ROMAN POTTERY PRODUCTION IN CIVITAS TUNGRORUM, CENTRAL BELGIUM, DURING THE FIRST-THIRD CENTURIES CE*

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Aspects of Roman pottery production at the workshops of Kontich, Tienen, Rumst, Grobbendonk and Clavier-Vervoz in the Civitas Tungrorum of central Belgium are explored. A total of 150 wasters from five sites were studied macroscopically, as well as via a combination of thin-section petrography, geochemistry and scanning electron microscopy, in order to gain insights into ceramic technology and aspects of the organization of production. Particular emphasis was given to the individual technological sequences and shared strategies of raw material selection, paste preparation and firing employed at the five adjacent sites. The integration of petrographic and geochemical data permitted the establishment of compositional reference groups for the Roman kiln sites of Civitas Tungrorum, which can be used to track their products within the surrounding landscape.

KEYWORDS: ROMAN CERAMIC TECHNOLOGY, ORGANIZATION OF POTTERY PRODUCTION, THIN-SECTION PETROGRAPHY, GEOCHEMISTRY, SCANNING ELECTRON MICROSCOPY, BELGIUM

INTRODUCTION

Central Belgium fell under Roman rule in 50 BCE, when Julius Caesar defeated the Eburones and Aduatuci. It was not until Octavian's demographic restructuring of population groups, and his administrative reforms, that the region became fully integrated into the Roman Empire. He allowed Germanic tribes from the east bank of the Rhine River to settle in the region: the Texuandri settled in the northern part, whereas the Tungri were transplanted to the old Eburonean and

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^{*}Received 23 April 2019; accepted 9 October 2019

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Aduatucian homelands. The general boundaries of the Civitas Tungrorum were established by 12 BCE, as well as the road from Boulogne on the North Sea coast to Cologne in the east (Mertens and Brulet 1982). Around the turn of the first century BCE/CE, the town of Tongeren was built (Vanderhoeven 1996): it served as the political, economic and religious centre of the civitas (Fig. 1). Other important settlements were Roman small towns involved in activities such as the processing of agricultural goods and manufacture of pottery (Willis 2007).

Roman pottery production commenced between 40 and 70 CE (Period 1) (Hanut 2010) at the towns of Momalle, Braives and Clavier-Vervoz (Fig. 1), which manufactured Romanized versions of Gallo-Belgic pottery, flagons and amphorae, following the general sequence of shape



Figure 1 Location of Roman small towns in Civitas Tungrorum in present-day Belgium with pottery workshops that are the subject of study. Source: Van Kerckhove et al. (2014), 784, fig. 1. [Colour figure can be viewed at wileyonlinelibrary.com]

and decoration of southern Gaul and the Rhine region (Fig. 2). During Period 2 (70–120 CE), pottery production continued at Clavier-Vervoz and commenced at the towns of Tienen, Kontich, Tillier and Amay (Fig. 1). In addition to forms common in the preceding period, the repertoire also included mortaria (grinding bowls) (Fig. 2). In the third (120–180 CE) and fourth (180– 280 CE) periods, the region developed its own pottery style with Haspengouwse flagons and Tungrian beakers. Pottery production took place at Jupille-sur-Meuse, Tienen, Rumst and Grobbendonk in Period 3 and at Clavier-Vervoz, Liberchies and Tienen in the fourth and final period (Fig. 1).

Studies on the pottery of Civitas Tungrorum have focused on its role in the Roman economy, highlighting regional distribution and trade by means of shape and macroscopic fabric analysis (e.g., Willems 2005). Rare technological studies have been undertaken on the production of specific types of pottery, including fine ware from the workshops at Braives (Hemptinne-Stöcklin in Brulet 1983), Tongeren (Geerts *et al.* 2016), and coarse ware from the kiln site of Kontich (De Clercq and Degryse 2008). Aside from these, little is known about the manufacturing technologies of Roman pottery, their influences and development over time within the region.

In order to examine the development of Roman pottery production in the Civitas Tungrorum region of Belgium, 150 waster sherds from the production sites of Kontich, Tienen, Rumst,



Figure 2 Gallo-Belgic pottery shapes produced at the Roman small town at Kontich, dated to Period 2 (70–120 CE). Scale = 1/3. Source: Reyns et al. (2017), 128, fig. 109.

Grobbendonk and Clavier-Vervoz were analysed in detail in order to reconstruct aspects of production technology, such as the choice of raw materials, paste preparation and firing. Of importance were the individual technological sequences of the various workshops and the existence of shared manufacturing strategies. Attention was also paid to possible changes in raw materials and technology over time at the sites and the meaning of this in terms of market forces and external influences. In order to achieve this, a combination of thin-section petrography, geochemistry and scanning electron microscopy (SEM) was applied to wasters from selected macroscopic categories. This also permitted the establishment of compositional and technological reference groups, which can be used by future compositional studies on the distribution of Roman pottery in the region.

STUDY SITES AND SAMPLES

Civitas Tungrorum was situated west of the Rhine and covered much of present-day central Belgium. The road from Bavay in the south-west to Cologne in the east was a major conduit for transport during the Roman period, as were the Sambre and Maas rivers (Fig. 1). The five studied production centres were selected from culturally and geologically different parts of the study area, including the lowland plain and the central and Condroz regions. The workshops at Kontich, Rumst, Grobbendonk, Tienen and Clavier-Vervoz were excavated during several field-work campaigns between the 1960s and 2000s (De Maeyer 1966; Willems and Lauwerijs 1973; Sevenants 1991; Verbeeck and Lauwers 1993; Martens 2012). They typically comprised of timber-built structures, wells, postholes that supported drying structures for wood or pottery, and circular pits with stored clay or tempering material. Possible tools for shaping and trimming or surface treatment were encountered at the sites.

Determining the exact nature of some of the kiln structures is difficult. However, three of Swan's (1984) categories can be identified. These include single- or twin-flued doublechambered updraft kilns with a tongue-support, circular kilns with lateral piers and rectangular shaped kilns. Single- or twin-flued circular kilns with tongue-support appear to have been very common in the region and were identified at Kontich, Grobbendonk, Tienen and Clavier-Vervoz. The combustion chamber and stokehole were cut in the natural soil leaving a pierced platform on which the pottery was placed. By contrast, only one circular kiln with lateral piers was identified at the workshop of Rumst. Broken tiles were used to construct the piers, which supported the clay platform. Fired clay pieces with impressions of rims and bases suggest that pottery was stacked from rim to rim and from base to base in the kilns. Although no kiln had a preserved roof at the time they were excavated, curved clay fragments with finger marks on one side and impressions of hay or grass on the other indicate that they were used to construct a domed roof above the firing chamber. A rectangular-shaped kiln with a raised oven floor was found at Clavier-Vervoz. At other sites in the Roman Empire, this kiln type was associated with tile manufacture (Peacock 1982, 69). Evidence at Clavier-Vervoz seems to confirm that tiles were also produced there (Borgers 2015). All the studied kilns appear to have been located in the open air and may have been covered by a shelter, or by a moveable wooden hurdle, to prevent gales pulling too much air through the structure during the course of a firing.

There seem to have existed differences in the size and scale of pottery production at the five sites studied, with Tienen and Clavier-Vervoz featuring seven and 15 kilns, respectively, compared with Kontich, Grobbendonk and Rumst, where only one or two kilns were found. The kilns at Tienen and Clavier-Vervoz were grouped in clusters of two or three, which may have enabled the potters to stack pottery in one kiln while the other kiln was cooling, permitting a more

continuous output and, therefore, larger scale output (Murphy and Poblome 2011; Borgers *et al.* 2016).

Potters working at Kontich, Rumst and Grobbendonk produced coarse ware jars and bowls. Other pottery types, such as fine ware plates and beakers, Gallo-Belgic ware, mortaria and flagons were recovered from these sites, but in much smaller quantities. By contrast, potters active at Tienen and Clavier-Vervoz produced mainly fine ware, Gallo-Belgic ware, mortaria, flagons and amphorae.

For the purpose of detailed compositional and technological characterization, 150 pottery waster sherds were selected. Whilst some authors have suggested that pottery wasters are liable to devitrification and may suffer chemical and mineral alteration during burial (e.g., Buxeda *et al.* 2001), the majority of the selected sherds were not vitrified and many seem to have been discarded at source for other reasons. Samples were chosen from kilns of all four periods in order to obtain a representative sample of pottery production from several sites in Civitas Tungrorum over time. The analysed sherds include fine ware, coarse ware, Gallo-Belgic ware, flagons, mortaria and amphorae fragments (Table 1).

In order to identify the possible raw materials used for ceramic manufacture at the five workshops, it was necessary to consider the bedrock and superficial geology of the study region. Grobbendonk, Kontich and Rumst are located in a lowland plain, which is characterized by estuarine sediments of Pleistocene age and marine deposits of Paleogene–Neogene age that were deposited during various sea-level fluctuations. The soils vary from clayey deposits to sands rich in glauconite. Tienen is situated on Pleistocene loess deposits, which overlie the sandy or clayey Paleogene–Neogene substrata. Clavier-Vervoz is located in the Condroz region, an area shaped by the Caledonian and Hercynian Orogeny, and characterized geologically by sandstone ridges and limestone depressions. Clay-rich soils typically formed on these strata and alluvial deposits occur along the Maas River (Wouters and Vandenberghe 1994; Wartel *et al.* 1996; Vandenberghe *et al.* 1998; Bogemans 1999) (Fig. 3).

The sourced clay deposits can be classified into three types, depending on the major clay minerals they contain. The first are Eocene age sediments of marine shelf origin that are rich in the clay mineral smectite. They fire to a reddish colour and have high shrink-swell capacity. A second group includes various deposits containing smectite/illite interlayer clay minerals, including Holocene alluvium, Pleistocene loess and estuarine clay, and lagoonal and marine clay deposits of Oligocene age. Some of these deposits contain glauconite and fire to a reddish or brown colour (Wouters and Vandenberghe 1994; De Weerdt *et al.* 1998; Zimmerle 1998; Bogemans 1999). The third type consists of clay sources of Miocene and Palaeocene age, which contain clay minerals such as kaolinite and halloysite and are relatively high in alumina. They fire to a buff white colour and exhibit low shrinkage (Ottenburgs *et al.* 1983; Rice 1987, 45–50; Knox 1998; Steurbaut *et al.* 2003; Goemaere and Quinif 2010).

Using geological maps of the region (e.g., Ottenburgs *et al.* 1983; DOV 2018; Service géologique de Wallonie 2018), targeted locations were chosen due to their accessibility and close proximity to the sites. Nine different clay deposits were sampled, as well as four loose sandy deposits that may have been used as tempering materials (Fig. 3) (see also Appendix A in the additional supporting information).

ANALYTICAL METHODS

All 150 ceramic sherds were analysed using a combination of thin-section petrography and geochemistry. These two methods of characterization and classification were performed

Table 1 Details of the 150 Roman ceramic samples analysed from the production sites of Grobbendonk, Kontich, Rumst, Tienen and Clavier-Vervoz, including their petrographic and geochemical classification

Production site	Period	Pottery ware	Fabric groups	Chemical groups	Samples	Samples/ period
Vervoz	1	Flagons, amphorae, coarse ware	Fabric 1. Silt-sized quartz in light-firing clay	g. oup 5 4	13	periou
		Flagons, fine ware,	Fabric 9. Sand-sized quartz in grey clay	5	9	
G 1 1	,	Gallo-Belgic ware	Fabric 11. Fine micrite		2	2.4
Subtotal	1					24
Vervoz	2	Gallo-Belgic ware, flagons	Fabric 1. Silt-sized quartz in light-firing clay	4	11	
		Gallo-Belgic ware, fine ware, coarse ware	Fabric 3. Sand-sized quartz, glauconite and clay pellets in light-firing clay		8	
Tienen	2	Gallo-Belgic ware, coarse ware	Fabric 4. Sand-sized quartz and clay pellets in light-firing	3	3	
		Flagons, mortaria, amphora	Fabric 7. Silt-sized quartz and		9	
Kontich	2	Coarse ware, Gallo-	Fabric 6. Sand-sized quartz in micaceous red-firing clay	2	13	
Subtotal	2	Deigie ware	meases rea ming endy			44
Tienen	3	Flagons, coarse ware	Fabric 3. Sand-sized quartz, glauconite and clay pellets in	3	6	
Rumst	3	Coarse ware, Gallo- Belgic ware, flagons,	Fabric 2. Fine micaceous red- firing clay	1	24	
Grobbendonk	3	mortarium Coarse ware, fine	Fabric 8. Sand-sized quartz	2	10	
		ware Amphora	and red clay pellets Fabric 12. Silt-sized quartz	1	1	
			and red clay pellets			
Subtotal	3					41
		Flagons	Fabric 1. Silt-sized quartz in light-firing clay	4	2	
		Fine ware, coarse ware	Fabric 5. Well-sorted sand- sized quartz in light-firing clay		13	
Vervoz	4	Coarse ware	Fabric 10. Grog in silty, inclusion-rich red-firing clay	2	4	
		Coarse ware	Fabric 13. Sand-sized quartz in light-firing clay	4	1	
		Mortarium	Fabric 14. Silty, inclusion-	2	1	
		Mortaria, fine ware, flagon, coarse ware	Fabric 3. Sand-sized quartz, glauconite and clay pellets in light fring clay		7	
Tienen	4	Fine ware, flagon, coarse ware	Fabric 4. Sand-sized quartz and clay pellets in light-firing clay	3	11	

		Mortarium, flagon	Fabric 7. Silt-sized quartz and clay pellets in light-firing clay	2
Subtotal Total	4			41 150

independently and then compared with one another. The samples were thin sectioned using a modification of the standard geological technique, then grouped in petrographic fabrics under the polarizing light microscope based upon the nature of their inclusions, clay matrix and voids (Quinn 2013, 73–9). Compositional, textural and shape criteria were used to detect the presence of specific practices, such as the addition of temper and clay mixing (Quinn 2013, 156–71).

Geochemical analysis was performed by inductively coupled plasma optical emission spectrometry instrument (ICP-OES) at the Department of Earth and Environmental Sciences, KU Leuven (Brems *et al.* 2012). Each ceramic sample was dried, its surface removed, then crushed into a powder using an agate mortar and pestle and pulverized in a planetary ball mill. The powdered samples (100 mg) were mixed with 500 mg of lithium metaborate and transferred into graphite crucibles. Samples were fused in a muffle furnace at 1000°C for 10 min. The resulting melts were then transferred into polypropylene beakers containing 50 ml of 0.42 M HNO₃. The solutions were stirred magnetically until complete dissolution and homogeneity was achieved then transferred to screw-capped polypropylene bottles. These solutions were further diluted 10 times with 0.42 M HNO₃, and analysed for 10 oxides (Al₂O₃, CaO, Fe₂O₃, K₂O, MgO, MnO, Na₂O₃, P₂O₅, SiO₂ and TiO₂; see Appendix B in the additional supporting information)



Figure 3 Geological map of the Civitas Tungrorum region of Belgium, with an indication of the five pottery production sites and the geological field samples analysed. Source: Ottenburgs et al. (1983), 4, fig. 1. [Colour figure can be viewed at wileyonlinelibrary.com]

with a Varian 720-ES ICP-OES (simultaneous ICP-OES with axially viewed plasma) equipped with a double-pass cyclonic spray chamber in combination with a Sea Spray nebulizer and a high solids torch. The calibration curves were obtained from a procedural blank and six calibration standard reference materials (Silica brick BCS-CRM267, Fire brick BCS-CRM269, Dolomite GBW07114, Psammite PRI-1, Silicate glass NIST SRM 610, Silicate glass NIST SRM 612), prepared in the same manner as the samples to ensure matrix matching. Data precision and accuracy were evaluated by the analysis of replicate and certified reference materials (Stream sediment GBW07311, and Soil standards SO-1 and SO-2). Precision was > 5% and accuracy was < 10% relative error for all elements.

The elemental data obtained by the ICP-OES was normalized by log-transformation to base-10 logarithms in order to account for the differences in the concentrations of the major elements that could have affected the subsequent statistical classification (Baxter and Freestone 2006). The log-transformed data were analysed via principal component analysis (PCA) in order to identify geochemical groups among the analysed archaeological samples (Glascock *et al.* 2004). The oxide P_2O_5 was left out of the data set as it can be affected by post-depositional contamination (Freestone 2001; Orton and Hughes 2013, 173). Both K₂O and MgO were deemed to be important as variation in the absolute content and ratio of these oxides correlate with differences in the clay mineralogy of the raw materials used for Roman pottery production in previously published studies (e.g., Poblome *et al.* 2002; De Clerq and Degryse 2008).

The microstructure of five ceramic samples, one from each production site, including a flagon from both Tienen and Clavier-Vervoz, a plate from Kontich, a bowl from Grobbendonk and a jar from Rumst, was examined with a Hitachi S-3400N SEM at the Institute of Archaeology, University College London, in order to assess their original firing temperature. Small 1 cm samples were refired at maximum temperatures of 800, 900 and 1000°C for a soaking time of 1 h. They were then carbon coated and examined in the SEM in fresh fracture. Their degree of vitrification was assessed, and an equivalent firing temperature assigned to each sample using the methodology pioneered by Maniatis and Tite (1981, 1982).

The geological field samples were dried, crushed, rehydrated and formed into briquettes. They were fired in an electric kiln at 800°C, and prepared as thin sections and also analysed geochemically. The fired clay samples were compared with the Roman ceramic samples from the relevant workshop in order to identify possible matches. Certain raw material samples were also mixed with one in an attempt to replicate the paste of specific sherds.

COMPOSITIONAL CLASSIFICATION

Thin-section petrographic classification suggested the presence of 14 fabrics among the 150 sherds analysed from the five sites (Table 1 and Fig. 4). These are specific to individual workshops and restricted to particular periods and pottery types. As is common with Roman pottery from north-west Europe, many are characterized by sand and silt-sized quartz and silt-sized mica (Fabrics 1–9 and 12–14). They are distinguished from one another by the size of the quartz grains (e.g., Fabric 13, coarse sand; Fabric 12, silt), the presence of other inclusions such as glauconite (Fabrics 2, 3, 6, 8 and 12) and clay pellets (Fabrics 2–4, 7, 8 and 12), and the nature the clay matrix (Fabrics 1, 3–5, 7, 11 and 13, light firing; Fabrics 2, 6, 8, 10, 12 and 14, red-firing; Fabric 11, yellowish-brown firing). Fabrics 8, 10 and 14 contain heterogeneity in the form of alternating silty and red clay-rich streaks.

Fabric 1 dominates the samples analysed from Clavier-Vervoz and comprises flagons, Gallo-Belgic pottery, amphorae and coarse ware, and occurs in Periods 1, 2 and 4 of the site (Fig. 4, a).



Figure 4 Thin-section photomicrographs of the petrographic fabric groups identified within the 150 Roman pottery sherds from Civitas Tungrorum: (a) Fabric 1: silt-sized quartz in light-firing clay; (b) Fabric 3: sand-sized quartz, glauconite and clay pellets in light-firing clay; (c) Fabric 4: sand-sized quartz and clay pellets in light-firing clay; (d) Fabric 8: sand-sized quartz and red clay pellets; (e) Fabric 2: fine micaceous red-firing clay; (f) Fabric 6: sand-sized quartz in micaceous red-firing clay; (g) Fabric 10: grog in silty, inclusion-rich red-firing clay; (h) Fabric 11: fine micrite; (i) Fabric 12: silt-sized quartz and red clay pellets; (j) Fabric 14: silty, inclusions-rich red-firing clay, exhibiting possible clay mixing; (k) parallel alignment of voids to the vessel walls in a vertical thin section of Fabric 4 that is indicative of wheel throwing; and (l) fining of the surface layer of the vessel wall in Fabric 5 that is indicative of burnishing. All images are captured in crossed polars. [Colour figure can be viewed at wileyonlinelibrary.com]

At Tienen, Fabric 3 occurs in Periods 2–4 as coarse ware, Gallo-Belgic pottery, fine ware, mortaria and a single flagon (Fig. 4, b). Fabric 4 is also common at this site, comprising fine ware, flagons, coarse ware and Gallo-Belgic pottery in Periods 2–4 (Fig. 4, c). The main petrographic composition at Grobbendonk is Fabric 8, which occurs as low-fired coarse and fine wares in Period 3 (Fig. 4, d). Fabric 2 dominates the samples analysed from Rumst and comprises high-fired coarse ware, Gallo-Belgic pottery, flagons and a single mortarium and occurs in Period 3 (Fig. 4, d).

e), while the main petrographic composition at Kontich is Fabric 6, which comprises both low-fired Gallo-Belgic pottery and high-fired coarse ware, and occurs in Period 2 (Fig. 4, f).

Only two fabrics stand out from the general sand and silt-rich quartz-dominated trend recorded in the analysed samples. These include Fabric 10, which is distinguished by the presence of 'grog' and was recorded in coarse ware in Period 4 at Clavier-Vervoz (Fig. 4, g), and Fabric 11, which contains micrite and comprises Gallo-Belgic ware in Period 1 at Clavier-Vervoz (Fig. 4, h).

PCA conducted on the log-transformed concentrations of the nine elements revealed that components 1 and 2 account for 79% of the total variance in the data set. By plotting these against one another, it is possible to define five geochemical groups within the pottery sherds from the five production sites (Fig. 5, a). The oxides Fe₂O₃, MgO, K₂O and Na₂O₃ strongly affect principal component 1, and Al₂O₃ and CaO score heavily for principal component 2. A scatterplot of MgO against K₂O (Fig. 5, b) reveals the same geochemical groups. Samples belonging to geochemical Groups 1 and 2 are characterized by high Fe₂O₃ (> 3%), MgO (> 1%) and K₂O (2– 3%) relative to the other three (Table 2). Groups 3 and 4 samples have high Al₂O₃ (> 15%) and low Fe₂O₃, whereas Group 5 has higher CaO (> 2%) compared with the other groups.

A comparison of the petrographic and geochemical classification of the 150 Roman pottery sherds reveals that they correspond well with one another (Fig. 5, c). As with the petrographic classification, the detected geochemical groups equate to specific sites, pottery types and periods (Fig. 5, a). In addition, links are suggested between fabrics from more than one site which might be suggestive of the use of similar raw materials and/or technology. For example, Fabric 2 from Rumst and Fabric 12 from Grobbendonk equate to geochemical Group 1 (Table 1), and Fabric 6 from Kontich and Fabric 8 from Grobbendonk classify as Group 2. All sherds from Tienen belonging to Fabrics 3, 4 and 7, which contain light-coloured clay pellets classify within geochemical Group 3 (Fig. 5, c, and Table 1). A broad split is visible in the pottery from Clavier-Vervoz with sherds of Fabrics 1, 5 and 13 equating more or less to geochemical Group 4, and samples of Fabrics 9 and 11 classifying into geochemical Group 5. The classification of the samples of Fabrics 1, 5 and 13 from Clavier-Vervoz with samples from Tienen in the scatterplot of MgO versus K_2O (Fig. 5, a, c) suggests links in terms of their raw materials.

MANUFACTURING TECHNOLOGY

The petrographic and geochemical analysis of the 150 Roman pottery sherds from Civitas Tungrorum has revealed several lines of evidence that can be used to interpret aspects of their manufacturing technology. This has been used in combination with the results of targeted SEM, comparisons with the geological field samples and macroscopic evidence on the sherds to reconstruct the various steps involved in the production of pottery at the five sites, from raw material choice and procurement to firing. An emphasis has been placed on the manufacturing characteristics specific to particular sites wares and sites, as well as commonalities that reflect broader trends.

Raw materials

In all cases the raw materials used to manufacture Roman pottery at the five sites appear to have been procured locally. This is based on connections and in some cases matches with the geological field samples (Fig. 5, d). Potters working at Clavier-Vervoz seem to have used Andenne clay for the production of pottery made of Fabrics 1, 5 and 13. This unit outcrops in the Condroz



Figure 5 Geochemical classification of multivariate geochemical data obtained by inductively coupled plasma optical emission spectrometry instrument (ICP-OES) of the 150 Roman pottery sherds from Clavier-Vervoz, Tienen, Kontich, Grobbendonk and Rumst, and comparison with geological field samples: (a) principal component analysis (PCA) scatterplot with samples labelled according to site; (b) scatterplot of the concentration of K_2O versus MgO with the sites indicated; (c) PCA scatterplot with the petrographic fabric classification indicated; and (d) PCA scatterplot of the 150 pottery sherds labelled according to the petrographic fabric classification and geological clay samples.

region (Fig. 3) and is characterized mineralogically by sand-sized quartz inclusions, associated feldspar and chert, and geochemically by high Al_2O_3 and low Fe_2O_3 (Fig. 5, d). Andenne clay may have also been used in the production of ceramics classified within Fabrics 10 and 14, but in this case mixed with another more iron-rich clay. Alluvium from the Maas River, which have high Fe_2O_3 , overlie Andenne clay deposits in the Condroz region (Fig. 3), and may have been the other clay source used in these two fabrics at Clavier-Vervoz. This is supported by the experimental mixing of Andenne and Maas River clay, which resembles these two ceramic fabrics (Fig. 5, d) (see also Appendix A, geological sample 8, in the additional supporting information).

 Table 2
 Summary of the main characteristics of the five geochemical groups detected within the 150 Roman ceramic samples analysed by inductively coupled plasma optical emission spectrometry instrument (ICP-OES) from the production sites of Grobbendonk, Kontich, Rumst, Tienen and Clavier-Vervoz

Geochemical	Al_2O_3	CaO	Fe ₂ O ₃	K20	MgO	MnO	Na 20	P_2O_5	SiO ₂	TiO ₂
group	2 5		2 5	2	0		2	2 5	2	2
1 (n=25)	17.06	0.71	6.81	3.14	1.38	0.02	0.38	0.82	68.09	1.02
	(0.75)*	(0.19)	(0.36)	(0.15)	(0.11)	(0.00)	(0.03)	(0.92)	(2.49)	(0.04)
2 (<i>n</i> = 23)	12.58	0.41	5.90	2.11	0.84	0.02	0.33	0.87	69.12	0.75
	(0.73)	(0.09)	(0.85)	(0.10)	(0.13)	(0.01)	(0.02)	(0.92)	(2.86)	(0.05)
3(n=46)	14.01	0.58	3.09	0.74	0.50	0.01	0.11	0.67	75.61	1.06
	(0.98)	(0.22)	(0.64)	(0.25)	(0.13)	(0.00)	(0.04)	(0.78)	(3.15)	(0.09)
4 (n = 40)	16.84	0.66	1.76	0.49	0.22	0.01	0.12	0.99	72.07	2.00
	(3.91)	(0.31)	(0.82)	(0.18)	(0.10)	(0.01)	(0.05)	(0.68)	(5.91)	(0.31)
5 (<i>n</i> = 11)	20.64	2.03	4.68	0.78	1.26	0.04	0.14	1.81	59.25	1.08
	(1.37)	(1.84)	(1.08)	(0.13)	(0.40)	(0.01)	(0.05)	(1.13)	(4.08)	(0.07)

*Standard deviations are given in parentheses.

Lime-rich clay of the Ieper group could have been used to produce the ceramics of Fabrics 9 and 11 (Fig. 5, d), despite the clay samples exhibiting high plasticity and shrinkage, which can be detrimental for pottery manufacture (see Appendix A, geological samples 14 and 15).

At Tienen, pottery of Fabrics 3, 4 and 7 appear to have been manufactured with clay from the Landen group. This is characterized mineralogically by sand-sized quartz and glauconite inclusions, and geochemically by high Al_2O_3 and low Fe_2O_3 (Fig. 5, d). It occurs to the south-east of the Roman small town (Fig. 3).

Field samples collected from the Rupel group and Campine clay have high concentrations of Fe_2O_3 , K_2O and MgO due to the presence of glauconite. This gives them a similar composition to the pottery produced at Kontich, Grobbendonk and Rumst (Fig. 5, d). The Rupel group has a widespread distribution in the north-west part of the study area, and Campine clay occurs in the northern-most part (Fig. 3). From a chemical point view, both clay deposits are potential raw material sources for Roman pottery production at the centres of Kontich, Grobbendonk and Rumst. However, when the mineralogical evidence is also taken into account, a more precise provenance might be suggested.

Rupel group clay deposits are characterized by quartz and glauconite. Their mineralogy is similar to the fine, silt-dominated Fabric 2 from Rumst, and Fabric 6 from Kontich. In the north-west area of the lowland plain, the Rupel group clay deposits have been exploited for traditional pottery production during the 20th century (Ottenburgs *et al.* 1983, 12). This use of this weathered Rupelian clay source might account for the slightly higher Al_2O_3 value that has been identified in the pottery from Rumst. The Campine clay also contains sand-sized quartz inclusions and glauconite, but is lighter coloured than that of the Rupel group (see Appendix A, geological samples 27–29, in the additional supporting information). Conspicuous clay pellets have been identified in the briquettes prepared from the Campine clay and are also present in Fabric 8 (Fig. 4, d) from Grobbendonk, which may have been produced from it.

Raw material processing and paste preparation

Using compositional, microstructural and textural evidence in thin section as well as comparisons with the above geological field samples it has been possible to interpret various techniques of raw

material processing and paste preparation applied by the potters of Civitas Tungrorum. These include cleaning, levigation, clay mixing and tempering. The ceramics of Fabric 6 from Kontich are likely to have been produced with relatively non-refined clay source containing poorly sorted inclusions. That this clay source, which could have come from the Rupel group, was not refined may also be indicated by the presence of small quantities of charred plant matter, perhaps from decomposed roots. This interpretation contrasts with that of De Clercq and Degryse (2008, 453), who considered organic matter, present in pottery from Kontich to be the result of tempering. Possible evidence for the refining of clay may be represented by Fabric 12 from Grobbendonk, which is characterized by abundant fine, silt-sized inclusions (Fig. 4, i). The source of this paste may have been the Campine clay, which was sieved or levigated, altering both its texture and its chemical composition (Kilikoglou *et al.* 1988). Conspicuous clay pellets that occur in Fabric 8 (Fig. 4, d) from the same site may signify the grinding of hard dry clay into powder, followed by the incomplete hydration of some of these particles (Quinn 2013, 171).

The intentional blending of two different clay types may be indicated by compositional heterogeneity within the clay matrix of Fabrics 10 (Fig. 4, g) and 14 (Fig. 4, j) from Vervoz, with the two components being the light firing Andenne clay and a red-firing alluvial clay. It is worth noting, however, that these two clay types overlie each other in the field and distinguishing intentional blending by potters from natural mixing or contamination during clay procurement can be difficult (Quinn 2013, 168).

Several petrographic fabrics in the present study display evidence of having been tempered. Sherds of Fabric 4 from Tienen (Fig. 4, c) may have been made with the addition of Cenozoic marine quartz and glauconite-containing sand, which is abundant in the vicinity of the Roman town and has been identified in pits associated with the pottery kilns (Borgers 2014, 120) (see Appendix A, geological sample 18, in the additional supporting information). Rounded quartzrich sand temper may have also been added as temper to Fabrics 8 (Fig. 4, d) and 13 from Grobbendonk and Vervoz, respectively, with possible sources being Cenozoic sands that occur near both sites (see Appendix A, geological samples 30 and 7, respectively). Crushed fired pottery temper or grog was added to the paste of Fabric 10 to produce coarse ware at Vervoz (Fig. 4, g), but is absent in the samples analysed from the other four workshops.

Forming

All vessel types analysed in the present study, including flagons, amphorae, mortaria, jars, bowls, plates and beakers, appear to have been made on a fast wheel. Many exhibit spiral rilling marks on their exterior and interior and cutting marks on the base (Rye 1981, 80). Despite the equant nature of the sand-sized inclusions in most of the coarse fabrics, it is possible to observe parallel alignment of voids to the vessel walls in a vertical thin section (Whitbread 1996; Quinn 2013, 176–7) (Fig. 4, k).

Finishing

Macroscopic examination of fine ware ceramics from the five sites studied reveals a distinct burnished layer on their exterior. This is confirmed in thin section by means of fining of the surface layer of the vessel walls (Fig. 4, 1). Simple decorative techniques occur on the beakers and Gallo-Belgic pottery, consisting of grooves, cordons or groups of oblique or brushed lines occurring in bands (Fig. 2). Numerous fragments of mortaria and flagons from Rumst exhibit traces of a light buff slip or wash.

Firing technology

The equivalent firing temperature (Maniatis and Tite 1981; Tite *et al.* 1982) of the ceramics examined in the present study seems to have varied. Vessels from Kontich have an anisotropic clay matrix in thin section and were not vitrified under the SEM, so cannot have been fired $> 800-850^{\circ}$ C for a sustained period. Pottery from Grobbendonk is also anisotropic in thin section, though one sherd exhibits initial vitrification in the SEM (Fig. 6, a–c). The analysed sherds from ceramics from Tienen, Clavier-Vervoz and Rumst have more glassy isotropic clay matrices under the petrographic microscope, and are therefore likely to have been fired $> 800-850^{\circ}$ C for a sustained period. In SEM, a sherd from Rumst shows vitrification equivalent to a firing temperature of about 900–950°C (Fig. 6, d–f).

Flagons, amphorae, mortaria and fine ware plates and beakers from the five production sites were fired in oxidizing conditions, whereas coarse ware jars and bowls were fired in a reducing atmosphere. Given that the clay deposits used at Rumst, Grobbendonk and Kontich were ironrich, the oxidized ceramics have a red colour in hand specimen. The single amphora from Grobbendonk exhibits a dark grey core and lighter reddish brown margin, which may be indicative of a short firing duration in which insufficient oxygen penetrated the body of the vessel. Ceramics from Tienen and Clavier-Vervoz fired in an oxidizing atmosphere have a light buff colour due to the iron-poor clay deposits used in their production.

Quality control

Potters appear to have discarded wasters for several reasons. At Kontich and Grobbendonk, the rims of several coarse ware bowls and jars exhibit sagged or warped shapes (Rye 1981, 110–14). This evidence, combined with numerous fire cracks, may indicate that the vessels were heated too rapidly in the initial phase of the firing (Rye 1981, 105–6, 112–14; Peña 2007, 33).



Figure 6 Scanning electron micrographs (SEMs) of refired Roman pottery sherds from Grobbendonk and Rumst, illustrating their vitrification microstructure: (a) microstructure of an original sherd from Grobbendonk; (b) fragment from Grobbendonk refired at 800°C with no noticeable change in microstructure; (c) sample from Grobbendonk refired at 900°C, exhibiting initial vitrification; (d) original sherd from Rumst with glass filaments; (e) sample from Rumst refired at 900°C exhibiting initial vitrification; and (f) sample from Rumst refired at 1000°C exhibiting complete vitrification.

At Tienen and Clavier-Vervoz, a substantial number of rims of flagons and amphorae were found among the waster vessels. There is evidence for converging irregularities on the interior of the neck of these types of vessels, which suggests that they were weak points in the production. The presence of a large number of detached handles further indicates that flagons and amphorae cooled too rapidly at the end of the firing (Rye 1981, 110–14; Peña 2007, 52–5).

DISCUSSION

The detailed analysis of pottery from the five workshops in Civitas Tungrorum has provided a window into the technologies of Roman potters in this region of Belgium during the first three centuries CE. In particular, it allows one to reconstruct the *chaîne opératoire* of the varied pottery wares they produced. It has also sheds a new light on the different technological sequences of the five kiln sites, the influences behind these and the evolution of production during the Roman occupation of the region.

A broad geographical split is apparent between the workshops of Grobbendonk, Rumst and Kontich, which are located in the lowland plain in the north of Civitas Tungrorum, and the sites of Tienen and Clavier-Vervoz situated, respectively, in the central and Condroz regions of the province (Fig. 1). These are distinctive in terms of the ceramic products they produced and the raw materials and technologies used during manufacture, their internal organization and external influences. The workshops of Tienen and Clavier-Vervoz mainly produced flagons, amphorae and mortaria in response to the demand from large Roman villa domains during Periods 1 and 2. These forms followed the general sequence of shape and decoration of the Rhine region and southern Gaul (Willems 2005; Hanut 2010). They had a buff or creamy colour from the use of light-firing, low-iron Miocene and Palaeocene clay. The coarse ware bowls and jars produced in this region were fired in oxidizing atmosphere in keeping with the Roman tradition.

In the lowland plain, the Roman influence on pottery production started to be felt in Period 2, although certain pre-existing local traditions persisted, such as local coarse ware bowls and jars fired in reducing atmosphere. The more iron-rich clay sources in the northern part of Civitas Tungrorum gave the ceramics of the three northern workshops a red-firing colour. Flagons and mortaria were not manufactured by the workshops in this area, with the exception of Rumst. Here, potters produced flagons and mortaria, and covered their red body with a white slip to conform to the prevailing Roman style. Pottery production at this site appears to have been short-lived and it may have been set up and/or operated by the Roman army (Borgers 2014). Similar raw materials were used for the production of coarse ware bowls at Kontich and Grobbendonk, suggesting that these sites shared knowledge or were linked in terms of their organization. The present analyses indicate that they may also have fired their pottery to lower maximum temperatures (about 800°C) than the other three workshops (about 900°C).

In Periods 3 and 4, potters in Civitas Tungrorum no longer copied vessel types that were imported from the Rhine or southern Gaul regions. Instead, they developed their own products, which were produced and used widely in the region including the Tungrian beaker and Haspengouwse flagon (Hanut 2010). In the later periods, coarse ware bowls and jars produced at workshops in the lowland plain were fired in an oxidizing atmosphere in keeping with those in the southern kiln sites.

The continuous production of pottery at Tienen and Clavier-Vervoz for two centuries might be attributed to the presence of favourable raw materials in this southern area. In addition, the number of the kilns identified and their grouping in clusters of two or three kilns, as well as their placement on the main roads to and from the small towns, is suggestive of the level of investment made in the craft by the owner (*patronus*) and their anticipation of marketing and distributing their products (Willis 2007; Martens 2012; Borgers 2015).

The compositional comparison between the analysed waster sherds, geological information and field samples indicate that Roman potters in Civitas Tungrorum procured their raw materials within a radius of 10 km, with the possible exception of Rumst where clay was obtained locally (Fig. 3). Given the geological heterogeneity of the region, specifically the distinction between the lowland plain and the central and Condroz regions, it is possible to distinguish chemically and petrographically the ceramics manufactured by the various kiln sites. This has permitted the establishment of several 'reference groups' or 'control groups' (Day and Kilikoglou 2001; Belfiore *et al.* 2007; Travé Allepuz *et al.* 2014), which can hopefully be used to detect their products in consumption contexts within and beyond Civitas Tungrorum. Such an approach holds significant potential when combined with macroscopic data on shape and decoration to investigate patterns of trade, distribution, consumption, markets, competition and the role of pottery in the Roman economy (Willems 2005). The size, scale and direction of pottery distribution within and beyond Civitas Tungrorum will be the topic of the next stage of this research.

ACKNOWLEDGEMENTS

The research presented in the present study forms part of a doctoral study undertaken at Vrije Universiteit Brussel, funded by two Ph.D. Research Mandates from the university (grant numbers PATR11-RECTAAP21 and OZR-1546). The authors thank the Department of Earth and Environmental Sciences, KU Leuven, and Vrije Universiteit Brussel for their additional support; Noël Vandenberghe, KU Leuven, for help and guidance during geological prospection in the region of study; the Royal Belgian Institute of Natural Sciences Geological Survey of Belgium for putting geological data at the authors' disposal; as well as Noémi Müller, Fitch Laboratory of the British School at Athens, for help in the interpretation of the results obtained by scanning electron microscopy (SEM) analysis. Several museum staff kindly provided the ceramic samples analysed: Jean-Luc Schütz, Musée Curtius, Liège; Liesbeth Van Camp, Archaeological Depot, Zellik; Henri Verbeeck, AVRA, Antwerp; Tom Debruyne, Erfgoedsite, Tienen; Marleen Martens, Onroerend Erfgoed; Claire Massart, Royal Museum of Arts and History, Brussels; and Danielle Horemans, Grobbendonk Museum, Grobbendonk. Steve Willis, University of Kent, Canterbury, and Sonja Willems, Inrap, provided much-needed support and advice throughout the project. Finally, the authors thank the two anonymous referees for comments made on an earlier version of this paper. All scientific preparations analysed are held by the corresponding author and can be accessed for comparative purposes with prior arrangement. BB acknowledges financial support of the Austrian Science Fund (FWF Project T-1085G).

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Appendix A

Details of the raw material field samples collected and compared with the Roman ceramics.

Appendix B

Geochemical composition of 150 Roman ceramic samples analysed from the production sites of Grobbendonk, Kontich, Rumst, Tienen and Clavier-Vervoz, as determined by inductively coupled plasma optical emission spectrometry instrument (ICP-OES). Elements are expressed as percentage weight oxides.