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On the Production and Distribution of the Ceramic Building Material in Vindobona

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ABSTRACT

This paper deals with the technical aspects of ceramic building material production in the brickyard located near the legionary fortress of Vindobona (nowdays Vienna, Austria). First, the general procedures of brick manufacture are described, then the paper focuses on the material from Vindobona itself. *Tegulae*, which make up most of the preserved evidence, are also treated at some length. In comparison to other ceramic building material, tiles are more distinguishable, thus more criteria can be observed. The observed criteria were: treatment of the surface, proportions, types of lower cutaways and shape of flanges. On the basis of these criteria, it is possible to distinguish differences in working procedures, which may relate to a change of units in the fortress and an exchange of workers within one unit.

Attention is also paid to the economic aspect of production, which is reconstructed on the basis of theoretical calculations. The amount of material necessary for the construction of camps was calculated along with the estimated time which it took to produce this material and the necessary work-power. The last part deals with the distribution of bricks to the forts in the upper Pannonian Limes, with an attempt to determine if the material was transported to the construction sites from Vindobona or was produced on the sites. The results show it was more cost effective to transport the material over even long distances.

KEYWORDS

Roman; ceramic building material; brick production; Vindobona; Pannonia.

INTRODUCTION

Building ceramics form an important body of material from Roman camps and buildings in general. Since building inscriptions are rather rare, the identification of individual building phases is (except for pottery and coins) also based on stamped material. For this reason, the research focus in the past used to be solely on stamped material. In this paper, I will talk about the technical aspects of brick production, which were almost completely overlooked in the past. More specifically, the focus will be on the area of the Roman legionary fortress of Vindobona and the brickyard located nearby. After a general description of brick production, attention moves to ceramic roofing, especially tiles. There are two main reasons for such a focus. The results presented in this paper are based on museum collections, which consist mostly of *tegulae*. *Tegulae* are also more complicated in shape than other ceramic building material, which allows one to create more comparison criteria. Since the research is still ongoing, the data and the observations mentioned in this article should not be considered final. The purpose is rather to show how the material should be approached and what procedures can be used to reconstruct the production and distribution of the ceramic building material.

HISTORICAL BACKGROUND

Judging by the stamped material, construction works in the upper Pannonian Limes were conducted mostly by three units, garrisoned in the *castra legionis* of Vindobona or at Carnun-

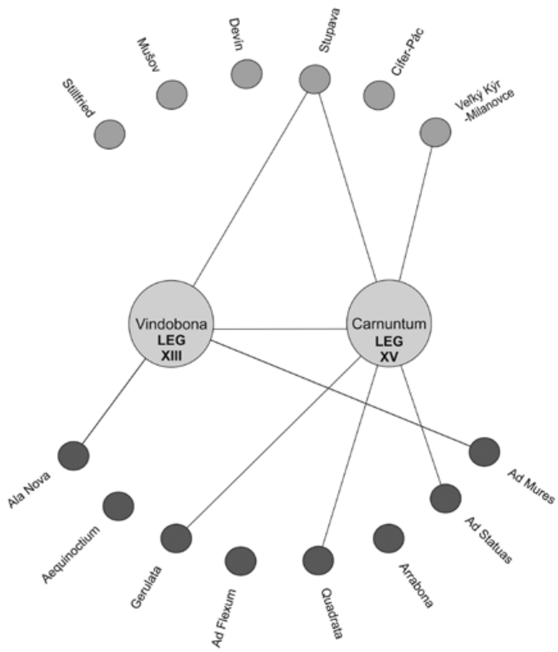


Fig. 1: Scheme of ceramic building material distribution produced by the 13th legion stationed in Vindobona and the 15th legion stationed in Carnuntum in the camps on the *limes* (the lower line) and buildings placed in Barbaricum (the upper line).

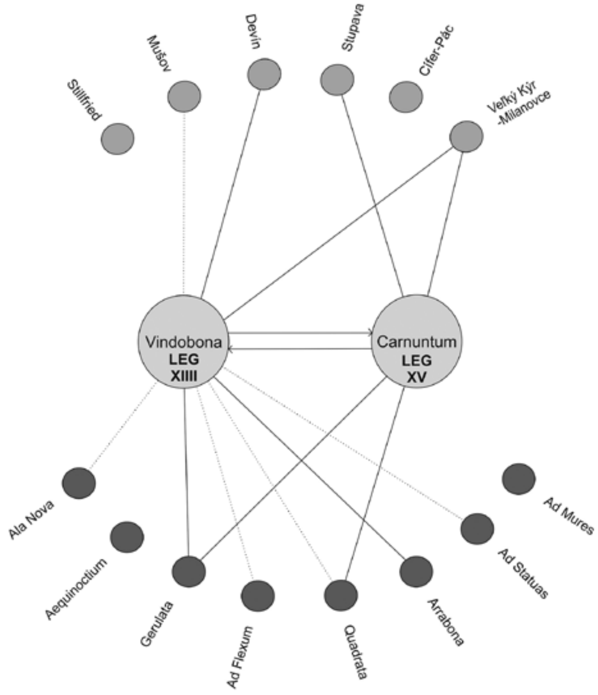


Fig. 2: Scheme of ceramic building material distribution produced by the 14th legion stationed in Vindobona and the 15th legion stationed in Carnuntum in the camps on the *limes* (the lower line) and buildings placed in Barbaricum (the upper line).

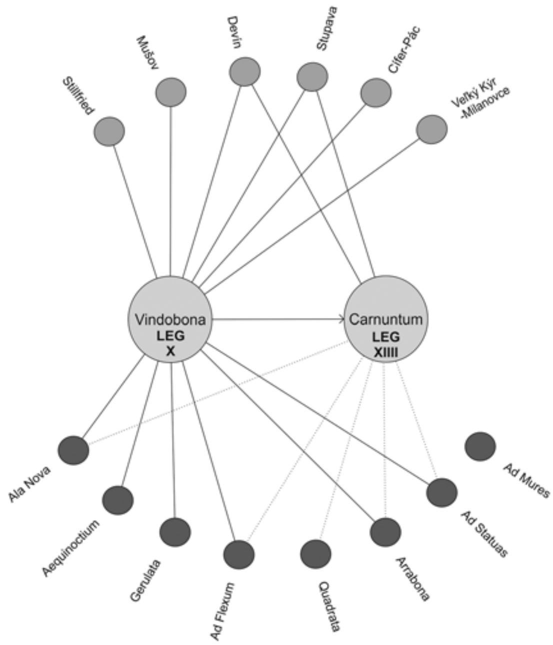


Fig. 3: Scheme of ceramic building material distribution produced by the 10th legion stationed in Vindobona and the 14th legion stationed in Carnuntum in the camps on the *limes* (the lower line) and buildings placed in Barbaricum (the upper line).

tum. The relationship between the units stationed in Vindobona and Carnuntum and their building activity is not very clear. The ratio between the relevant stamps and their spread across the sites is very similar and sometimes they are even found next to each other. There is evidence of a brickyard in Vindobona (Mosser 2013, 161), but we have found none in Carnuntum so far, although analysis of the clay suggests that production also took place there. The first unit stationed in Vindobona was the 13th legion, which started the construction of the fortress around the year 97/98 AD. It did not stay for long and after four years the legion was transferred to participate in the Dacian Wars (Mosser 2005, 131). During this period, the construction works on this part of the *limes* seem to be mostly conducted by the 15th legion, stationed in Carnuntum (**Fig. 1**). Around the year 101 AD the 14th legion arrived in Vindobona and continued working on the construction of the fortress (Brandl 1999, 150). It is however possible, that the unit arrived to Vindobona already in 97/98 AD and started the construction works along with 13th legion (Mosser 2014, 203). Stamps of this unit are common on sites along the *limes* and even in Barbaricum (**Fig. 2**), though it is not clear whether they made the building material during their stay in Vindobona or after moving to Carnuntum in 114 AD (Mosser 2014, 205). The last unit garrisoned in Vindobona was the 10th legion, which remained in the fortress till Late Antiquity (Brandl 1999, 116) and participated on most construction works on the *limes* (**Fig. 3**).

DESCRIPTION OF CERAMIC BUILDING MATERIAL PRODUCTION

SOURCES

The only ancient source we have about the brick production is Vitruvius (II, 3.1). Although he gives us just the description of the mud bricks manufacture in the Mediterranean, many details can also be applied for the production of fired bricks in the Roman provinces. Because this is the only source from antiquity, we need to seek further information and parallels in medieval and early modern times. In these periods, production of hand-made fired bricks was widely spread and can provide us with more technical information and descriptions of practical experience. By combining these sources with finds from archaeological excavations, it is possible to reconstruct the processes of the Roman provincial brick manufacture. Practical experience acquired by experimental archaeology also plays an important role in this research.

PROCEDURES OF BRICK PRODUCTION

If the brickmakers wanted to attain high quality products, the procedures of choosing and preparing the clay had remained the same since the time of Vitruvius. The most important step was choosing the clay: 'They should not be made of sandy or pebbly clay, or of fine gravel, because when made of these kinds they are in the first place heavy; and, secondly, when washed by the rain as they stand in walls, they go to pieces and break up, and the straw in them does not hold together on account of the roughness of the material. They should rather be made of white and chalky or of red clay, or even of a coarse grained gravelly clay. These materials are smooth and therefore durable; they are not heavy to work with, and are readily laid' (Vitruvius II, 3.1). If there was no suitable source near the brickyard, the clay could be transported from distant places. The raw material needed to be further processed. The clay was put in the working pits and watered to clean out undesirable objects. Heavy parts such as stones sank to the bottom, while light particles like grass, roots and wood fragments floated and could be removed. Large amounts of water were needed, therefore the brickyard had to be located near a water source. Workers helped the process by stomping the clay with their bare feet to more efficiently mix the material (Federhofer 2007, 13). This ensured that the clay was more homogenous and solid after firing. It also lowered the possibility of cracking during the firing process.

After the clay was prepared, it needed to be put in moulds. The most common types of building ceramics were *lateres* and *tubuli* for floors and walls, and *tegulae* and *imbrices* for roofing. The sizes were derived from the Roman foot. *Lateres* were divided into *bessalis* (20×20 cm), *pedalis* (30×30 cm), *sesquipedalis* (45×45 cm) and *bipedalis* (60×60 cm). *Tegulae* usually measured one and a half Roman feet (Federhofer 2007, 14). To achieve the same proportions and shape, wooden moulds were used (Warry 2006, 9). The use of various types of moulds and technologies can be observed on the building ceramics. Those variations may be associated with technological change in different periods or may be related to the diverse working habits of the brickmakers. Raw building ceramics firstly needed to dry in the wooden moulds so it could preserve its shape and become detached from the wood (Warry 2006, 28). For this purpose, large drying halls were used, which could have had a width from 8 to 18 m and a length of over 50 m (Mosser 2013, 148). The prolonged shape facilitated better air circulation. Drying had to be slow and it took approximately one week. The clay was checked using the fingers, which left marks of various shapes (Kurzmann 2006, 18). Some of the shapes appear repetitively and the marks can therefore also have a secondary meaning, which is unknown to us. If everything was all right, the brick was probably stamped, though the true meaning of the stamping is also unknown. The stamps could have served as a sign of quality control, or marked military property. Dies for stamping were made of wood, iron and probably also clay (Kurzmann 2006, 24). After the brick was stamped and removed from the form, it needed to dry for another week before it could be fired in a kiln (Warry 2006, 28).

Apart from stamps and finger-marks, there are exceptional bricks which bear numeric inscriptions made by the workers before firing. They are potentially a valuable source of information about the amount of daily production, or the date when the bricks were made. They can be interpreted as proof of production control by officials, or they could have served as some sort of 'delivery note'. Inscriptions are usually in the form of rows of numbers. Bricks from Lauriacum held 16 numerals separated into four rows: 1 – *XLII XXXII XLII XX XXXX* (total 176); 2 – *XXX XXX XXX LXXX* (total 170); 3 – *XXX XL XXX LXXXX* (total 190); 4 – *XXX XXX XXXX* (total 100) (Ruzicka 1919, 110). Three different people wrote these values and their total sum is 636 bricks. Similar values were inscribed on bricks from Siscia: *...I kal iunias / Candidus CCXX / Iustinus CCXX / Felicio CCXX / in uno DCLX* (29th June / Candidus 220 / Iustinus 220 / Felicio 220 / altogether 660); *XIII k octobr(es) / Fortis CCXXII / Candidus CCXXV / Iustinus CXXXVII / Artemas CLXXXXVIII / min XXI* (20th October / Fortis 222 / Candidus 225 / Iustinus 137 / Artemas 198/...21).

These numerals can be interpreted as the daily production of one worker. The edict of Diocletian only supports this theory with the prescribed norms of daily production: one man had to make 100–120 large bricks or 220 small bricks. According to the inscribed dates, which stretch from June to October, the production was seasonal. As was described by Vitruvius (II, 3.2), the climate of continental Europe was not suitable for making bricks during the winter. The low temperatures prevented most of the brick making works, starting with digging the soil to drying the formed bricks.

The last, technologically most difficult step, was the firing of the bricks. Roman kilns were sunk in the ground and consisted of a working pit, a furnace opening and a firing chamber of rectangular shape with a bottom grate (Federhofer 2007, 33). Peter Warry claims on the basis of an experiment that ten people were necessary to maintain one kiln (Warry 2006, 121). Two people controlled the firing process and regulated the temperature. Eight people were required to carry the wood and to keep the fire burning. During the firing, the temperature in the kiln reached over 900 °C and the whole process took four days or more (Federhofer 2007, 18). After cooling, the kiln was opened, the bricks removed and probably stored in the warehouses, or in the part of drying hall waiting to be distributed to the construction sites.

SIGNS OF DIFFERENT PRODUCTION TECHNIQUES LEFT ON TILES

The technical aspect of brick production discussed in this article is based on the examination of bricks from the Roman sites of Bratislava-Rusovce and Stupava (the Slovak National Museum), Mušov-Burgstall (the Institute of Archaeology of the Czech Academy of Sciences, Brno) and Vienna (Wien Museum). The most important is the collection deposited in the Wien Museum, consisting of more than 4,500 stamped bricks. The majority of bricks from these sites had their origin in the brickyard located in Vienna's city district of Hernals. The main goal was to distinguish traces of technical procedures carried out during the brick making. Although various production techniques were observed also on *lateres* and *imbrices*, a special focus is placed on *tegulae* only, which form the majority of finds.

The observed criteria are based on Peter Warry's research of tiles in the Roman province of *Britannia*. The criteria were: the treatment of the surface and proportions and types of lower cutaways. The most important are the cutaways, the bottom edges of tiles, which were on one part cut away, so they can fit better to each other. Their various forms can be used as dating criteria (Warry 2006, 43–45). In this observation, the aim was to verify if the different types of cutaways also appear on the material from the examined sites. The shape of flanges was also included in the observations.

RESULTS OF OBSERVATIONS

Due to the mostly fragmentary condition of the finds it was not possible to observe the complete dimensions of the tiles. The thickness was measured on the breaks and varies from 2 cm to 4 cm, however groups with the same thickness seem to appear. The upper surface of the *tegulae* was always carefully levelled, probably with a stave, leaving small straight scratches. The bottom surface shows various kinds of treatment, based on how the tile was separated from the workbench. Four basic methods were distinguished:

1. The workbench was lined with coarse sand, which got stuck to the bottom of the tile. The clay was thus not moulded precisely, leaving an uneven surface with folds (**Pl. 3/1**).
2. The workbench was lined with fine sand, traces of which can be found at the bottom of the tile. The surface is now straight and the clay was moulded carefully.
3. The workbench was lined with coarse sand, which was later removed from the bottom of the tile with a knife or similar device. This kind of treatment can be distinguished by preserved cutting marks, which are often in various directions (**Pl. 3/2**).
4. The clay was put directly on the surface of the workbench and removed afterwards with a wire, leaving long shallow scratches from grains swept away by the wire (**Pl. 3/3**).

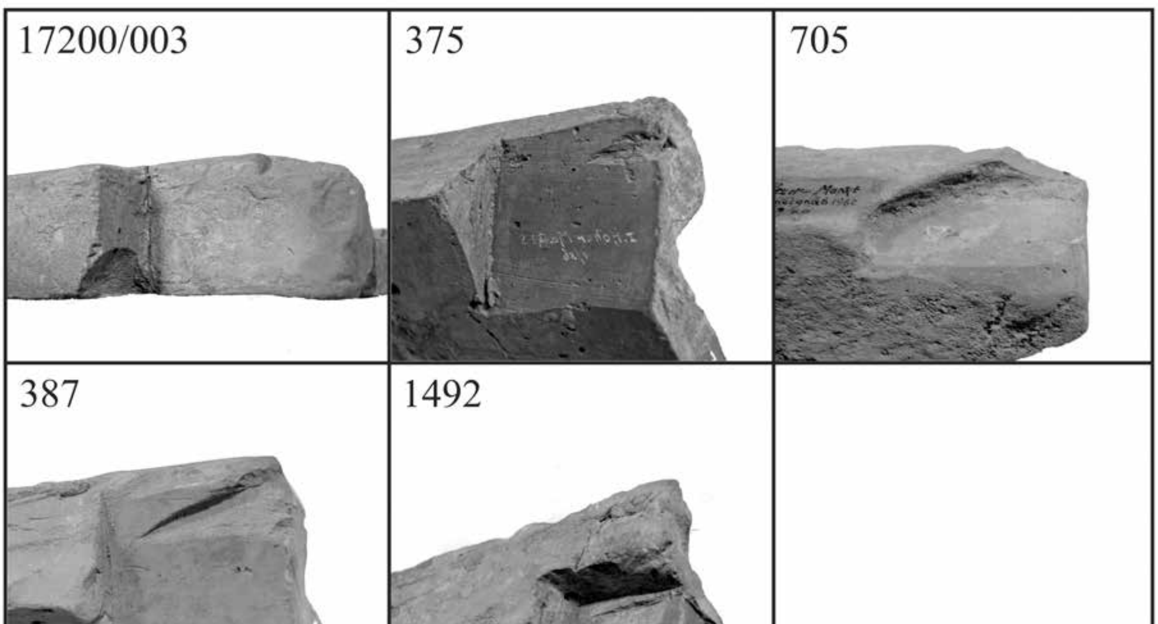


Fig. 4: Photographs of various cutaway types on tiles (Wien Museum). Photo by author.

The different kinds of treatment seem to be linked to the various working habits. The difference in quality might be the result of changing demand for the material, lowering the quality of treatment in a period of larger building activity and higher demand for the building material.

For the lower cutaways, five different types were observed in the deposits of the Wien Museum (**Figs. 4** and **5**):

Type A is created by inserting two rectangular blocks into the moulding form, covering the whole width of the flanges. All such tiles were stamped by the 13th legion (Vienna, Wildpretmarkt 8–10; Wien Museum, Inv. 17200/003).

Type B is created by two cuts, one diagonal along the flanges, the other vertical to the former. This type appears on tiles stamped by both the 10th and 14th legions (Vienna, Hoher Markt 9; Wien Museum, Inv. Neumann 375).

Type C is created by inserting a rectangular block into the form, curved on one side, covering half of the height of the flanges. This type appears on tiles stamped by the 10th legion (Wien Museum, Inv. Neumann 705).

Type D represents a very interesting group, which at first was moulded as the Type C cutaway and afterwards adjusted with two diagonal cuts to match the Type B. Sometimes the partial imprints of the wooden blocks from the form remain and sometimes they are almost completely cut away. This type appears on tiles stamped by the 10th legion. Some finds bear the stamp 'LEG X GPF AN' and can thus be dated to the reign of Caracalla (Vienna, Hoher Markt 9–11; Wien Museum, Inv. Neumann 387).

Type E is created by three cuts, removing a small rectangular block from the bottom. This type appeared on tiles stamped by the 14th legion (Vienna, stray find; Wien Museum, Inv. Neumann 1492).

The flanges have various profiles. After the clay was bent into the flanges, they were further shaped with the hands or other devices. The side, facing the inside of the *tegula*, was finished with a sharp edge or with a long line made with one or two fingers. The different forms are represented in the table (**Fig. 6**). Further research is needed to determine if the typology can be used for dating purposes.

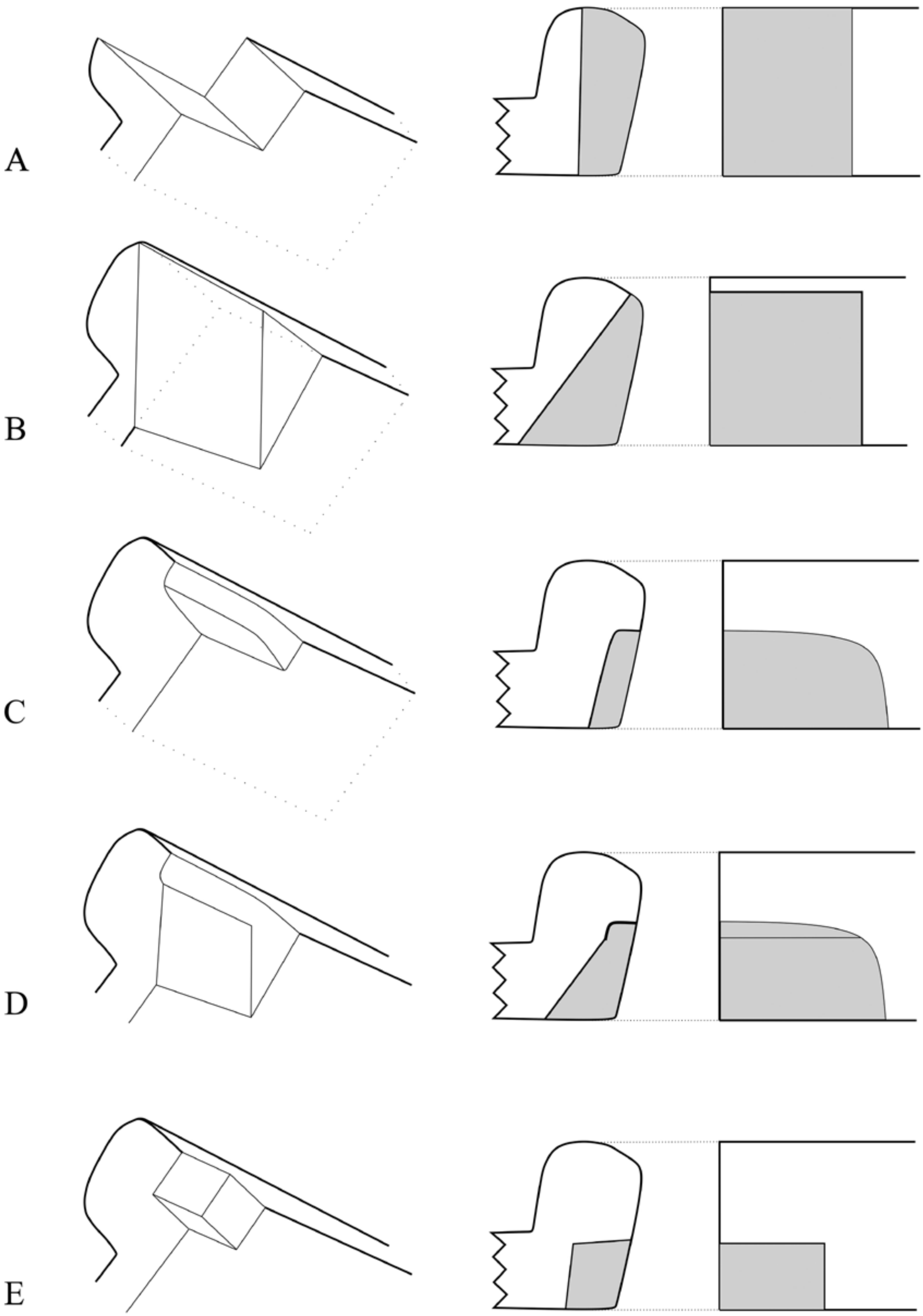


Fig. 5: Table with ideal drawings of cutaway types on tiles, based on the finds from Vienna. Drawings by author.

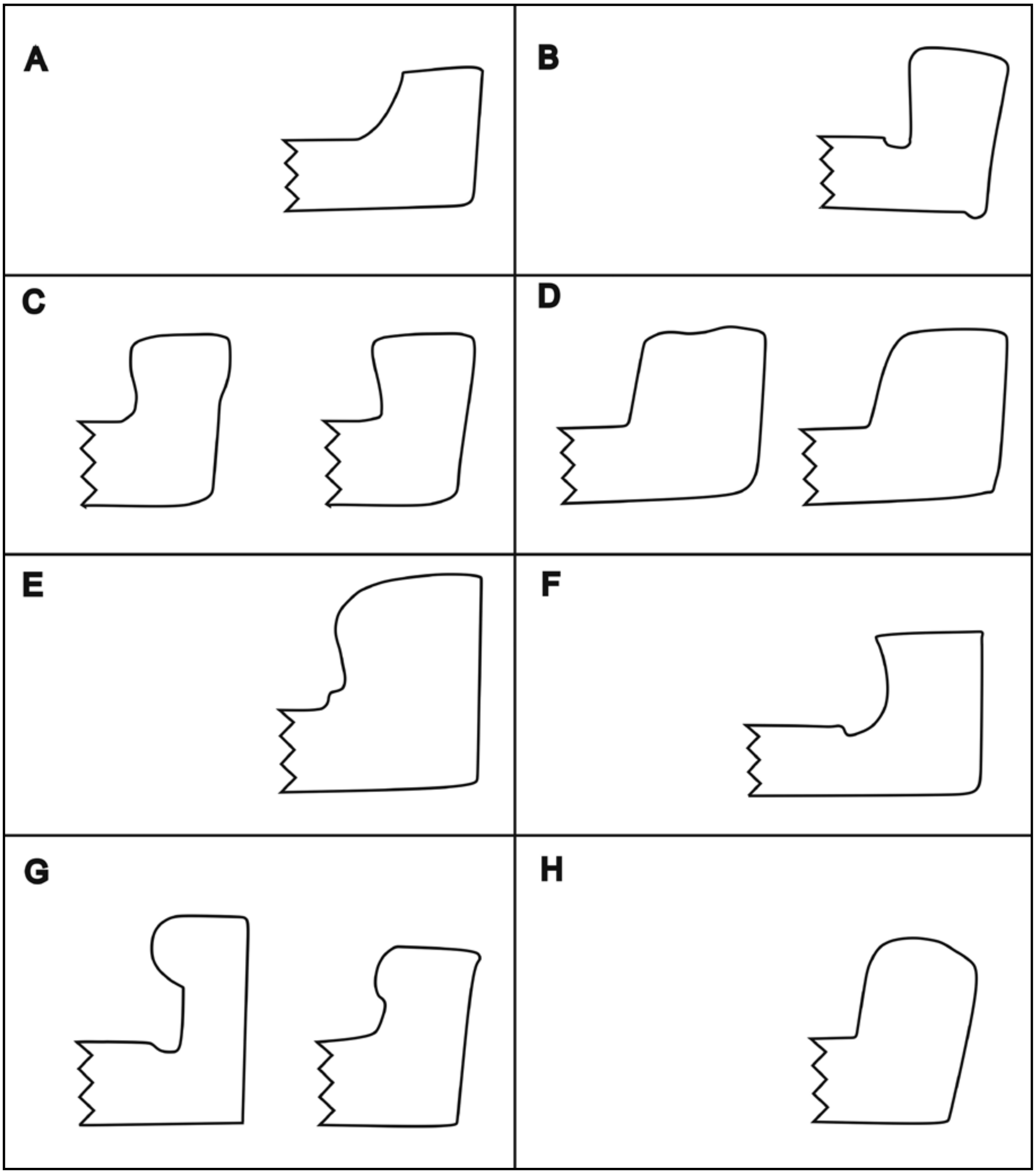


Fig. 6: Table with ideal profile drawings of tile flanges, based on the finds from Vienna.

ECONOMIC ASPECTS OF THE BRICK/TILE PRODUCTION

To reconstruct the economic aspects of brick production in Vindobona, I have tried to calculate how much material was needed for the construction, how long it took to prepare this material along with the number of workers necessary to produce it and how the material was transported to the construction sites.

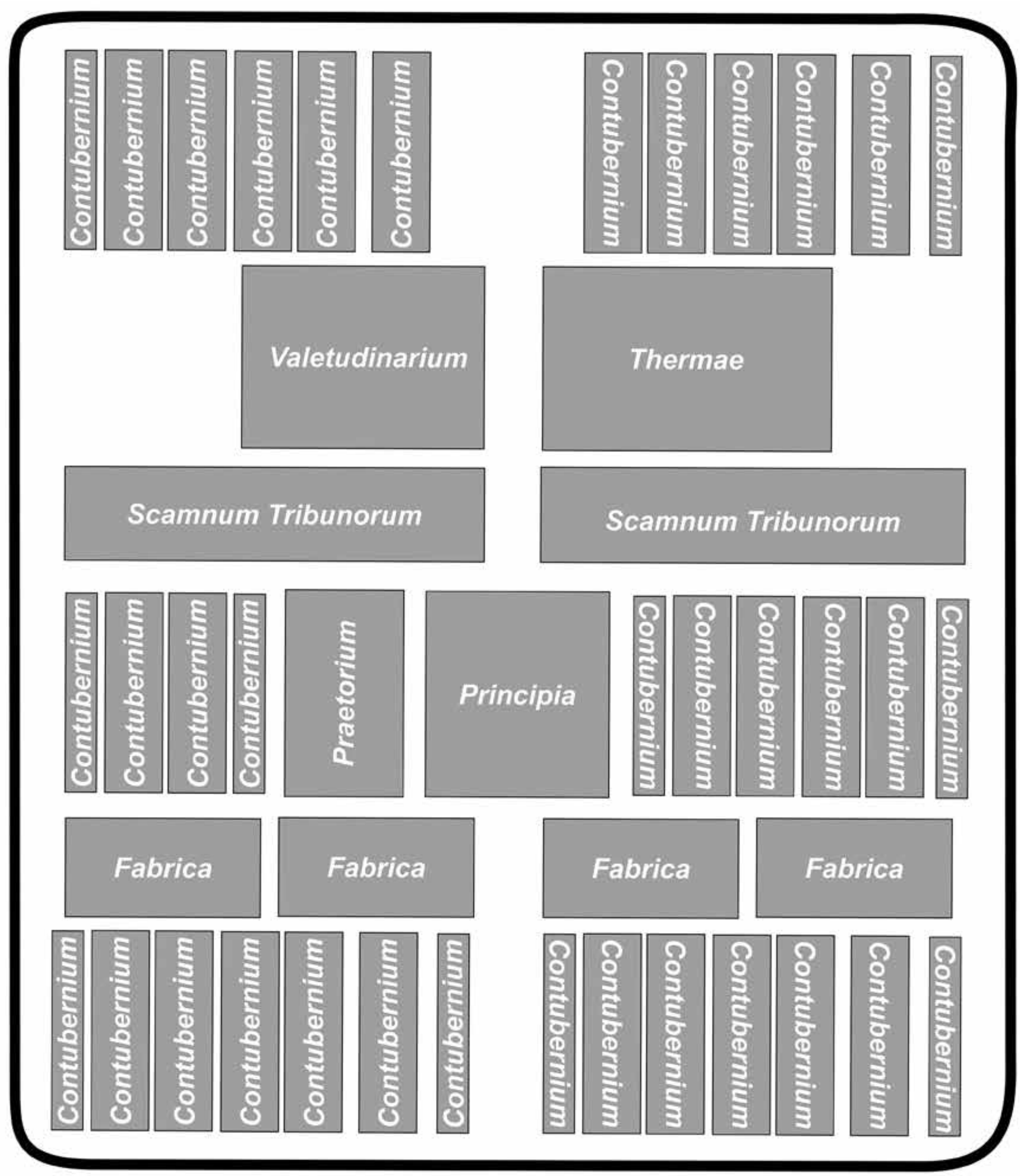


Fig. 7: Ideal plan reconstruction of the legionary camp of Vindobona (Plan based on MOSSER 2015, 76).

Firstly, an attempt to calculate the necessary amount of ceramic building material for constructing *castra legionis* has been made. Since the exact plan of the buildings is not known for Vindobona, the proportions were taken mostly from Carnuntum. The building types included in the calculations are shown on the ideal plan (**Fig. 7**). The calculations of the materials focus solely on the ceramic building material used for roofing and were intentionally calculated for the stone construction phases. During the earth-timber phase, wooden shingles were in common use and we can presume that terracotta tiles were used just on a few main buildings. Even during the 'stone' phase, we cannot be sure how many buildings in the fortress had roofs made of ceramic tiles, but there is no need to be completely accurate. The goal is rather to see what options the Romans had. The roofing was not calculated precisely for every building, but for one type of building in the camp each and then multiplied. A 30 degree angle was presumed for the roof tilt. The proportions of one *tegula*, based on completely preserved finds, was set at 45×53 cm and its weight at 14 kg (the actual weights of *tegulae* from Vindobona vary from 12 to 19 kg). The amount of *imbrices* used is derived from the number of *tegulae*, with the weight set at 5 kg. The results show that the construction of the legionary fortress required a significant amount of material, approximately 900,000 pieces of *tegulae* and *imbrices* combined, weighing more than 8,500 tonnes (**Tab. 1**).

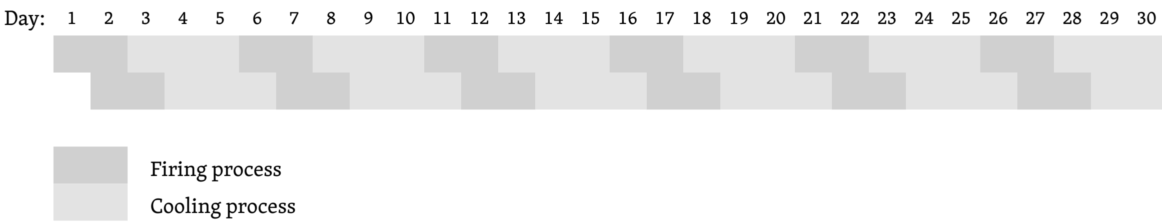
Vindobona	Building proportions			number of buildings	total surface	*tegulae*	*imbrices*
Type of building	x	y	surface				
contubernium	15	80	1200	62	74400	311950	311950
praetorium	60	70	4200	1	4200	17610	17610
principia	60	80	4800	1	4800	20126	20126
valetudinarium	86	76	6536	1	6536	27405	27405
fabrica	46	64	2944	3	8832	37031	37031
thermae	106	76	8056	1	8056	33778	33778
					total ammount	447899	447899
					total wieght	6271	2239

Tab. 1: Calculations of ceramic roofing material needed for the building of the legionary camp Vindobona.

In the next step, it was necessary to determine how long it took to produce the ceramic roofing material. Unfortunately, we have no information about the size of the brickyard, the number of kilns used, or the number of workers. The only possibility of estimating these values are model calculations. The capacity of a kiln was based on the size of the firing chamber. The internal proportions of the firing chamber of the kiln found at Steinergasse in Vienna were 2.2×2.6 m (Mosser 2013, 150) and the height of the chamber can be reconstructed to 2 m (Warry 2006, 120). If the dimensions of one *tegula* were 45 cm for width, 53 cm for height and 5 cm for thickness, based on the size of the flange, the total amount of tiles which could fit in the chamber is 959. Since the tiles could be stacked in various ways resulting in different capacities, a total sum of 1,000 will be used in the calculations. For the *imbrices* we can assume that the capacity was at least double the amount.

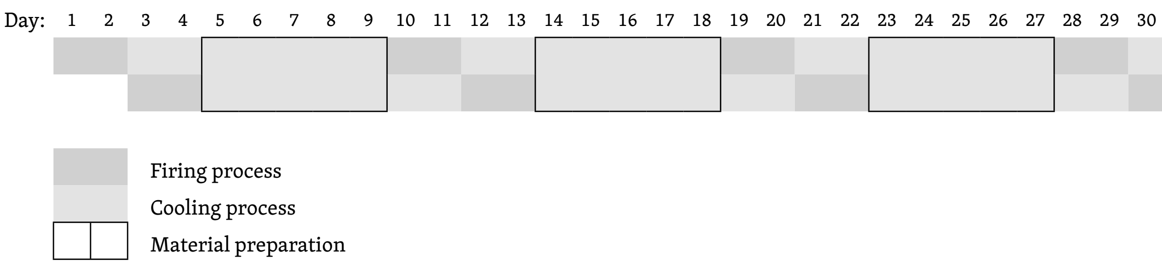
The procedures for calculating the time of production are (on the contrary) simple: first the total amount of material is divided into batches based on kiln capacity. Then the batches of *tegulae* and *imbrices* are added up together and divided by the number of kilns used. The resulting sum is afterwards multiplied by the length of the firing process in days. Since the production of bricks was seasonal, in the last step the sum is divided by the number of working days. The result is the number of seasons (years) which were necessary to produce the material.

The most problematic part is how to determine the number of the kilns used and the real length of the firing process. It is known from experiments that the time necessary for firing is four days (Federhofer 2007, 18). Two days of feeding the fire to heat the kiln up in order to reach the necessary temperature and the same time for cooling it down. However, we cannot be sure how long the Romans left the kiln to cool for. For this reason, two model situations are proposed. The kilns are usually found in pairs of two and were probably maintained by one working group (Mosser 2015, 60). The first model represents the most efficient method in terms of time and is based on the data gathered from experiments (**Tab. 2**). While one kiln is cooling down, a second batch is being fired in the other one. The material is taken away right after two days of cooling. While the material from the second kiln is being removed, the firing in the first kiln starts again. In this model, two people are necessary to control the temperature in the kilns and eight people keep feeding the fire with wood. Another group of people work on moulding the bricks.



Tab. 2: Model of labour division during the firing process, most time-efficient.

The second model is based on keeping the least number of workers (**Tab. 3**). Again, the firing starts in one kiln, and during the ongoing cooling process the second kiln is used. Both kilns are left to cool down for several days, during which the workers, who initially watched over the firing process, are preparing new bricks. In this scenario nine days are necessary to finish one cycle.



Tab. 3: Model of labour division during the firing process, lowest number of workers.

As a result, it seems that – in order to fully cover the tile production needed for the construction of the *castra legionis* at Vindobona – one theoretical pair of kilns would require 16 years to achieve the aim. Should the material have been produced in a single season, five pairs of kilns would be necessary (**Tab. 4**). Note, that both cases assume continuous production during the 'summer' period only, which lasted five months (based on date inscriptions). It is sure that the production was continuous, but the results of these model calculations suggest that probably no more than ten kilns were in use at the same time.

Number of kilns	Days needed to produce material	Number of seasons	Brickmakers	Regular workers	Total workingpower
2	2360	16	2	8	10
6	787	5	6	24	30
10	472	3	10	40	50
14	337	2	14	56	70
18	262	2	18	72	90
22	215	1	22	88	110

Tab. 4: Calculation of the time needed to produce the material necessary for the construction of the legionary camp Vindobona along with the number of workers.

DISTRIBUTION OF THE CERAMIC ROOFING MATERIAL

Bricks stamped by the Vindobona legions are widely spread among auxiliary forts along the Danube and buildings located in the area across the Danube, in Barbaricum. It would be interesting to know whether this material was produced directly in the places of construction works in *ad hoc* established smaller brickyards, or rather if it was distributed from Vindobona, where the large brickyard already existed. First, I calculated the amount of material necessary to build an auxiliary fort. As a basis for these calculations, the best-preserved plans were used: the auxiliary fort in Iža (Rajtár 2005, 15) and the auxiliary fort in Carnuntum (Kandler 2003, 58), which both garrisoned 500 men. Since we do not have a completely preserved plan of an auxiliary fort for 1,000 men, the number of contubernia in Carnuntum was artificially increased to 20 to match this capacity. The Roman camps were always planned in the same way, thus this modification will not cause problems to the final results. The approach was the same as in the case of Vindobona, the amount of material was calculated for just one type of building and then multiplied.

auxiliary fort Carnuntum	Building proportions			number of buildings	total surface	*tegulae*	*imbrices*
Type of building	x	y	surface				
contubernium	8	53	443	20	8854	37122	37122
praetorium	42	36	739	1	739	3098	3098
thermae	29	37	1047	1	1047	4389	4389
principia	33	43	1074	1	711	2979	2979
house	47	6	694	2	1388	5821	5821
scamnum tribunorum	15	22	332	2	664	2784	2784
unknown building	41	33	1347	1	1347	5649	5649
					total amount	447899	447899
					total wieght (t)	6271	2239

Tab. 5: Calculations of material needed for building the auxiliary camp of Carnuntum.

Kelemantia / Iža	Building proportions			number of buildings	total surface	*tegulae*	*imbrices*
Type of building	x	y	surface				
contubernium	54	18	972	5	4860	20377	20377
horreum	50	12	600	3	1800	7547	7547
praetorium	66	22	1452	1	1452	6088	6088
scamnum tribunorum	28	15	420	1	420	1761	1761
thermae	19.5	32	624	1	624	2616	2616
stables	12.5	51.6	645	2	1290	5409	5409
					total amount	43799	43799
					total wieght (t)	613	219

Tab. 6: Calculations of material needed for building the auxiliary fort in Iža.

The results are 1,175 tonnes of building material for the larger fort (**Tab. 5**) and 832 tonnes of material for the smaller one (**Tab. 6**). The time needed for the production of this amount of material along with the numbers of workers needed, is shown in **Tab. 7** and **8**.

Number of kilns	Days needed to produce material	Number of seasons	Brickmakers	Regular workers	Total workingpower
2	667	4	4	8	12
4	334	2	8	16	24
6	222	1	12	24	36
8	167	1	16	32	48
10	133	1	20	40	60

Tab. 7: Calculation of the time needed to produce the material necessary for the construction of the auxiliary fort of Carnuntum along with the number of workers.

Number of kilns	Days needed to produce material	Number of seasons	Brickmakers	Regular workers	Total workingpower
2	443	3	4	8	12
4	222	1	8	16	24
6	148	1	12	24	36
8	111	1	16	32	48
10	89	1	20	40	60

Tab. 8: Calculation of the time needed to produce the material necessary for the construction of the auxiliary fort in Iža along with the number of workers.

In the last step, the time necessary for producing the bricks in the construction sites was compared with the time which it took to transport the material from Vindobona (**Tab. 9**). The capacity of one cargo ship was set at 10 or 20 tonnes based on the finds of shipwrecks found in the Upper Rhine. The speed of the ships was estimated at 2.5 km/h. For the needs of this model, we presume that five ships were involved at a time, undertaking the transport without stopovers. The results show that it was quicker to produce the material in Vindobona, where a large brickyard was already built and then transport it to the construction sites, even to the furthest one. If the material had to be produced at the construction sites, the brickyards had to be established in each place first, which would be too complicated. It is necessary to keep in mind, that the real amount of material was much lower, because not all the buildings were covered with terracotta roofing.

Ship capacity (t)	10	20
Speed of ship (km/h)	2.5	2.5
GERULATA	60 km	
Days needed for shipping	**75**	**38**
AD FLEXUM	97 km	
Days needed for shipping	**121**	**61**
QUADRATA	138 km	
Days needed for shipping	**173**	**86**
ARRABONA	172 km	
Days needed for shipping	**215**	**108**
AD STATUAS	195 km	
Days needed for shipping	**244**	**122**
AD MURES	202 km	
Days needed for shipping	**253**	**126**

Tab. 9: Calculations of the time necessary to transport the material to the construction sites.

CONCLUSIONS

Until now, the only criteria which could be used for the classification of the ceramic building material from Vindobona were the stamps. The focus in this article was on roofing ceramic, especially the tiles. Differences in handling the tile surface, cutaway types and flange profiles can widen our knowledge of how the brick production worked and can reveal the development in production over the years. Various production techniques were identified on the examined material and can be connected not only with the change of units in the fortress, but also with the change of people who oversaw the production. It is even possible that the working habits of individuals can be distinguished, enabling a more accurate dating of the finds. The various types of tiles shown in this article are not diverse only in their shape, but also in the quality of treatment of the material. This may reflect the increase in building activity along *Limes Romanus,* resulting in a lower quality material. The outcome of the theoretical calculation, although based on the roofing ceramic, can also be applied to the bricks in general. Only a small number of specialized workers were necessary to produce large quantities of material. They also show that the transport of building material over large distances was possible and could be more efficient for the Romans than small scale production near the construction sites. With further research and more attention paid to the details occurring on the bricks, it will be possible to reconstruct the production and distribution system more precisely, enabling us to understand how the *Limes Romanus* was constructed and developed.

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Pl. 3/1: Bottom of tegula spilled with coarse sand (Vienna, stray find, Vienna Museum inv. 1492).

Pl. 3/2: Bottom of tegula, sand was removed with knife or similar device (Vienna, Hoher Markt 3, Vienna Museum inv. 319).

Pl. 3/3: Wired bottom of tegula (Vienna, Hoher Markt 4, Vienna Museum inv. 378).