A 3rd-century AD metalworking yard at Wijnaldum (prov. of Friesland, the Netherlands) and its smithy floor: A contextual and micromorphological reference description

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ABSTRACT: This paper describes a metalworking yard from the 3rd and early 4th century AD, which was excavated in 1993 in the terp settlement known as Wijnaldum-Tjitsma (NL). This site is situated in a dynamic salt-marsh landscape. We describe the various features that belong to the workshop and provide a micromorphological description of one of its components: a smithy floor. The reconstructed house and adjacent metalworking yard provide data for the production of several, different metals, besides iron. The Wadden Sea region itself is devoid of metal ores though rich in cattle that probably provided surplus. The metals recovered in Wijnaldum largely come from scraps probably obtained through exchange with Germanic communities to the South and East and also with the Roman Empire. Based on the examination of the metallurgical and other traces in the yard, a contextual interpretation is given of the metalworking activities and the degree of specialisation achieved.

Introduction

The Wadden Sea coastal region of the northern Netherlands in the Roman Period was a salt marsh area, where habitation was only possible on artificial dwelling mounds, so-called terps (*wierden* or *terpen* in Dutch; Nieuwhof *et al.* 2019). In the western part of the province of Friesland, Westergo, dense rows of terps were found on salt marsh ridges that mark former coastlines. Such a row is found east of and including the present-day village of Wijnaldum (Fig. 1).

One of the terps on the Wijnaldum ridge is known as Wijnaldum-Tjitsma. It was excavated during three summer campaigns, from 1991 to 1993 (Besteman *et al.* 1999; Nieuwhof 2020). Habitation began in the first half of the 1st century AD (Kaspers 2020, 221–223). The terp region was gradually abandoned in the course of the 3rd century (Nieuwhof 2011; Nieuwhof *et al.* 2020). Wijnaldum was one of the last terps to be abandoned; it was still inhabited at the end of the 3rd century AD, but habitation ended no later than *c.* AD 325 (Gerrets and De Koning 1999). Only in the 5th century, the area was repopulated and Wijnaldum became inhabited again.

The 1991-1993 excavations were primarily aimed at providing a context to the early-7th-century gold and ‘regal’ disc-on-bow brooch that was found in the early 1950s after ploughing of the terp (De Langen 2020; Nijboer and van Reekum 1999). However, not only the early-medieval but also Roman-Period features were interesting, although these received less attention during the excavation. One of these was a metalworking yard with a still-intact smithy floor, dating to the end of the 3rd century.

During the excavation, systematic metal detecting and wet screening of the soil from features was standard procedure. This resulted in numerous finds associated with metalworking. These, however, still await full

ISSN 0142-3304 (print)
ISSN 2755-0249 (online)

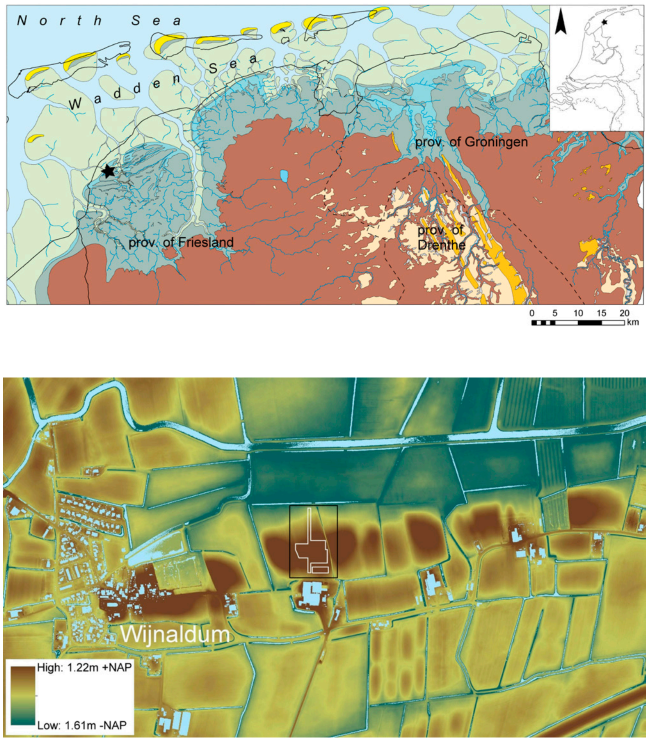


Figure 1: (top) The northern Netherlands with the location of Wijnaldum. The North Sea and the intertidal area of the Wadden Sea are separated by barrier islands. To the south of the coastal salt marshes and salt-marsh ridges (grey-blue) is a large peat area (brown), which encloses the higher grounds of the Drenthe-Frisian Plateau. Palaeogeographic map representing the landscape c. AD 100 by P. C. Vos and S. de Vries, TNO. Reprinted with permission. (bottom) Altitude map of the terp row east of the village of Wijnaldum. The black rectangle shows the location of the partly excavated terp of Wijnaldum-Tjitsma, the white line within represents the excavation trenches. Base map: Actueel Hoogtebestand Nederland (AHN4), adjusted by A. Nieuwhof.

analysis and publication. In the excavation volume, the metalworking workshop was only published in a reconstruction drawing (Fig. 2) and a footnote (Gerrets and De Koning 1999, 81 and footnote 28). A concise description of the smithy floor with microscope and X-ray photographs was published as a separate paper (Nijboer and Tulp 1997). The present paper, which draws on an unpublished inventory of all Wijnaldum finds that were related to metalworking (Tulp 1996), presents the results of new context studies and micromorphological analyses of the workshop and more specifically the smithy floor, by the first and second author respectively, and new insights regarding the general interpretation of such metalworking sites by the third author. The metalworking workshop provides the opportunity to investigate the role of metalworking in a small settlement in the Roman Period. A detailed description may also serve as a reference that can help to identify similar features in other excavations.

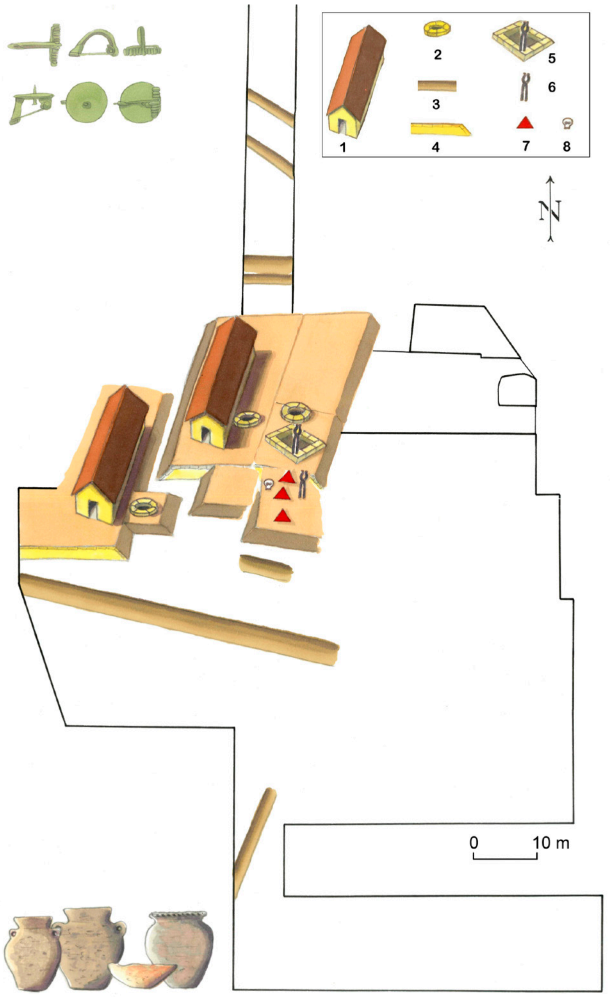


Figure 2: Reconstruction of the settlement of Wijnaldum in Phase II, c. AD 250-325, published in the first excavation volume. Legend: 1. house; 2. well; 3. ditch; 4. sod terp platform; 5 and 6. metalworking area; 7. fireplace; 8. infant inhumation (Gerrets and De Koning 1999, fig. 6; drawing: J. de Koning).

The context: a metalworking area from the 3rd century AD

Method

The published reconstruction drawing of habitation phase II, dated *c.* 250-325 (Fig. 2), was made on the basis of excavated features and finds from this period (Gerrets and De Koning 1999, 81). There were two buildings, probably farmhouses with built-in byres as were common in the terp area, both with wells, built on low terp platforms made of salt-marsh sods. Adjacent to the eastern house platform is a metalworking yard on a platform of its own. The features that belong to the metalworking area include three outdoor fireplaces, two metalworking places (including an open sunken hut), a well and an infant burial.

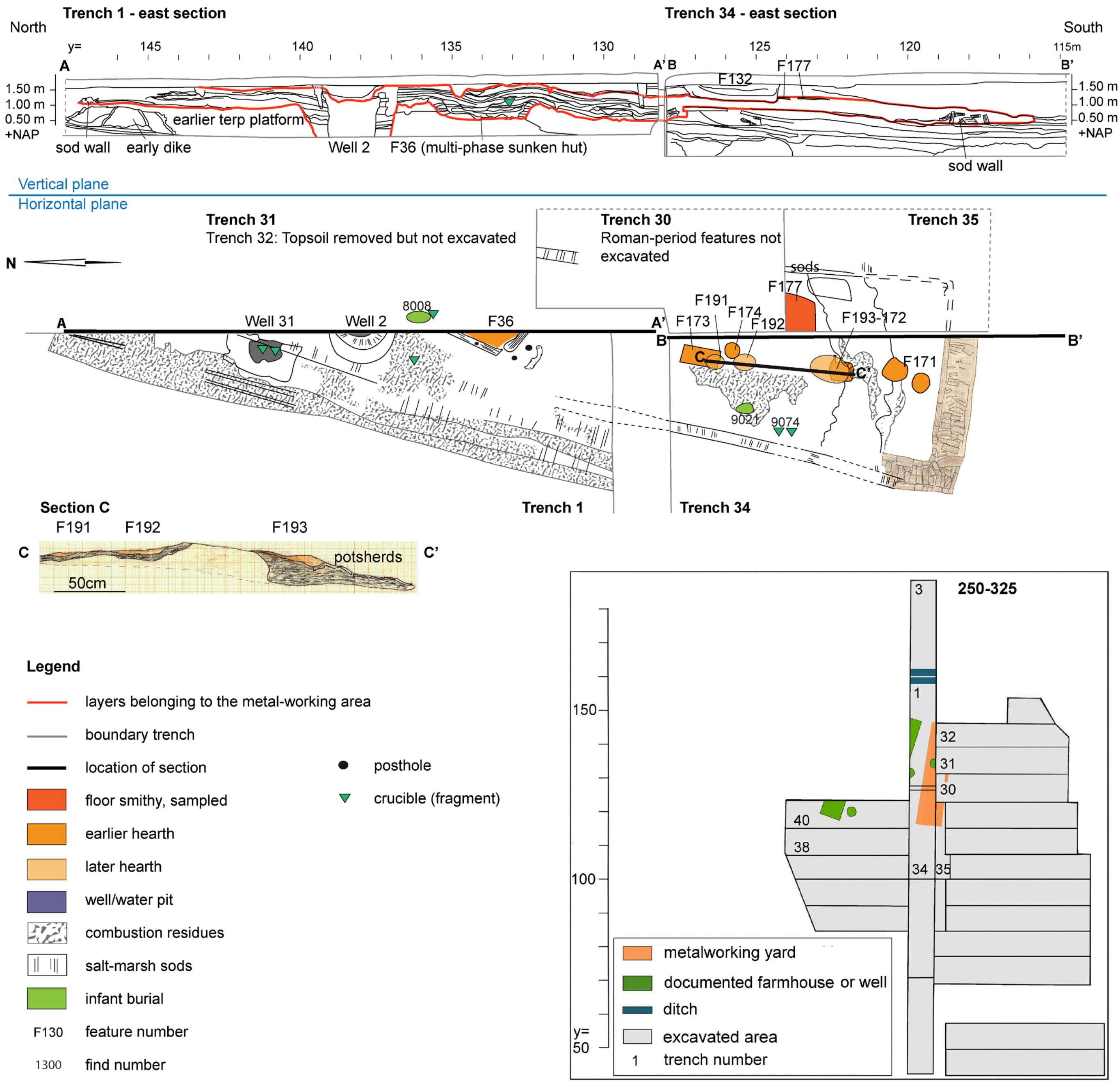


Figure 3: Finds and features from the metalworking workshop from the period 200-325, as documented in horizontal and vertical planes in different trenches. Samples from the smithy floor (dark-orange) were analysed and discussed in this paper. The overview map at the bottom right shows the location of the excavation trenches and the main excavated structures from this period. Drawing: A. Nieuwhof.

For the purpose of this context analysis, field drawings of vertical and horizontal planes in several excavation trenches (trenches 1, 34 and 35) were combined to be able to draw and show the metalworking area with more precision, also including somewhat older features from the first half of the 3rd century (Fig. 3). Since not all Roman-Period features were documented during the excavation and we have hardly any information from the trenches 30, 31 and 32, it is not possible to portray the metalworking yard in full.

Features

The NE-SW metalworking platform measured approximately 30 x 8 m^2 and was at least partly surrounded by a 1.2 m wide and *c.* 0.4 m high wall of carefully placed salt-marsh sods. Its northern part was situated on the remains of a small dike and the sod platform that was built against it from an earlier phase. The platform slightly sloped to the south; whether this was a deliberate effect, or just caused by differences in subsidence of the layers beneath, is not clear. The sod wall probably was made to keep floods from entering the area, just like the

Figure 4: Two hearths from the metalworking workshop. (top) Round hearth with a diameter of c. 60 cm with an orange centre, Feature 174 (see Fig. 3). (bottom) Rectangular hearth paved with four layers of potsherds (Feature 173). Photographs: University of Groningen, Groningen Institute of Archaeology.

house platforms were meant to prevent the houses from being flooded.

The area within the sod wall was gradually filled with layers of ashes and charcoal, probably debris from fireplaces, and with sods that must have been applied from time to time to create new and firm working surfaces.

The surface within the low wall was uneven, with several fireplaces, one or two wells, a sunken hut, and a smithy floor. Seven or eight fireplaces, in trenches 1 and 34, appear to be aligned in the longitudinal direction of the platform, slightly west of its centre. The hearths partly overlapped and were apparently not all in use at the same time. A section drawing shows that some of these outdoor fireplaces were situated on the slopes of a pile of earth of *c.* 0.4 m high (see section C in Fig. 3). Five of the hearths are more or less round; as far as documented they have an orange centre on a thick black layer of charcoal (Fig. 4, top). One or possibly two fireplaces (Features 72 and 173) had a pavement of potsherds. F173

Figure 5: A rectangular feature lined with sods (Feature 36), filled with cinders. Photograph: University of Groningen, Groningen Institute of Archaeology.

is documented best (Fig. 4, bottom); this rectangular fireplace, measuring *c.* 1.3 x 0.7 m^2, consisted of four layers of sherds with a total thickness of 10 cm (Taayke 2020, 53–55 and fig. 3.6).

To the north of these fireplaces was another type of feature, of which only a corner was found in trench 1 (F36; Fig. 5). The section drawing (Fig. 3, section A) shows that this feature was a large pit, completely lined with sods. It was marked as a location for 'bronze working' in the photo record. This feature is the rectangular sunken hut in figure 2. Postholes in trench 1 indicate that it had a roof of some kind.

In the northern part of the metalworking yard were two wells, of different ages. The elder of the two is well 31, a water pit rather than a well with a depth of 1.90 m; its fill included furnace wall fragments, slag and fragments of crucibles. Well 31 was succeeded by well 2, which was dug in from a higher level.

Right to the east of the series of fireplaces in trench 34 was a rectangular, thick orange-brown layer (Fig. 6). It was only found in trench 35, but it is visible as a thin orange-brown layer in the drawing of Section B, on the east side of trench 34 (F177). This feature was intersected by a 5th-century sunken hut (F132), leaving only a part of 1 x 1.3 m^2 intact. This is the feature that was identified as a smithy floor and is discussed in more detail below. The most compact part of the floor was rounded in the middle of one side, forming a depression with a diameter of *c.* 13 cm (Fig. 6, bottom). This also is the location where the floor was thinnest, 12 mm, while it was up to 50 mm thick elsewhere. The depression probably was the location of the anvil, as also indicated by the sheer quantity of hammerscale in the floor deposits immediately surrounding it (see below).

Figure 6: The smithy floor (Feature 177). (top) The first stage of the excavation of the rectangular, orange-brown-and-black floor layer; in the foreground is the east side of trench 34 (Section B in Figure 3). (bottom) The most compact part of the floor, which was collected as a whole. Photographs: University of Groningen, Groningen Institute of Archaeology.

The fireplaces mentioned above are found at a distance of 1m to a maximum of 3 m from this floor.

A feature of a different character is the inhumation burial of an infant in the top layer of the metalworking platform, found with a brooch (find no. 9021; F133). A radiocarbon date (see below) confirmed that it was contemporaneous with the metalworking yard. There was still another infant burial in the same area, find no. 8008, which was associated with slag and a crucible fragment, and allegedly belongs to this same period. Both skeletons were incomplete, probably because of recent ploughing, as they were found directly under the topsoil. Both infants were male, according to DNA research (see Cuijpers *et al.* 1999, 309; Richards *et al.* 1999).

Date

The features of the metalworking yard and its surroundings are dated on the basis of the stratigraphy, datable types of hand-built pottery (Taayke 2020), a dendrodate, two radiocarbon dates, and datable coins and brooches from contexts associated with the metalworking yard or its surroundings. Pottery types make it possible to distinguish earlier from later 3rd-century features, as recognisable new shapes were introduced in the 3rd century. Associations with the older types of pottery make it clear that metalworking already occurred here in the first half of the 3rd century AD.

The older (but not the younger) types of pottery were also found in well 31, which dates it earlier in the 3rd century than well 2. Wood from the construction of well 2 has a dendrochronological felling date of AD 263, which provides a date *post quem* for its construction.

Charcoal from the smithy floor (GrN-22068) was radiocarbon-dated 1780 ± 50 BP, or 201-406 cal yr AD (90.8% probability). The infant burial in the metalworking yard (find no. 9021, F133) was also radiocarbon dated, resulting in a date of 1744 ± 22 BP (GrM-35074), 244-381 cal yr AD (95.4% probability).

Thirteen so-called Germanic brooches (*i.e.* not of Roman provenance) were associated with features from the metalworking yard and surroundings, including the infant burial. These were all dated *c.* AD 175-275, but they were all damaged and at the end of their lifetimes, so they may have landed in these contexts after AD 275 (Erdrich 1999, 181; Supplementary Information). Twelve Roman coins from this area range from AD 98 to 295, the last a cut copper *antoninianus* (find no. 297) dated AD 280-295 (van der Vin 1999; Supplementary Information).

As far as they were not disturbed by ploughing, layers immediately overlying the area of the metalworking workshop date to the 5th century and later (Gerrets and De Koning 1999, 96). These are identifiable by the different material culture, especially pottery and brooches, of the new population that settled here in the 5th century.

It may be concluded that the metalworking yard was probably in use in the entire 3rd century AD, while a slightly longer period of use, into the early 4th century, seems likely.

Finds

Finds associated with metalworking in this area consist of metallurgical waste such as iron slag and cinders (2.4 kg and 6.8 kg, respectively), many scrap pieces of copper and lead, copper and lead sheet fragments, three small copper ingots, two fragments of moulds for casting ingots, furnace wall and bottom fragments, fragments of twelve small crucibles (Fig. 7), and some meltage and casting residue of copper and lead. The finds are summarised in Table 1; the Supplementary information provides a detailed overview, including sizes and weights determined by Tulp (1996) and the contexts of the finds. Since archaeometric analysis of the debris has not yet been done, 'copper' in these tables also includes copper alloy. The copper sheet and scrap fragments were rather small, on average 12-14 x 22 mm^2, the lead fragments even smaller (see Table 1). Coins were sometimes used as raw material, as some cut coins indicate. One of these, found directly west of the most western of the two houses with other scraps, was half a silver *antoninianus* of Valerianus (AD 253-260) depicting a temple with Vulcan, the god of fire and forging, holding hammer and tongs (Fig. 8). It is the only silver object related to the metalworking area.

Objects and materials belonging to iron and copper-alloy working were often found together in the same contexts, for instance in the sampled smithy floor. There is no debris related to other pyrotechnic activities such as bead production.

Most of these finds were spread over the yard and its surroundings, often incorporated in layers of ashes and charcoal particles, including the neighbouring house platform and two parallel ditches to the north of the house and metalworking platforms. This indicates that the metalworking platform and the houses belonged together. Besides the sampled smithy floor, the rectangular sunken hut (F36) stands out; it contained more than 5 kg of cinders, as well as a crucible fragment.

Soil analysis of the smithy floor

The conspicuous orange-brown floor layer was sampled during the excavation (F177; find no. 9903): the thickest and most compact part (Fig. 6, bottom) was collected

Table 1: Metalworking debris by category from the 3rd and early 4th century AD, from the metalworking yard and its immediate surroundings, also including the area surrounding the two houses and two ditches north of the platforms. 'Copper' includes copper-alloys. For full details, see Supplementary Information. Based on the inventory by Tulp (1996).

Category	Finds (n)	Average thickness (mm)	Average dimensions (mm)	Total weight (g)	Average weight (g)	Remarks
Crucible, fragment	12	8 (range 2-12)	21 x 25 (range 9-42 x 11-59)			
Mould, fragment	2	15 (range 11-19)	32 (range 21-28 x 27-37)			
Copper, ingot	3	6 (range 6-11)	12 x 48 (range 10-15 x 20-70)			
Copper sheet, fragment	27	1 (range 0.4-3)	14 x 22 (range 5-54 x 8-69)			
Copper, scrap[1]	46	5 (range 1-14)	12 x 22 (range 3-45 x 5-92)			
Meltage of copper-alloy	2	7 (range 5-9)	14 x 20 (range 7-22 x 12-28)			
Copper, casting residue	1	9	21 x 25			
Silver, scrap	1					cut silver antoninianus
Lead, casting residue	1	3	11 x 12			
Meltage of lead	1	4	6 x 7			
Lead, rod	2	5.5 (range 5-6)	6.5 x 13 (range 6-7 x 11-15)			
Lead, sheet	8	1.5 (range 1-2)	12 x 18 (range 8-19 x 8-34)			
Lead, scrap[1]	28	5 (range 1-9)	11 x 17 (range 4-26 x 8-42)			
Iron, furnace wall	34	13 (range 2-43)	34 x 43 (range 16-70 x 21-88)	624	18 (range 1-234)	
Iron, slag	119	18 (range 1-42)	27 x 36 (range 11-87 x 18-103)	2421	21 (range 1-288)	19 fragments smaller than 2 mm were not measured
Cinders	54	not measured	not measured	6799	126 (range 1-3528)	24 fragments smaller than 2 mm were not measured

[1] Scrap here means: fragments of artefacts.

Figure 7: Fragments of two crucibles (find no. 9074), found in the SW part of the metalworking platform. Photographs: University of Groningen, Groningen Institute of Archaeology.

as a whole and handed over in the form of some large chunks of dried soil to the Laboratory for Conservation and Material Studies of the Groningen Institute of Archaeology (LCM/GIA).

The sampled floor had clear macroscopic characteristics differentiating it from the surrounding soil:

- A preserved layer of 70 cm by 50 cm and a depth of 1 to 5 cm
- An orange-brown colour hinting at iron corrosion
- A layered structure of loam and corrosion
- Mixing with charcoal particles and
- A relatively high weight

X-ray photographs revealed scrap metal in the form of copper-alloy plate, lead and iron, often hacked. The crushed samples of the feature disclosed highly magnetic, spheroid and flaky hammerscale (Fig. 9), indicating that the feature was the remnant of a smithy floor, probably in the vicinity of an anvil. The scrap metal and hammerscale resulted in the relatively high weight; the floor was mostly held together by the corrosion products (Nijboer and Tulp 1997).

Figure 8: Cut-up silver antoninian of Valerian I (AD 253-260) depicting the god Vulcan in a temple, holding hammer and tongs. Find no. 11436; collection and photo: Northern Archaeological Depot, Nuis.

Micromorphological analysis of a thin section of the smithy floor

Materials & methods

For micromorphological study, an undisturbed subsample was removed from the smithy-floor remains still preserved at the LCM. It was strengthened with plaster of Paris to protect it during transport and subsequent treatment. At the Cultural Heritage Agency of the Netherlands in Amersfoort, the subsample was impregnated under vacuum with a clear polyester resin. The impregnated sample was then irradiated with gamma rays to facilitate polymerisation and hardening of the resin. A slice was cut as a cross-section of the impregnated block, mounted on a glass plate and subsequently ground, lapped and polished to a thickness of 25-30 microns. A cover slip was then mounted on the thin section.

This thin section was studied with a polarisation microscope, using plane polarised light (PPL), crossed polarisers (XPL), oblique incident light (OIL) and – in some cases – a combination of XPL and OIL (XPOIL). Terminology follows Stoops (2003) and Nicosia and Stoops (2017).

Results

Micromorphological observations

The lower *c.* 2 to 3.5 cm of the thin section (Fig. 10) consists of a deposit of calcareous silt, with irregular domains of clay. It has a compact structure in which massive strongly accommodating aggregates can be discerned. Considerable amounts of iron (hydr)oxides have precipitated in the groundmass and in some of the few pores. This deposit has a sharp, straight boundary to the overlying deposit.

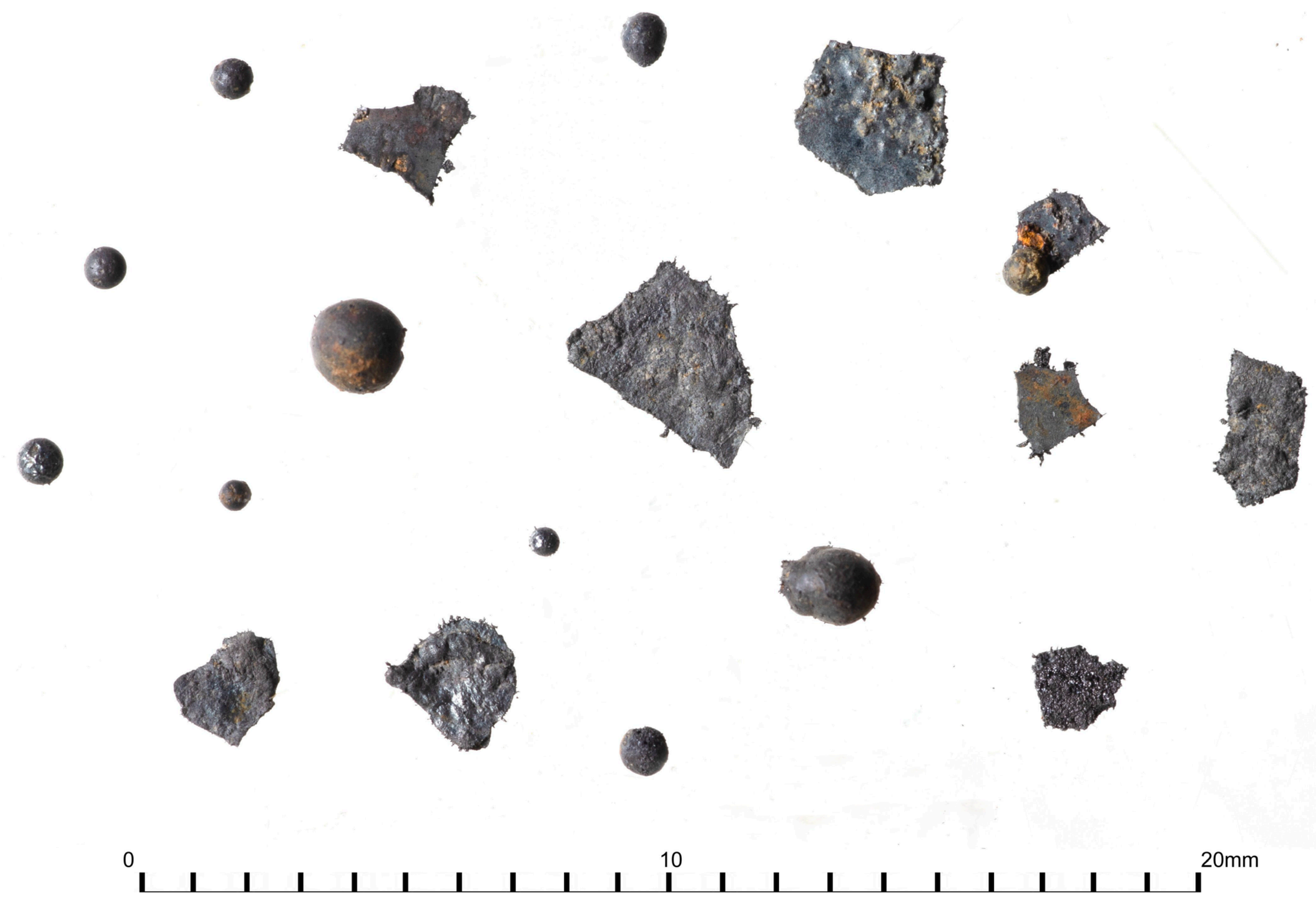


Figure 9: Micrography of hammerscale from the smithy floor at Wijnaldum. Photograph: G. van Oortmerssen, LCM.

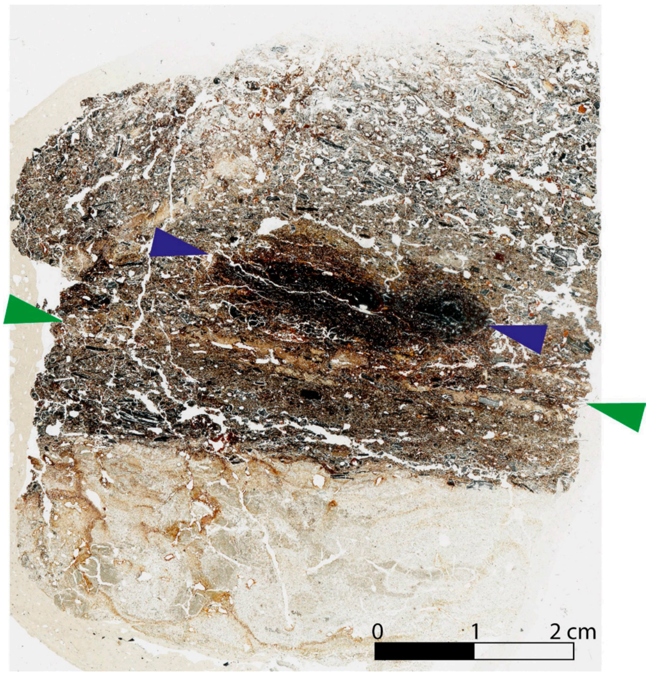


Figure 10: Scan of the thin section. The basal light grey calcareous silt with irregular clayey domains is overlain by a dark strongly layered deposit. The green arrows indicate a thin band with clay or silt aggregates. The blue arrows indicate an iron fragment surrounded by a groundmass that is encrusted with massive iron oxides. Photograph: H. Huisman.

The overlying deposit is strongly layered. It consists primarily of (wood) charcoal and fragments of slag and iron (hammerscale); see next section for a characterisation of this slag and the hammerscale. Small amounts of silt-size quartz grains are scattered throughout the groundmass, and some glauconite grains can be recognised. Small domains of clay are embedded in this groundmass, forming at least two discontinuous thin bands; the most prominent one is indicated with green arrows in Figure 10. The clay in these domains shows birefringent domains that indicate that they have been compressed in the past. Some are rounded aggregates, others have irregular shapes and show evidence of plastic deformation (Figs. 11A, 11B). In addition to the charcoal, slag and hammerscale, a bone and an eggshell fragment were identified.

Orange-yellow iron(hydr)oxides (red in OIL images) are present in large amounts in the groundmass as amorphous or fan-shaped coatings and concretions. Locally yellowish precipitates occur that may be calcium-iron phosphates; in one case it is associated with vivianite. A massive (*c.* 2.5 x 1 cm^2) aggregate is present in the centre of the thin section. At its core is a fragment of metallic iron. The rest of the aggregate consists of massive iron(hydr)oxides with embedded ample charcoal, slag and hammerscale (see Fig. 10).

The slag fragments can be divided into iron slag and silica slag. Silica slag has a transparent non-birefringent groundmass, with some embedded silt grains. Only one example was encountered in the Wijnaldum thin section, but they are well known from many other terp sites (Huisman 2023). The iron slag fragments consist of molten silica (transparent and non-birefringent) with large amounts of embedded minerals that are black opaque PPL and XPL (Fig. 11C). Two types of minerals are apparent: Fine dendritic (identified as wuestite, FeO) and columnar ones (probably magnetite, Fe_3O_4). These minerals light up silver-grey in OIL. In some cases, wuestite has been oxidised to Fe(III)(hydr)oxides at the edges of slag fragments. The iron slags can be divided in groups depending on their morphology:

Spherical vesicular slag
Fragments of iron slag that are more or less perfectly rounded, and contain empty spherical cavities (Fig. 11D).

Complex rounded iron slag fragments
Rounded or incomplete vesicular slag fragments that have a heterogeneous composition of molten silica with variable amounts of wuestite or magnetite, Fe(III)(hydr) oxides and possibly also metallic iron (Figs. 11E, 11F).

Banded slag
Elongated slag fragments in which bands with dendritic wuestite alternate with bands with columnar magnetite. In some cases, rounded complex slag fragments seem to be incorporated in these fragments (Fig. 11G).

Hammerscale
Hammerscale and other iron fragments are characterised by their opaque black colour (PPL, XPL) and their strong silvery reflectance in OIL. The main optical difference with the slag-hosted iron minerals is that the OIL reflection is less strong, and that no mineral shapes can be recognised. Iron fragments may be (partially) transformed into Fe(III)(hydr)oxides. Several shapes can be distinguished:

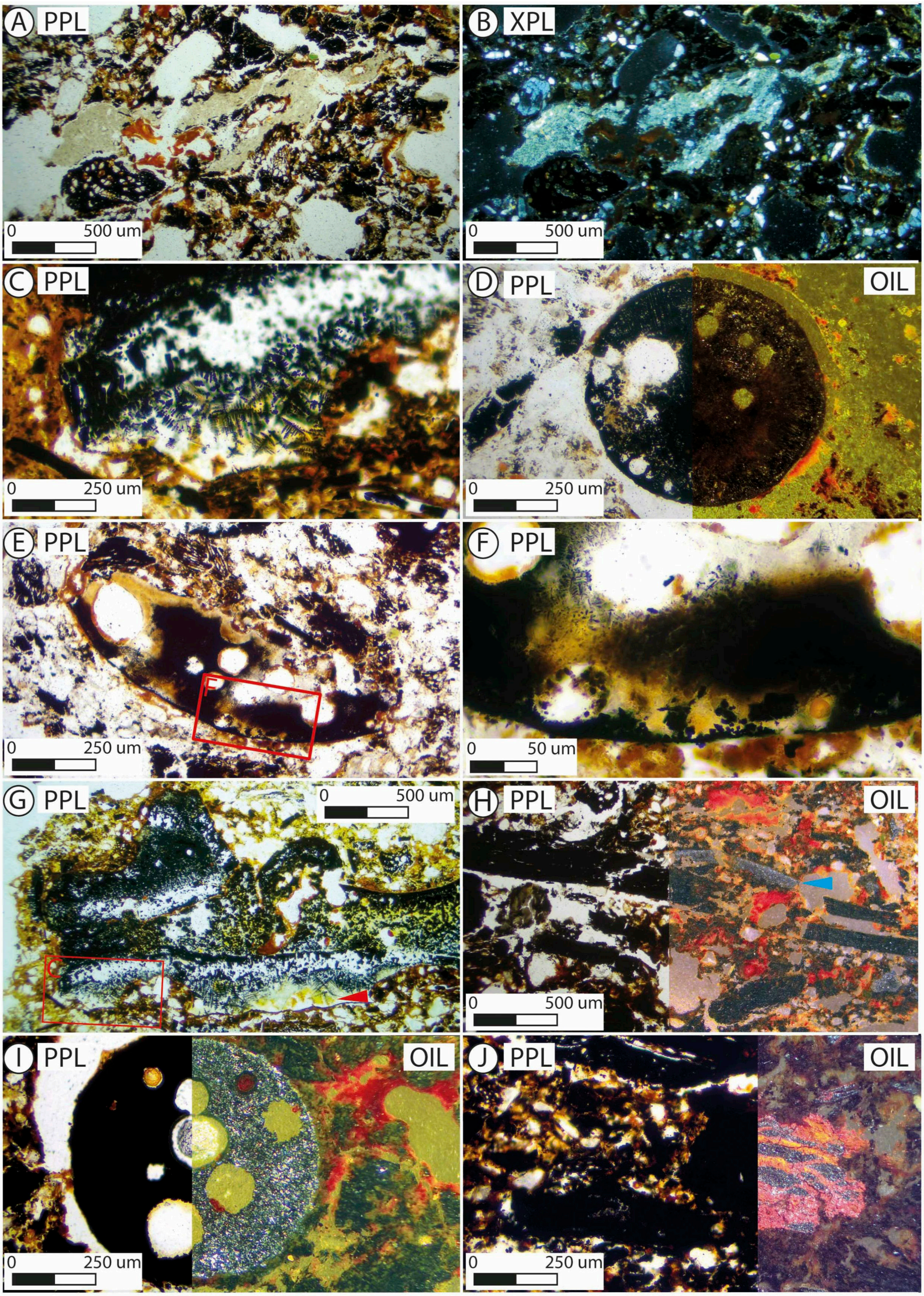
- Platy hammerscale: Angular iron fragments that are elongated or lath-shaped in thin section (Fig. 11H).
- Spherical vesicular hammerscale: Fragments of iron that are more or less perfectly rounded, and contain empty spherical cavities (Fig. 11I).
- Irregular iron fragments: Iron fragments with no clearly defined shape. This material may be hammerscale, but might as well be broken-off iron fragments or iron filing.
- Red hammerscale: Fragments that consists of iron and haematite (very dark red in PPL, very bright red colour in OIL). Some hammerscale fragments have one haematite side, but there are also fragments in which metallic iron and haematite bands alternate (Fig. 11J), or that consist of haematite only.

Discussion

The smithy floor

Micromorphological investigations in the terp region have shown that a floor typically can contain three layers (Huisman 2023): At the base is a deposit that consists of compressed aggregates being formed by trampling during construction of the building, or was applied on purpose as a base layer. Sometimes a layer of (clean) clay or loam is applied on top to form the floor surface, but this is not always the case. The base layer or the floor layer can be capped by a layer that forms during the use of the floor. Such layers are typically finely laminated or banded, and contain large amounts of anthropogenic material. The sequence of aggregate-dominated silt or loam layer, followed by a final, laminated or layered deposit with ample anthropogenic refuse that we see in the Wijnaldum thin section is therefore a typical sequence of a floor deposit. The lower unit was probably made on purpose during construction, whereas the banded upper section was formed by the accumulation of waste during the use of the smithy.

(Next page) Figure 11: Micrographs of the dark floor deposit. A, B: Deformed elongated clay aggregate embedded in the groundmass. The strongly oriented birefringence indicates that this aggregate has been compressed, causing parallel orientation of the clay minerals. C: Slag fragment, consisting of a glassy groundmass with embedded opaque black minerals, probably wuestite (dendritic; FeO) and magnetite (Fe_3O_4; columnar). D: Spherical slag fragment. The black opaque minerals are dominated by wuestite. E: Complex slag, consisting of a yellowish glassy groundmass with black opaque iron oxide minerals. F: Detail of E (red rectangle), showing columnar magnetite on the outside and dendritic wuestite on the inside of the slag fragment. G: Banded slag. At least three bands can be identified that each contain wuestite as well as magnetite crystals. The red arrow points to a section of the slag fragment where some of the wuestite minerals have oxidised to Fe(III)minerals. The red rectangle indicates the area depicted in C. H: Fragment of platy hammerscale (blue arrow) between elongated fragments of charcoal. I: Spherical hammerscale fragment. J: Fragment of hammerscale in which red (haematite) domains alternate with metallic iron or magnetite. PPL = plain polarised light, XPL = Crossed polarisers, OIL = Oblique Incident Light. Photographs: H. Huisman.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The scattered silt grains probably entered the area by wind deposition or – more likely – under the feet of people. The thin clay band may have been applied on purpose, or was walked into the building during a wet spell. There is ethnographic documentation of regular application of fine materials like clay, dung or ash to floors as part of regular cleaning and maintenance (Lisá *et al.* 2020; Milek and Roberts 2013); this could have happened here as well. Whatever the origin, it is clear that the clay was subsequently trampled, deformed and buried during the use of the smithy.

The origin of the charcoal and the iron fragments that occur so frequently in the upper deposit is clear: the charcoal fragments are remains of the fuel, while the iron fragments are the debris of the iron objects that were made or treated in the forge. The spherical hammerscale fragments fly off in molten state during hammering of iron objects and solidify while airborne. The elongated hammerscale fragments probably broke off from the objects' surface in non-molten state like scales. The other iron fragments may have broken off from iron objects in other ways, or formed *e.g.* by filing.

Of the slag fragments, the iron slags are clearly related to iron working. At locations where iron was produced and where for instance bloom was forged, one would expect fayalitic slags. As these are easily distinguished from silica-based slags by their bright birefringence colours in XPL, it is most likely that at this location only secondary production occurred, *i.e.* the production of iron objects from bars, ingots or recycled iron objects. The patterning of iron minerals in the slag fragments, with alternations between wuestite and (probably) magnetite may reflect repeated phases with more and less oxygen available. Like the spherical hammerscale, the spherical slag fragments probably formed by molten droplets that were released during welding or hammering, and that solidified while airborne.

No indications of the working of non-ferrous metals were encountered in the thin section. This is remarkable since several pieces of copper, lead and copper alloy were found on and in the floor (Nijboer and Tulp 1999, and above), suggesting that at least copper-alloy working did occur in the smithy. One reason could be that non-ferrous metalworking produces much less refuse than iron working. The quantities worked are smaller, and part of the process occurs within crucibles and moulds. Still, one would expect fine metallic particles from *e.g.* filing to end up on the floor. Non-ferrous metalworking certainly took place in other parts of the metalworking yard, for instance some 10 m from the smithy floor in the sunken hut, F36, where several kilograms of non-ferrous cinders and a crucible were found. This may indicate that separate areas were assigned to iron and copper alloy working within the metalworking yard.

The silica-slag fragment probably has no relation with the iron working. Such slag fragments occur frequently in terp mounds. They formed by the melting of plant-derived silica-phytoliths, probably during the burning of dried dung as fuel (Huisman 2015). It is unlikely that it is linked the use of *e.g.* quartz sand as additive or stripper. Pure quartz does not melt at temperatures below 1460 °C. Mixed with flux and used in forging, it would melt at lower temperatures, but then produce the wuestite- or magnetite-bearing slags seen in other parts of the sample. Phytoliths melt at much lower temperatures (starting at 600 °C), and can produce the relatively pure silica slag seen here. Like the eggshell and the bone fragment, it is best interpreted as anthropogenic waste material that ended up in this forge floor deposit by accident.

Raw Materials and Processed Metals

In the past decades, traces of metalworking from many settlements in the wider Wadden Sea region (Holocene and Pleistocene landscapes) have been documented and described (*cf.* De Rijk 2007; 2008; 2015; Hüser 2013). The provenance of the metals used and worked in this area is not self-evident as the coastal area along the Wadden Sea is devoid of ores of iron, copper, lead, and silver. These raw materials had to be imported, copper, lead and silver mostly in the form of scrap metal for recycling. There must have been an active, regional trade in scrap metal during the 1st to 3rd centuries AD.

A striking 3rd-century scrap-metal hoard was found in Hallum in the eastern part of Friesland (Daleman *et al.* 2011; Caspers 2010). It consists of 3.9 kg of scrap metal, including 1518 fragments of mostly copper and copper-alloy objects. The chemical composition strongly suggests a Roman origin of this material, and so does the presence of recognisable fragments of Roman wine sieves (Caspers 2010, 121). Also at Wijnaldum, many pieces of hacked copper and lead, sometimes of recognisable Roman objects, can be interpreted as scrap, suitable for recycling (*cf.* Erdrich 1999, 174). Whether silver was worked at Wijnaldum is not clear, as we have only one hacked silver coin that, as scrap, may point to silver working.

Iron ore is not found in the Holocene clay district along the coast, but it can be found inland in Pleistocene areas. In the Netherlands, bar or primary iron was produced from local ores in communities north of the

Roman limes, on a large scale especially in the province Overijssel near Raalte (Joosten 2004; De Rijk 2008, note 20). However, not all the primary iron used in the northern Netherlands came from Raalte (De Rijk 2008, 411–412). The iron used in Wijnaldum probably came from Pleistocene areas to the south of the terp region (Nikulka 2000; Hüser 2013, 88).

Regional Significance

We have only a few indications of the kinds of objects that were produced at Wijnaldum. Copper ingots, fragments of copper and lead sheet and scrap suggest local production of copper-alloy objects. The sizes of the crucible fragments imply the manufacture of small items such as needles, or the contemporaneous Germanic brooches, several of which were also found near the smithy (Erdrich 1999, fig. 4, Period II).

Did the metalworking activities cater just for the local community or were various metals and materials worked to provide for a regional demand? Schuster and De Rijk (2001) asked similar questions for the metalworking activities at Feddersen Wierde, a large terp settlement during the Roman Period on the coast of Lower Saxony. The metallurgical waste recovered at this site is far more substantial than at Wijnaldum. Nonetheless, the authors conclude that there was a poly-technical workshop at the site with a limited amount of specialisation. Several materials, such as iron and copper alloys, were worked at the smithy, and metalworking was probably combined with agricultural labour (Schuster and De Rijk 2001).

This may also be the case at Wijnaldum. Nonetheless, some smithies in this coastal region may have obtained a more central function, producing a wider range of commodities. It is striking that both households from this period in Wijnaldum may have been engaged in metalworking, possibly in the same metalworking yard. Moreover, there may have been some form of specialisation in the kinds of metal that were worked, as is suggested by the separate spaces where hammerscale and copper-alloy debris were found. We do as yet not have the information to decide whether metalworking was a strictly household activity and part of a subsistence strategy that mainly revolved around agriculture, or a household industry of perhaps supralocal significance in which both households participated.

The Metalworking Yard

A metalworking layout consists of four types of spaces: the actual working area, consisting of a fireplace, an anvil, a water basin; a general storage area; a domestic area, and a refuse area (*cf.* Light 1984). The remains of the actual working area are clearly present in the metalworking yard of Wijnaldum. A general storage area is not identified. Scrap metal is found dispersed over the yard and also found in the vicinity of the two houses of this period (see above). It may have been stored in the houses. The domestic area is mainly represented by the house on the adjacent platform but was not strictly separated from the metalworking area, as is shown by the presence of the infant burials. Metalworking may have been a family affair. Refuse not only appears to be dispersed over the yard, but seems to be concentrated along the edges of the platform, which therefore may be identified as the primary refuse area. Unfortunately, the platform has not been fully excavated. It is likely that storage, dumping waste and production also took place in the unexcavated part of the platform.

Although the metalworking finds of Wijnaldum have been excavated already thirty years ago, they are still largely unexplored. There is still much to be gained by studying the morphology of the metallurgical waste, and the chemical composition of slag, scrap metal, crucibles and finished artefacts. Future research of this type has the potential to provide new insights into aspects of metalworking such as the provenance of the raw materials and the kinds of objects that were produced.

Conclusions

The present research into the 3rd-century metalworking remains at Wijnaldum has revealed several aspects of metalworking in this settlement. The metalworking yard was dated between AD 250 and 325, but metalworking certainly started earlier here.

The yard was located on a specially constructed platform and associated with adjacent farmhouses. On this platform, several fireplaces, two wells, a sunken hut and a compact smithy floor were identified. Metalworking debris, including layers of ashes and charcoal, slag and cinders, hammerscale, copper-alloy ingots, copper and lead sheet fragments and scrap, mould fragments and crucible fragments, indicate both iron working and production or working of copper alloy and possibly lead objects. Whether silver was processed is unknown, as the evidence consists of only one half coin. None of the raw materials is of local origin. They came from elsewhere, in the form of scrap, ingots and bars, and possibly coins. The observed charcoal might also have been imported.

Micromorphological analysis of a sample from the smithy floor found clear evidence of iron working (charcoal, iron slag, hammerscale, larger iron fragments), combined with other, more domestic remains (trampled clay, eggshell, silica slag). The mixing of the domestic and artisanal spheres is also evident from the infant burials in the metalworking yard. Crucibles and non-ferrous cinders in a sunken hut suggest that iron and copper-alloy working were separate activities assigned to different spaces.

The metalworking yard as such seems to have been in use for approximately 75 years, several generations. The quantity and distribution of metalworking activities over the yard indicate regular use, while the allocation of a specially constructed quite large area for these activities indicates that metalworking was not insignificant. However, the scale does not seem large enough to assume these were full-time metallurgical activities, and the apparently polytechnic character of the metalworking yard suggests a low degree of specialisation, even though different types of metal working seem to have been carried out in different locations within the yard. We conclude that metalworking in Wijnaldum-Tjitsma was a side activity next to agriculture, possibly not only aimed at the household's own use, but producing for a slightly wider region such as the Wijnaldum terp row.

Supplementary Information

Supplementary information to this article can be found online at https://doi.org/10.54841/hm.677.

Acknowledgements

The authors like to thank Caroline Tulp for her permission to draw on her unpublished MA thesis, Mario van IJzendoorn (Cultural Heritage Agency of the Netherlands) for impregnating the sample and for producing the thin section, Jelle Schokker of the Northern Archaeological Depot in Nuis for photographing the coin depicting Vulcan, and Gert van Oortmerssen (LCM/GIA) for his support at various stages of this research.

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