RECONSTRUCTING THE PRODUCTION PROCESS OF CLAY TOBACCO PIPES WITH THIN SECTION PETROGRAPHY

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Introduction

Research on clay tobacco pipes has provided a large amount of historical and archaeological information regarding their introduction in Europe during the 16th century and of their quick rise as a commodity in the following centuries. These studies provided typological references, catalogues with stamps and marks from various pipemaker workshops that allow archaeologists to use them as a diagnostic tool that helps determine the chronology and economic connections of archaeological sites (Higgins 2017). Despite its rich research tradition, not many compositional analyses have been performed on clay tobacco pipes. As they are made from so-called pipeclay, a tertiary ball clay rich in kaolin that results in a white fabric colour when fired. It is generally assumed that only very fine and homogenous fabrics have been produced that do not allow for a good distinction between pipe workshops and productions. The ideas of indistinguishable homogenous materials, and little use of archaeometrical techniques in Early Modern and Modern archaeology, has resulted in the lack of compositional studies on clay tobacco pipes.

Contrary to this notion, a few geochemical studies have been carried out with the aim to distinguish workshops based on chemical differences in the various natural clays that were used. The two main studies consist of Mehler's (2010; 2009a; 2009b) research on pipes from Bavaria, Germany and Vince and Peacey's (2006; 2003) research into the clay tobacco pipe industry in England. In their study, Vince and Peacey dismissed thin section petrography as a suitable technique to study clay tobacco pipes because "*the range of inclusion types is so limited and because the technique depends to a great extent on being able to compare side-by-side, looking at roundness, grain size distribution, and the character of the grains (mostly quartz)*" (Vince and Peacey 2006, 21). They concluded that thin section petrography is only suitable to study pipes that are made from coarser coal measure clays and that it is best used to answer simple questions that compare two specific groups of pipes. While it is correct that most fabrics of clay pipes have a limited mineralogical diversity and granulometry, the value of thin section petrography has been judged solely based on its limited contribution in establishing a clay provenance. This overlooks the capacity to distil technological information from ceramic thin sections. This paper aims to demonstrate the potential of ceramic petrography to study the production process of clay tobacco pipes by connecting thin section observations with various phases in the *chaîne opératoire* (production sequence).

Pipemakers and their workshop in the Low Countries

The production of clay tobacco pipes was introduced to the European mainland at the end of the 16th century by English craftsman. Many were soldiers involved in the Eighty Years' War, others were religious outcasts that fled their homeland. At this time, the first pipemakers settled in the Northern Low Countries (currently the Netherlands) and by the first half the 17th century the technology of pipemaking was spread all over Northwest Europe (Duco 1981).

In the Netherlands and the UK, the study of clay tobacco pipes has been well established in the 20th century (Higgins 2017; Mehler 2018) since the Dutch and British pipe industries had developed into a global export business during the 17th and 18th centuries (Duco 1987; Oswald 1975). This resulted in a good documentation of their industries and products, both historically and archaeologically. In contrast, the 'Belgian' pipe production remained a modest industry (Caro 2004; Fraikin 1981) generating little to no interest in this field of study for the historical Southern Low Countries (currently Belgium) (Herremans and De Clercq 2013). Therefore, their pipemakers are quite invisible in the written record. As they often imitated Dutch and French (from the 19th century onwards) clay pipes, their products are also difficult to distinguish from imported wares and their characteristics remain largely unknown.

The Ghent clay tobacco pipe project (Herremans and Van Thienen 2022a) studied the pipes from the historical city of Ghent and its urban periphery as an archaeological and sociocultural phenomenon in the 17th - 19th centuries. During this time, local pipemakers were actively producing pipes in and around Flemish cities. Archaeological, historical and archaeometrical techniques were combined to investigate current assumptions about its production in Ghent and explore new techniques for the study, identification and dating of clay pipes. The development of a thin section petrography method aims to offer new insights in the local production process as a basis to distinguish the Ghent pipes from other productions.

The general production process is known from historical sources and remained almost unchanged between the 16th and 20th centuries due to a high degree of standardisation. The process consisted of selection, processing and preparing of the clay, followed by forcing the clay into a press mould to create the shape of the clay pipe. Before and after firing, several finishing and decorating actions occurred, resulting in the desired clay pipe. The entire process was mainly handmade with little to no use of machinery (Fraikin 1978; Walker 1971). The premise of the current study is that the standardisation of the production process and homogeneity of the material is overestimated, and that compositional and technological differences can be observed through thin section microscopy.

Methodology

The dataset for this project consists of 55 clay tobacco pipes dating to the 17th, 18th and 19th centuries collected from 11 sites within the city of Ghent (Flanders, Belgium). Based on typology, decoration, stamps and marks, the pipes are considered to have been produced in Belgian and Dutch workshops (Herremans and Van Thienen 2022a; Van Thienen and Herremans 2022, 122). Four samples have been taken from production waste excavated at the site of Fratersplein, dated in the second half of the 17th century. The remainder of the dataset derives from used pipe contexts.

The pipes have been sampled by breaking off a fragment of the stem and prepared for thin sectioning. Two to six cross-sections have been placed on one thin section slide, due to the small diameters of most stems (*ca.* 5 – 10 mm on average), to increase the amount of observable fabric. A few thin sections also contain lateral sections or a section from a pipe bowl for comparison (Van Thienen and Herremans 2022, 175-179). The thin sections have been studied by using an Olympus BX41 polarising microscope for the thin section descriptions, groupings and photomicrographs. A digital Dino-Lite AM4113ZT with built-in polariser, in combination with a Dino-Lite Back Light Pad BL-ZW1 with rotatable polariser, was used to perform textural and modal analyses with the imaging software DinoCapture 2.0.

A *chaîne opératoire* of clay tobacco pipes: thin section observations

The strength of thin section petrography lies with its capacity to reconstruct elements of the production process based on indications that are observable in the paste (e.g. temper, small or large inclusions and their distribution, homogeneity or inhomogeneity in the fabric mixing, layered features or banding in the clay, colour and porosity). The following observations have been linked to their historically or archaeologically documented production phases.

Raw material selection

The story of the clay tobacco pipe starts with the selection of raw materials. Ideally, a pipeclay was selected of a certain degree of plasticity, fine granulometry and the capacity to produce a white-firing fabric. In most cases, this resulted in the selection of a ball clay rich in kaolin. Typically, these present themselves as fine clays consisting mainly of quartz with a low amount of iron oxides and muscovite mica (Vince and Peacy 2006, 14). In the current dataset, all white, grey and brown pipes appear to have been produced with a pipeclay (Figure 1a-c).

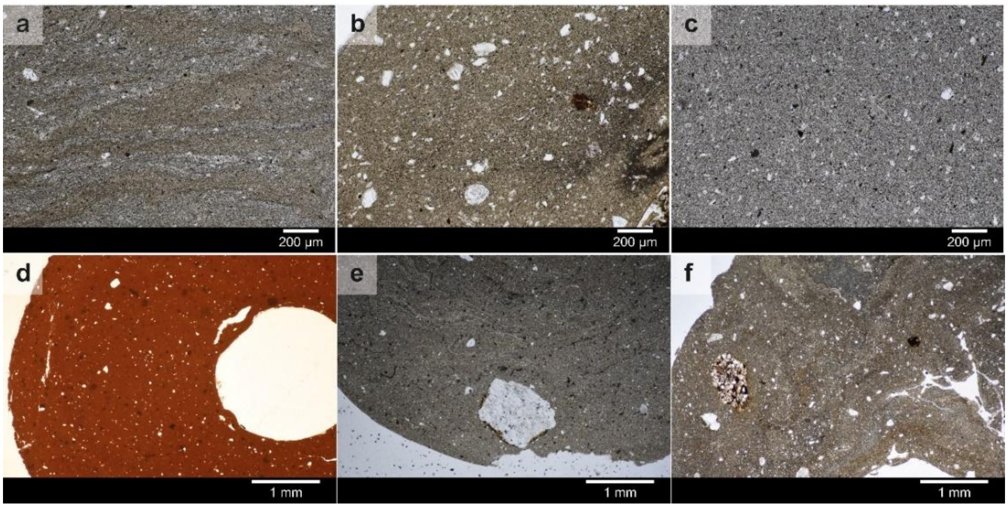

Figure 1. Raw material selection: a-c. fine silt-rich pipeclay fabrics (samples PvM-22, PvM-40, PvM-11); d. red-firing clay with higher iron content (sample, PvM-21); e-f. single coarse sandstone inclusion (samples PvM-44, PvM-05) (all images taken in plane polarised light [PPL]).

Such clay is not available in Flanders and had to be imported from elsewhere (see further). One red-fired pipe has also been sampled which has been made with a fine clay with a higher iron content (Figure 1d).

In addition to clay, a number of thin sections revealed the presence of a sand temper. This sand consisted solely of quartz minerals, with exceptionally one sandstone or large iron oxide inclusion present (Figure 1e-f). The absence of microfossils and other minerals characteristic for many sands in Flanders, suggests that also the sand for tempering was specifically and carefully selected.

Raw material processing

After careful selection, the raw materials still had to be processed thoroughly to maximise the quality of the clay mass. Historical sources (Paape 1794) documented the clay preparation process of imported white firing clays (Figure 2): the clay was put into large pits or crates with water and left to settle. The clay liquid was frequently stirred to prevent the forming of lumps and a sieve was used to remove large particles. The described process can be identified as a levigation process in which the clay is soaked in water to the extent that the coarse particles settled out of the suspension (Quinn 2013, 154-156; Rice 2015, 133).

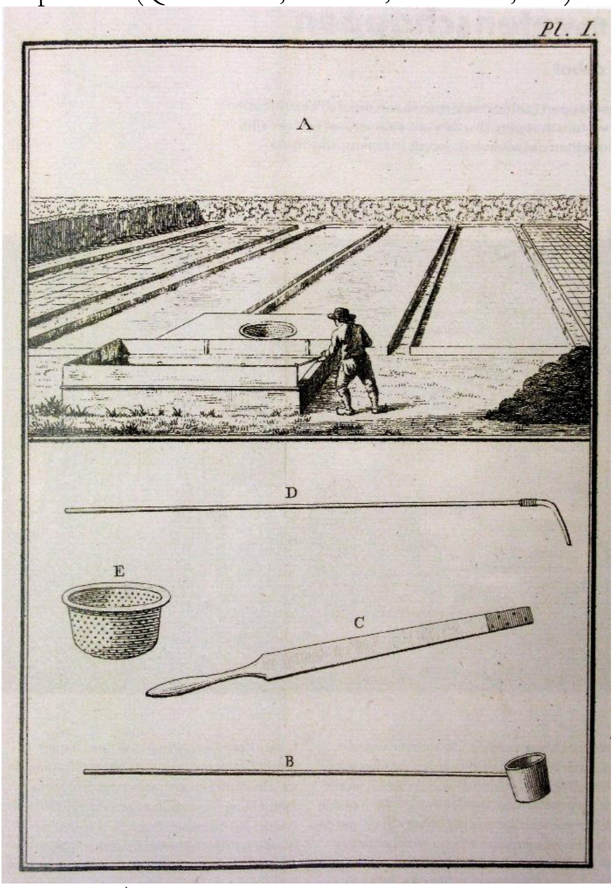

Figure 2. 18th century drawing illustrating the settling of raw clay in large basins and the tools that were used for this process (Gerrit Paape, De Plateelbakker of Delftsch Aardewerkmaaker, 1794).

After a period of time, the clay was left to dry out and cut into blocks that were taken to the pipemaker's workshop.

It is difficult to recognise levigation in thin section or distinguish it from a natural very fine homogenous clay. Nevertheless, the absence of coarse inclusions and organic material might serve as an indication of this type of clay processing (Figure 3a-c). Despite the observation of grains between 0.25 and 1 mm, they have a relative low frequency within the fabric and can often be linked to an added sand temper by means of a bimodal grain size distribution.

Based on the observed grain size restrictions, the sand temper itself could have been carefully processed as well. In this group of thin sections, only two grains larger than 1 mm have been observed, suggesting that the sand might have been sieved with 1 mm mesh sizes. The absence of plant material, shells and fossils supports a thorough cleaning of the sand temper.

In general, the pipe fabrics can be characterised as a homogenous silt-rich fabric with a good sorting of the fine fraction and a low inclusion-to-matrix ratio with inclusion frequencies generally lower than 20%. Overall, it appears as if levigation could have been the preferred processing method for pipeclay, although it is possible that certain workshops or pipemakers chose a different method. For example, a different clay processing method is indicated by one sample with a much coarser fabric consisting of ca. 43% matrix and 55% inclusions on average and a high amount of fine and medium sand-sized inclusions (max. grain ca. 0.47 mm).

In a number of thin sections, clay banding can be observed as fine alternating dark and light-coloured lines, often arranged in a wave-like pattern (Figure 3d-f). Davidson and Davey (1982, 316, plate 18) were the first to observe these microstructures and posited that they are either the result of clay mixing or due to the clays natural heterogeneity. While it cannot be ruled out that they are a relic from the natural clay, these particular type of very fine clay bands are considered here to more likely be the result from the sorting of the clay in its liquified state when soaked in the levigation tanks. Larger clay banding as the result of clay mixing has also been observed (see below).

Preparing the clay mixture

The clay mixture forms the foundation of the fabric that determines many of the final products' properties. According to historical sources, the clay pipes from Gouda were the result of the mixing of a clay from Andenne, located in the Belgian Meuse valley, and a

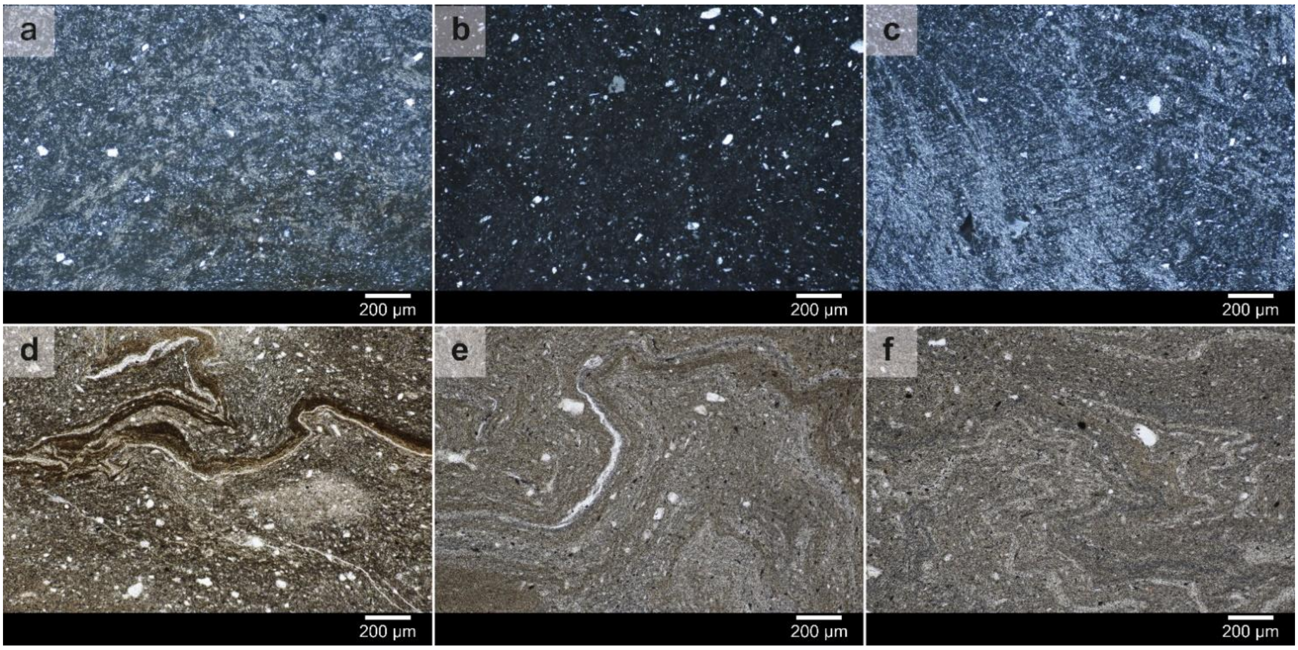

Figure 3. Raw material processing: a-c. fine fabrics characterised by levigation are rich in silt, poor in sand and lack coarse particles or organic materials (samples PvM-22, PvM-02, PvM-48, images taken with crossed polars [XP]); d-f. fine clay banding as the result of soaking during the levigation process (samples PvM-01, PvM-22, PvM-25, images taken in PPL).

clay from Westerwald, Germany (Stam 2019, 128). Many thin sections contain traces that can be associated with the action of clay mixing and the working of the clay. We distinguish here between clay layers (Figure 4a-c), clay zones (Figure 4d-f), and clay pellets (Figure 4g, h, i). Clay layers are clearly different bands or layers that differentiate from each other based on mineralogy or texture and are distributed throughout a large part of the cross-section. Clay zones are relatively large and irregular zones with a different minerology or texture which often have clear boundaries that make it easy to distinguish from the rest of the fabric. Clay pellets are the typical smaller plastic or semi-plastic inclusions that often result from being in a different state of hydration during the clay homogenisation. These clay layers, zones and pellets can have a higher or lower inclusion frequency than the surrounding fabric.

In addition to these types of clay mixing relics, the degree of mixing can provide some indication as to how the homogenisation of the clay was performed, and can be judged based on the overall sorting of the fabric. A poorly sorted fabric might indicate a more manual homogenisation of the clay, such as beating and kneading, where a well sorted fabric might indicate the involvement of grinding the clay mass. The presence or absence of clay mixing relics can aid in deducing which actions the pipemaker performed during the preparation of the clay mixture.

As mentioned above, some thin sections contain an added quartz-rich sand temper (Figure 4j-l). The sand might have been added to compensate the shrinkage of the kaolin clay during drying and firing of the pipe as the volume of quartz can expand up to 3% under temperatures higher than 575°C (Rice 2015, 108). The observed sand temper consists of a relatively low amount of fine and medium sand-sized grains distributed unevenly throughout the fabric. This light sand temper could have sufficed to prevent drying cracks and tearing as kaolin only has a relatively low shrinking capacity (Rice 2015, 50-53). Its uneven distribution might indicate that the sand was spread through the clay mass by hand.

After the clay mixture had the right composition and was sufficiently homogenised, it was cut into cube shaped blocks with iron wire and left to dry until the mixture was 'malleable' and suitable to shape the pipes.

Shaping the pipes

The pipe itself was made from the malleable clay mixture by rolling and piercing the stem, modelling the bowl in a mould, and manipulating the initial form by cutting the pipe to the right size. All these actions leave very little to no traces that can be observed in thin sections, except the rolling of the pipe stems. The rolling movement causes the inclusions and pores to have a circular orientation that can be observed in a cross-section, similar to that of coils (Figure 5).

Firing the pipes

The firing is a critical phase in the production of the pipe. From historical and archaeological studies, it is known that there was a specialised type of kiln used for the firing of pipes, called a muffle kiln. In his clay

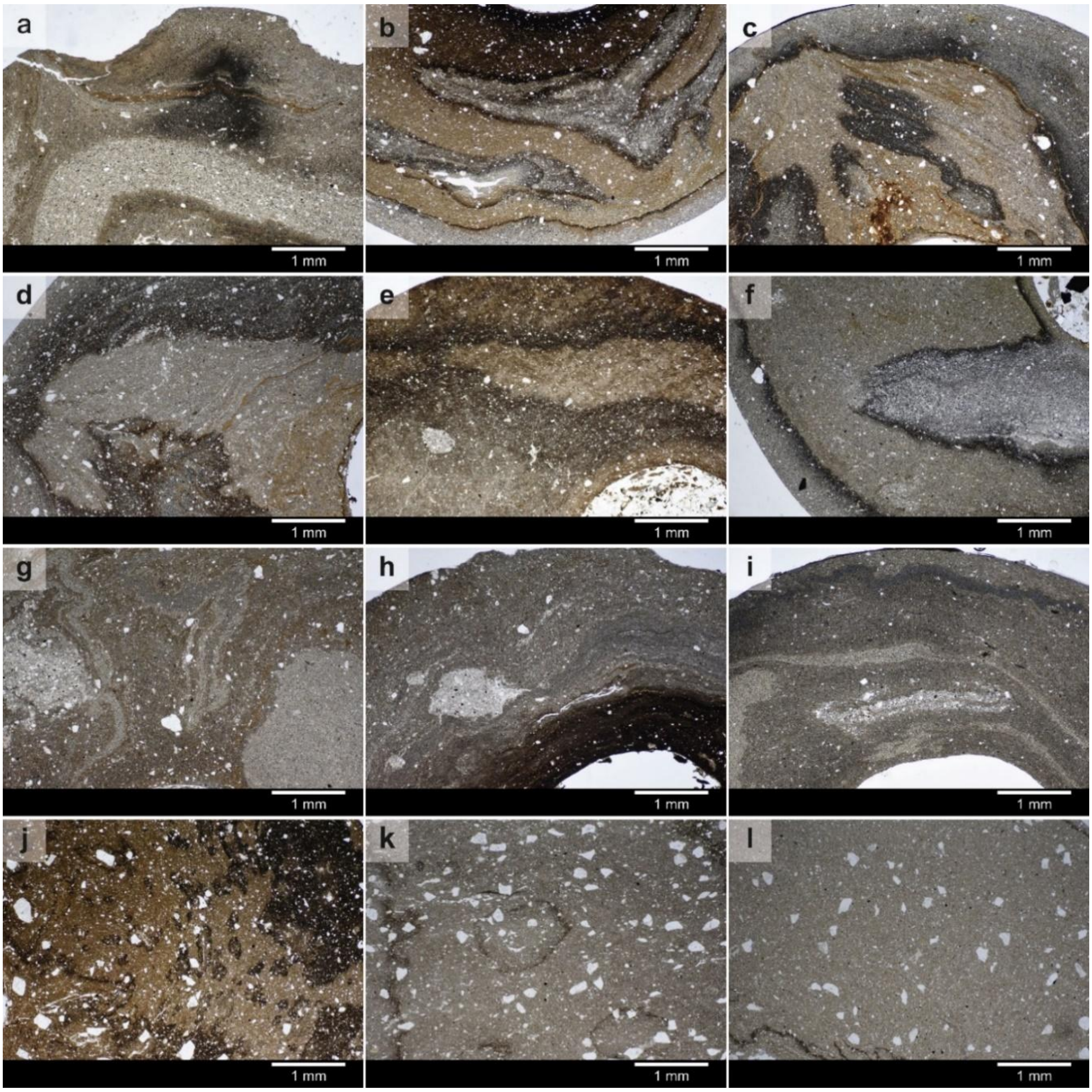

Figure 4. Preparing the clay mixture: a-c. clay layers (samples PvM-34, PvM-32, PvM-53); d-f. clay zones (samples PvM-04, PvM-01, PvM-45); g-i. clay pellets (samples PvM-35, PvM-31, PvM-25) – these features are indicative of the clay mixing and homogenisation process and are often the result of uneven hydration during the working of the clay; j-l. presence of a quartz-rich sand temper (samples PvM-07, PvM-16, PvM-27, all images taken in PPL).

tobacco pipe glossary, Higgins (2017) describes it as follows: "*The muffle was a large ceramic chamber built within a pipe kiln within which the pipes were stacked for firing. The muffle was completely sealed once loaded so as to exclude smoke and gasses from combustion of the fuel, which could discolour the pipes.*" Yet not every workshop had access to this type of kiln. In that case, the pipes would have been collected in a closed pipepot that was placed in a pottery kiln. Historical records indicate that the firing duration could range from 8 to 9 hours and extend up to 24 hours or more, as for instance referenced in the 1849 permit application by Jos Rogiers to build a muffle kiln in Ghent (Herremans and Van Thienen 2022b, 50-51).

To reconstruct the firing temperature and atmosphere in which the pipes were fires, certain changes in mineralogical properties can be observed in ceramic thin sections. The optical activity of the matrix in polarised light can provide a first indication as the matrix tends to become inactive when the sample is exposed to temperatures higher than *ca.* 800 - 850°C, although this range is variable depending on the ceramic composition (Quinn 2013, 188-203; Rice 2015, 99-100). About 80% of the samples within our dataset exhibit a degree of optical activity, indicating that the intended temperature range to fire clay pipes would be situated around 800-850°C. About 20% of the thin sections contain fabrics with optically inactive

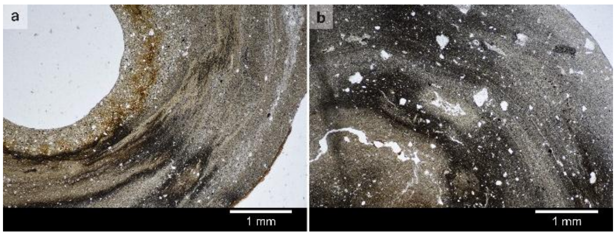

Figure 5. Shaping the pipe: the rolling of the stem results in an overall circular orientation visible in the fabric (samples PvM-37, PvM-24, images taken in PPL).

matrices that also exhibit some degree of vitrification (Figure 6b-c). This indicates that these pipes could have been exposed to temperatures higher than *ca.* 850-900°C or exceeded the optimal firing duration. Only some of these samples are production waste, meaning that slightly overfired pipes were not considered unfit for use.

In addition, the fabric of a handful of pipes shows a brown discoloration, here considered as the result of sintering (Figure 6a, d-f) (Gaimster 1997). Only in two samples did this coincide with an inactive matrix or vitrification, indicating that a high firing temperature is not necessarily responsible for the observed discoloration. The discoloration appears to spread through the fabric starting at the inner and outer surfaces of the pipe stem, suggesting that it could be the result of long firing duration or a late oxidation. The latter might be caused by opening the kiln or pipepot before the pipes were fully cooled down.

The placement of pipes in a sealed pot or chamber suggests that pipes were produced under reduced atmospheric conditions. This assumption is supported by the observation that iron oxides appear almost exclusively as opaque inclusions, colouring black in PPL and XP, indicating that they could be identified as magnetite which is the state of iron oxides under reduced conditions opposed to hematite in oxidised firing conditions (Quinn 2013, 199-200). The identification of these opaques as iron oxides has yet to be verified, but is important to explain the observation of microstructures consisting of dark lines that are suspected to be made up of layers of fine iron oxide grains (Figure 7). These lines are observed to trace the inner and outer circumferences of the pipe stem, delineate certain clay zones, or appear without any apparent pattern or association. At the moment, it remains unclear as to what causes these microstructures to form. Possible explanations include relics from the natural clay, the creation of thin iron oxide layers during levigation due to their heavier mass than other minerals, or the migration of grains as the result of water evaporation during the drying and firing of the paste. As this is not a consistent feature among the clay pipes, it could be a meaningful indicator for certain actions in the production process.

Finishing before and after firing

The actions in the finishing phases before and after firing are rarely visible in thin section as it pertains to modifying the shape of the pipe, burnishing and

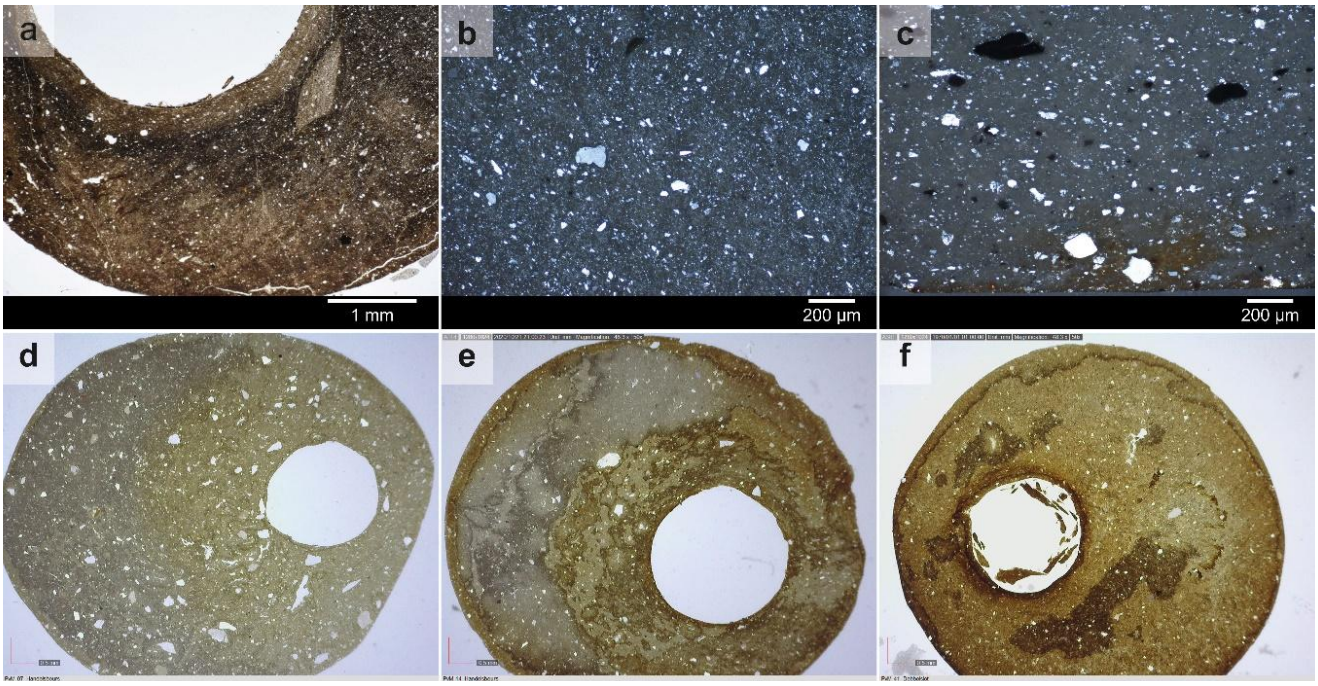

Figure 6. Firing the pipe: a. complete brown discoloration of the fabric from sintering (sample PvM-01, image taken in PPL); b-c. high temperatures can result in the loss of optical activity and vitrification of the matrix (samples PvM-03, PvM-19, image taken with crossed polars); d-f. partial or complete yellow or brown sintering discoloration from sintering can be observed in low magnification or even in hand-held specimens (samples PvM-07, PvM-14, PvM-41, images taken in PPL).

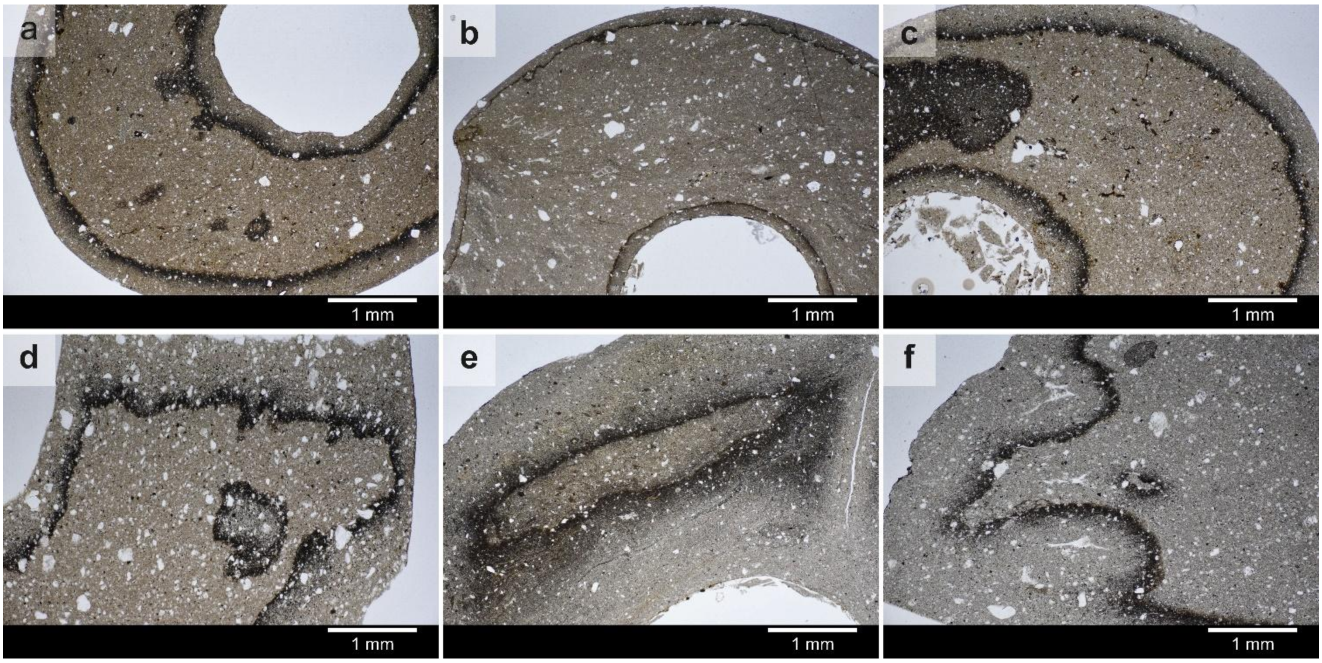

Figure 7. Observed unidentified microstructures of suspected iron oxides in various patterns. Its formation process is unclear and might be related to remnants of the natural clay, iron oxide layers created during the levigation, or grain migration as the result of water evaporation during drying and firing (samples PvM-08, PvM-15, PvM-54, PvM-12, PvM-26, PvM-28, all images taken in PPL).

waxing the outer surface, and adding decorations, stamps and marks (Figure 8 top, image of pipe) (for illustrations, see Herremans and Van Thienen 2022a). Nevertheless, a glaze layer was observed on two samples.

The first glaze (sample PvM-37) is visible on the pipe as a yellow glaze on the mouth-end section of the stem and is observed in thin section as a thin yellow layer in plane polarised light (PPL) and dark in crossed polars (XP) (Figure 8a). Presumably, this is an intentional lead glaze applied before firing to enhance the smoking comfort as some mouthpieces are documented to have been treated with milk, wax or glaze to prevent the clay pipe from sticking to smokers' lips (Higgins 2017, 6.6). It is possible that this glaze was not intentional, but an accidental dripping from lead glazed pottery that was placed in the same kiln as the clay pipes. This would then indicate that the container in which the clay pipes were gathered, was not closed off. The second sample (PvM-55) derives from the production waste and exhibits a clear transparent glaze that covers only part of the outer surface and which went undetected in the hand-held specimen (Figure 8b). This is most likely an accidental salt glazing as the result of ashes flying around in the kiln during firing, as has been documented on production waste and certain stoneware categories (Gaimster 1997).

Smoking the pipe

Finally, the smoking of tobacco in the clay pipe also leaves a discoloration that can be observed in thin section. Davidson and Davey (1982, 316) already noted that nicotine staining can be observed around the bore of the stem which decreases in effect towards the outer surface. This yellow-brown ring results from the oxidation of nicotine during the smoking (Figure 9). It can be distinguished from sintering

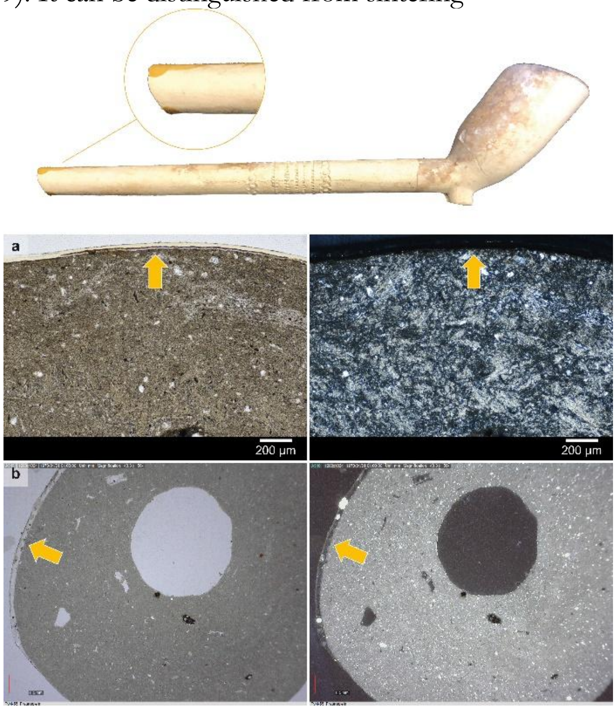

Figure 8. Traces of intentional or accidental glazing: a. yellow lead glaze applied on the pipe mouthpiece could enhance the comfort of smoking (sample PvM-37) (note, glaze is dark in XP); b. clear transparent glaze as the result of accidental salt glazing from flying ashes during the firing (sample PvM-55). Images on the left taken in PPL, images on the right taken with XP.

discoloration, since the ring is mainly limited in size surrounding the bore of the stem and is not present at the edges of the outer surface. It can be observed that the size of the nicotine staining does vary, which indicates that its size might be used to judge the frequency with which the pipe was smoked. However, this does not allow a reconstruction of the lifespan of the clay pipe, as this would have been dependent on the smoking behaviour of the smoker.

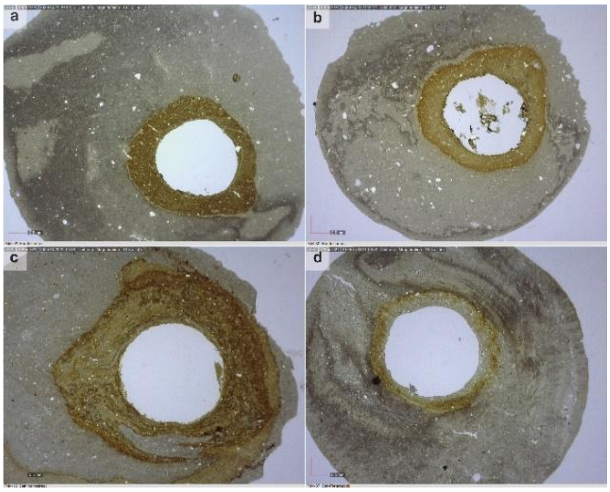

Figure 9. Smoking the pipe: a-d. yellow-brown tobacco staining around the stem bore as the result of nicotine oxidation during smoking (samples PvM-09, PvM-30, PvM-36, PvM-37, images taken in PPL).

The pipemakers recipe

We offer here a model for the general *chaîne opératoire* for clay tobacco pipes deriving from a combination of historical, archaeological and thin section information (Figure 10). It is important to note that this model represents a general recipe for making clay pipes from which pipemakers could deviate by making different choices or by undertaking different actions in any phase of the process to arrive at the desired end-product.

Despite the removal of many diagnostic mineralogical features during the production of clay tobacco pipes, the complexity of the process increases the chance that individual pipemakers or workshops can be distinguished from one another based on their individual processes that are shaped by their skills, knowledge, tools, infrastructure and raw materials. Furthermore, pipemaker workshops produced pipes for a specific audience which resulted in a distinction in quality, related to the cost of the pipe. The intended consumption market did also influence the choices made in the production. Overall, the reconstruction of the *chaîne opératoire* for clay tobacco pipe workshops might aid the archaeological study of socio-economic dynamics in the 16th - 20th centuries.

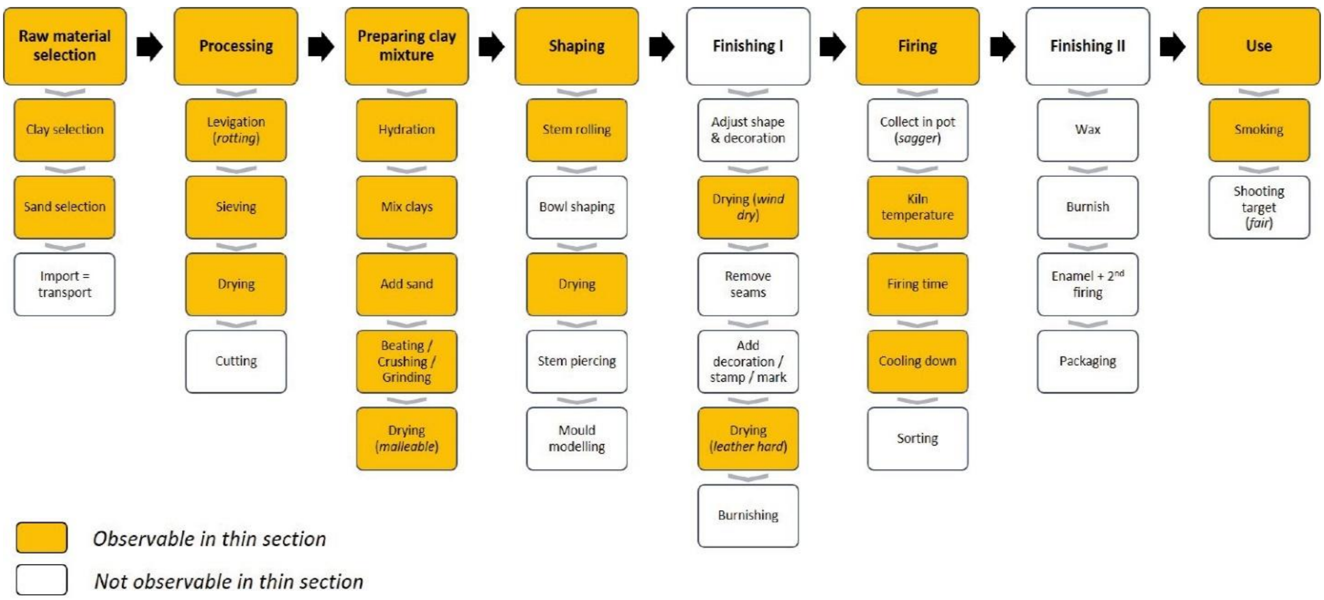

Figure 10. General model of the chaîne opératoire for clay tobacco pipes deriving from a combination of historical, archaeological and thin section information. Marked in yellow are actions that leave traces that can be observed within clay pipe thin sections

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