have revealed granite millstones (Benoit *et al*. 1997, 62-69.).

The diversity of the cases encountered shows that the miners tended to make do with the rocks at their disposal. Whether the sandstone and conglomerate of Brandes, or the granite of Pampailly, what these rocks have in common is that the majority are present *in situ*. It was not as much about making choices as it was about adapting to the situations encountered.

1.3. Extraction techniques

The methods used to extract millstones are fully representative of the various quarries studied in Europe (Anderson 2003, 49-50; Jaccotey and Milleville 2008, 16-23; Belmont 2008). We can differentiate however between the blocks used to extract several millstones and the blocks intended to produce a single item.

First, there was the cutting out of a ring-shaped channel to outline the future millstone. This operation was carried out using a unique tool with a circular tip slightly more than 1 cm in diameter, in three cuts (Fig. 6.): the first one as close as possible to the rough-out, the second 10 cm further

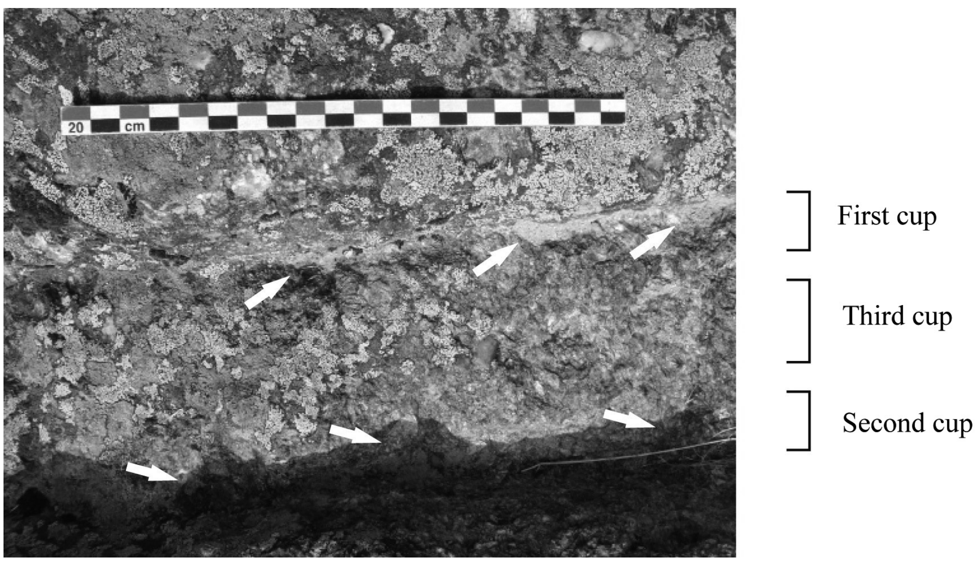


Figure 6. Details of the ring-shaped channel of Millstone Grit B 106.

Figure 7. Overview of the rough-out 2009-1-9.

Figure 8. Details of the rough-out 2009-1-9.

along and the last one in the middle, after the second cut was made. This method, which in all likelihood involved the oblique 'thrown percussion' or 'pecking' technique, is common in the millstone grits studied. The squaring off of the edges of the blocks was done using rougher tools, which fractured the rock. The millstone makers worked step by step in order to 'test' the rock. They tackled it in different ways and in different locations to make sure it was worthwhile to continue working on it. If the rock yielded at any time, they did not pursue their art any further, so as not to waste time fully shaping a part of the millstone whereas the other part was bound to fracture.

Regarding the blocks cut for the production of a single millstone, the cutting method differs slightly. The various steps involved in the cutting of these blocks proposed by Gary Adams and Gérard Serres are fully applicable to the rough-outs of Brandes (6 steps of cutting. Cited by Hockensmith 2006, 193-194; Serres unpublished, 1995. Diagram produced from the medieval ore millstones in Peyrusse-le-Roc (Aveyron - France)). First, the gross block is roughly hewn to a shape that is rounded at best or at least plane-parallel. This step can consist initially of rough work, leaving corners, after which the operation is finalised on the edges with a sledge hammer or a pick. There is little trace of this phase still visible on the rough-

Figure 9. Rough-out of an eye on the 2009-1-10.

outs present, since the millstone makers continued their work. However, on the 2009-1-09, a clean cut can be observed on the bottom of the block, attesting to the first actions of the tradesmen of Brandes (Fig. 7). At the second step, the reduced block was cut, much more rigorously this time in order to give it its rounded shape. Again, on the 2009-1-09, traces of a pick or chipping chisel 1 cm wide resulting from this operation are visible on the major part of the edge of the block (Fig. 8). Then, the upper surface of the block was flattened. Apart from preparing a possible grinding surface, this task was also used to test the rock. If the rock proved to be inappropriate for cutting, it might break and by testing, the millstone makers could avoid wasting their time.

The methods used to extract millstones for ore grinding are therefore no different from those intended for the milling of grain. The millstones could only be adapted for specialised use after extraction.

1.4 Shaping

The coring out of the eye is a step still common to both usages. In the centre of the potential millstone, the millstone maker would first cut a circular vein that was progressively enlarged with the aim of being sunk in as work progressed. The task was carried out using a tool with a round tip 7 mm in diameter as shown by the marks left at the bottom of the incision made on rough-out 2009-1-10 (Fig. 9). Once the incision was made, the millstone cutter removed the first section in order to complete the circle, still using the same tool. The eye was only completed after the future millstone was the right thickness.

The next step consisted of making the notch in the millrynd. The widths vary from 4.5 cm to 7 cm for the 2009-1-38 (Fig. 10). As for lengths, they are seldom preserved in their entirety. For the 2009-1-38, for example, one is 29.5 cm long and another is slightly more than 28 cm. The thickness varies from 2 to 3 cm, no notches being fully regular.
Finally, the furrowing of the millstones is clearly similar

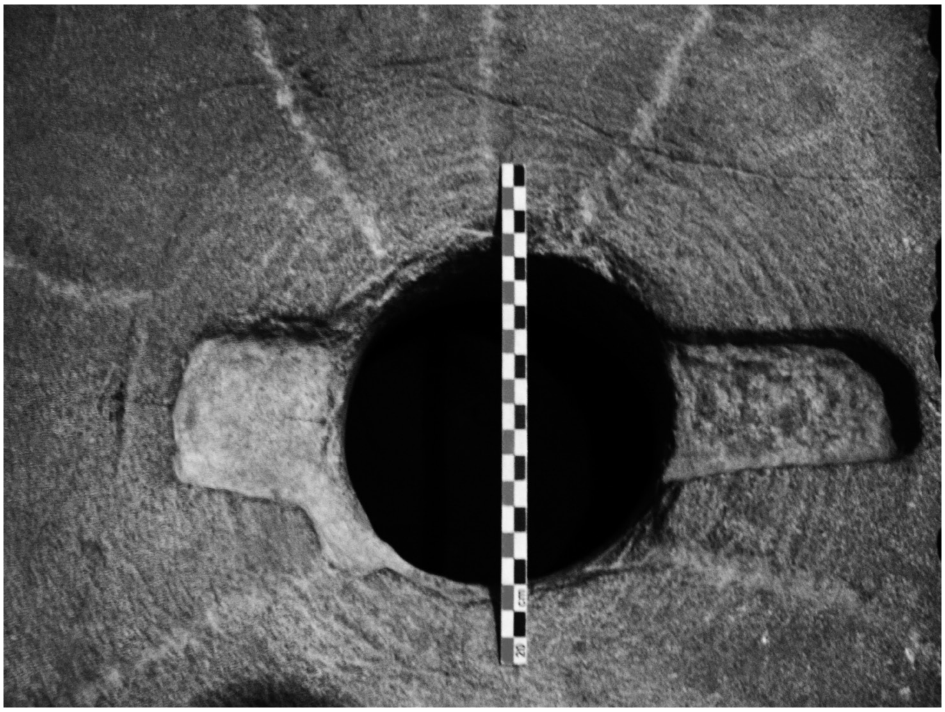


Figure 10. Eye and millrind of the 2009-1-38.

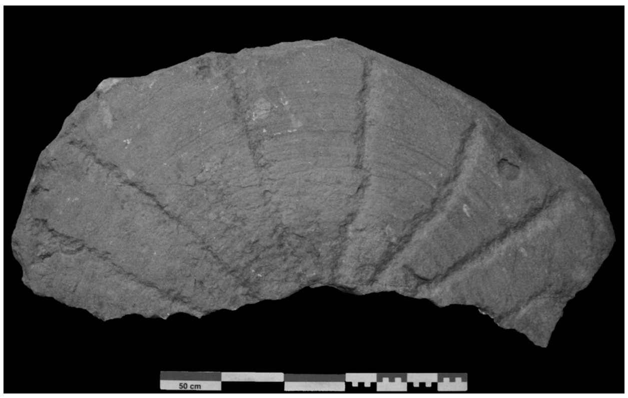


Figure 11. View of millstone 2009-1-52. It contained 16 furrows across the surface.

here for the grinding of ore. Although during Antiquity, the grinding surfaces of grain millstones could be furrowed or at least covered by multiple grooves (Belmont 2006, 41), this process appears to have been abandoned afterwards, only reappearing at the end of the 18th century (Amouric 1984, 272; Perry 198, 155). In the meantime, the millers preferred to peck at their stones randomly. The furrowing technique, however, did not disappear forever during the Middle Ages. It was adapted for the grinding of ore not only in Brandes, but throughout the mining works equipped with such artifices. The furrowing of wheat millstones is a more complicated task than the cutting out of furrows for ore, but the skilled Medieval tradesmen were familiar with and mastered both types of know-how as they used them both at the same time.

A high degree of consistency is noted in the method used to cut out the furrows. The quarry workers appear to have preferred a particular type of tool fitted with a circular tip ranging from about 5 mm to 1 cm in diameter. In a few more isolated cases, they may also have used rougher tools such as chipping chisels, leaving marks measuring more than a centimetre. They began by cutting out a central recess which they would then enlarge by one or two shallower cuts using a pick (Fig. 11).

Several types of furrowing are observed on the ore millstones. Factors such as the number of furrows, their distribution on the millstone and their dimensions are taken into account. This typology is in the process of being drawn up using a diachronic approach (Lepareux-Couturier and Jodry 2010; Minvielle Larousse and Bailly-Maître 2010).

In making a final assessment, we can state that ore millstone quarries do not differ from those that produced wheat millstones. The methods and steps of extraction were similar as well. From squaring off to cutting out the notch for the millrynd, all of the Brandes tradesmen's actions are representative of a more general context. Only the size of the furrows and, perhaps, the thickness truly differentiate ore millstones, the variations in diameters being too fine to opt for one of the two uses.

After having compared the methods of shaping ore millstones with those used for wheat millstones, we are also in a position to link up millstone making techniques with quarrying techniques. This parallel has already been made, centred more on the way of working underground extractions (Bailly-Maître 2006, 163-170.). We propose to extend these considerations to encompass the entire chain of operations. The tool marks left by the tradesmen are clearly reminiscent of the tools used in mining work: tapers, sledge hammers, chipping chisels, picks, etc. The miners used their skills and their tools in the open air to shape the millstones which we are now going to present in detail.

2. Millstones, 'memory' of grinding

As regards traces left on the grinding surfaces, ore millstones have a sizeable advantage over wheat millstones, for two main reasons. The first concerns the material precipitated into the eye of the upper millstone. Grain is no rival to rock and always ends up being cleaned out by the asperities, without leaving any evident traces. Ore, on the other hand, mixed with gangue, is a much tougher adversary for millstones. The results are, admittedly, practically the same, with a fine powder at the outlet, but in the meantime the millstones were lacerated by the passage of ore which left thousands of indelible marks, traces that will enable us to better understand the rotation and operation of the grinding mills. The second reason is related to millstone maintenance. By regularly dressing the grain millstones, the millers also eliminated the minute traces of the previous grinding. Miners, though, did not do the same for their ore stones, thereby leaving a multitude of testimony. To propose an interpretation of the traces of grinding, we will first analyse the surfaces of fragments before more closely examining the ridges.

2.1 Intensive use

It is a useful statement of the obvious to say that the rotation of millstones progressively wears away the grinding surface. What is remarkable about this phenomenon is its intensity. The millstones that have been preserved are worn down to the chord. By extension, it is likely that ore millstones received no intermediate treatment as grain mills did.

Not content to mercilessly whittle down one side of

Figure 12. 2009-1-36.

the millstone, when the millstone became unsuitable for grinding, rather than re-employ it differently, the miners sometimes preferred to turn it over in order to extend its service life. Out of a corpus of 84 millstone fragments (excluding small fragments and rough-outs), 14 items, i.e. 16.6% were used successively on both sides. Among these items, despite a high proportion of undetermined ones (a flat surface or fragments still too small), three points stand out. First of all, no fragments are convex on both sides at the same time. The use of the millstone as a bedstone on both sides is therefore to be eliminated. However, two specimens are concave on both sides: runner stones that were always turned over to serve the same purpose. The rest of the time though (6 items), they are concave on one side and convex on the other. In this case, dual usage is indeed to be considered, but in an order that is still to be defined.

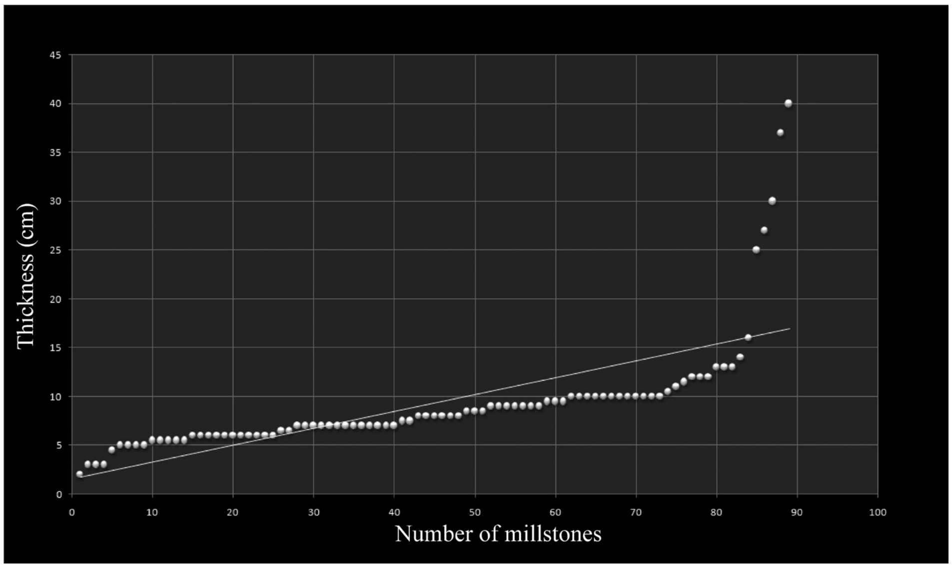


Figure 13. Millstone thickness distribution chart.

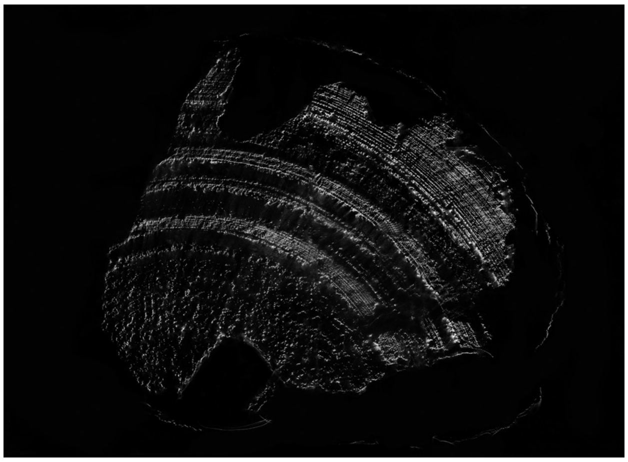


Figure 14. Negative view of the 2009-1-39.

Regarding grain mills, normally runner stones arriving at the end of their service lives are re-employed as bedstones, which have less stringent quality demands (Belmont 2006, 39.). But the grinding of ore does not have to meet the same constraints as the grinding of grain, so the question is still open. The study of the millstones concerned here has not answered it, due to similar wear on both sides. It is still likely that the miners worked not according to habit but according to the conditions encountered in particular cases.

The consequence of such intensive usage is the inexorable reduction of millstone thickness. From an initial 30 cm, if we can trust the rough-outs or the almost-new half-millstone still in context on the right bank of the source (Fig. 12), much more modest figures are found for most of the fragments. The chart below (Fig. 13) summarises the data and highlights a distribution of maximum fragment thicknesses of between 5 and 15 cm. The initial thickness of the millstone, which may appear very large at first glance, is actually in line with an average. In the 14th century, the bread baking stones purchased by the Lords of the Dauphiné were massive blocks that could be up to 2 feet thick (66 cm) for bedstones and 1.5 feet (49.5 cm) for runner stones (AD 38, 8B 83, Accounts of the Lord's domain of Claix 1382-1383.).

It would appear to have been established that the requirements for ore millstones were not the same as those for grain millstones. What remains to be found is if this type of millstone management was intentional, without any compromising of ore enrichment, or, to the contrary, if it shows that the miners were growing away from the process.

2.2 Ridges

The other visible manifestation and testimony of grinding on the millstones are ridges, discreet or obvious traces of the passage of ore and gangue (Fig. 14).

The immense majority of millstones or millstone fragments that have been preserved display these ridges. Out of a group of 84 items, 72 have ridges, i.e. 85.7%. This figure is even liable to be increased, since it only accounts for ridges that are visible to the naked eye or those appearing on tracing paper (Regarding the methodology of the acquisition of ridges: Minvielle Larousse and Bailly-Maître 2010). Generally speaking, the marks become finer from the centre of the millstone towards the edge as shown in the example of the 2009-1-39 (Fig. 14.). This is directly linked to the distance between and relative placement of the rotating millstone in relation to the bedstone. First of all, the shape of the stones, convex for the bedstone and concave for the runner stone, prepare for this flow. The runner millstones are placed in such a way that the material poured into the eye is accompanied as it is reduced. The distance between the millstones is greater at the centre of the stones, since the ore module is at its largest, and it is then smaller towards the outside so as to reduce the ore. Marks of grinding surfaces result from this arrangement. Near the eye, the ridges are wide and rough, or even absent.. They become finer towards the outside as the millstones move closer together, through the breast and finally the edge to make the ore become similar to flour. Moreover, this is exactly the same procedure as the one used for grain, minus the ridges cut by a material much harder than rye or oats.

All of these steps are found almost systematically on all of the whole millstones, half millstones and millstone segments. The fragments are classified according to their position on the millstone, by centre, breast and edge (Fig. 15). The first observation that can be made upon reading the graph is that a large majority of the fragments have been identified without difficulty. A mere 13.10% of them have remained outside classification for various reasons, related in particular to too few samples to be able to take a decision. Nevertheless, in most cases, there is hesitation between the edge and the breast. And these same edges and breast account for the lion's share. With 32.14% of edges and 17.86% of breast, the 2.38% of centres is very much a minority. This is all the more valid if double zones are added (15.48%). As a result, even if segments and whole millstones are added up, centres and eyes are underrepresented. It makes sense for the millstone to become more fragmented at the outer edge, which is more fragile than the massive central part. This does not mean however that centres would not be found as well, fewer of them certainly, but here there is a virtual absence. Nor can this difference be totally ascribed to salvaging and successive reuse. This point deserves further attention, which it will be given further on.

Once the classification is carried out, close and attentive examination of the ridges shows that under cover of surface consistency, the ridges are actually highly unequal and recut in many locations. The examples are infinite and an example is illustrated from fragment 2007-0-1515 (Fig.

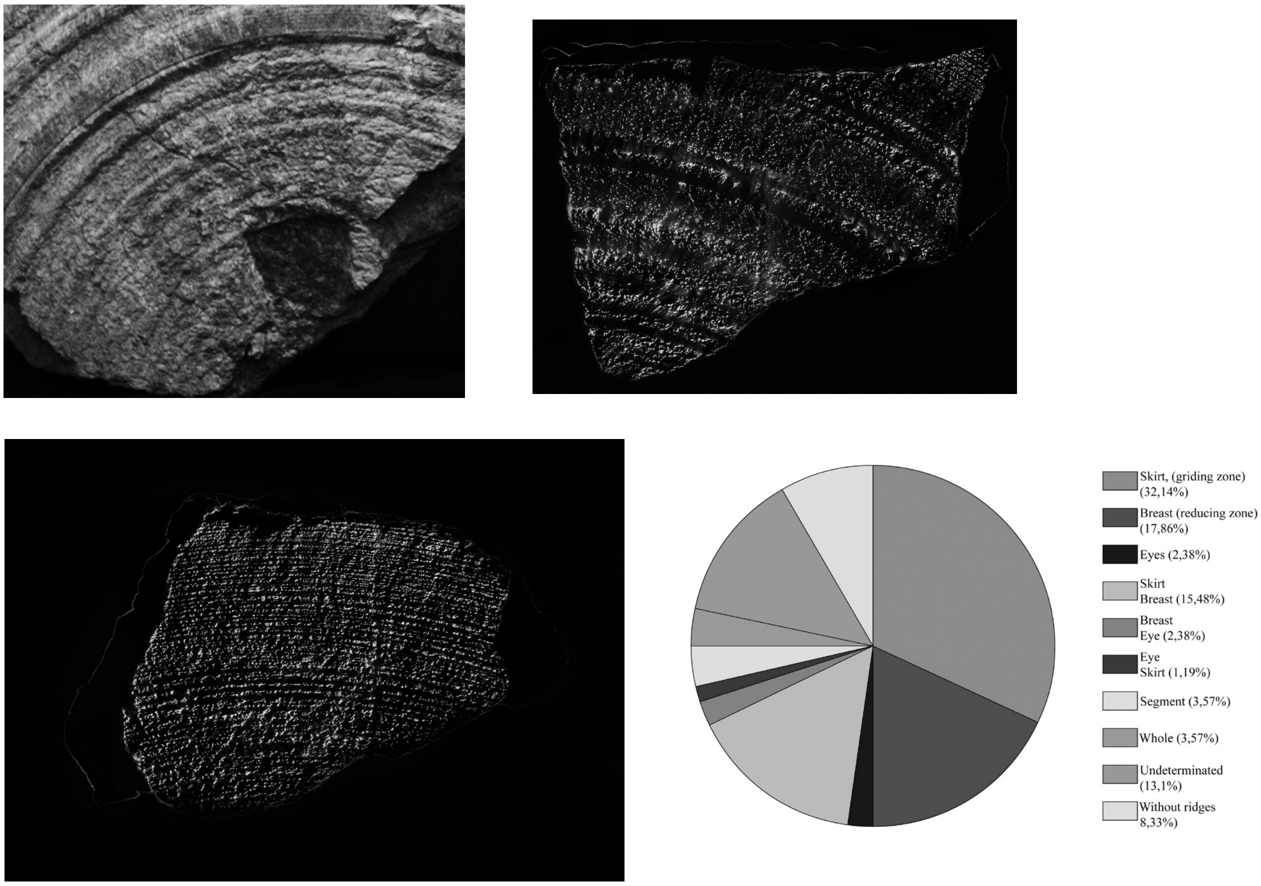


Figure 15 a, b, c and d. Views of a core (top left, 2009-1-39), a breast (top right, 2007-0-1515) and an edge (bottom left, 2007-0-1488) and distribution of fragments according to position on millstone (bottom right).

16). An initial 3 mm wide ridge is very clearly perceived and it splits a first time. The lower ridge then disappears a bit further on while the upper ridge, which had started as a fine bevel, progressively widens and ends up splitting and finally evaporating. The ridges are therefore not rigorously concentric. They evolve as the millstone rotates over time. Here, we have seen changes of direction, creation and destruction, but many fragments display ridges that have been whittled down by repeated use.

The grinding surfaces have therefore been kept 'in memory' with a quantity of information on grinding techniques, as well as on the workmen's method and actions. The ridges underwent a complex evolution, linked directly to the operation of the mills. They were furrowed consistently by the first rotations, but then continued grinding ended up by whittling them down and segmenting them. Since the axis of rotation was more or less flexible, the matching of ridges between the two millstones was not ensured for long and the ore finished cutting out the summits it had initially formed, sometimes in a direction that had more or less shifted. All of these observations have only been made macroscopically. It therefore clearly appears that a study of this type would call for a much more detailed approach than ours. Microscopic analyses would no doubt provide a number of additional elements in the quest for detail that is inherent in tribology. As an example, micro centre samples taken from antique ore millstones from the Les Forges domain (hand mill) have revealed grain still embedded at the end of a ridge that has been characterised chemically to define the type of material ground (Domergue *et al*. 1997, 48-61). Having said that, based on observations made, we are in a position to propose a number of interpretation schemes regarding ore grinding in Brandes.

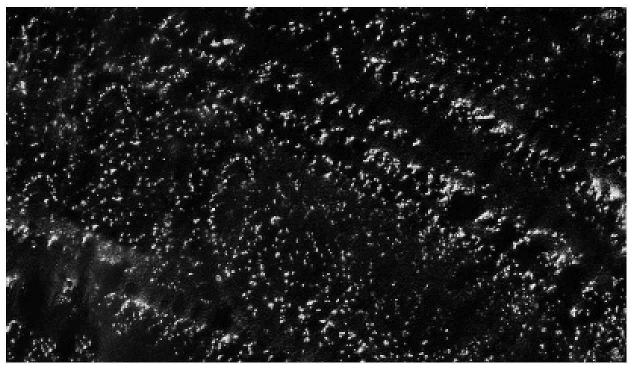
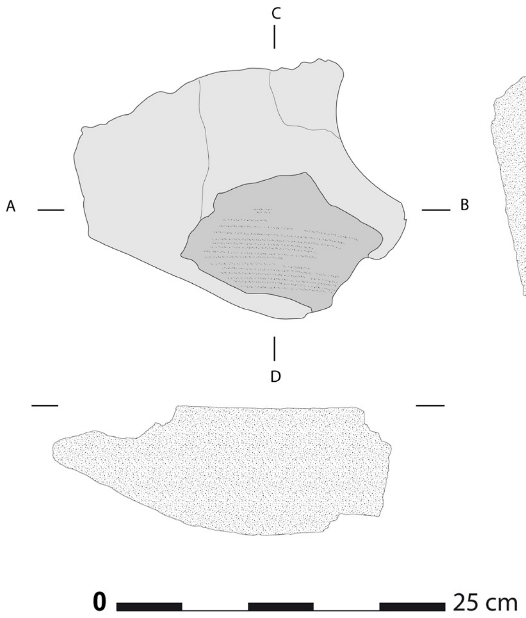
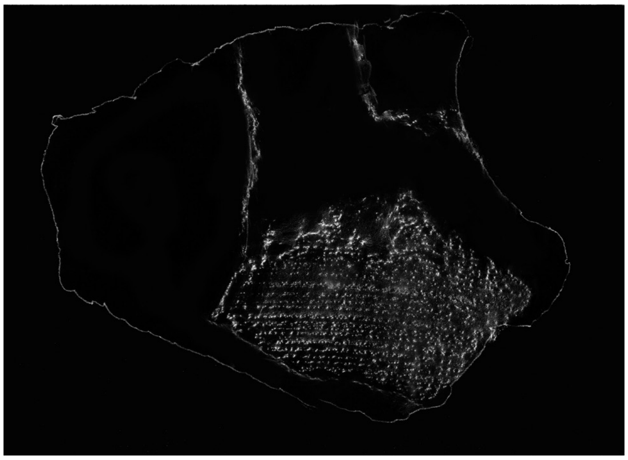


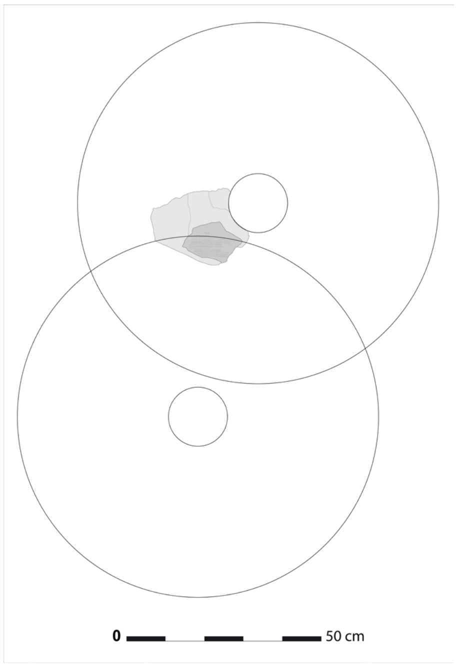
Figure 16. Details of negative of 2007-0-1515.

3. Millstones in their mills

'L'impossible description technique' is the title chosen by Aline Durand to propose a typology of Carolingien mills in the Languedoc region (Durand 2002, 33.). Despite the







Figures 17 a (top left), b (top right) and c (right). Views of fragment 2007-0-1504 and projection of the presumed axes of rotation.

poverty of sources during the early Middle Ages, this observation has subsequently been widely contradicted in the development that has since taken place. Yet, understanding a discreet building and a complex technology is not easy, even if such artifices literally abound in western towns and rural areas (Regarding the distribution of mills in rural areas, refer to: Pichot 2002, 260.). Although, in the Oisans, nearly each parish, including Brandes, had at least one wheat mill available, there was evidently not the same demand for ore mills. *De facto*, the sources reporting on their activity are truncated and leave this type of artifice in the dark. It will be necessary to use every detail of every source, whether textual, iconographic or archaeological, in order to endeavour to shed light on certain aspects of the issue. To do so, we will first analyse the only tangible remnants of the mills, namely their millstones. Secondly, we will propose an interpretation based on iconographic sources combined with the historical context. And thirdly, we will situate ore grinding within its process, mineralurgy, in order to understand the role of the ore mill in Brandes.

3.1 Segmented millstones?

Side by side with monolithic millstones, it would appear that the miners also used segmented millstones.

The subject of segmented millstones, addressed by Henri Amouric in 1984, is a thorny issue that is continually being revisited. At the time he wrote his thesis, no examples prior to the 19th century were known for segmented millstones, regardless of the type (Amouric 1984, 266-267). Since then, the first references have been pushed back further and further as historians look into the question. Still in 1984, Dorothée Kleinmann reported on the appearance of this new type of millstone between 1760 and 1775 (Kleinmann 1984, 1107-1116). The perspective of the late 18th century would appear to receive the assent of researchers. For Jean Bruggeman, who studied the millstones of Flanders for the symposium in La Ferté-sous-Jouarre in 2003, there is no possible doubt: ‘Medieval millstones are always monolithic. Black basalt stones were still used in the centuries that followed. White stones were used too, up to the end of the 18th century. But bedstones could be made of several irregular-shaped pieces. They were bonded with plaster, held together by an iron or wooden band and sometimes rested on a bed of cemented bricks’ (Bruggeman 2003, 232). However, Benoît Deffontaine, at the same symposium, dated these stones back yet another 150 years or so thanks to fortunate textual references to ‘milling stones’ in 1647, 1652 and 1680. According to him, ‘nothing prevents us from believing [that production] could even date back to before the first half of the 17th century’ (Deffontaine 2003, 297-298). Alain Belmont, again at the La Ferté symposium, reported on an agreement dated 3 May 1452 whereby ‘a merchant from Rouen named Robert Le Cornu agreed to convey one or more ships loaded with 35 millstones, 5 eyes, 100 tiles and a tombstone to Normany' (Belmont 2003, 282). The above-mentioned tiles obviously came from the famous quarry of La Ferté. That is the extent of research at the present time. Remember, however, that this brief review of the question only concerns wheat millstones.

In Brandes, one fragment of the corpus stands out (Fig. 17). At first glance, it is a core fragment, since a piece of the eye and millrynd notch have been saved. Below the eye, a ridged surface is present, displaying very fine ridges, of the edge type. This is atypical, but may remain possible under multiple conditions. However, the outstanding element is the direction of the ridges in relation to the eye. They are completely reversed and it is not possible for the axis of rotation to have simply been modified, since the difference is far too great. This would indeed appear to be a 'piece' of a millstone and not just a fragment.

In the light of this assumption, we must reconsider certain cases such as these half-millstones, photographed in the context in which they were abandoned at the beginning of the 20th century (Fig. 18). The break is very clear for the three visible items. It is therefore also possible that these were millstones put together from two segments.

The miners would appear to have used all of the methods at their disposal. If, and only if this assumption proves to be true, some ore millstones would have to be seen as an assembly of extremely diverse pieces of stone, difficult to connect to any typology whatsoever as such. When a piece was worn, it was replaced straight away by another one cut for the occasion, or sometimes even by a used piece that was recut. This ranges from modest-sized pieces to half-millstones. There would appear to be no general *de facto* trend in the matter. This possibility would explain the module of most of the fragments preserved and thereby the small numer of known monolithic millstones for operations that lasted nearly 150 years. It would also explain the distribution of the same fragments: many edges and breasts for very few centres. On the other hand, this amounts to saying that it is impossible to estimate a minimum number of items (MNI) for the millstones that were used in Brandes. Several points can be put forward against these elements:

1. Firstly, the existence of a single explicit fragment may appear rather insufficient. It is true that its presence is just an exception, in the end. An exception, but not one that confirms the rule; instead it raises questions.
2. Secondly, it is known that considerable salvaging of millstones was done on the plateau. As soon as the operations were abandoned in the mid-14th century, the neighbouring community of Huez was certain to have hurried over to salvage the millstones in good condition to take them down to the mills of the Sarenne, treat them and 're-dress' them to make them more suitable for grinding

Figure 18. View of half-millstones in the context in which they were abandoned. Taken by Hyppolite Müller, at the start of the 20th century. Musée Dauphinois collection.

wheat. This type of salvaging has gone on up to the present day, with the original stones becoming objects to decorate the gardens of the Alpe d'Huez resort. There were many more monolithic millstones in situ. However, we cannot conclude that there were no segmented millstones simply by the presence of monolithic millstones. Both forms may very well have cohabited.
3. Thirdly, a question is raised by this operating method in relation to the way of holding the pieces together. Customarily, they are bonded together with plaster and made solid with an iron or wooden band, or with masonry mountings. However, so far, we have found nothing of this sort on the millstones. The ends of some of them are even so irregular that it may be wondered how strapping could have been put in place. There are no traces of iron fasteners in the fragments either.
4. Lastly, we are not familiar so far with any rough-outs cut out for this process. But we saw above that this is a more general problem. Up to now, only three millstone grit quarries have been recognized. Nonetheless, this is an element that can contribute considerably in terms of understanding the fragments. Provided, of course, that their working is not confused with that of ashlar.

The question therefore remains open and can only be resolved by the contribution of other comparable mining works, lacking new elements from Brandes. Regarding the chronology of the process, this would move back its date of appearance by more than 150 years. Reference is made to circular millstones, but was there not another type of mill that already used segmented millstones some 1400 years earlier? In was in 1987 on the Island of Délos that 'G. Siebert discovered the remains of a dislocated mill on the ground of one of the rooms of the main floor of the Maison des Sceaux' (Brunet 1997, 29-38). It was equipped with millstones in separate parts assembled by clamps for the rotating stone and simply held in a wooden frame for the bedstone. Of course, these are cone-shaped millstones like in the mills found in the bakeries of Pompei, and not circular, but this process had already been conceived of by man, probably back in the middle of the 3th century BC.

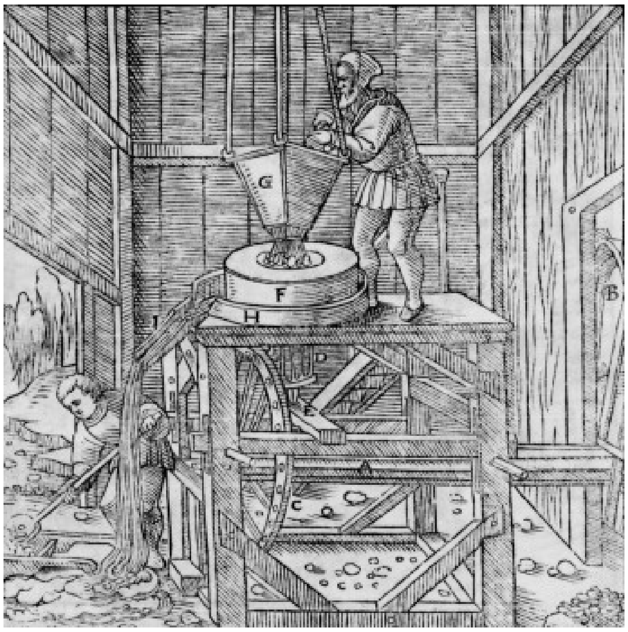


Figure 19. Representation of an ore mill according to Agricola.

4. Mills

The sole representation of an ore mill comes to us from Georgius Agricola for the 16th century, in his *De re metallica* (Agricola 1556). In this work, he proposes a functional though highly schematic model, without being truly attached to the proportions of the component parts (Fig. 19).

Several comments can be made about this representation. First of all, there is Agricola's desire to be didactic. All of the parts are shown clearly, sometimes to the detriment of reality. For example, the eye of the millstone is out of proportion to the millstone. It is true that on the proper scale, it would have been nearly invisible for his readers. The same is observed for the diameters of the millstones, which are much too small. This representation must therefore be seen as a model more theoretical than practical. Nevertheless, nothing is missing and no frills have been added. There is no doubt that Agricola knew his subject well. On the other hand, it is unlikely that this type of mill existed in Brandes. The wheel was the stumbling block. It is what determines the mechanism that follows and how water is to be brought within its range. In other words, it is the wheel that makes the mill. For Brandes, it is necessary to look at a much wider technological context. Claude Rivals has shown that the breakdown between horizontal wheels ('*rodets*') and vertical wheels noticeably matches the cultural areas of the '*langue d'oïl'* and the '*langue d'oc'* (Rivals 2000). A majority of horizontal wheels are used in the south whereas vertical wheels blossom in the north. There are always exceptions, but on the whole, the various regional studies carried out before and after these findings have not challenged this fact, the reasons for which are still relatively unknown, but, on the contrary, have confirmed it (Amouric 1984). This distinction was moreover reported several centuries ago with Belidor, who spoke in 1739 of the mills of Provence and the Dauphiné region customarily built with a horizontal wheel (Bélidor 1739, 301). Regarding the Dauphiné and hence the Lord›s domain of Oisan to which the village belonged, the registers of the 'Chambre des comptes et des maîtres des œuvres' [Chamber of accounts and contractors] have led to same conclusion (Minvielle Larousse 2009, 130-132). The operating method for this mill was simpler than as described by Agricola. Henri Amouric even speaks of a 'childish mechanism': a gear point with wheel and trundle, but a single engine shaft linking the horizontal wheel and the rotating millstone by means of the millrynd (Amouric 1984, 130).

This gives a process comprising a flume, a holding basin with its weir, running stone, mill and tail race to finish. The simple fact of including a running stone in water-mills can completely separate the mill from the water supply channels. It may be very short or several metres long like a mill serving in Valence in the late 15th century and including a running stone 4 'toises' long (approximately 7 m) (AD 38, B 3128, not numbered. Bail à prix fait du moulin de Valence du 5 février 1490 : 'Item due canales longitudinis qualibet quatuor tesiarulm et grossitudinis unius pedis cum dymidio'). This point is important since in the field, a hiatus may be formed in this way between the major hydraulic facilities and the place of grinding.

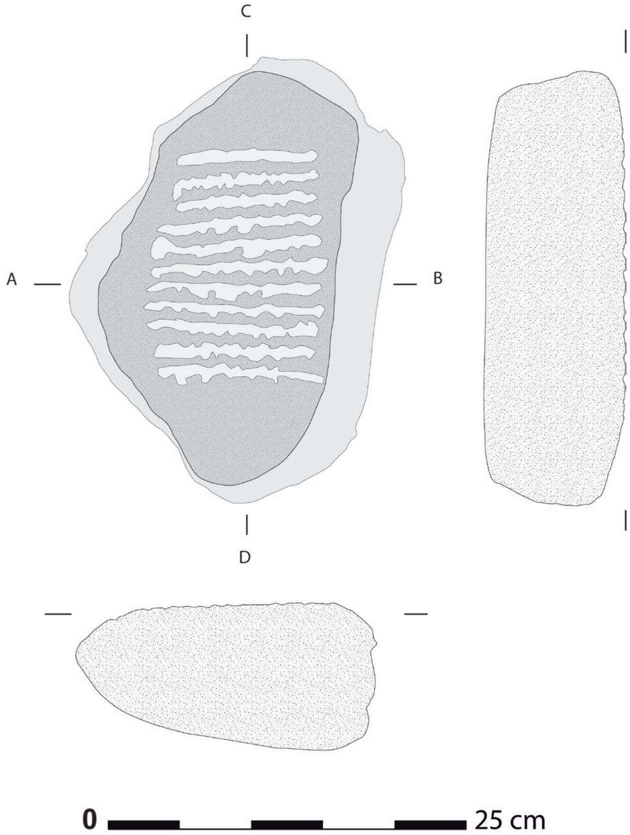
These ore mills are difficult to observe by excavation because of the materials used (wood), the relatively small size of the structures and the salvaging of iron parts after they were abandoned for use in other mills. In this respect, the quest for details in excavations is essential.

5. Mills and ore enrichment

Mills are only one item among others in the mining context. Based on this, their place in the system and the role they play are called into question. In fact, the industrial installations of Brandes must only have included a small number of mills. When this is put into perspective with the moderate number of fragments, the possibility of counting segmented millstones and remnants in the field, all of this combined with the period of activity of the mine, we are able to propose this conclusion. Moreover, the situation appears to be the same in Pampailly where documents mention during the middle of the 15th century, barely 'three mills to grind the ore and gangue in Cosne, Brussieu and Vernay' (Benoit 1997, 70).

To explain this, it is necessary to recall the purpose of mineralurgy: the whole process is to separate the ore from gangue. The smaller the module of the mix, the longer and more difficult it is for the miners. The 'flour' produced by the grinding of the ore and gangue is therefore often complicated to treat, even in the washing basins (Marconnet

Figure 20 a (above) and b (right). Views of 2009-1-56.



2006). In Brandes, since the gangue is essentially barite, the use of mortar and strikers is sufficient to reduce it to powder, as witnessed by the numerous experiments carried out. The very high number of experiments points in favour of the massive use of these tools.

In these conditions, ore mills played only a complementary role in the enrichment of ore. The miners used them in certain cases, which still need to be precisely defined. Was it for a particular module or for a specific composition? Additional analyses will be useful to determine this. Whatever the case may be, we have observed a wide variety of techniques used for the grinding of ore. Mortar and strikers are by far the most used, followed by water-mills and then a third, more singular but also more marginal. The corpus of millstone includes an alternative hand mill, with parallel 'furrows' made with a pick using the same method as described above (Fig. 20).

Conclusion

At the end of the study, it goes without saying that many questions have still not been answered and that further queries have arisen.

We have observed, in particular, that the extraction of ore millstones is in many ways similar to the extraction of wheat millstones, which shows that use of the methods was widespread. Generally speaking, the extraction or cutting techniques used by the millstone makers, miner and quarry workers are very similar to each other, with respect to both tools and actions. This raises the question of the specialisation of rock tradesmen in specific areas. For Brandes, we do not know, for instance, if the extraction and cutting of millstones were done by a millstone making tradesman who was called in for the occasion or by the miners themselves. Regarding the use of millstones, it appears that they were not serviced regularly by the miners, apart from the cleaning out and recutting out of the furrows as the thickness of the millstone decreased. The immense majority of the items show grinding surfaces that are extremely smooth unlike wheat millstones which are dotted, whereas the context in which they were abandoned is the same. This point relating to the properties of the rocks, the maintenance of the millstones and the miners' grinding quality requirements can only be truly clarified by experimental archaeology. By taking into consideration the diversity of the methods linked to Medieval mineralurgy (crushing, decrepitation, grinding) and knowing that ore mills were probably not numerous in Brandes as in Pampailly, mechanical grinding, by means of water-mills should not be viewed as an innovation in relation to the manual treatment undergone by the ore. They are situated in an auxiliary branch of the process and did not replace crushing, since they were not suitable for that work. Innovation would come much later with the stamp mill which transformed rotational motion into alternative motion by means of a camshaft. This device reproduced the same actions performed earlier by the miners equipped with strikers, but at a virtually industrial stage. Stamp mills appeared for the first time in the literature with the 'Graduel de Saint-Dié' produced between 1494 and 1513. But the camshaft is attested to at least in the 10th century and since the advances in archaeology regularly date technologies further back in time, there is nothing against prior use of these mills. Later excavation may clarify this point.

Acknowledgements

We are particularly grateful to: Timothy Anderson, Alain Belmont, Kathleen Lewis, David Peacock, Flavien Perraza, Francis Pierre, Stéphane Rouméjon, Gérard Serres and David Williams

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