



Remnants of a Bronze Age Rampart in Upper Bavaria: A Mössbauer Study

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Abstract. The remains of a Bronze age rampart found near Bernstorf, above the Amper valley some 30 km north of Munich in Upper Bavaria, were studied by Mössbauer spectroscopy and X-ray diffraction (XRD). The properties of the finds confirm the assumption that the rampart was destroyed by a fire, which caused much of the material to reach temperatures well above 1000°C. The results demonstrate the usefulness of Mössbauer spectroscopy and XRD in studies of materials heated in disastrous fires.

Key words: Mössbauer spectroscopy, X-ray diffraction, Bronze age rampart, technical ceramics, vitrification

1. Introduction

The existence of a Bronze age rampart at Bernstorf, some 30 km north of Munich in Upper Bavaria (Figure 1), was still known around 1900 [1, 2]. This knowledge was, however, lost until the rediscovery and beginning of the excavation of the site in 1990 [3]. Surprisingly a high amount of vitrified material was encountered during the excavation of an area of several hundred square metres. The first suspicion that a Celtic iron workshop had been discovered turned out to be wrong, while the idea of a fortification destroyed by a fire was confirmed by further excavations in 1996. The unexpected find of some outstanding bronze age gold and amber objects [1, 4] in the region of the rampart in 1999 underlines the archaeological importance of the location.

The idea of material having been heated in a devastating fire raised the question of the temperatures reached during this conflagration. The present work was undertaken to shed light on this aspect by Mössbauer spectroscopy and X-ray diffraction studies. The main application of Mössbauer spectroscopy to questions of archaeology deals with the description of pottery and pottery making techniques. A great number of studies has been published on the classification of pottery and the reconstruction of early firing techniques [5]. Here an attempt is made to apply the approaches developed for pottery to describe an architectural structure and its destruction by a devastating fire.

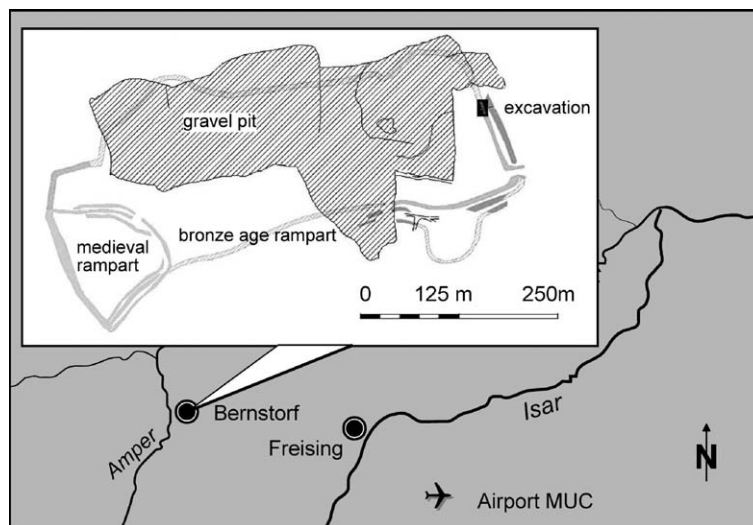


Figure 1. Location of the Bronze age rampart above the Amper valley, north of Munich. The modern gravel pit is shown hatched, the excavation site as a black rectangle.

2. The excavation site

The bronze age rampart appears to have protected a settlement on the escarpment of the Amper river against attacks from the Amper valley some 50 m below on the western and northern side and also from the highland to the east and south of the settlement. At the site of the excavation, the rampart stretched in a nearly north–south direction. About 100 m south of the excavation site, it turns west, and at the western end a medieval rampart is known to have existed (Figure 1). A substantial part of the ancient site has been destroyed by the exploitation of a modern gravel pit.

A stratigraphy of the underlying sediments [6] shows a heterogeneous structure of layers that vary from sandy gravel to marl. The uppermost geological layer at the excavation site consists of fine sand and gravel, with a layer of sandy loam on top. In the area of the rampart this top soil was removed and used as fill and plaster in the construction of the rampart, which consisted of a wooden skeleton filled with soil and gravel and presumably covered with mudplaster as a protection [7]. Charred oakwood timbers permitted a dendrochronological dating to about 1370 BC [1]. ^{14}C dating had placed charred wood from the rampart to the time span between 1675 and 1330 BC [2], while the 2σ ^{14}C calibrated date for charred wood found together with gold objects at the excavation site is 1400–1100 BC [4].

From the arrangement of the postholes of the wooden structure of the rampart as documented during the excavation in the 2nd half of 1990 (Figure 2), the design of the rampart could be reconstructed [7]. It had a triangular cross-section about 4 m wide at its base and a vertical outside height of about 4 m with a parapet on top. The outer side of the rampart and of the parapet is supposed to have been covered

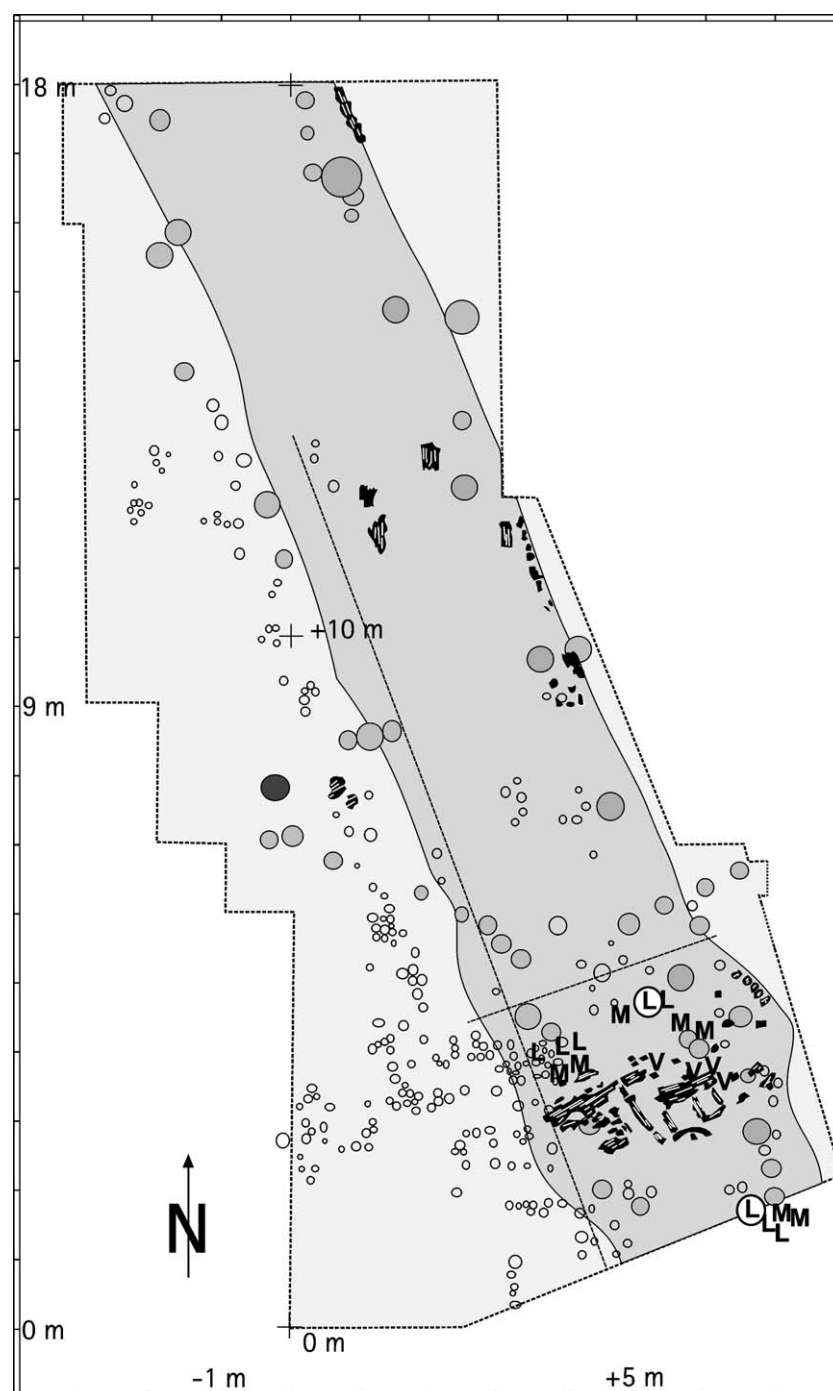


Figure 2. Excavation plan and reconstruction of a section of the rampart (shaded dark gray) using the information of the postholes (shaded circles). The spots where the studied specimens were taken are marked with L (loam), M (temperatures around 1000°C) and V (vitrified material). An L inside a circle indicates the location where the model loams 36/1 and 36/20 were found.

with mudplaster made from the local loam as a protection against being set on fire – a protection that seems to have been insufficient. Such walls appear to have been common in central Europe down to Celtic times [8].

3. Material and experiments

The material found at the excavation site was exceedingly manifold, showing a wide variety of colours, ranging from dull yellow to red and dark brown. Some of the material was visibly vitrified. At least part of these pieces are gray or greenish in colour and very hard.

For the present study a total of 30 lumps of loam, ceramic-like pieces and apparently vitrified material was chosen according to its appearance; 21 of these specimens were studied in detail by Mössbauer spectroscopy [9] and X-ray diffraction [10, 11]. An attempt was made to select examples of specimens of all occurring colours and of different consistencies.

The Mössbauer spectra observed in the ancient specimens cover a wide variety of different patterns. Some samples were very inhomogeneous, and occasionally several spectra were taken from spots of different appearance on the same chunk of material only several centimetres in size. According to its visual aspect and consistency, the material must have been exposed to different temperatures and redox conditions during the progress of the fire sustained by the massive wooden construction.

A total of 130 Mössbauer spectra were measured of the 21 studied specimens, 77 at room temperature (RT) and 53 at 4.2 K (liquid helium temperature). The source of ^{57}Co in Rh was always at the same temperature as the absorber. The isomer shifts are given with respect to the source of ^{57}Co in Rh [9]. The studied specimens are listed under the numbers used in the Munich data base. X-ray diffraction patterns were measured with Co K_α radiation for a number of samples to supplement the interpretation of the Mössbauer data.

4. Measurements on local loam

4.1. UNTREATED LOCAL LOAM

For comparison with the spectra of the material heated in ancient times, it is imperative to have reference data obtained by firing local, hitherto unfired material in the laboratory under controlled conditions. In this section, such measurements will be described.

4.2. LOCAL LOAM

Local loam is ubiquitous at the site of the rampart, forming the uppermost layer of the soil [6, 7]. Loam is a loose mixture of clay, silt and sand, mixed with iron oxides, mainly goethite. The sand consists mainly of quartz with some admixture of

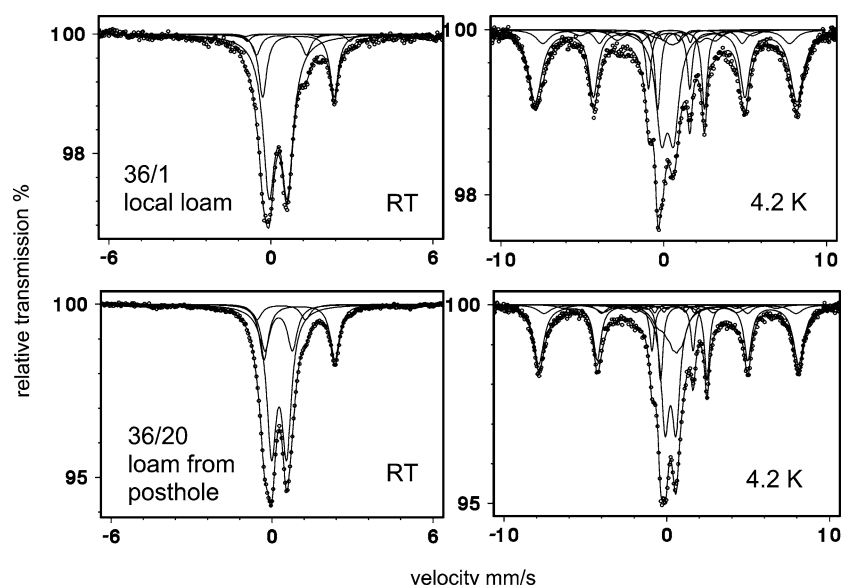


Figure 3. Mössbauer spectra of two loams (36/1) and (36/20) from the excavation site measured at RT and 4.2 K. Note the different velocity scales.

feldspars and mica. One studied specimen of presumably unheated loam (36/1) was taken from the centre of the excavation site, the other (36/20) was from a spot from near to a posthole (Figure 2). Both specimens have the ochre colour typical for the local loam and arising from the substantial content of goethite. They show the same Mössbauer patterns and were used as model materials for laboratory studies. Their RT and 4.2 K Mössbauer spectra are shown in Figure 3. The RT spectra show the small Fe^{3+} quadrupole splitting of about 0.6 mm/s characteristic for unfired clay and for superparamagnetic goethite [12]. The origin of a weak Fe^{3+} doublet with a larger splitting of 1.74 mm/s and an isomer shift of 0.43 mm/s is not clear at this time. The quadrupole doublets with large splittings of about $Q\text{-Fe}^{2+} = 2.65$ mm/s and with isomer shifts of $IS = 1.02$ mm/s arise from the Fe^{2+} components in the clay fraction. Six of the studied specimens exhibit this kind of Mössbauer pattern and thus qualify as local loam that has not been heated in the fire. In the 4.2 K spectra a sextet with an intense hyperfine field of 50 T and a fractional area of about 44% for 36/1 and 35% for 36/20 appears. It can be attributed to goethite that is so fine-grained that it is superparamagnetic at RT [9]. The presence of goethite, which transforms to hematite when heated to about 200°C (see Section 4.3), shows that these specimens have indeed not been heated much in antiquity and represent bona fide local loam. A minor, ill defined broad background in the 4.2 K spectra is probably due to slow paramagnetic relaxation of iron in the clay fraction [12]. The Fe^{3+} quadrupole doublet remaining at 4.2 K as well as the Fe^{2+} doublet are caused by structural iron in the clay minerals and micas. X-ray diffraction patterns of the local loams 36/1 and 36/27 show the presence of 14 Å clay minerals, mainly

chlorite, and of mica (see Section 6). A weak Fe^{2+} doublet in the Mössbauer spectra with a rather large quadrupole splitting of about 3.7 mm/s can be attributed to the garnet almandine [13], which is a common heavy accessory in aluvial sediments in the alpine foreland of Bavaria.

4.3. LABORATORY TEST FIRING OF LOCAL LOAM

4.3.1. *Firing in air*

Samples of loam 36/1 were heated in air for 48 h with a fresh sample for each of the firing temperatures increasing from 50°C to 1300°C in steps of 50°C. Mössbauer spectra of the specimens thus obtained were measured at RT and at 4.2 K (Figures 4 and 5) [11, 14]. The characteristic parameters, namely the quadrupole splitting ($Q\text{-Fe}^{3+}$) and isomer shift ($IS\text{-Fe}^{3+}$) of the main Fe^{3+} quadrupole doublet, the fractional area of Fe^{2+} ($A\text{-Fe}^{2+}$) and the total area of all species that show no magnetic splitting (A_{nm}) are plotted in Figures 6 and 7.

The RT spectra change very little on heating up to about 400°C. The 4.2 K spectra, however, show that already on heating to 200°C most of the goethite has transformed into hematite that is easily recognised by its typical hyperfine field of about 52 T. The lines of the hematite are still broad on heating to 200°C, but become narrow on heating to 300°C. Most of the hematite thus formed is, however, still superparamagnetic at RT and remains so up to about 800°C. The magnetically split pattern in the RT spectra thus increases but very little in intensity up to that firing temperature. On heating between 400°C and 600°C, the RT quadrupole splitting of the Fe^{3+} component increases from about 0.7 mm/s to about 1.2 mm/s. In the RT spectra the doublet of the superparamagnetic hematite is superimposed on

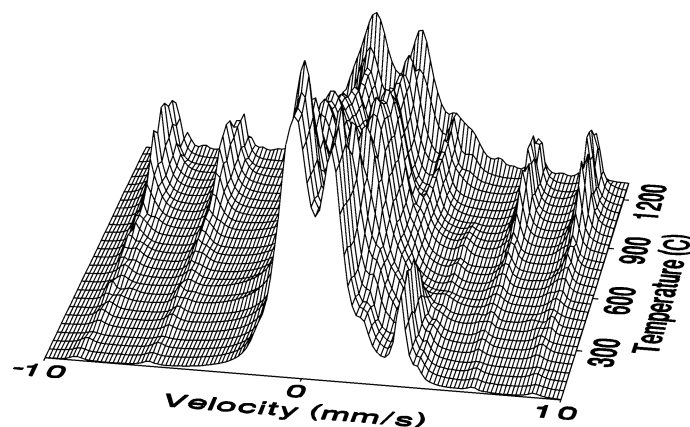


Figure 4. Three-dimensional plot of the RT Mössbauer spectra of loam Bernstorf (36/1) after firing in air at temperatures increasing from 50°C to 1300°C in steps of 50°C. The firing time was 48 h. The patterns are simulations using the parameters returned by least squares fits of the spectra, the data points being omitted for the sake of clarity.

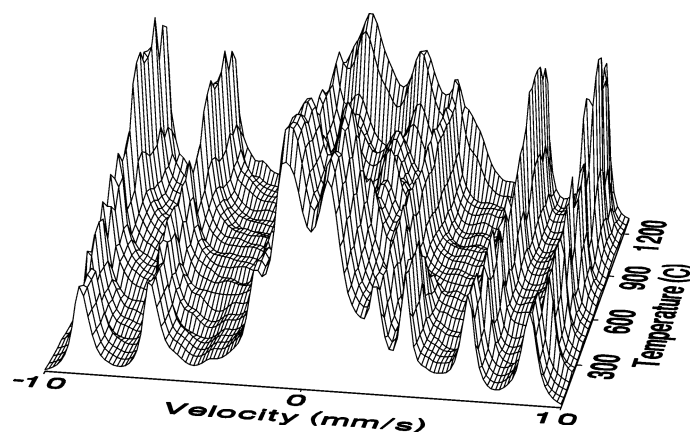


Figure 5. Three-dimensional plots of the 4.2 K Mössbauer spectra of loam Bernstorf (36/1) after firing in air at temperatures increasing from 50°C to 1300°C in steps of 50°C. The firing time was 48 h. The patterns are simulations using the parameters returned by least squares fits of the spectra, the data points being omitted for the sake of clarity.

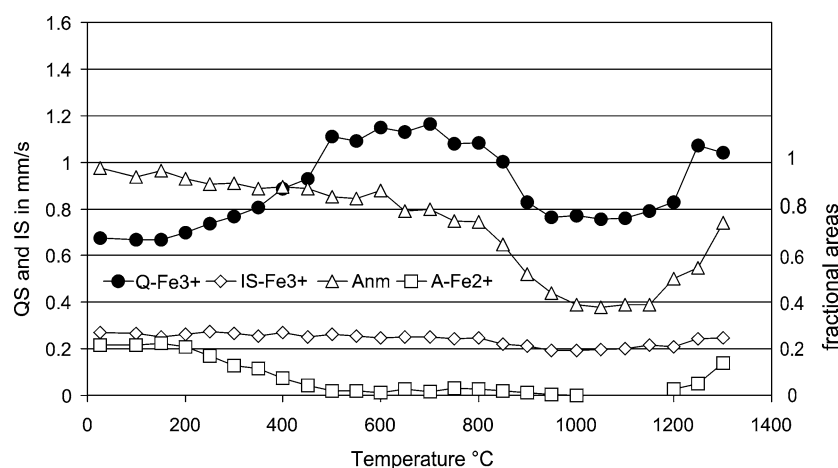


Figure 6. RT Mössbauer parameters obtained for loam Bernstorf (36/1) subjected to firing in air at different temperatures. Q-Fe³⁺ and IS-Fe³⁺ are the quadrupole splitting and isomer shift of the main Fe³⁺ doublet, A-Fe²⁺ is the fractional area of the Fe²⁺ doublet and A_{nm} the cumulated fractional area of all species that show no magnetic splitting.

that of the ferric iron in the clays, which leads to the composite mean value of the Fe³⁺ quadrupole splitting of 1.2 mm/s. The quadrupole doublet remaining at 4.2 K represents only the iron in the sheet silicates, i.e. the clays and micas. The quadrupole splitting of Fe³⁺ now increases to a value of over 1.4 mm/s.

The RT isomer shift of the Fe³⁺ component shows a slight but distinct decrease at firing temperatures of and above 900°C, from about 0.24 mm/s to values clearly below 0.2 mm/s (Figure 6). At 4.2 K, were the hematite no longer contributes to the doublet, the isomer shifts of the Fe³⁺ doublet becomes as low as 0.15 mm/s

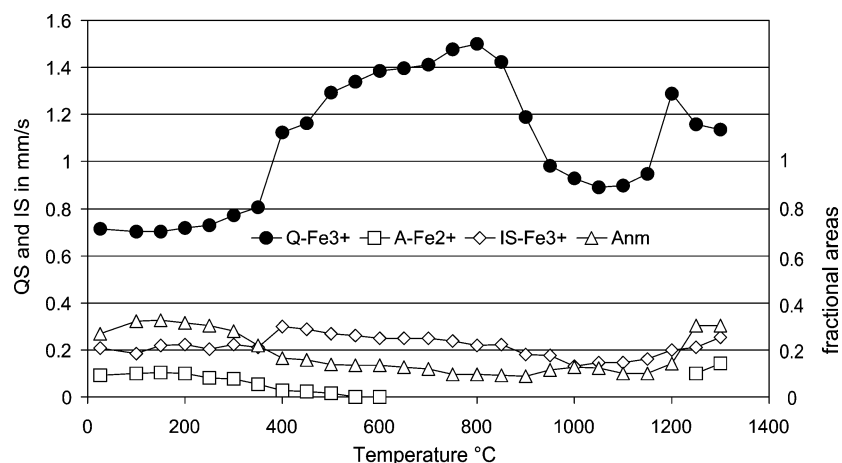


Figure 7. 4.2 K Mössbauer parameters obtained for loam Bernstorf (36/1) subjected to firing in air at different temperatures. Q-Fe³⁺ and IS-Fe³⁺ are the quadrupole splitting and isomer shift of the main Fe³⁺ doublet, A-Fe²⁺ is the fractional area of the Fe²⁺ doublet and A_{nm} the cumulated fractional area of all species that show no magnetic splitting.

on firing between 800°C and 900°C. This decrease of the isomer shifts indicates an increased covalency of the iron bonds. That it is more pronounced in the 4.2 K spectra and can be attributed to the magnetic splitting of the hematite component, which then does no longer contribute to the Fe³⁺ doublet.

The intensity of the Fe²⁺ component in the RT spectra decreases to almost zero when the firing temperature exceeds 400°C. The remaining trace of Fe²⁺ arises from the presence of the garnet almandine [13], which is ubiquitous in trace amounts in Bavarian sediments. Almandine is characterised by its very high Fe²⁺ quadrupole splitting of 3.7 mm/s and an isomer shift of 1.07 mm/s. The almandine is stable up to about 950°C during firing in both reducing and oxidising atmospheres and thus can serve as a thermometer for the maximum firing temperature experienced by a specimen. Due to its magnetic hyperfine splitting at low temperatures [13] and its low concentration, almandine is not observed in the 4.2 K spectra.

4.4. FIRING IN AN OXYGEN-DEFICIENT ENVIRONMENT

Mössbauer spectra of samples obtained by firing loam 36/1 in a reducing environment at temperatures between 800°C and 1000°C are shown in Figure 8. The samples were obtained by reduction with charcoal in a closed vessel for 3 h. The spectra consist of several doublets of Fe²⁺ species. On firing at 800°C doublets with rather large splittings of 2.4 mm/s are dominant, while on firing at 900°C and 950°C doublets with smaller quadrupole splittings grow in intensity. This behaviour has been explained by the collapse of the layer structure of the dehydroxylised clays going along with the formation of spinel phases [12] during reducing firing above

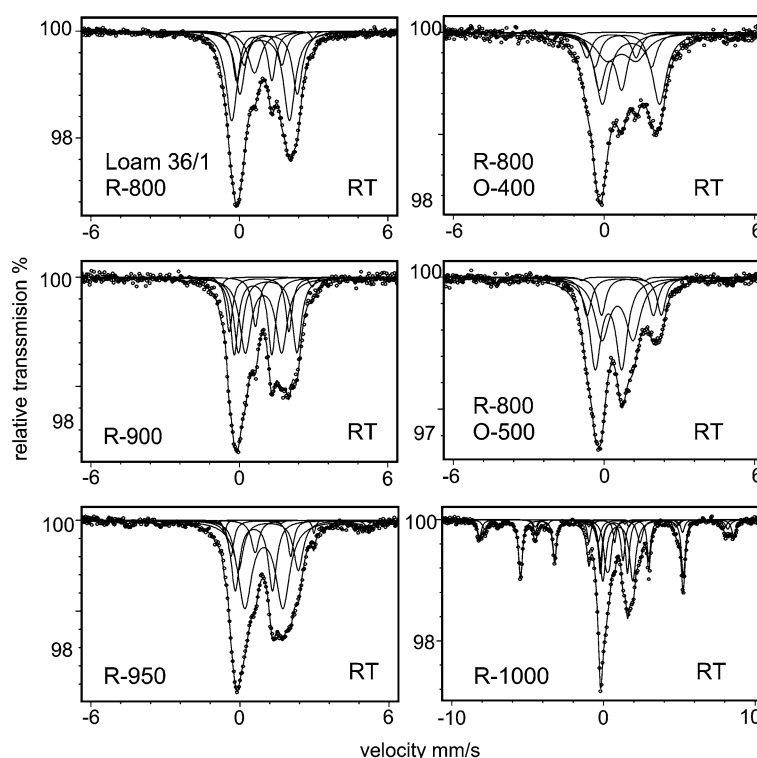


Figure 8. RT Mössbauer spectra obtained for loam Bernstorf (36/1) subjected to reducing firing for 3 h at different temperatures. After reduction at 1000°C the magnetic patterns of metallic iron and of minor amounts of magnetite and hematite appear. (Note the different velocity scale of this spectrum.) Spectra measured after a 3 h re-oxidation following the reducing firing are also shown.

800°C. An effort to identify the iron species formed in a reducing environment by X-ray diffractometry was unsuccessful, probably due to poor crystallinity. Iron metal, easily identified by its small magnetic hyperfine field of 33 T, is formed during reduction at 1000°C, along with minor amounts of magnetite and hematite. Iron metal is, however, rarely observed in archaeological material [15, 16] due to its oxidation during burial in the moist soil. Re-oxidation of this sample at 1000°C for 3 h leads to hematite. Since oxidation and reduction followed by re-oxidation at temperatures above 800°C cannot be distinguished [17] many of the reduced samples may have been re-oxidised during the raging of the fire devastating the rampart. This could be a reason for the almost total absence of reduced specimens.

On the right side of Figure 8 there are two examples of spectra of loam 36/1 that were first reduced at 800°C for 3 h and then re-oxidised in air for 48 h at 400°C and 500°C. Such Mössbauer patterns, however, have not been encountered in our studies of heated material from the rampart, although such a sequence of firing would appear possible in a fire destroying the rampart, which may have given rise to a reducing environment while combustible material was available. When

all combustibles had been consumed, air may have penetrated into the hot debris during the cooling phase.

5. Studies of ancient material

As opposed to the ochre coloured local loam, the material that has been heated during the conflagration of the rampart is strongly coloured with hues between brick red and dark brown. Some of this material is rather soft and crumbles easily, while some is quite hard, though hardly ever as hard as well fired ceramics. Some of the finds, however, differ from this in being very hard and visibly vitrified at least in some places. Such lumps of material usually are rather inhomogeneous, exhibiting gray and greenish patches where vitrification has taken place, and being reddish or brown in other places.

The Mössbauer spectra of the red and brown specimens are all quite similar and will be discussed first. These specimens contain practically only trivalent iron and all seem to have experienced temperatures above 900°C in an oxidising atmosphere. The vitrified material shows a wide variety of Mössbauer spectra, which vary considerably from spot to spot of the same lump of material. These specimens also contain varying amounts of divalent iron, indicating reducing conditions during the fire which are, indeed, not surprising if one considers that charcoal is abundant in the debris.

5.1. COMPLETELY OXIDISED MATERIAL

Mössbauer spectra like those shown in Figure 9 are typical for all the red and brown specimens. At room temperature these spectra all exhibit a slightly asymmetric Fe^{3+} quadrupole doublet with splittings in the range of 0.70 to 0.83 mm/s and isomer shifts between 0.17 and 0.20 mm/s. According to Figure 6 such quadrupole splittings and isomer shifts are to be expected for firing temperatures between 900°C and 1200°C. In addition to the Fe^{3+} doublet, all spectra exhibit a sextet attributable to hematite that is so well crystallised that it splits magnetically at RT with hyperfine fields between 50.1 and 50.8 T. The amount of such hematite ranges from 25 to 56% of the total area. Most of this hematite would have been formed by thermal decomposition of goethite around 200°C (cf. Section 4.3.1). The strongly variable hematite fraction in the Mössbauer spectra can be attributed to variable goethite contents of the local loam compared to the total iron content of the material.

At 4.2 K part of the iron that contributes to the RT quadrupole doublet splits magnetically. The amount of well-split hematite with hyperfine fields of 52 to 53 T, however, is hardly any larger than at RT. The iron that contributes to the Fe^{3+} doublet at RT rather gives rise to a broad magnetic background at 4.2 K. This background has been fitted with several sextets but its origin is still unclear. It may arise from a spin glass like magnetic order of part of the iron that gives rise to the

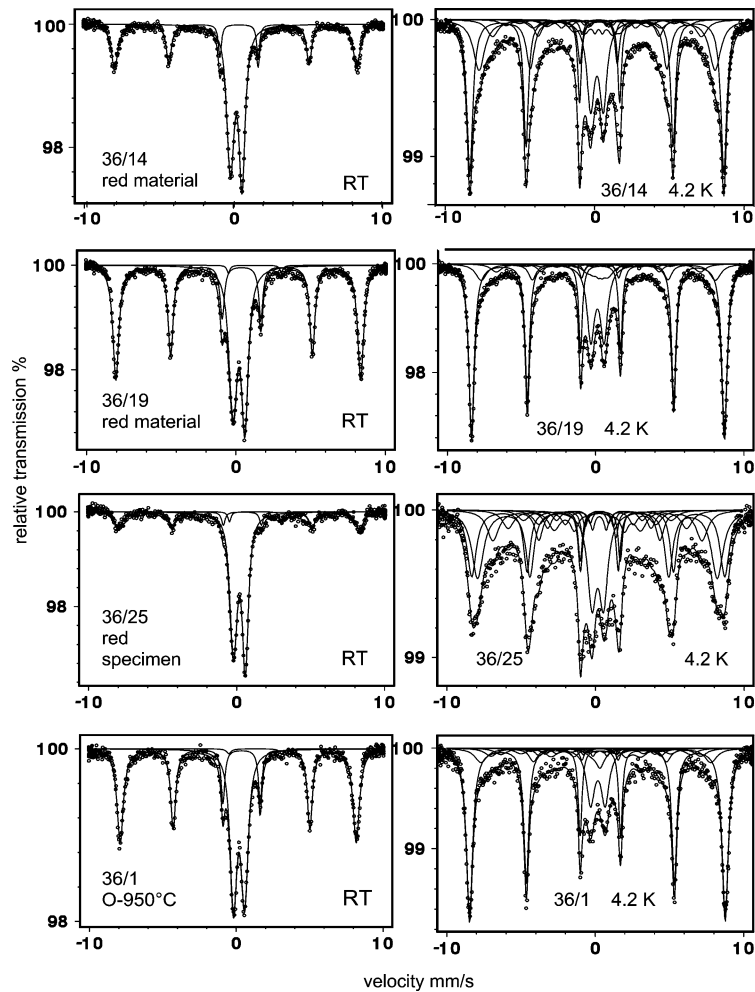


Figure 9. Room temperature and 4.2 K Mössbauer spectra of the specimen 36/14, 36/19 and 36/25. For comparison the RT and 4.2 K spectra of model loam 36/1 fired at 950°C in air in the laboratory are shown on the *bottom*.

doublet at RT, or to slow paramagnetic relaxations of Fe^{3+} spins, or even to both if the iron is inhomogeneously distributed. This background is, however, too broad to be attributed to impure hematite. The hematite in the samples thus all occurs in grains large enough to yield a magnetic splitting already at RT. According to the laboratory test firings of the loam, this is the case only after firing at temperatures between about 900°C and 1200°C. The hematite component thus yields another indication that the red and brown specimens reached temperatures in this range during the conflagration.

The Fe^{3+} doublet remaining at 4.2 K has splittings between 0.85 and 0.90 mm/s and isomer shifts between 0.12 and 0.15 mm/s. These values are in good agreement

with the results from the laboratory firings at temperatures between 950°C and 1150°C.

As has been mentioned in Section 4, the local loam uses to contain minor amounts of the garnet almandine which contains Fe^{2+} with quadrupole splitting of 3.7 mm/s and an isomer shift of 1.1 mm/s [13]. Almandine is stable up to about 950°C and can therefore be used to distinguish between samples that became hotter than this temperature and samples that did not. Some of the red and brown specimens still show indications of the presence of almandine, while others do not. This indicates that some of the samples have reached temperatures of 900°C to 950°C only, while others reached higher temperatures. Further information on the temperatures reached by these specimens can be derived from X-ray diffraction (Section 6), which shows that some samples must have reached temperatures above 1100°C.

Remains the question about the chemical form of the iron giving rise to the quadrupole doublet at room temperature and to the doublet plus broad magnetic pattern at 4.2 K. This question cannot be answered with any reliability at this time. Answering it might also answer another question, namely why the RT Fe^{3+} doublet in all specimens heated in prehistory is slightly asymmetric, while the doublets found in the laboratory heated samples are not. This asymmetry can technically be explained by a distribution of quadrupole splittings and correlated isomer shifts, but why such a correlation should exist in the ancient, but not in the laboratory fired samples is as yet unclear.

5.2. VITRIFIED AND REDUCED MATERIAL

The specimens that are visibly vitrified in some places show a rather wide variety of spectra, of which some are shown in Figure 10. Spectra containing virtually only Fe^{2+} are frequent in these specimens. Some spectra seem to be mixtures of patterns of the type described in Section 5.1 and patterns containing Fe^{2+} only, perhaps because regions of the two types are contiguous and were not well separated when the samples were taken with a corundum drill.

The Fe^{2+} patterns always consist of several doublets with splittings in the range between about 1.8 and 2.5 mm/s. The spectra resemble those obtained by reducing laboratory firing at temperatures of 900°C or 950°C. At higher temperatures metallic iron was formed under laboratory conditions, but this would not necessarily be so if the oxygen fugacity under the conditions of the fire were higher than in the quartz vessel filled with charcoal used in the laboratory experiments. Temperatures well above 900°C therefore cannot be excluded on the basis of the Mössbauer spectra. The X-ray diffraction data for specimen 36/4, for instance, indicate a firing temperature of above 1100°C (Section 6).

In any case, the presence of Fe^{2+} in the visibly vitrified pieces shows that reducing conditions prevailed at least during part of the conflagration of the rampart. This is, indeed, not surprising if one considers that appreciable amounts of charcoal

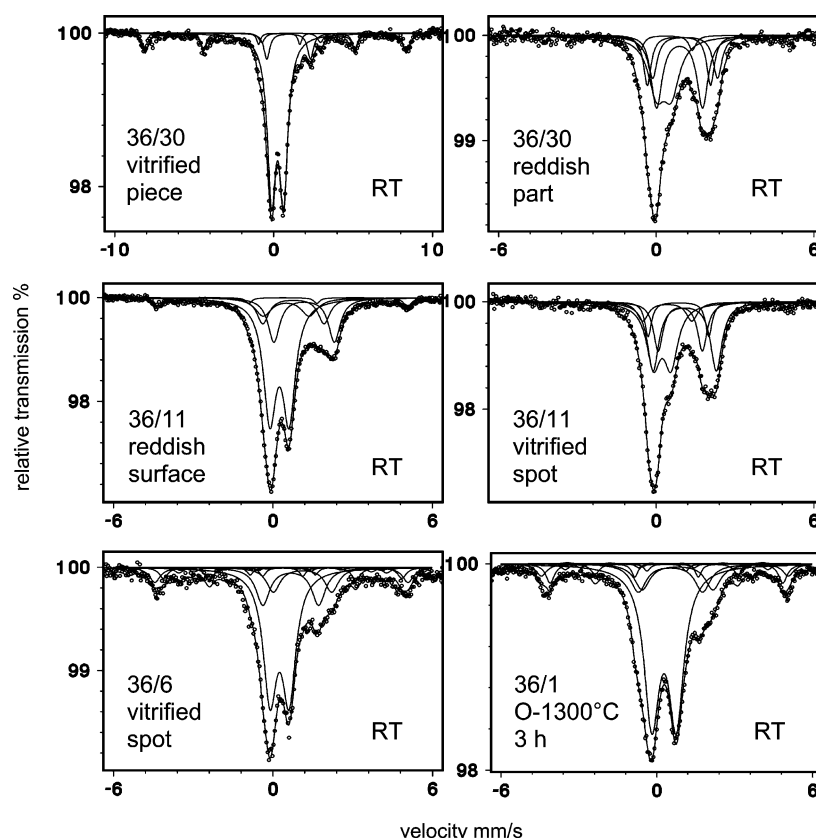


Figure 10. RT Mössbauer spectra of different vitrified parts of 3 specimens. 36/30 (*top*), 36/11 (*middle*) and 36/6 (*bottom left*). A RT spectrum of a sample of model loam 36/1 fired in air at 1300°C for 3 h is also shown (*bottom right*).

have been found in the debris. Vitrification may have prevented the re-oxidation of reduced iron towards the end of the fire, when most of the combustible material had been consumed and oxygen penetrated into the debris at still very high temperatures. In vitrified parts the access of oxygen may then have been slow due to the dense and impenetrable vitrified matrix. This may, in fact, be the reason why Fe^{2+} is only found in pieces that are visibly vitrified.

There is one observation that may also be of importance in this context: a sample of loam 36/1 fired in the laboratory at 1300°C in air for 3 hours yields a Mössbauer spectrum (Figures 4 and 10) that contains a substantial amount of Fe^{2+} , although the atmosphere was not reducing at all. This shows that the formation of Fe^{2+} is thermodynamically favoured at very high temperatures, while its re-oxidation during the cooling phase seems to be delayed by enclosure of the Fe^{2+} into a vitrified phase, be it as tiny crystallites or dissolved in the glass matrix. The spectrum of 36/1 fired at 1300°C is, indeed, quite similar to a spectrum measured for material from a vitrified spot of specimen 36/6 (Figure 10).

6. X-ray diffraction

Model loam 36/1 and another loam (36/27) from the centre of the excavation site show the typical composition of sheet silicates in loam from this area, namely 14 Å minerals (mainly chlorite), mica and kaolinite (Figure 11). Feldspars and traces of amphiboles are also present.

After firing the model loam in air at 1000°C for 48 h, only feldspars and quartz remain. After firing at 1100°C, some of the quartz has transformed into cristobalite, whose (101) reflection appears at $25.5^\circ 2\theta$ (Figure 11). Mullite also first becomes visible after firing at 1100°C and increases in intensity on firing at 1200°C [18]. After firing at 1200°C (Figure 11) cristobalite has increased in intensity and indialite, the high temperature form of cordierite, becomes visible at $12^\circ 2\theta$ [19]. Therefore this mineral provides a thermometer for the high temperature region [11], allowing one to say that samples containing indialite have reached temperatures higher than 1100°C, where indialite is still absent. A comparison with the diffraction patterns of four ancient specimens from the rampart (36/2, 36/4, 36/10 and 36/14) sug-

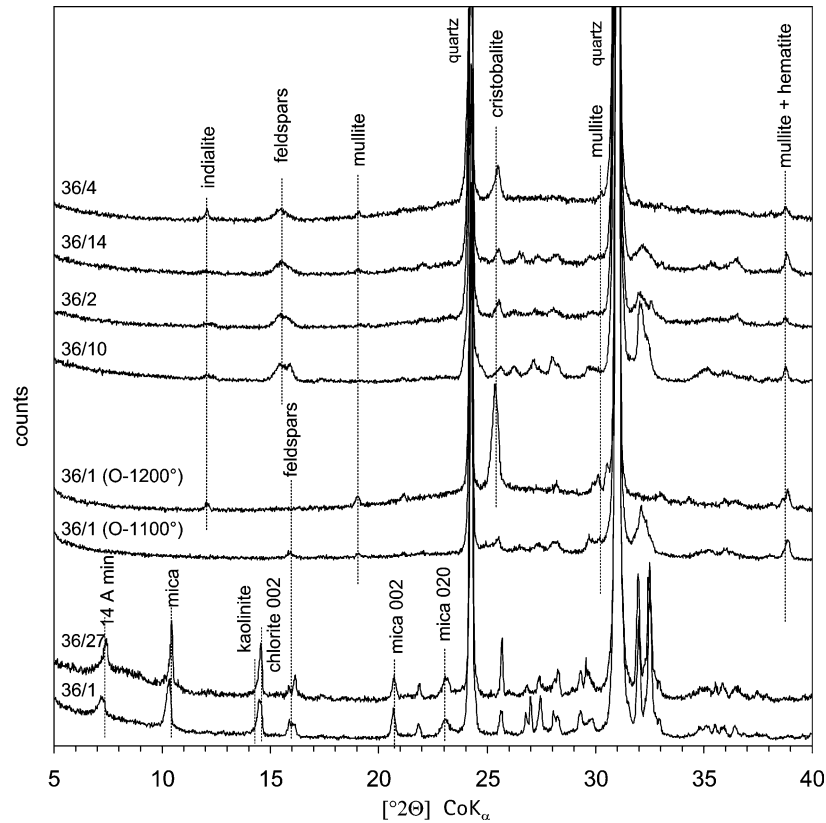


Figure 11. XRD patterns of loam 36/1 and 36/27 (bottom), of loam 36/1 heated in air to 1100°C and to 1200°C (middle) and of various finds from different locations of the rampart (top).

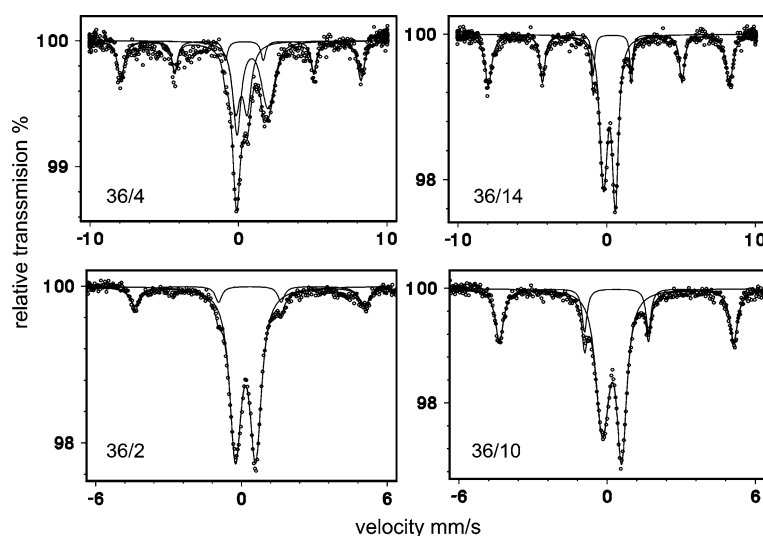


Figure 12. RT Mössbauer spectra of specimens 36/4, 36/14, 36/2 and 36/10. The XRD scans of these specimens are shown in Figure 11.

gests that the firing temperature of these specimens has surpassed 1100°C. The RT Mössbauer spectra of these samples are shown in Figure 12. All these samples contain some mullite and indialite and none of them contains any more mica, which decomposes around 950°C [20]. The presence of feldspars in the material from the rampart may be due to the short duration of the firing in comparison to the 48 h the model materials were fired.

7. Summary and conclusions

We have shown that Mössbauer spectroscopy and X-ray diffraction supplement each other ideally in reconstructing aspects of the temperature and redox conditions that prevail in the devastating fires. The firing products from the rampart at Bernstorf are typical for very high temperatures and differ from those usually found in archaeological pottery mainly because of these high temperatures. After the wooden framework had caught fire, charcoal formed and supported the extremely high temperatures of up to 1200°C observed in the remnants.

For a number of specimens the find spots are marked on the plan of the excavation site (Figure 2). The high degree of preservation of the firing debris and even of the fill of the postholes is worth mentioning. No systematic pattern of the properties of the material at the excavation site could be observed. This was in fact not to be expected, for the collapse of the wooden construction would have resulted in a rather thorough mixing of the remnants. Fired and unfired material were located in close proximity. It is surprising that practically unheated material and material that must have reached 1200°C or more were found together. This may be due to

relocation of debris after the cooling of the remnants, but the pure heat conductivity of loose loams may also have played a role. A study of the temperature gradient in a piece of furnace lining from a metal workshop in Batán Grande, Peru, for instance, also showed that the thermal insulation of ceramic material during a short exposure to the high temperatures necessary for melting metal was enough to prevent material only a few centimetres away from getting very hot [14]. A surprising result of the present studies is that no material having reached temperatures above 150°C but below about 900°C has been found, although Unger [7] in his studies of debris from Bernstorf under the optical microscope has identified such material. This may be connected with the difficulty of taking a representative set of samples in such studies.

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