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Ceramics from the Celtic Oppidum of Manching and Its Influence in Central Europe

R. GEBHARD[1], R. BOTT[2], N. DISTLER[2], J. MICHÀLEK[3], J. RIEDERER[4], F. E. WAGNER[2] and U. WAGNER[2]
[1]*Archäologische Staatssammlung München, Lerchenfeldstraße 2, 80538 München, Germany*
[2]*Physik-Department E15, Technische Universität München, 85747 Garching, Germany; e-mail: uwagner@ph.tum.de*
[3]*Muzeum Stredniha Pootavi, CZ 38611 Strakonice, Cech Republic*
[4]*Rathgen-Forschungslabor, Schloss-Str. 1a, 14059 Berlin, Germany*

Abstract. We present an overview on an extended study of Celtic ceramics from the oppidum of Manching and from some contemporary Celtic sites. The results of neutron activation analysis, thin section microscopy and Mössbauer spectroscopy are combined with the existing detailed archaeological typology to provide information on the provenance of Celtic pottery and on details of its production. The data indicate that there was only very limited exchange of material but far reaching transfer of technology.

Key words: Celtic oppidum of Manching, analysis of artefacts, provenance, distribution, production.

1. Introduction

The study of various groups of finds helps in an assessment of the economical and cultural situation in the Celtic oppidum of Manching (300–40 BC) located 80 km north of Munich [1]. A variety of precious objects, mainly fibulae made of bronze or noble metals [2], glass jewellery and glass vessels [3, 4] and gold coins [5] are major indicators for import and long distance trade. Finds like iron objects retrieved in limited numbers yield only scarce information. Large quantities of ceramic material are ubiquitous throughout the Celtic civilisation. The finds made in Manching are well described by a detailed archaeological typology [6–9]. By proper study and interpretation, ceramics can, in fact, serve as important indicator of commercial exchange in the Celtic world.

The oppidum of Manching is part of the highly developed economic and political system of Celtic Central Europe. Reconstructing the exchange routes of Manching depends on the ability to distinguish between locally made objects and imported ones. It is therefore necessary to analyse object groups, such as pottery, that has been excavated in extremely high quantities, classified well and interpreted with the help of statistical methods. The late iron age pottery has been produced in astoundingly uniform types over a wide area and cannot easily be separated into

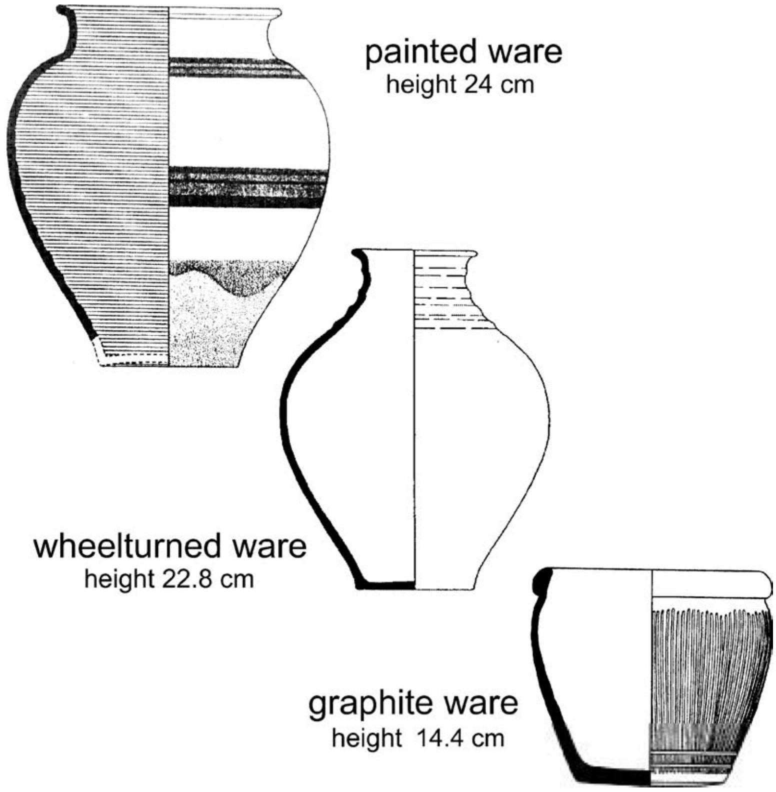

Figure 1. Characteristic forms and decorations of painted ware, wheelturned ware and graphite ware. Figures taken from [6–8].

local groups by description of shape, form and style (Figure 1). It has, however, been shown that a careful analysis of the material properties allows a distinction of local production from imported ware. The study of late iron age pottery is a typical example that the key for the reconstruction of the past lies in material analyses combining various techniques.

Here we give a general overview on a comprehensive study of the material properties of large quantities of Celtic ceramics by neutron activation analysis [10], Mössbauer spectroscopy [11] and optical thin-section microscopy [12]. By combining these methods with the archaeological typology [6–9], a reliable classification could be reached and information on the provenance of certain typical pottery wares and on details of the techniques used in their production could be obtained.

2. Material

The data presented here are a selection showing only the most characteristic observations. For the purpose of this overview the studied ceramics were divided into five groups: painted ware, grey wheelturned ware, graphite ware, coarse ware and technical ceramics. A total of 1400 specimens are listed in our data base for the Manching project. All of them were studied by neutron activation analysis. More than 1600 Mössbauer spectra were recorded at room temperature (RT) and for selected samples also at liquid helium temperature (4.2 K). The number of thin-section micrographs taken so far is more than 700.

A problem in this study is the absence of local clays, either ancient or recent, that could serve in laboratory firing experiments as reference materials for the ceramic material from Manching. No appropriate clays could be found, although material from all neighbouring quarries used by contemporary brick factories was analysed by neutron activation analysis. In these comparisons, misfired and hence obviously locally made sherds found at Manching were used to obtain reference data for the element contents in the local materials from the oppidum of Manching [13].

3. Methods

3.1. NEUTRON ACTIVATION ANALYSIS

Neutron activation analysis was performed according to the standard procedure applied in Munich: the samples were irradiated in the Research Reactor Munich I in a neutron flux of 2×10^{13} n/sec cm^2 for 1 min for the determination of short-lived radioisotopes and for 16 h for long-lived ones. 18 trace elements and 3 major elements were determined. Cluster analyses of the logarithmic element concentration data were performed on special subgroups of the total data set [13]. A principal component plot of the element concentrations is shown in Figure 2 for 133 specimens of graphite ware from different locations.

Finds from Modlešovice in Bohemia form a group well separated from the rest. Two dropout cases, 19/653 and 19/660 (Figure 2), also have Mössbauer spectra completely different from those of the other specimens from Modlešovice. Sherd 19/655 found in Modlešovice exhibits the element concentrations of the Manching ware. This indicates that a vessel from Manching was brought to Bohemia.

The finds from Baden-Württemberg are also rather well separated from the Manching group. Finds from Berching Pollanten, located in the neighbourhood of Manching and serving as an industrial area for Manching, split into two groups. One is indistinguishable from the Manching material, the other is clearly different. This supports the notion that part of the vessels found in Berching Pollanten were locally made, while another part was brought from Manching to Berching Pollanten, probably with food supplied by the central oppidum of Manching.

3.2. THIN-SECTION MICROSCOPY

Examples of typical thin section micrographs for the different studied wares are shown in Figure 3. The painted ware (Figure 3, left, top) is a medium grained pottery with a relatively high amount of temper of about 35%. The grain size of

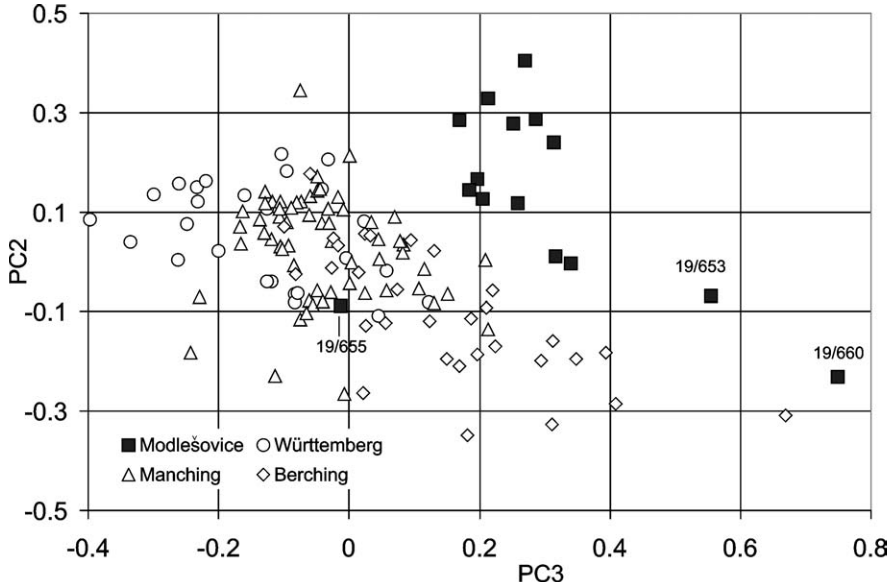

Figure 2. Principal component analysis of 133 sherds of graphite ware from Manching, Berching Pollanten, and Baden-Württemberg compared with graphite ware found in Modlešovice in Bohemia.

the temper is uniform in a range of about 0.1 mm. There is a distinct orientation of elongated minerals parallel to the surface of the sherd. The matrix consists of clay minerals. Among the minerals of the temper quartz predominates. The quartz grains show sharp edges and no signs of attrition from transport by wind and water. They are free from fractures and inclusions. Feldspars are very rare. Muscovite appears mostly in the form of tiny flakes, but there are also occasional larger sheets. Opaque ore minerals are quite frequent. Apart from isolated minerals there are still some unweathered fragments of stone, first of all of micaceous schists rich in muscovite.

The wheelturned ware from Manching (Figure 3, right, top) is also medium grained, but compared with the painted ware, the amount of temper is lower and does not exceed 10%. The maximum grain size goes up to 0.5 mm. The matrix consists of fine flakes of sericite, which show a perfect orientation parallel to the sherd's surface. As a temper, quartz is the most abundant mineral. The grains have sharp edges. The quartz grains are covered by a narrow net of fractures probably caused by a high firing temperature. Muscovite is also quite frequent as small flakes in the matrix and in the form of large sheets. Feldspars could not be found. The content of opaque ore particles is very low.

The misfired ware from Manching (Figure 3, middle, left) is again a medium grained pottery with a fine siliceous matrix. The amount of temper is quite low with an average value of 10%. The temper is predominantly well-rounded quartz, with grain sizes between 0.02 and 0.3 mm. As a peculiar feature of this ware, the amount of rounded particles of quarzite is very high. The amount of microcline

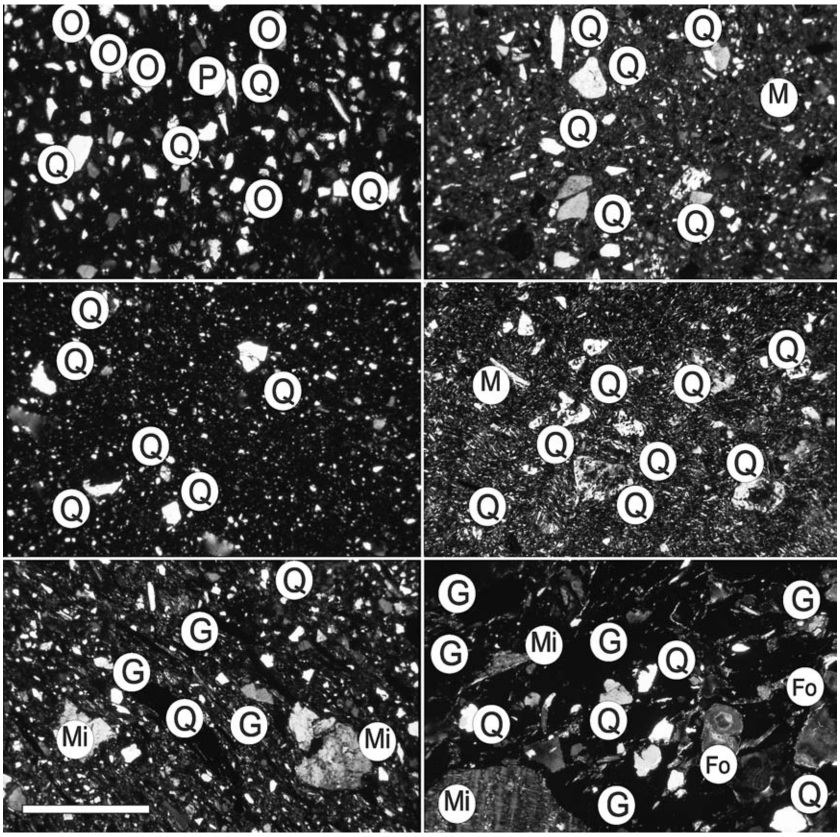

Figure 3. Characteristic thin sections. First row: painted ware (*19/4, left*) and wheelturned ware (*19/9, right*) both from Manching. Second row: misfired ware from Manching (*19/397, left*) and wheelturned ware from Bopfingen (*19/859, right*). Third row: graphite ware found in Manching with the typical shape of the Manching vessels (*19/322, left*) and graphite ware from Modlešovice (*19/655, right*). The main minerals are quartz (Q), plagioclase (P), opaque ores (O), muscovite (M), graphite (G), microcline (Mi) and fossils (Fo). Scale = 1 mm.

with a well developed twinning is also relatively high. Plagioclase occurs only as small, intensely weathered crystals. No micas, neither muscovite nor biotite, could be found.

A sample of wheelturned ware from Bopfingen (Figure 3, middle, right) is quite different from the samples described above. It is medium grained and strongly tempered. The grain size is heterogeneous and covers the range between 0.05 and 0.5 mm. The matrix consists of clay minerals with fine siliceous compounds. The elongated mineral grains show a good orientation parallel to the surface of the sherd. As a temper quartz is the main mineral. Muscovite has all dimensions between tiny flakes and larger sheets of about 0.2 mm size. Apart from muscovite, there is a substantial amount of biotite showing an intense pleochroism between heavy dark brown and pale brown. The biotite shows weak signs of a transformation into a discoloured variety of mica. Additionally there are numerous well-rounded particles with a well developed twinning. Opaque ore minerals occur in the usual manner.

The graphite pottery from Manching (Figure 3, bottom, left) is fine to medium grained with a high amount of temper of about 35%. The grain size of the temper is heterogeneous and goes up to 1 mm. The matrix consists of clay minerals. Quartz is the most abundant mineral of the temper, but large microclines with well-developed twinning are quite frequent too. Plagioclase is very rare, and muscovite is also comparatively seldom. Large flakes of a dark brown, sometimes intensely weathered biotite are frequent. The amount of various types of siliceous rocks, first of all granites and micaschists, is high. Graphite is the most obvious component of this ware. It occurs in the form of small, elongated flakes, which show a perfect orientation parallel to the surface of the pot.

The graphite ware of from Modlešovice (Figure 3, bottom, right) is medium to coarse grained with a maximum grain size of 1 mm. The amount of temper does not exceed 15%. Quartz is the most frequent tempering mineral. Large flakes of muscovite are present in higher amounts than in the graphite ware from Manching. Microcline is present in the form of large, well twinned crystals. The most remarkable components of the temper are fragments of limestone and fossils. The graphite forms large compact concretions of irregular shape. Among the stone particles, fragments of granite predominate. Besides these, there are schists containing calcite, graphite, muscovite and quartz.

The microscopical properties of the six groups of pottery shown in Figure 3 are relatively homogeneous, though in each group there are some distinguishing features. Thus the pottery from Bopfingen differs strongly from the products of Manching by a coarser temper and a different mineralogical composition. The wheelturned ware from Manching has a matrix which is extremely rich in tiny flakes of mica. The matrix of the painted ware is composed of clay minerals of smaller dimensions. Also the amount of temper is quite different in these wares. The misfired ware from Manching has a peculiar matrix with a high amount of very fine quartz particles.

The different groups of pottery can thus be distinguished rather well by their thin-section micrographs. Some of the observed features have been described above. Besides that, the shape of the coarser minerals and the relation of the quantity of the different minerals of the temper of the individual groups of ceramics also contribute to characterise and to differentiate sherds of different origin.

3.3. MÖSSBAUER SPECTROSCOPY

Generally Mössbauer spectroscopy is used to assess production techniques used in antiquity. However, the Mössbauer patterns also depend on the iron-bearing minerals present in the raw materials and therefore on the provenance of the pottery [11]. A much better picture can be gained by combining the results from the Mössbauer

Table I. Number of specimens compiled for the different studied wares

Ware	Number of specimens
Clay recent	40
Coarse ware	194
Combed ware	28
Graphite ware*	244
Misfired ware*	28
Painted ware*	120
Soil	61
Technical ceramics*	111
Wheelturned ware*	374
Unclassified	105

*Examples described in the overview.

spectroscopy with the information on the non-iron-bearing minerals in the ceramics gained from thin-section microscopy [12] and from X-ray diffraction [14, 15]. The different groups of materials studied by Mössbauer within the Manching project are listed in Table I. All specimens of pottery and other ceramic materials stem from Manching or from other sites connected with Manching. In the following Mössbauer spectra for characteristic samples of the main groups of wares are shown and described.

Although no model firing curves exist due to the lack of appropriate model materials, general deductions will be made relying on firing curves for other pottery clays from Bavarian sites, although such an approach is clearly less desirable than a comparison with firing experiments of appropriate materials. In this work, firing curves of loess from Schmiedorf [16] and loam from Bernstorf [17] are used for comparison. A contemporary clay from Straubing (19/755) was used as model material for test firing of coin moulds and graphite ware [18–20].

3.3.1. *Painted ware*

Painted ware is an extremely fine pottery with a gray core, a brick coloured outer layer and with pigments on the outside of the vessel. For Mössbauer spectroscopy the different layers were carefully separated before measurement. The room temperature and 4.2 K Mössbauer spectra of material of the core and the outer layer of sherd 19/4 are shown in Figure 4. The relative Fe^{2+} content in the gray core is 60%. It exhibits a distribution of quadrupole splittings with a maximum value of 2.4 mm/s, while the outer layer contains 68% Fe^{3+} with a quadrupole splitting of 0.83 mm/s. The latter value is characteristic for material previously reduced and then reoxidised at temperatures of 800°C to 900°C [21]. Small traces of the garnet

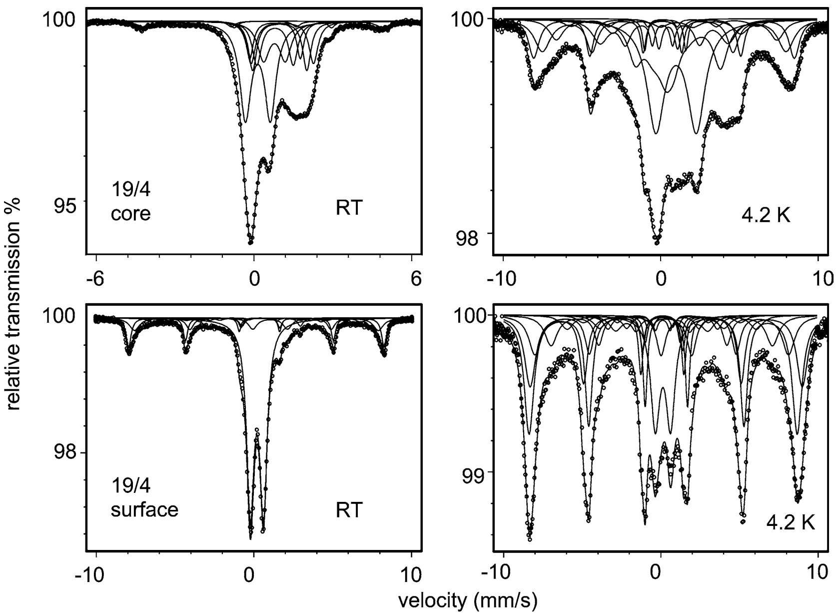

Figure 4. Mössbauer spectra of material from the core and the outer layer of sherd 19/4 of painted ware from Manching measured at RT and at 4.2 K. Note the different velocity scale.

almandine are observed in sherd 19/4. Almandine is a common accessory mineral in aluvial sediments in the alpine foreland of Bavaria. Its room temperature Mössbauer parameters are Q-Fe^{2+} = 3.54 mm/s and IS-Fe^{2+} = 1.17 mm/s with respect to ^{57}Co in Rh [22]. It is stable up to 930°C in oxidising and reducing environment and, if present, can serve as a thermometer for the maximum temperature reached by the specimen during firing. Sherd 19/4 therefore cannot have been fired above 930°C.

The 4.2 K spectrum of the material from the core shows that 29% of the Fe^{2+} species split magnetically, which means that this Fe^{2+} is most probably contained in hercynite, while 27% of the spectral area are still present as a Fe^{2+} doublet. A complicated magnetic hyperfine pattern of Fe^{3+} with a relative intensity of 84% is observed at 4.2 K in the outer layer. The Mössbauer patterns vary somewhat in the different samples of painted ware. However, all painted ware exhibits a well defined gray core with a high amount of Fe^{2+} species, where quadrupole splittings vary between maximum values of 2.3 mm/s to 2.7 mm/s, with the lower value indicative of a higher firing temperature [23].

The red pigment is pure hematite, which is easily identified by the six-line Mössbauer pattern of hematite with the characteristic hyperfine filed of 51 T at RT. It was measured in a small sample of material scraped off the painted surface of sherd 19/4 [13]. This is in agreement with Guichard *et al.* [24], who also state that the white pigment on painted ware probably consists of iron-free illitic clay.

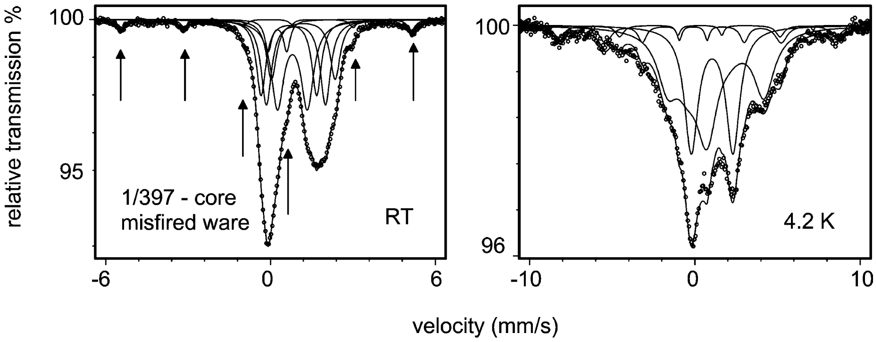

Figure 5. RT and 4.2 K Mössbauer spectra of material from the core of sherd 19/397 of misfired painted ware. The positions of the 6 absorption lines of iron metal are indicated by arrows. Note the different velocity scales.

3.3.2. *Misfired ware*

RT and 4.2 K Mössbauer spectra of material of the core of a visibly misfired sherd of painted ware from Manching (19/397) are shown in Figure 5. Misfired ware is of special interest in the context of this study, because it represents local production. The sherd must have been heated under exclusion of air before reoxidation of the outer layer at the end of the firing cycle, probably during cooling. Only a trace of 5.8% of Fe^{3+} is present in the core of the sherd. The maximum temperature experienced by the sherd has surpassed 1000°C, because a trace of 4.5% of iron metal and no almandine is observed. Iron is easily identified by its small magnetic hyperfine field of 33 T. The iron metal could only have survived 2000 years of burial in the ground if it was covered by glass formed by vitrification during the period of uncontrolled heating. The high amount of magnetically ordered Fe^{2+} species of 54% in the 4.2 K spectrum (Figure 5) is an additional indication of the very high temperature the sherd was exposed to, causing much of the Fe^{2+} species to crystallise as hercynite.

All 123 misfired sherds were studied by neutron activation analysis. So far Mössbauer spectra were taken of 28 sherds of misfired painted, wheelturned and combed ware. All Mössbauer patterns exhibit a high amount of Fe^{2+} species, almost always with the relatively low Fe^{2+} quadrupole splitting of around 2.3 mm/s characteristic for high reduction temperatures. The formation of iron metal was only observed in sherd 19/397 and in traces in two more sherds. Clearly all misfired sherds were overheated in a reducing environment. Reduction to iron might have happened more frequently than observed today, because in most cases it may not have survived during burial.

3.3.3. *Wheelturned ware*

Figure 6 shows the RT and 4.2 K spectra of material from the cores of two sherds of wheelturned ware, one from Manching (19/9) and one from Bopfingen (19/859) in

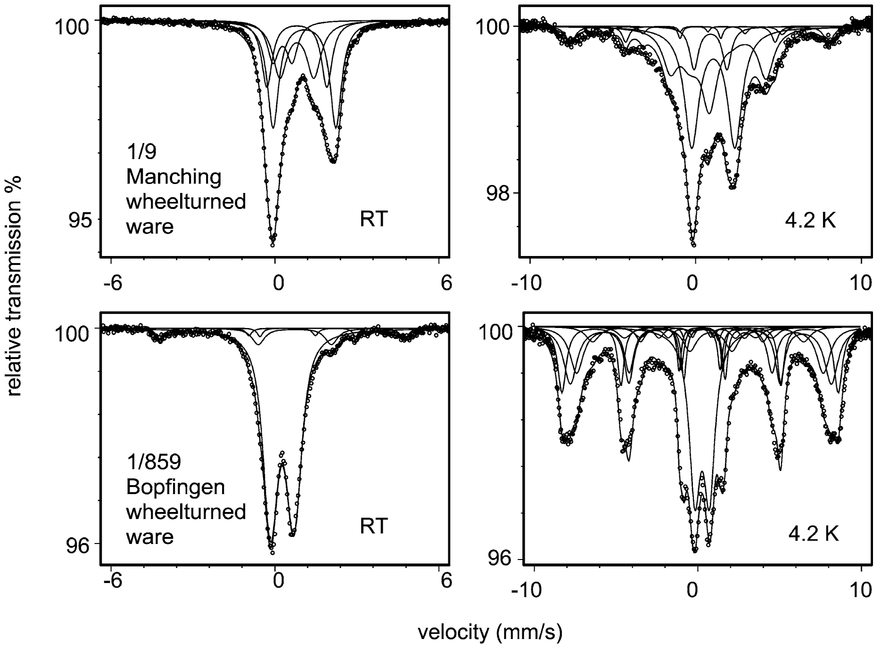

Figure 6. RT and 4.2 K Mössbauer spectra of two sherds of wheelturned ware. Sherd 1/9 is from Manching (*top row*) and sherd 19/859 was found in Baden-Württemberg (*bottom row*). Note the different velocity scales.

Baden-Württemberg. Sherd 19/9 is grey throughout, sherd 19/859 is black on the surface and has a reddish core. The pattern observed for sherd 19/9 is characteristic for most of wheelturned material found in Manching and not much different of the patterns observed for the cores of some of the painted ware. It shows almost complete reduction with a maximum value for the Fe^{2+} quadrupole splitting of 2.25 mm/s and a low temperature spectrum with a considerable amount of 36% of magnetically ordered Fe^{2+}.

Mössbauer patterns like that of sherd 19/859 are less frequently observed in wheelturned ware and indicate a much lower firing temperature. Almost no reduction has occurred, most of the iron is still in the Fe^{3+} state with a quadrupole splitting of 0.79 mm/s, and traces of almandine are present. It can be assumed that the material was practically only dried around 400°C to 500°C. This notion is confirmed by the 4.2 K spectrum (Figure 6, bottom), which shows a complicated magnetic hyperfine pattern. The maximum hyperfine field of 52 T is characteristic of hematite. A broad distribution of magnetic hyperfine patterns with smaller hyperfine fields represents about 55% of the area. This component could be goethite or a product of its thermal composition not yet forming well-crystallised hematite. The Fe^{3+} doublet has a relative intensity of 25% and a quadrupole splitting of 0.9 mm/s. The black colour of the surface is not caused by the formation of Fe^{2+} phases. It is probably due to carbon deposition.

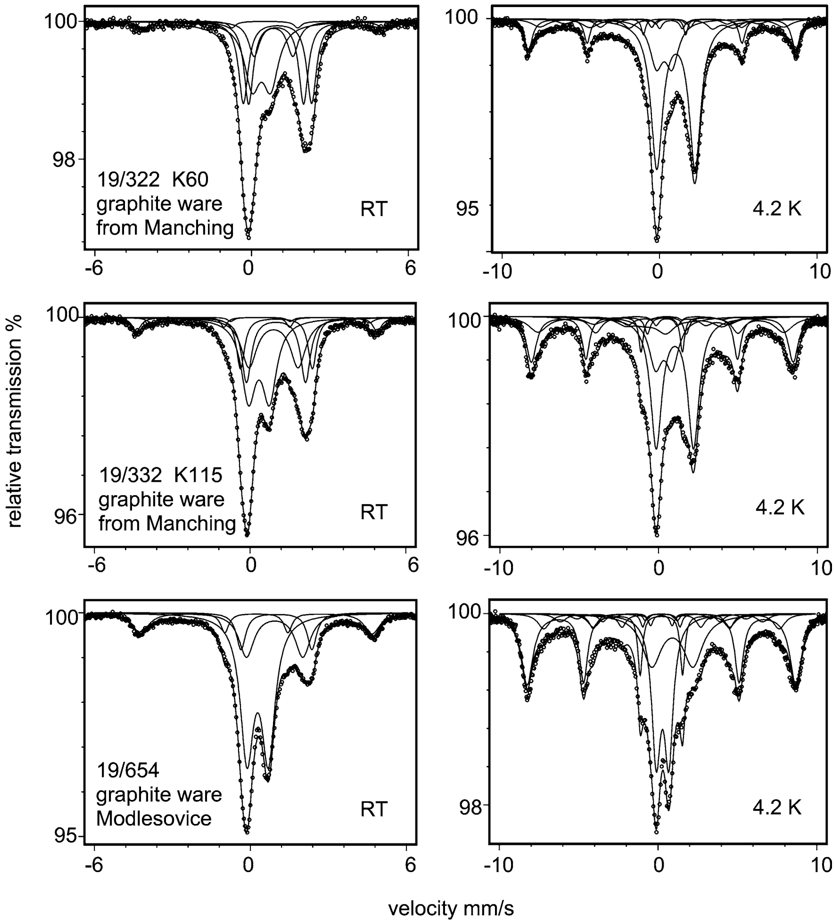

Figure 7. RT and 4.2 K Mössbauer spectra of material of three samples graphite ware. Sherd 19/322 is of from Manching (*top row*), sherd 19/332 was also found in Manching, but exhibits a eastern shape (*middle row*) and sherd 19/654 was found in Modlešovice Bohemia (*bottom row*). Note the different velocity scales.

3.3.4. *Graphite ware*

Graphite ware was made from a mixture of local clays with up to 30 wt.% of graphite. It was used in all of Celtic Central Europe, but is dominant in the eastern part. Neutron activation analysis of graphite ware is complicated by the fact that the trace element patterns of the clay used for making the pottery and that of the added graphite are superimposed. Nevertheless it yields a definite separation between graphite ware from Manching and from the east (Figure 2).

The graphite used in Manching was imported from Kropfmühl [8], on the northern bank of the Danube about 190 km from Manching. This is in fact the only deposit in the region. For the production of graphite ware found in the east, local deposits in Bohemia were used [8, 25]. The different types of graphite could not be distinguished in the thin-section micrographs. The Mössbauer spectra of three examples of graphite ware are shown in Figure 7. One sherd is from Manching, (19/322), a second sherd was also found in Manching but exhibits, the characteristic eastern shape (19/332). The third example (19/654) was found in Modlešovice in Bohemia.

Sherd 19/322 is well reduced with a fraction of 60% of Fe^{2+} in the RT spectrum (Figure 7). Only 9% of the total iron are magnetically ordered. This fraction increases to 34% in the 4.2 K spectrum, part of it in a broad magnetic background, which probably contains some of the Fe^{2+} species, whose quadrupole doublets decreased by 10% to 50% area at 4.2 K. Sherd 19/332 exhibits very similar Mössbauer patterns (Figure 7, middle), the differences observed between sherds 19/322 and 19/332 being only gradual. Sherd 19/654 found in Modlešovice, with only 27% Fe^{2+}, is clearly different. At 4.2 K 55.0% of the Fe^{3+} shows a distribution of magnetic hyperfine fields, indicating that sherd 19/654 was fired at a lower temperature than the graphite ware from Manching. In the production of graphite ware the maximum firing temperature had to be kept below 850°C, to avoid loosing the graphite by accidental oxidation. At higher temperatures, the graphite would react and cause strongly reducing conditions inside the sherds irrespective of the kiln atmosphere.

Generally, the amounts of Fe^{2+} vary considerably, also between different sherds from the same findspot. Graphite ware from Manching is, however, reduced more strongly than the finds from Modlešovice [20]. During production of graphite ware not so much attention was paid to the firing temperatures, while the conservation of the black graphite colour was all-important.

3.3.5. *Coin moulds*

Neutron activation analysis of technical ceramics from Manching yields a very different element content than that typical for the pottery [13]. This indicates that a detailed knowledge of raw materials existed and the appropriate ones were chosen for special purposes. The group of technical ceramics comprises mudplaster from wattle and doub houses and, most importantly, pieces of furnaces and moulds for the melting of blanks for gold coins. The moulds have the from of rectangular plates of about 7 cm × 12 cm × 2 cm with several pits to take up metal pieces or powder.

Coin moulds were studied in detail [18, 19, 26]. The production of coin blanks could be reconstructed from their Mössbauer spectra and the procedure deduced from the Mössbauer study was tested in several field experiments [19]. According to the investigations, the coin blanks were made as follows: after the pits of the coin moulds were filled with the metal mixtures for the coins, the moulds were placed in a preheated rectangular furnace filled with a layer of glowing charcoal and then covered with another layer of red glowing charcoal. The temperature in the top layer of the coin mould quickly rose to above 1000°C when air was blown into the top charcoal layer using bellows. This temperature is sufficient to melt gold or gold

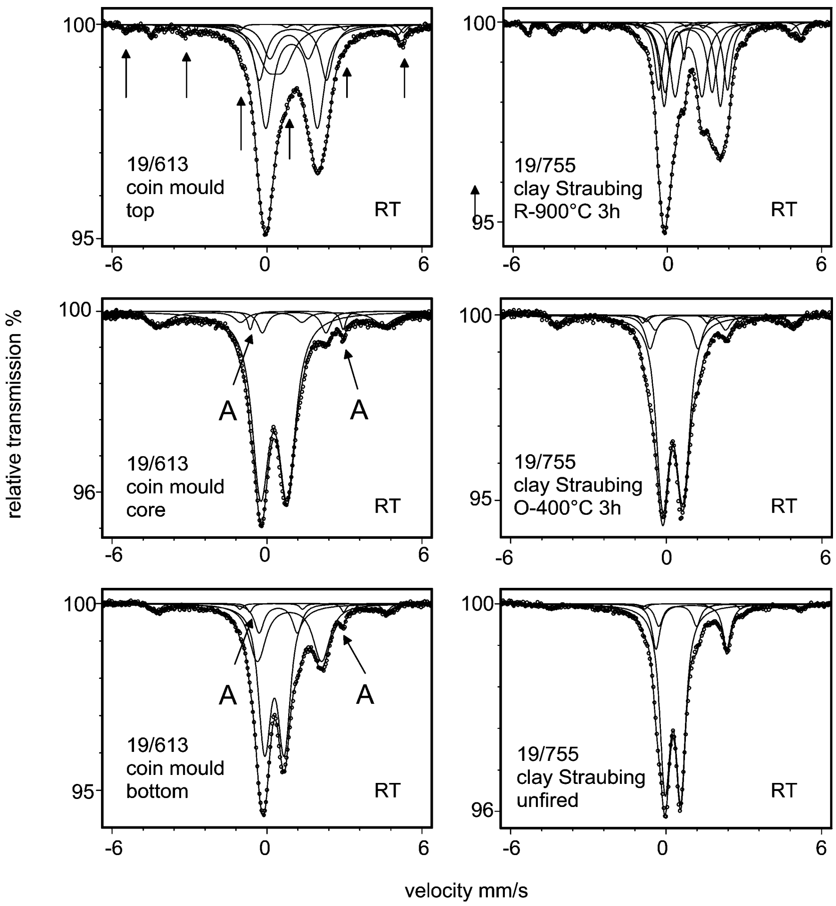

Figure 8. RT Mössbauer spectra of different layers of coin mould 19/613 on the *left*. The positions of the 6 absorption lines of iron metal are indicated by arrows in the top spectraum. The lines of almandine (A) are indicated in the spectra of the middle part and of the bottom of the coin mould. Samples of clay 19/755 fired in the laboratory are shown on the *right* for comparison. The firing conditions used for emulating the spectra are shown in the plots.

alloys. The top of the mould becomes almost totally reduced and partly vitrified. The temperatures which were reached in the centre and at the bottom of the moulds during the fields experiments were much lower because of the short duration of the firing. The same temperature gradient could be shown to have existed in ancient coin moulds by Mössbauer studies. In the coin mould 16/613, whose Mössbauer spectra are shown in Figure 8, these temperatures were around 800°C and 400°C, respectively. The formation of metallic iron and the absence of almandine in the top layer are an indication of a temperature above 1000°C. The temperature behaviour in coin moulds from Manching was measured during a replica experiment and simulated mathematically using the heat transfer properties for ceramic material [19]. All in all, 17 coin moulds from Manching were studied. They all exhibit the described gradient of maximum firing temperatures from to bottom. Four coin moulds from Verulamium in the south of England do not show this structure [27]. They are reduced and have reached high temperatures throughout. Apparently, they were treated longer and more thoroughly.

4. Conclusions and outlook

A detailed evaluation of all existing data on Celtic ceramics together with the archaeological typology along the lines presented here will be published later. The preliminary results already show that the uniform material culture observed in the Celtic civilisation in Central Europe was highly developed. Valuable goods, like glass and jewellery, were traded and transported over wide distances. Gold coins were probably used as currency in far distance trade. On the other hand, ceramics were mostly produced from local raw materials at the different sites, adhering to the style of the period. Special raw materials necessary for the ceramic production had to be imported, e.g., graphite or pigments. The ceramics were used mainly around the production centres. If a long distance distribution is observed, it can be explained by the function of the vessels as transport containers of goods like the famous celtic cheese [28] or other specialities. The scientific analysis of the late iron age pottery helps the archaeologists to understand the economic relations between the Celts in Central Europe. For the first time it gives us an idea about the extension of regional trade systems within about 30 to 60 km around the big cities. It could also be confirmed that there were strong relations between the regions of big tribes like those of Bavaria and Bohemia that cover a distance of 200 to 300 km. Further analysis will almost certainly lead to a more detailed and specific understanding of the existing data.

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