Scales and spheres

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ABSTRACT: In archaeological contexts hammerscale and slag spheres (spheroidal hammerscale) are indicative of iron smithing. Often they are not considered to hold any other information, but scale and spheres are the result of a number of different processes, and analyses can provide more detailed information on the type of work that was going on in a smithy. This paper provides a brief overview of the study of samples from 18 smithies in Denmark, Norway and Sweden dating from the Iron Age to the 18th century. A total of around 2000 hammerscale fragments, and 800 slag spheres, have so far been analysed.

Introduction

On its way from iron ore to finished object, iron undergoes a number of different processes. Hammerscale will be produced in all of these, and most of the processes will also produce slag spheres (spheroidal hammerscale). Looking at the analyses of hammerscale from different archaeological excavations, it is clear that smithies might be divided into different groups or classes on the basis of differences in the composition of the hammerscale. This might in turn reflect differences in the types of work going on in the different smithies. The following is an attempt to explain why different types of hammerscale arise from different processes. The dividing lines used in the diagrams should only be taken as tentative, as there will be some overlap between the different groups. The interpretations are based on the comparison of hammerscale from experimental smithing (Dungworth and Wilkes 2007; Lyngstrøm 2010), the different types of hammerscale found in archaeological excavations and slag inclusions in archaeological iron objects (Jouttijärvi 2013).

Iron production processes

Smelting

The smelting process might lead to the formation of slag spheres, but is not normally closely connected to the actual smithies, and is fairly easily detectable based on the presence of diagnostic smelting slags from the smelting process. More interesting, from the point of view of interpreting smithing waste, is that variable quantities of smelting slag remain as inclusions within the iron produced. The analyses of these inclusions might be used as an indicator of the geographical origin of the iron, but this aspect will not be dealt with in any detail in this paper. Basically the slag inclusions will consist of iron silicate (fayalite), but as the ore also contains clay minerals, lime, and sometimes phosphorous, the slag will not be purely fayalitic in composition. A simplified understanding of the slag composition can be gained from the diagram shown in Figure 1, in which the circles represent the inclusions within each individual piece of iron used for the construction of a Viking period knife (*ie* the remains of smelting slag).

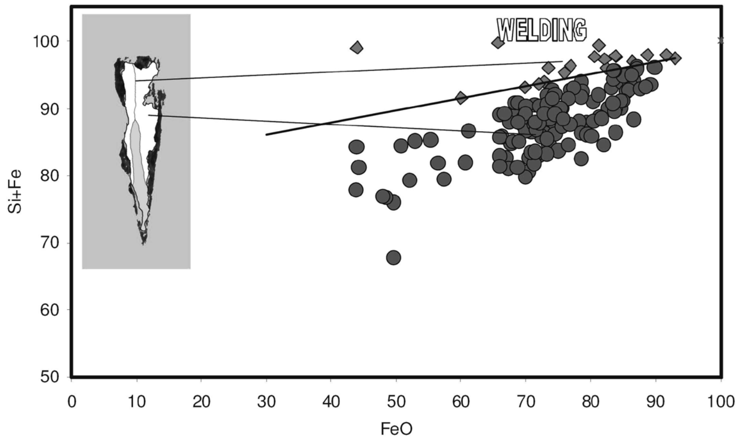

Figure 1: The composition of smelting slag (circles) and welding slag (diamonds) within a Viking period knife (the axes indicate iron oxide and combined iron and silicon oxide).

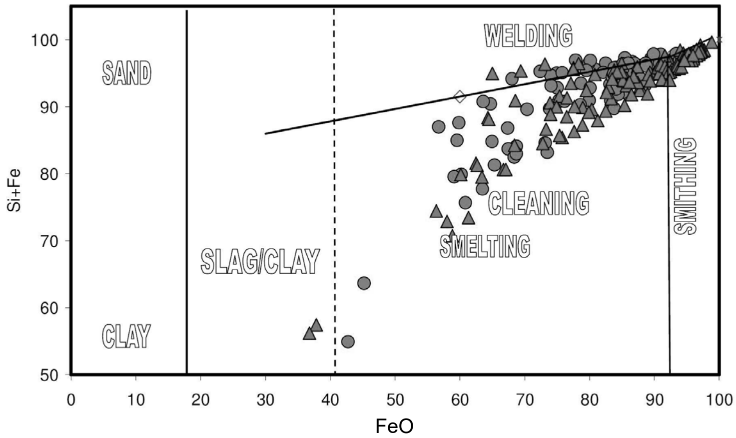

Figure 2: The composition of hammerscale (triangles) and slag spheres (circles) from a 13th-century smithy where blooms were refined (Klosterbakken, southeastern Jutland).

Cleaning and refining of the bloom

Excessive amounts of slag in the iron bloom will have to be removed by a cleaning or refining process (primary smithing) before the iron can be used for the production of artefacts. The refining might also have included grading the iron into different qualities, such as pure iron, steel and phosphoric iron. This might have been done on the basis of visible assessment of fractured surfaces, as it is done in traditional Japanese sword smithing (Kapp *et al* 1987).

In the cleaning process, the iron is heated in a forge, and the molten slag is expelled as droplets during hammering; these droplets solidify as spheres in the air. As the iron cools, a layer of slag will solidify on its surface and crack off as thick hammerscale when the iron is hammered. These hammerscale fragments and slag spheres must be expected to have a composition identical to the smelting slag and the slag inclusions in the iron (Fig 2).

Scale fragments from the refining of bloom iron are rather thick with an uneven surface and a dull greyish-black colour. The thickness varies widely from around 200µm to around 1.5mm, most of them being within the range 200 to 800µm (Fig 3). Seen in cross-section, it is obvious from the dendritic structure that the scale was formed by the solidification of a molten slag (Fig 4).

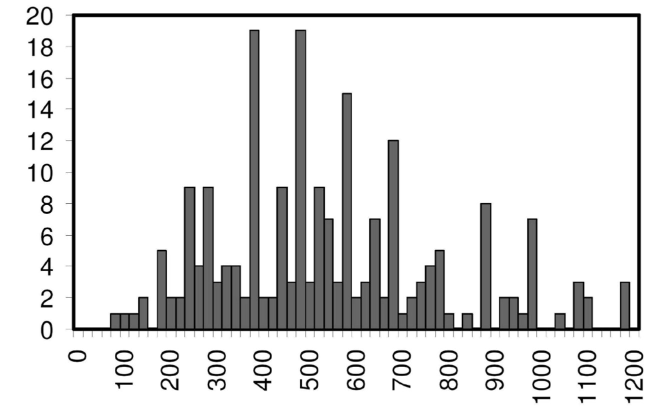

Figure 3: Histogram showing the thickness of refining scale (µm).

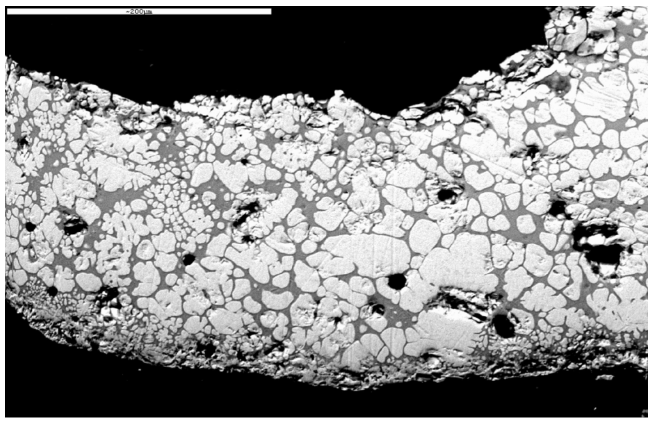

Figure 4: Microscope image showing the dendritic structure of refining scale (scale 200µm).

Welding

The slag inclusions evident in the well-defined weld-lines of the Viking knife shown in Figure 1, whilst basically fayalitic slags, differ in composition from the inclusions of smelting slag in the rest of the metal; in Figure 1 they are represented by diamonds. The main difference between the two types of slag is that the welding slag is a more 'pure' iron silicate slag. The reason for this is that it is formed by the reaction between the iron oxide on the surface of the iron and the relatively pure quartz sand used as a flux by the blacksmith. Analysis of weld-line slags in more than 50 iron objects from Denmark strongly indicates that from the Iron Age to the Renaissance only pure silica was used as a flux for welding. The presence of burnt flint in connection with many excavated smithing sites indicates that it was deliberately used as a source of pure silica.

Again slag spheres and scale will be formed during the welding process, and again they are expected to have a composition similar to the slag inclusions. At first glance the scale thought to have been formed by welding is very similar to the scale formed in the refining process. They are both relatively thick (Fig 5) and uneven, with a dull greyish-black colour. In cross-section the scale from welding has a dendritic structure, but often the remains of reacting smithing slag can be identified (Fig 6). In a few cases the scale fragments may even contain undissolved grains of sand.

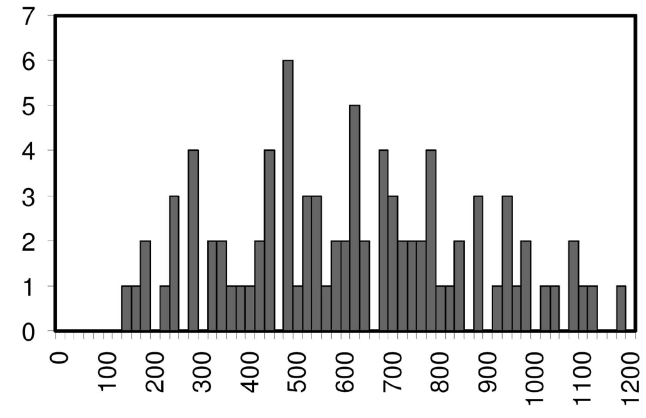

Figure 5: Histogram showing the thickness of welding scale (µm).

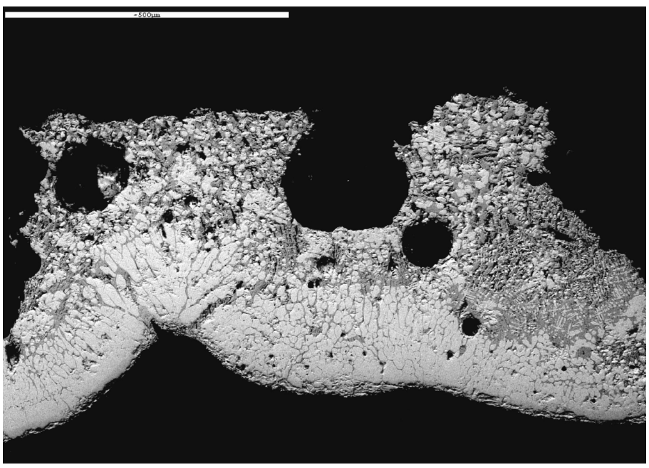

Figure 6: Microscope image of welding scale. The original iron oxide scale (bottom) is partly dissolved in the slag formed by the addition of quartz (top). Small quartz grains are present in the upper layer (scale 500µm).

Smithing

In this context the term smithing is understood as the heating of the iron and the forming of the actual object, a process taking place after cleaning and welding, if these are used. During smithing only very small amounts of slag, primarily originating in slag inclusions near the surface of the iron, are present. A surface layer of molten slag and slag droplets will therefore not form. Smithing will however give rise to hammerscale formed in the solid state by the oxidation of the iron surface. These scale fragments do not show a dendritic structure, but it is often possible to see more or less columnar crystals (Fig 7) showing the growth of iron oxide from the iron surface. The composition of smithing scale is almost pure iron oxide (Fig 8).

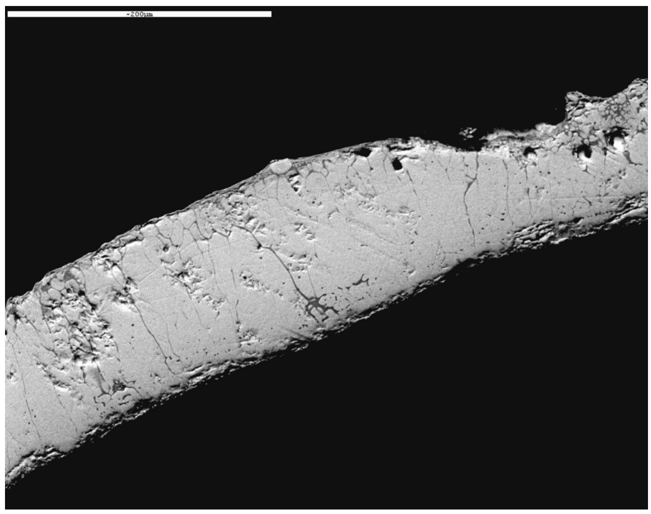

Figure 7: Microscope image of smithing scale showing columnar crystals (scale 200µm).

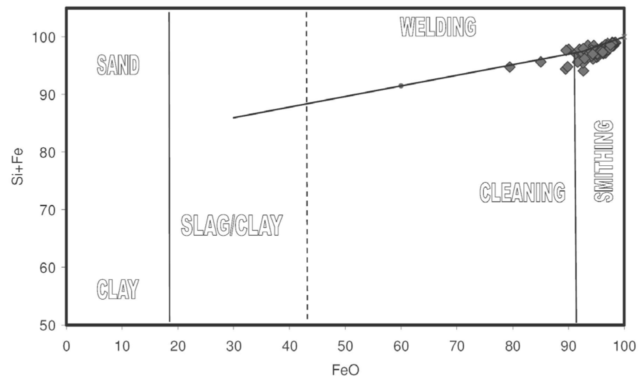

Figure 8: The composition of smithing scales, which are composed of almost pure iron oxide.

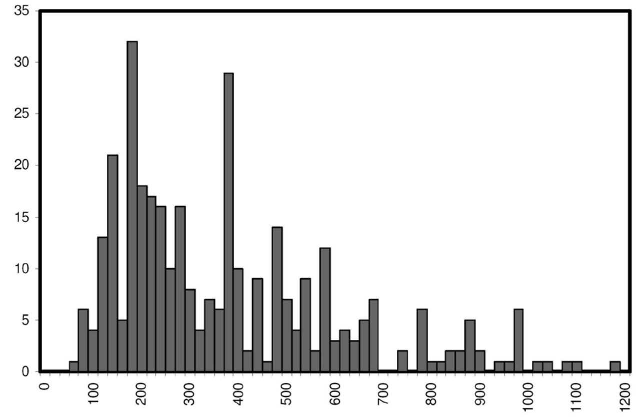

Fig 9: Histogram showing the thickness of smithing scale (µm).

To some extent the hammerscale from smithing can be identified visually as it tends to be smoother and more even in thickness than the slag scale from refining or welding. The colour is often metallic bluish-black. Most smithing scales are relatively thin (100 to 300µm), but the thickness is probably dependant on the size of the object and therefore the duration of heating (Fig 9). Some of the thickest smithing scale seen was found in a cannon smithy from the middle of the 18th century. A thickness of almost 1mm clearly indicated that the large amount of iron necessary for cannon required a prolonged heating in the hearth.

Carburisation

According to Theophilus (Hawthorne and Smith 1963) iron could be carburised by wrapping it in leather and then covering it with a clay envelope. This package was then heated in the hearth for a long time. Finally the package was removed from the fire and the partly molten clay broken away on the anvil. This might have resulted in a special type of slag sphere, which have been found in a few smithies primarily dated to the 12th to 14th century. Although superficially similar to conventional slag spheres, the composition proves that these atypical spheres were formed from molten clay or mixtures of clay and sand. The iron oxide content is generally low (5 to 10wt%) giving the spheres a grey to green, or black, colour (Fig 10). They can normally be distinguished from typical slag spheres as they don't react to a magnet. Scale fragments of a similar composition are very rarely found.

Carburisation is not the only process involving a clay packing and giving rise to the formation of clay spheres. Complex iron items, like locks, were often not welded, but brazed with copper or copper alloys. This was done by covering the assembled parts with copper sheet or filings, covering it with clay and heating the whole object in the hearth. Where fragments of the clay packing are found it will often be possible to determine the type of article being made, and analysis will usually reveal traces of copper in the clay package.

Differentiation of smithing workshops

The proposed interpretation of the different types of hammerscale and slag spheres is supported by the fact that different smithies tend to contain hammerscale and slag spheres corresponding to one or more of these groups, probably due to the different character of the work being done in the workshops. A tentative classification of different types of workshops will be given in the following sections.

The simple smithy

The simplest smithies are the workshops where there is little sign of anything but the forming of objects. Examples might be farm workshops used by the local farmer for repair work, like the straightening of bent tools and probably for the fabrication of simple nails and fittings. Without the knowledge required for forge welding, the blacksmith must have been limited to making objects from whatever pieces of iron were available. The example shown in Figure 11 is an 18th-century

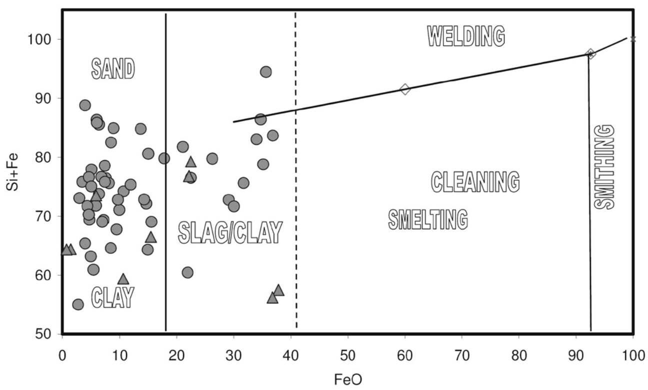

Figure 10: The composition of slag spheres, consisting of molten clay or slag/clay mixtures, of the type that might be produced by carburisation.

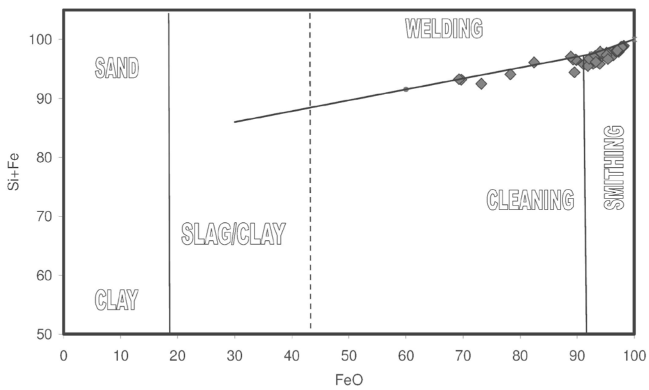

Figure 11: The composition of hammerscale from a simple smithy (Fors 28 near Trollhättean, Sweden).

smithy located in an agricultural area, near Trollhättan in Sweden (Jouttijärvi 2010a and b). Only a few of the analysed hammerscale fragments might indicate the use of welding and the main products of the workshop were probably nails, horseshoes and fittings. No slag spheres were found.

Local iron production and smithing

Other types of smithy seem to have had connections with local iron smelting sites. An example is a workshop from the 13th century at Klosterbakken, in the south-eastern part of Jutland (Jouttijärvi 2007). A large number of complete or fragmented plano-convex slags were found around the building and in the postholes. This indicated bloom cleaning had taken place and analyses of the hammerscale and slag spheres also showed that around 57% of the scales probably originated in this process (Jouttijärvi 2007) (Fig 2).

From this workshop, only the postholes remained, but the distribution of vitrified clay and slag indicated the presence of two hearths and anvils (Fig 12). Through the analysis of hammerscale and slag spheres from a number of postholes, it could be seen that the scale and spheres interpreted as originating from refining were concentrated around the eastern hearth, whereas the majority of the hammerscale near the western hearth seemed to be the result of smithing. Probably the work within the smithy was divided so that the refining was done at one hearth and anvil, and then the iron was passed to the other hearth for the final forming of items. Welding seems to have been used to a very limited degree, and the products of the workshop were probably nails, fittings and simple tools for use in the nearby villages. The composition of the plano-convex slags found in the postholes of the refining hearth was similar to smelting slags from the eastern part of Jutland, and probably the iron worked at Klosterbakken was the product of local smelting (Jouttijärvi 2007).

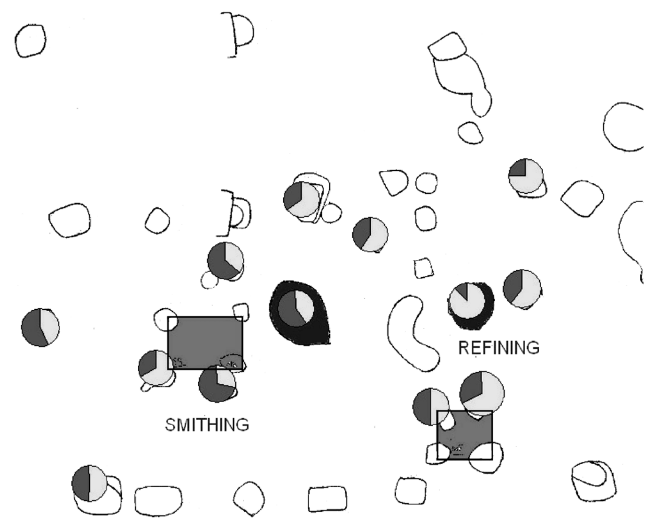

Figure 12: The two hearths (grey rectangles) and anvils (black circular features) in a smithy from Klosterbakken. The pie charts show the relative amount of scale from refining (light grey) and smithing (dark grey) in each sample. Area shown is 7m by 10m.

The smithy from Klosterbakken is also the latest one showing evidence of refining of blooms. Hammerscale of this type has yet to be found at sites dating to around the 14th century and onwards. As it is known that iron production in Denmark continued until around 1600, this might indicate a change in the organisation and distribution of iron production. The refining in the intervening period might have been concentrated at a number of hammermills, probably controlled by the church or nobility.

Advanced smithing

The fabrication of more advanced tools and weapons, utilising a combination of soft iron and steel, required knowledge of forge welding. Apparently such skills were not widespread among blacksmiths, at least not in the Iron Age. Only a few of the examined smithies showed obvious signs of welding, and they are almost exclusively dated later than the 12th century. This is in quite good agreement with the fact that evidence of more sophisticated combinations of iron and steel in tools and weapons is very rare before the Viking period. One example of a workshop of this type is a smithy from Guldager, near Esbjerg, in the western part of Jutland (Fig 13) (Jouttijärvi 2008; Poulsen-Hansen 2010).

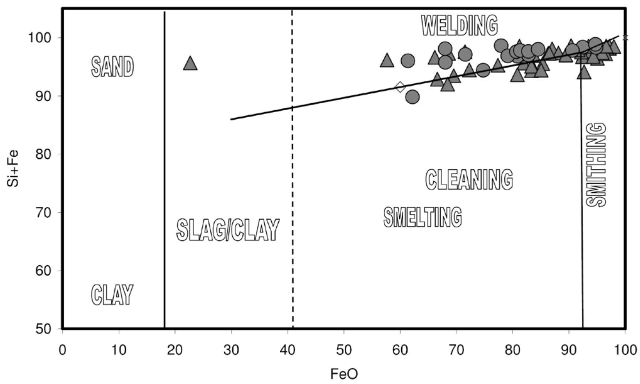

Figure 13: Hammerscale (triangles) and slag spheres (circles) from a smithy showing signs of welding (Guldager 1, western Jutland).

The art of carburisation

Even fewer smithies have been found showing any evidence of carburisation in the form of spheres formed from droplets of molten clay; these smithies too are so far exclusively dated to the medieval period. The example shown in Figure 14 is a workshop from Lund, near

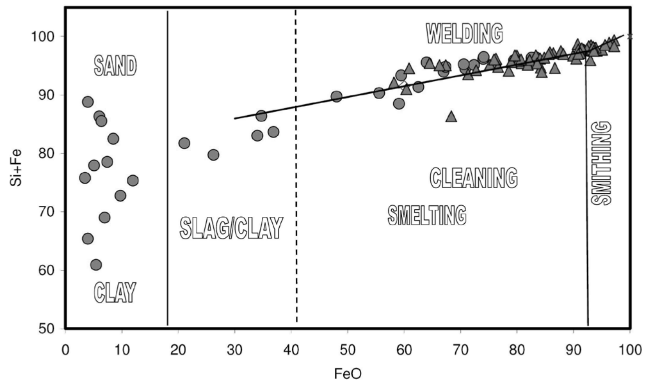

Figure 14: Hammerscale (triangles) and slag spheres (circles) from a smithy showing signs of welding and carburization (Guldager 1, western Jutland).

Horsens, in eastern Jutland (Jouttijärvi 2009b). The finds included pieces of the clay packing used in the process. In addition to carburisation, the analyses also showed that a large proportion of the scale (70%) and spheres (55%) were formed by welding. Apparently the technological level of the workshop was rather advanced and the blacksmith was capable of making tools or weapons of a high quality using both iron and steel. The raw material was probably bars of either Danish or imported iron, which had been refined elsewhere. Unfortunately the investigations have so far not given any indication as to the type of objects produced.

Conclusions

Detailed analysis of hammerscale fragments and slag spheres might give us a better insight into the use and development of smithies from the Iron Age to the 18th century, and make it possible to differentiate between workshops used for simple repairs and more advanced smithies. Apart from the chemical composition of the hammerscale, it is however also important to consider its physical distribution, as described elsewhere (Jouttijärvi 2009a).

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