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# PETROGRAPHIC ANALYSIS OF CERAMICS FROM SWIFTERBANT S3 (PROV. FLEVOLAND / NL) (c. 4300–4000 cal BC)

Petrographic analysis of ceramics allows a detailed understanding of both the clay matrix and the tempering strategies of potters. As such, it allows a technological approach to the ceramic craft, here defined as the complete set of practices used by potters in the production process, from selecting clay sources to tempering, forming and decorating, and firing. Here we present the first detailed petrographic analysis of ceramics from Swifterbant S3, the type site of the Swifterbant culture. We hope that, for future petrographic studies on other Swifterbant culture assemblages, this dataset will prompt discussions on craft traditions, intergenerational knowledge transfer and knowledge exchange between neighbouring communities.
The site of S3 is located along a small river system and is part of a cluster of sites in the micro-region of Swifterbant (prov. Flevoland / NL; **fig. 1**). The river system and site have been dated to c. 4300–4000 cal BC. The site's occupants can be characterised as hunter-gatherer-farmers. The zoological data indicate that both domesticated and wild animals were consumed, with wild and domesticated pigs as the dominant species. Some bones of sheep / goat and wild and domesticated cattle were found as well (Zeiler 1997; Çakırlar et al. 2020). The botanical data also include wild and cultivated species, with the cereals emmer wheat (*Triticum dicoccum*) and naked barley (*Hordeum vulgare*) both being present (van Zeist / Palfenier-Vegter 1981). Local cultivation is attested by several preserved cereal fields (Huisman et al. 2009; Huisman / Raemaekers 2014; Raemaekers / de Roever 2020; Schepers / Woltinge 2020). Excavated in the 1970s, S3 has yielded the largest assemblage of Swifterbant ceramics to date and provides a clear picture of the variability in Swifterbant ceramics in terms of technology, morphology and decoration (de Roever 2004). The Swifterbant ceramic tradition starts around 5000 cal BC, in a fully Mesolithic setting (Raemaekers 2001). The S3 assemblage is therefore to be understood as a developed stage of this ceramic tradition.
The importance of this assemblage has also been underlined by the functional analysis of a selection of vessels, in which macroscopic analysis of their temper was combined with scanning electron microscopy (SEM) and direct temperature-resolved mass spectrometry (DTMS) analysis of preserved food crusts. We concluded that the ceramic variability was related to function, and two subgroups were proposed. One subgroup comprises relatively fine-fabric vessels tempered with plant material and stone grit, and these vessels were used in the production of meals, including emmer wheat. The other subgroup consists of relatively coarse-fabric vessels tempered with only plant material and used for meals without emmer wheat (Raemaekers et al. 2013). We will return to this study, making use of the petrographic analysis to test the previously proposed patterning in the dataset. A further lipid analysis of this assemblage (but on different vessels) is especially clear about the animal fats found in the pots. Evidence for the processing of fish is abundant, while there is no evidence for the processing of pig or cattle (Demirci et al. 2020). The latter two were apparently consumed following cooking or other processing that did not involve ceramic vessels. Plants are more difficult to detect with lipid analysis, and their presence is mostly attested through the SEM analysis referred to above. The plant material includes tissues from emmer wheat, green vegetables, and root or other parenchymatous plant material.

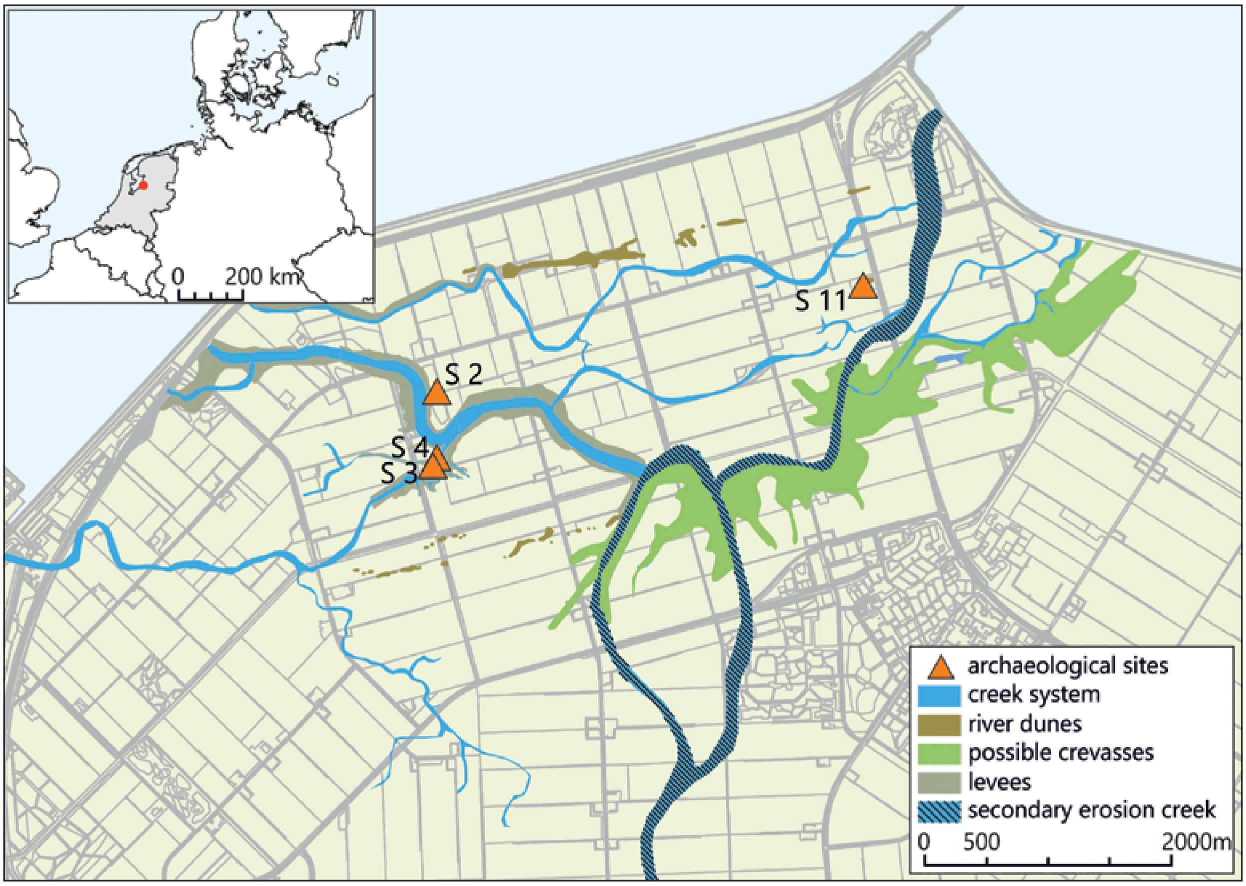


**Fig. 1** The location of Swifterbant S3 and other sites in the Swifterbant region. – (After Devriendt 2014, fig. 2).

The main focus here is on the use of clays and tempering materials as part of the Swifterbant craft. What are the characteristics of the clay? Which tempering materials were used? How varied (or standardised) were the clay sources and tempering strategies? Answering these questions will allow us to define the local ceramic craft. Ever since its discovery, Swifterbant has been argued to be a »western branch« of the Ertebølle culture (e. g. de Roever 1979, 2004; Kampffmeyer 1991), primarily based on the presence of point-based pottery in both areas (de Roever 1979; Raemaekers/de Roever 2010). Over the years, an alternative narrative has developed as well, in which the cultures are considered to be unrelated (Raemaekers 1997; 1999, 185–187; ten Anscher 2012, 131–134; 2015). We will contribute to this debate by introducing petrographic data, which previously played no role in the discussion.

## TEMPER AND ADDED TEMPER – A DISCUSSION

All raw clays gathered in nature contain a certain proportion of non-plastics, in the form of stone (of different origin and size) or organic material (plant, shell or other) (Rye 1981, 12–13; Worrall 1986, 55–56; Velde/Druc 1999, 58–60; Huggett 2005; Quinn 2013, 119–122). The potter may choose to add further non-plastic materials as temper – most often crushed stone, sand, organic material or grog (Rye 1981, 31–36; Velde/Druc 1999, 140–141; Stilborg 2017). This means that the non-plastic component in a ceramic fabric consists of natural temper, possibly augmented with added temper. From a craft-technological view-point, the complete, prepared paste – including clay, natural temper and any added temper – represents what the potter deemed suitable as a raw material for making the pots intended.

Plant materials in a ceramic fabric may have two origins: they may be a natural (i.e. embedded) part of the clay or an added substance (temper). The naturally embedded plant fragments may be of almost any size, type and amount, from a few small roots, which is common in clays from most surface clay deposits, to large amounts of plant fragments, which is common in clays in wetland deposits of different kinds. They may be much more evenly distributed in the clay than the humanly added material, because of a slow, ordered sedimentation process. The best way to ascertain whether plant fragments are natural inclusions is to study the organic contents of the locally available clay deposits. A narrower variation in type and, perhaps, size should be characteristic of the plant fragments added to achieve a plant-tempered fabric. However, if finely fragmented dung is the source – which is possible – the variation in both type and size could be very similar to that of natural inclusions. The same pertains to finely crumbled dry moss (often combined with other types of temper), as has been suggested by C. Constantin and W. Kuijper (2002, 777).

Specifically in the case of plant temper, another potential function comes into play, complicating the functional role of this type of non-plastic. Some fresh plant material can be added to clay and, by allowing it to ferment within the mixture while the clay mix is stored, increase the plasticity of the clay. While fermenting the clay is a well-known practice, good ethnographic examples of a particular fermenting practice still seem to be lacking, although fermenting is a logical possibility. In these cases, another type of non-plastics may have been added as well as temper. We may also imagine a real two-component added temper with plant material as one of the non-plastics. Observed differences in the archaeological material, primarily in the distribution of the different materials in two-component tempering – plant and stone, plant and grog, etc. – seem to imply a two-stage mixing of the materials and thus, apparently, different goals for the non-plastic additions. One possibility is that adding the plant material was not classified by the potter as adding temper proper but, rather, as some form of preconditioning of the clay. Experiments have shown that the two-fold kneading and homogenization that this two-stage mixing entailed result in different distributions in the fabric (Stilborg unpubl. data). Plant and stone temper added at the same time will tend to cluster near each other (Stilborg unpubl. data). When it comes to the amount of temper, a logical expectation would be that the total amount of non-plastics in fabrics made within the same craft tradition (and for the same type and size of pot) should be roughly the same if both types of non-plastics were added (and therefore explicitly controlled). Prehistoric potters in Scandinavia took relatively less notice in general of the amount of naturally occurring non-plastics in the clay when adding temper. In other words, the prescribed amount of temper to add was more important than the total amount of non-plastics in the fabric (Stilborg 2006).

Although the mixing of different types of clay is well known from the ethnographic literature on pottery making (Lindahl / Pikarayi 2010, 144), it is very difficult to find modern-day or historic examples of the mixing of different types of temper. In the fabrics of casting moulds, you may encounter organic inclusions and crushed stone together, the latter providing the fabric with mechanical or thermal strength and the former ensuring permeability for gases to escape. In pots, it is much more difficult to imagine a practical reason for a combination of organic and inorganic temper, but there could be a historical reason, with one temper type being an original choice and the other temper being a later addition, instead of a substitution.

Formulating this list of expectations, unfortunately, does not lead us to any infallible tools for discriminating between different origins for the plant fragments we observe in the fabrics. We still, to a large extent, have to rely on knowledge of the local raw materials and logical reasoning to arrive at a possible interpretation.

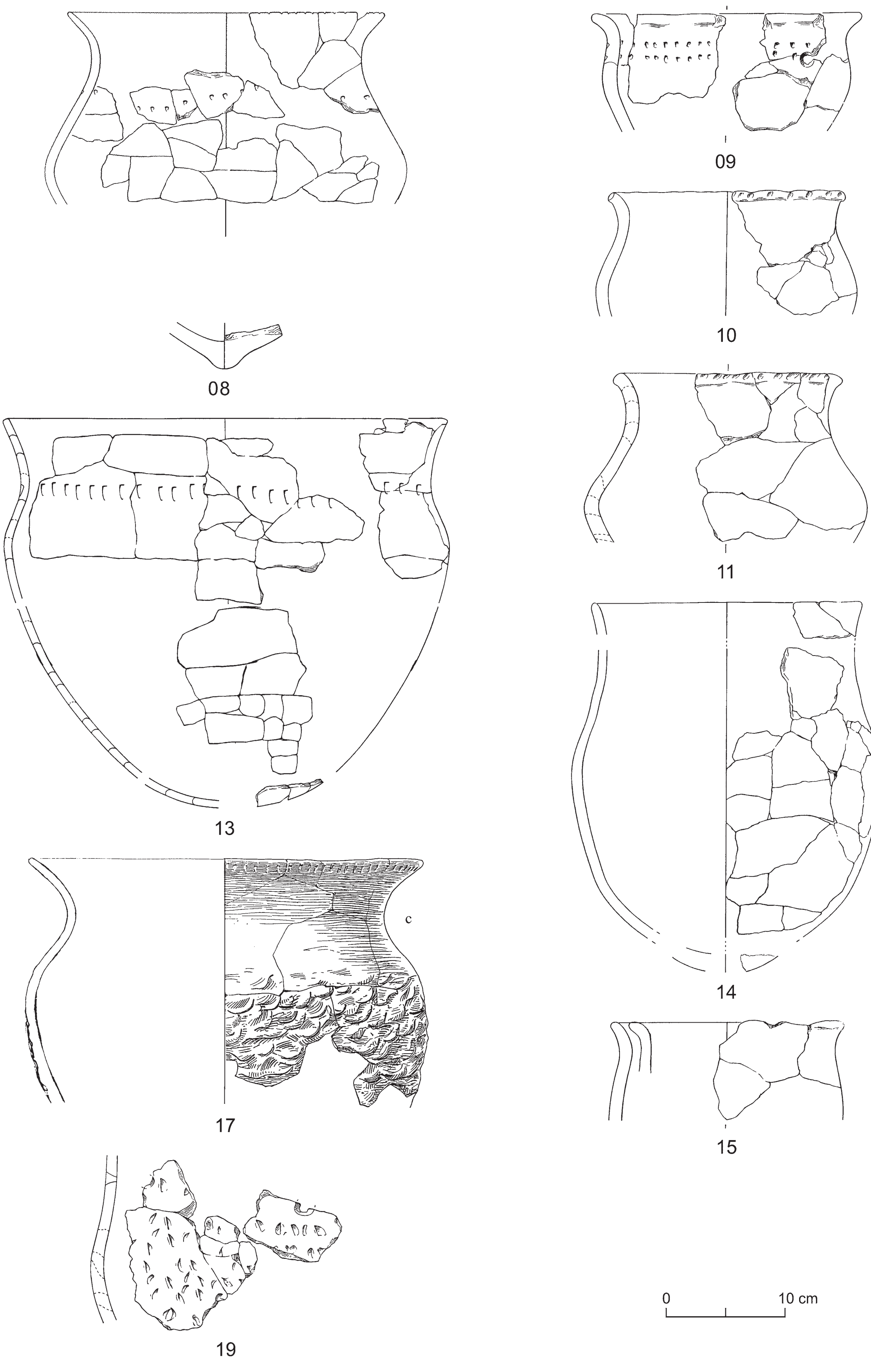


**Fig. 2** Selection of the analysed pots. Numbers refer to the **Appendix**. – (After de Roever 2004). – Scale 1:5.

## METHODS

The ceramics studied have been selected from those that were studied with SEM and DTMS (Raemaekers et al. 2013). This strategy was chosen in order to add high-quality technological information to the functional analysis of the same sherds. A total of 18 sherds from 18 vessels were sampled (**fig. 2**). All petrographic, SEM and DTMS data are found in the **Appendix**.

The thin sections were produced by Servizi per la Geologia (Piombino, Italy), and the second author studied the samples. In the present study, magnifications between X20 and X600 were used. The first step, carried out at X20 magnification, entailed estimation of the coarseness of the clay (amount of naturally occurring silt, fine sand and sand) and the degree of sorting of the clay, as well as estimation of the relative calcium, mica and iron oxide contents. The second step, carried out at X100 magnification, entailed scanning the entire sample in both crossed-polarised and plane-polarised light in order to identify and estimate the frequency of accessory minerals, ore and organic inclusions. Possibly added temper was identified and the temper quality (maximum grain size and volume) was measured. The distribution of added temper and other structures (such as cracks) reveals information about the kneading of the fabric and, sometimes, about the construction technique. In a third step, a scan of the edges of the sample was carried out, at X600 magnification in plane-polarised light, in order to search for diatoms and other types of fossils. When discussing the results, we use the term »temper quality« for a specific relation between temper size and amount.

## RESULTS

### Clay Characteristics

To prevent circularity in the definition of different clay types used for the ceramics in this study, we have excluded the presence of plant material, since the origin of the plant fragments in the fabric is one of the key questions for the study.

#### Clay 1a

This clay is defined by the content of diatoms and spongia needles, a small amount of dark minerals and some mica. The medium-coarse clay is sorted. The frequencies of diatoms and spongia needles vary. Of the 18 samples, 12 belong to this temper quality group (vessels 02, 05, 06, 07, 09, 10, 11, 13, 15, 23, 28 and 32).

#### Clay 1b

This clay is defined by the content of diatoms and spongia needles, a small amount of dark minerals and a high mica content, the latter aspect setting it apart from clay 1a. The two samples are sorted medium-coarse clay (vessel 20) and coarse, unsorted clay (vessel 14). The frequencies of diatoms and spongia needles vary.

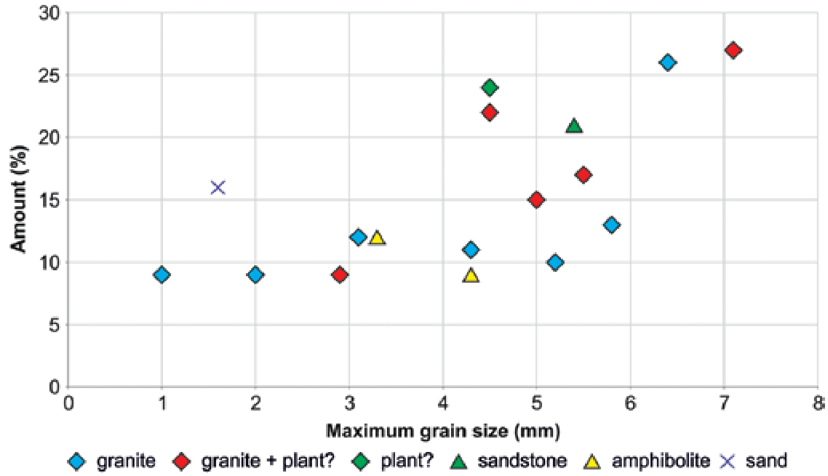


**Fig. 3** The relation between the temper volume (%) and the maximum grain size (mm) for the various temper types. – (Drawing E. Bolhuis, University of Groningen/Groningen Institute of Archaeology).

Clay 2

This clay is coarse and unsorted, and it lacks fossils. Mica and dark mineral grains are scarce (vessels 19 and 26).

Other Clays

Vessel 17 is made from a fine, sorted clay without fossils. Mica and dark mineral grains are scarce, but there is a fair amount of small ore grains. Vessel 03 is made from a fine, unsorted clay (some sand grains) without fossils. The mica content is high, while the dark mineral grains are few. The clay is also characterised by several ferrihydroxide concentrations and clay pellets (some possibly clay schist), which appear macroscopically as lumps in the fabric.

## Temper

Temper consisting of crushed stone is the most frequently occurring temper type represented and is therefore chosen as a starting point for the presentation here. In many cases, the amount of added stone temper is fairly low or the temper grains are large, one-mineral grains, which makes it difficult to achieve a more specific determination to type. Examples of different types of temper are found in figure 3; all sampled sherds are depicted in the Appendix.

Stone with Granitic Composition

Seven vessels (03, 06, 07, 09, 11, 20 and 28) have been tempered with crushed stone in quantities ranging from 12 % (maximum grain size 3.1 mm) to 26 % (maximum grain size 6.4 mm). Six of these vessels have been tempered with stone of granitic composition (quartz, feldspars, mica, some dark minerals), but it is difficult to evaluate the temper of vessel 11. It consists of only a couple of grains of stone, up to 1 mm in size, but they are clearly crushed fragments of a stone containing quartz and feldspar and have thus been included in this temper group. In the case of the temper in vessels 07, 09, 20 and 28, the stone is characterised by the occurrence of microcrystalline quartz (quartzite-like structure). Most of the fabrics in this temper group were made from clay 1a, but vessel 20 is made from clay 1b and vessel 03 from a member of the group of other clays. Granitic stone was transported to the site as source material for a large number of tools (Devriendt 2013, 86), opening up the possibility that discarded tools or tool fragments may have been used as a source material for temper.

All of these fabrics also contain a large amount of plant fragments. The distribution of the predominantly small to medium-sized plant fragments (maximum grain size 4–5 mm) is more even than that of the added stone temper where it was possible to evaluate this (it was not possible to evaluate this in vessel 11) and there is no tendency to cluster near stone temper grains (as was observed in experimental fabrics with two-component temper [Stilborg unpubl. data]). Since plant material is common in the geological samples of clay material in the area (de Roever 2004, 104; Huisman et al. 2008, 37), the plant content has been interpreted as a natural temper, rather than material added as temper or to improve the plasticity. Because of the later inundation of the area, resulting in an organic-rich environment, it is difficult to know with certainty what the available clays looked like at the time of the pottery making at site S3 (Huisman et al. 2008, 37). We know that clay from streams is, in general, often used by potters, and the many streams in the Swifterbant area certainly would have provided access to organic-rich clay.

### Stone with Granitic Composition (plus Plant Material?)

Five vessels (02, 13, 14, 15 and 17) have been tempered with crushed stone and possibly with some plant material too. The quality of the stone temper varies from 9 % with a maximum grain size of 2.9 mm to 27 % with a maximum grain size of 7.1 mm. For vessels 02 and 13, a granitic stone characterised by microcrystalline quartz was used. The granite in vessels 14 and 15 was characterised primarily by the type of quartz-feldspar intergrowth called myrmekite. The stone in vessel 17 seems to be a rather different granite. Vessels 02, 13, 14 and 15 are made from clays 1a and 1b, while vessel 17 is made from a fine clay in the group of other clays.

All of these fabrics contained a large amount of plant fragments. In vessel 02, the plant content mostly consists of thin fibres up to 4 mm in length, often occurring in concentrations. The distribution of the plant fragments shows no apparent spatial correlation with that of the larger stone temper grains, but on the basis of the somewhat uneven distribution of the plant fragments (although this is less uneven than that of the stone temper) and the number of larger fragments, we deem it possible that at least the latter may have been added. The amount is very difficult to estimate, and 20–30 % (volume) is merely an educated guess. The same observations and the same argument hold for the fabrics of vessels 14, 15 and 17. In vessels 14 and 17, the plant inclusions are mostly larger straw fragments up to 3 mm in length, while in vessel 15, they are mainly fine fibres, as is the case in vessel 02, up to a length of 3 mm. The amounts are also more or less the same as in vessel 02. Only in the fabric for vessel 13 do we see a tendency for the plant fragments to cluster around stone temper grains, which is what we would expect to see if the two materials were added at the same time. Here the fibres are up to 2 mm. Thus vessels 02, 14, 15 and 17 seem to have been made with another *chaîne opératoire* than the vessels where the organic component most likely has a natural origin. However, the difference in craft strategy may not be large, as it is easy to imagine a potter deciding to add plant material to a clay that did not naturally contain the desired (normal) amount of organic material.

### Amphibolite

Two fabrics – vessel 05, of clay 1a, and vessel 19, of clay 2 – have been tempered with crushed amphibolite. The qualities are 12 % with a maximum grain size of 3.3 mm and 9 % with a maximum grain size of 4.3 mm, respectively. Amphibolite does not occur in the natural environment surrounding the site, but because there are several amphibolite tool fragments from S3 (Devriendt 2013, tab. 4.16), local ceramic production cannot be excluded as an option on the basis of this temper. In both cases, the fabric also contains plant fragments that have been interpreted as natural temper on the same grounds as the fabrics tempered with granitic stone have been.

### Sandstone

The fabric of vessel 32 was tempered with 21 % crushed sandstone with a maximum grain size of 5.4 mm. The clay was of the 1a type and also contains a fairly large amount of plant fragments. Sandstone may also have been collected locally as tempering material, as S3 has yielded several sandstone items, including anvils, grinding tools and ornaments (Devriendt 2013, 114–118). The mostly small to medium-sized plant fragments (up to 2.5 mm in size) were present in all parts of the sample, but with clear concentrations. However, none of these concentrations were correlated with the distribution of the stone temper, and we therefore deemed the plant content to be a natural temper.

### Sand

The fabric of vessel 10 is made of clay 1a, tempered with 16 % sand with a maximum grain size of 1.6 mm. The homogenisation of the sand temper is good, but poorer than the distribution of the plant fragments (medium-sized to large straw fragments) in the fabric. The latter are thus interpreted as a natural temper. Sand is not found at S3, but the various sand ridges in the region may have provided the temper.

### Natural Temper

The fabric of vessel 23 is made of clay 1a, containing a large amount of plant fragments. Most of them appear in the form of small, round cavities (seeds or moss?) as well as a few larger fragments (maximum length 3.7 mm). Given the even distribution and the small size, it seems the most reasonable to interpret the fabric as naturally tempered. However, closer comparisons with the moss-tempered fabrics from the Scheldt Valley (Teetaert 2020) need to be conducted to better understand this fabric.

### Plant Temper?

The plant fragments in the fabric of vessel 26 (of clay 2) are mainly large (up to 4.5 mm in length) and occur in concentrations in the fabric. For these reasons, it is likely that they have been added as temper. The amount has been estimated to around 24 %.

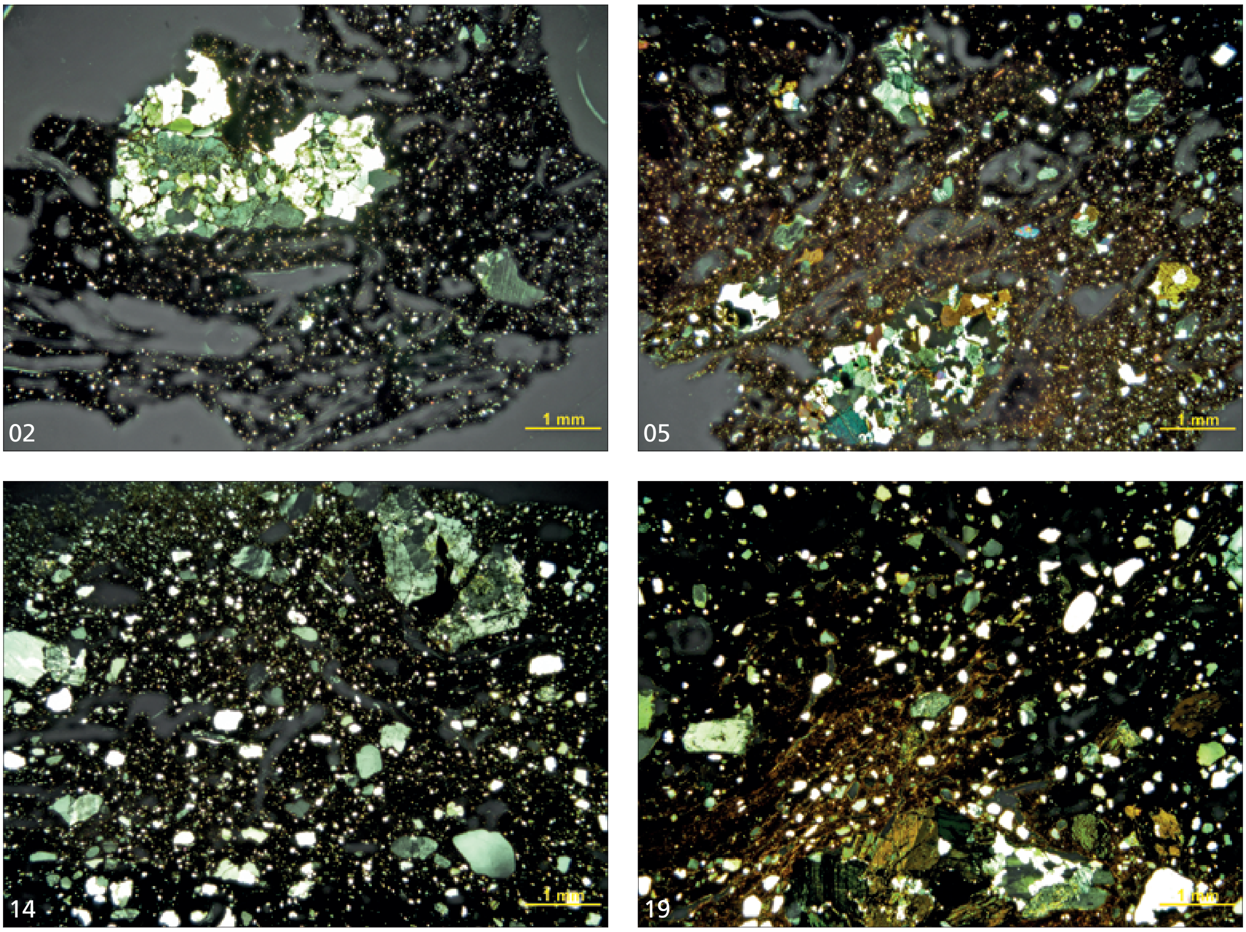


**Fig. 4** Examples of different temper groups, based on the petrographic analysis. – Pot 2 fabric with diatoms and spongia needles, a small amount of dark minerals and some mica, tempered with granite plus plant material? – Pot 5 fabric with diatoms and spongia needles, a small amount of dark minerals and some mica, tempered with amphibolite. – Pot 14 fabric with diatoms and spongia needles, a small amount of dark minerals and a high mica content, tempered with granite plus plant material. – Pot 19 coarse and unsorted fabric lacking fossils. Mica and dark minerals grains are scarce, tempered with amphibolite. – (Photos O. Stilborg).

## Temper Qualities

As is evident from the interpretations above, the tempering of the different fabrics falls into four main groups – crushed stone (granitic, amphibolite and sandstone); sand; crushed stone and plant temper (?); and natural / plant temper (?). Due to the small number of samples per group, it is only for the crushed stone and sand tempers that the temper quality can be calculated with a reasonable degree of certainty (**fig. 4**). We see that the amphibolite-tempered fabrics have a very similar tempering quality and that the sand-tempered fabric, quite naturally, has a different quality. There is a weak tendency for the crushed stone temper in the fabrics containing potential plant temper as well to be coarser and more plentiful on average than in the other stone-tempered fabrics. Referring to the discussion above about the relationship between non-plastics of different origin in the fabric, we note that this relationship goes contrary to the purely craft-technological logic, which privileges two temper ingredients supplementing each other, maintaining an optimal balance between clay and temper. The easy explanation – that the Swifterbant pottery craft allowed such variation although it is less than optimal – should not automatically be adopted. Instead, we should consider that the possible existence of two groups of different stone temper qualities indicates the co-occurrence of two different traditions preferring different qualities of temper. Whether this is so needs to be tested further, on a larger sample. This testing should include investigating whether there are other technological traits that support the existence of two different craft traditions.

### Post-Depositional Alterations

Pyrite and calcium/gypsum are found in the cavities of a majority of the samples, having entered the poriferous sherds from the depositional environment. Even vivianite and siderite have been observed in the samples. This is in accordance with the observations by H. Huisman et al. (2008, 38–39) in the analyses of the depositional environment at site S2 (located some 500 m from S3).

### Comparisons with Other Petrographic Data from Swifterbant

An early pilot petrographic study was executed by B. Hulthén (Lund University) and published by J. P. de Roever (1979, 30), who later on carried out an extended study (de Roever 2004, 104–111). The first study included four sherds, from S2 (find number 1042), S3 (48152), S5 (an isolated find from the creek) and S11 (211). The petrographic analyses by B. Hulthén revealed that two samples (211 and 1042) have been tempered with a combination of quartzitic stone and plant material similar to fabric groups in the current S3 analysis. The sample from S5 was tempered with sandstone and a small amount of grog (and natural plant material) and is thus a parallel to the sandstone fabric (without grog) in the current analysis. The last sample (48152) contained quartzitic stone and grog in a total volume of 10 % (maximum grain size 2.5 mm), in addition to natural plant material. The stone fragments may be part of a grog temper derived from an earlier stone-tempered fabric. This grog temper has no parallels in the current study of S3 samples, but it does have one possible parallel in the later sample analysed by J. P. de Roever (2004). This later sample included samples from S3 and from three neighbouring sites (**Appendix table 2**). The thin sections from 2004 were re-studied here in order to increase our sample size.

J. P. de Roever's dataset includes four samples from S3. Only sample 25164 matches the fabrics in the new study. This clay can be classified as group clay 2, and the stone used for tempering is characterised by a partly quartzitic structure. The three other samples are made from other clays (none of them containing fossils), although the fabric of sample 21188 is of the same temper quality as that of vessel 03. The same sample contains some grains that could be grog grains. The clay of the potential grog grains is the same as the matrix in the new vessel, but the old vessel used for grog may in turn have been sand-tempered. Of the two remaining samples, sample 49920 is made from a sorted, medium-coarse clay with large clay pellets and almost no plant material, tempered with crushed granite. Sample 910005 is made from a coarse, unsorted clay with some plant inclusions and is tempered with crushed granite, like the previous sample. Our results from these four samples from S3 make clear that the range of variability in fabrics has increased by adding just a small number of new samples – a warning that the current analysis should be interpreted as a pilot study.

Sample 3592 from S2 may also be grog-tempered. Here the grains are also few and of the same fabric as the matrix, which makes it difficult to tell them apart from clay pellets. If they are indeed grog grains, it is reasonable to assume that the crushed grains of granite also occurring in the fabric are part of the temper in the old vessel used for the grog tempering rather than a separate granite temper.

S23 is a trench on one of the sand ridges that are found alongside the river system (see **fig. 1**). This means that the three samples from this site may date anywhere between 5000 cal BC (the start of the Swifterbant ceramic tradition) and 3700 cal BC (the inundation of the sand ridge; Raemaekers et al. 2014). These three samples are made from clays that match the new S3 samples well. The clays in two of them are like clay 2, and the clay in the third matches clay 1a. S11 is a trench on another sand ridge (see **fig. 1**), with similar imprecision regarding the date of the ceramics. Sample 3520 is tempered with the same type of stone with quartzitic structure as was used for several of the fabrics in the new S3 sample. However, the clay, while of the same quality as that used for S3–03, contains no fossils. Sample 12736 is made from a clay like clay 2 and may have been tempered with grog. The few grog grains are of the same fabric as the matrix. Sample 226 is different from all of the other samples. The clay contains no fossils and no plant material, and it is tempered with grog derived from an established grog temper tradition: We know that grog tempering had been going on for several generations of pots, through the presence of several different fabrics among the grog grains and of secondary grog grains inside some of these grog grains (**fig. 5**). The very well sorted clay also deviates from the other Swifterbant raw materials (de Roever 2004, 188. 266).

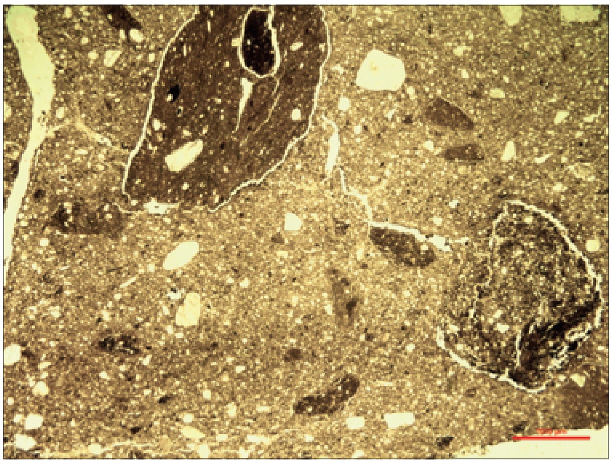

**Fig. 5** Sample S11-226, with evidence of grog temper. – (Photo O. Stilborg).

All of the fabrics in J. P. de Roever's dataset contain varying amounts of plant material. There is no clear indication for any of the sherds that plant material was added as a temper, following the criteria set out above. Furthermore, the experimental grog- and plant-tempered fabric that was included in J. P. de Roever's analysis met these criteria. While there were a number of small plant fragments, there were also a number of large (up to 2 mm) round pieces that match the appearance of the experimental plant-tempered fabrics (Stilborg unpubl. data).

While the current S3 dataset did not provide evidence for grog-tempered fabrics, the de Roever dataset does. Most evident is sample 226, from site S11, with secondary grog grains within the primary grog grains of the vessel. Three more samples, from S2, S3 and S11, underline that grog temper although represented seems to remain a minor aspect of Swifterbant craft and in most cases of the simpler kind where sherds from one older vessel have been crushed to provide the grog temper.

## DISCUSSION

### Swifterbant Craft

Clay and Temper

Although four clay and six temper groups were identified, the Swifterbant ceramic craft is rather homogeneous (**tab. 1**). Most vessels (n=14) are made from a clay which comprises diatoms, spongia needles and mica (clays 1a and 1b) and are tempered with stone material that may have been collected on-site (granites, amphibolite and sandstone). The vessels tempered with crushed stone reveal a positive correlation between the amount of temper and the maximum grain size, which is quite normal for prehistoric pottery. The remaining six vessels have unique combinations of clay and temper.

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="6">temper</td></tr>
<tr><td>granite</td><td>granite + plant?</td><td>amphibolite</td><td>sandstone</td><td>sand</td><td>plant?</td></tr>
<tr><td rowspan="6">clays</td><td rowspan="3">1a: diatoms and spongia needles</td><td>06</td><td rowspan="2">02, 13</td><td rowspan="3">5</td><td rowspan="3">32</td><td rowspan="3">10</td><td rowspan="3">23</td></tr>
<tr><td>07, 09, 11</td></tr>
<tr><td>28</td><td>15</td></tr>
<tr><td>1b: same as 1a, with mica</td><td>20</td><td>14</td><td></td><td></td><td></td><td></td></tr>
<tr><td>2: coarse and unsorted</td><td></td><td></td><td>19</td><td></td><td></td><td>26</td></tr>
<tr><td>other clays</td><td>3</td><td>17</td><td></td><td></td><td></td><td></td></tr>
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**Tab. 1** Correlation between clays, tempers and SEM results. – Gray = emmer grain. – green = green vegetables. – blue = possibly root or other parenchymatous food.

Plant Temper

This study has not been able to solve the problem of added plant temper. In our opinion, there are a number of arguments that speak in favour of the plant fragments being primarily natural inclusions. Compared with the plant material in experimentally made fabrics, the plant material in a number of the studied samples is best explained as natural inclusions (Stilborg unpubl. data). This argues against a tradition of two-component tempering. Finally, it is reasonable to assume that at least some of the local clays near the Swifterbant sites would have been rich in organic materials because of the natural environment. If the plant content is indeed natural, the potters would, however, have chosen these clays in the knowledge that they contained a lot of plant material, and it is entirely possible that they occasionally added more plant fragments if they felt that the consistency of the clay needed it.

Grog Temper

Although the current sample did not comprise any vessels with grog temper, the de Roever samples include some vessels with evidence for grog temper. In three samples, grog tempering entailed taking sherds from one and the same older pot, which in turn is made from naturally tempered clay or, alternatively, of a granite-/sand-tempered fabric of the same clay that the potter used for the new pot. It seems reasonable to interpret these as locally produced vessels. The clay used in the fabric with advanced grog temper (sample 226) does not belong to the clay types likely to be of local origin and therefore probably concerns an imported vessel.

## The Correlation between Technology and Function of Swifterbant Ceramics

The petrographic analysis has made clear that the correlation between temper and function is not as clear-cut as had been proposed earlier (contra Raemaekers et al. 2013). First of all, the presence of plant temper has been problematised. Whereas visual analysis of these sherds identified plant temper in most sherds, the petrographic analysis has made clear that although plant content can be confirmed, it is not possible to say with certainty whether it concerns added plant temper. In most cases, it now seems more likely that the plant material was part of the clays used.

The petrographic analysis is dominated by vessels in which the SEM analysis found emmer wheat. As a result, it has become difficult to determine the correlation between function, clay and temper. **Table 1** suggests that there is no correlation: emmer was found in pots made from all clays and with almost all tempers. The petrographic analysis of the samples collected by J. P. de Roever has made clear that the vessels studied as part of the functional analysis did not adequately cover the ceramic variability of the assemblage, as vessels with grog temper were not included in the functional analysis. Further SEM analysis should include vessels with microscopically determined grog temper to understand the possible correlations between clay, temper and function.

## Comparison with the Ertebølle Craft

Ertebølle pottery is found in the coastal regions of Scania (Sweden), in Denmark and in northern Germany. It is broadly contemporaneous with the Swifterbant ceramics, but appears to have started several centuries later (c. 4800–4600 cal BC; Hartz/Lübke 2006). Here we present the available petrographic data from this area and period. The fabrics of pots from Vik and Hagestad (eastern Scania; Hulthén 1977, 27) and from Skateholm and Soldattorpet (western Scania; Stilborg/Bergenstråhle 2000, 29–37; Dumpe et al. 2008, 434) are dominated by a stone tempering tradition. A variety of non-calciferous, fine to coarse clays were used, tempered primarily with crushed granite or quartzite in fabric qualities varying from less than 15 % temper (volume), with a maximum grain size between 1–2 mm, to more than 25 % temper (volume), with a maximum grain size between 7–8 mm. Most often the fabrics are poorly homogenised and contain varying amounts of large-grained temper (6 mm maximum grain size). No relationship to vessel dimensions could be discerned. Combinations with plant temper have been observed in a few pots (i. e. Ivetofta, eastern Scania; Hulthén 1977, 33), and one bowl/lamp from Vik was tempered with plant material and grog (Hulthén 1977, 26–27). Grog-tempered pots from three sites on Jutland, Denmark, were analysed by B. Hulthén (1977, 42–43). The few analyses that have been conducted on the Danish finds have led to the impression that plant, grog and plant-and-grog temper are exceptions. In the German finds from Neustadt, Rosenhof (both Ostholstein) and Hamburg-Boberg, the variation is much the same (Hulthén 1977, 45; Glykou 2016, 80–84; Thielen 2020, 113–122). Stone temper using a coarsely crushed, granitic stone (3–7 mm maximum grain size at Neustadt; Glykou 2016, 82) is the dominant choice, but a few grog-tempered fabrics also occur (Thielen 2020, 113–122), while »true plant temper« has not been observed and clays with more than a few natural inclusions are rarely used. The grog temper observed so far has been of the simple kind, using crushed pottery fragments from one older, stone-tempered pot.

Compared with the Swifterbant ceramic craft at S3, the Ertebølle ceramic craft shows both obvious and more subtle differences. Plant tempering and/or the regular preferred use of clays rich in plant material is a trait of the Swifterbant ceramic craft that is not found in the Ertebølle craft (with the few exceptions mentioned above). We consider this difference a cultural choice: plant material suitable for temper (such as moss or grass) was probably available in both regions. Both groups of potters used temper of crushed stone (mainly granitic) with maximum grain sizes up to 6–7 mm, but the amounts of temper are generally smaller in the Swifterbant fabrics. Both crafts use grog temper occasionally, involving fragments from a single older, often stone-tempered pot, but more advanced grog tempering has so far been seen only in Swifterbant culture pottery (S3 [this study]; the Scheldt valley, Belgium [Teetaert 2020]; and Hüde, Lower Saxony [Stilborg unpubl. data]). Sand temper is another rare phenomenon that has so far been observed only within the Swifterbant craft and not in any Ertebølle pot.

Stone tempering is a characteristic that is shared between Swifterbant and Ertebølle and that sets these two ceramic craft groups apart from the Asian organic tempering traditions (Stilborg 2017). The biggest and likely most meaningful difference between them lies in the use of plant and plant-and-stone tempering within the Swifterbant craft (leaving aside for the moment the question of natural vs added). It is not improbable that this difference is an effect of the presence of naturally plant-rich clays in the wetland environment of Swifterbant S3. Establishing whether this is a cultural trait for the Swifterbant culture at large would require further petrographic analyses from Swifterbant culture sites in other types of environments. Moreover, Swifterbant S3 is located in an environment in which naturally occurring stone pieces are sparse. This is the likely reason for a larger diversity in the stone types used. The single sand-tempered fabric so far stands alone, and more research is needed to ascertain what role that type of ware played within the Swifterbant craft. So far there are no parallels within the Ertebølle craft.

## CONCLUSION

This exploration of the petrographic characteristics of the Swifterbant S3 ceramic craft has made clear that locally available clays and tempering materials were used in all 18 analysed samples. Most sherds have been tempered with stone material, while all contained some plant material.

The interpretation of this plant material is far from straightforward. It has been proposed, from a theoretical point of view, that it may be plant material present in the clay, it may have been added to improve the plasticity of the clay or it may be a proper tempering material. We propose that, because of the variety in density and size of the plant particles, most if not all the plant fragments are to be interpreted as natural inclusions.

We conclude that the current sample is too small to appreciate the variability in the ceramic craft of Swifterbant S3. The addition of the 10 sherds that had already been studied by J. P. de Roever (2004) added variety. This implies that we should be cautious in quantifying our results: the predominance of certain clays and tempers in our new samples may be the result of too small a dataset.

Our petrographic analysis also makes clear that macroscopic analysis of temper should be used with caution and tested with microscopic analysis. Using petrography, stone temper has now been identified in many sherds that had been thought to lack this temper based on the macroscopic analysis. Given the proposed correlation between stone temper and function (Raemaekers et al. 2013), our microscopic analysis now creates a more fuzzy result, where temper is of less importance to distinguish between the two functional groups. Nevertheless, the differences in wall thickness, decorative schemes and firing quality (however vague that latter notion may be) do suggest that there was an idea of two types of cooking vessels. This is certainly a topic that would benefit from further analysis.

Our analysis also adds to the existing debate on the similarities and differences between the ceramics of the Swifterbant culture and the Ertebølle culture. The debate primarily centred on the significance of the shared characteristic of the pointed base – see D. Raemaekers and J. P. de Roever (2010) for both viewpoints in this discussion – and the difference in coiling techniques (Raemaekers 2008; Glykou 2016). We may now introduce petrographic data into the discussion. These data underline the differences: The use of clays rich in plant material (whether it concerns temper or plant material naturally present in the clay) sets the ceramic craft of Swifterbant apart from that of all analysed Ertebølle culture pots.

## APPENDIX

This appendix presents three types of data:

| vessel no | petrography | SEM results | DTMS results |
|---|---|---|---|
| 1 | no | none | |
| 2 | yes | none | proteins + lipids |
| 3 | yes | emmer grain food | |
| 4 | no | none | starch |
| 5 | yes | emmer grain food | starch |
| 6 | yes | none | starch |
| 7 | yes | emmer grain food | |
| 8 | no | none | starch |
| 9 | yes | emmer grain food | starch |
| 10 | yes | none | starch |
| 11 | yes | emmer grain food | starch |
| 13 | yes | none | |
| 14 | yes | emmer grain food | starch |
| 15 | yes | emmer grain food with fish | |
| 17 | yes | green vegetables with fish | starch + resin |
| 19 | yes | emmer grain food | |
| 20 | yes | emmer grain food | starch |
| 22 | no | none | proteins + lipids |
| 23 | yes | green vegetables with fish | |
| 24 | no | green vegetables | starch |
| 26 | yes | emmer grain food | |
| 28 | yes | possibly root or other parenchymatous food | starch |
| 29 | no | none | proteins + lipids |
| 31 | no | green vegetables | starch |
| 32 | yes | none | starch |

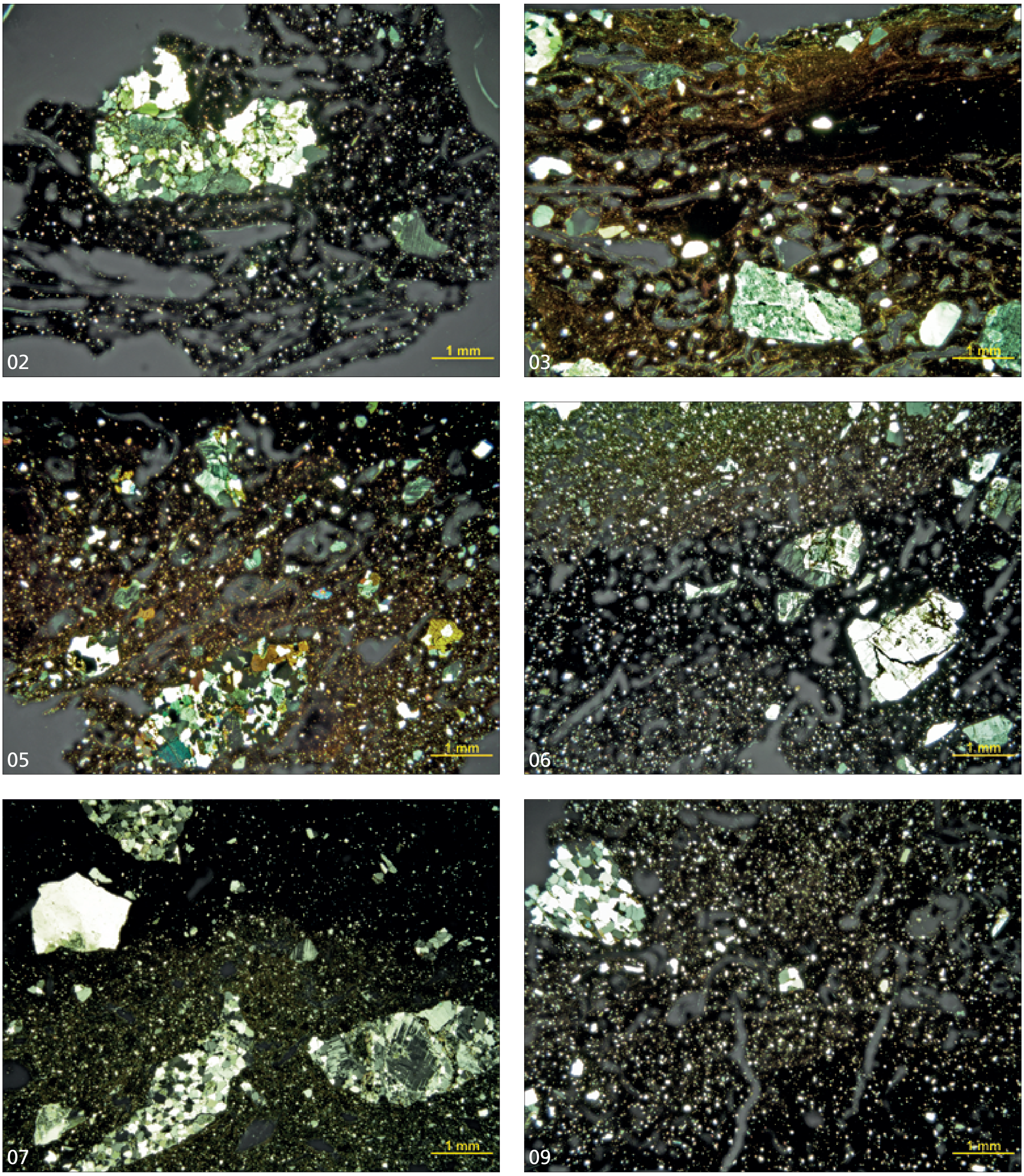
**Appendix Table 1** correlates the ceramics that were studied in the current petrographic study to the functional analysis carried out previously (Raemaekers et al. 2013). – SEM = scanning-electron microscopy. – DTMS = temperature-resolved mass spectrometry.

| thin section | site | sample | clay | temper | fabric group | plant | comparison to our samples |
|---|---|---|---|---|---|---|---|
| 8044 | S2 | 3592 | Si-, Fs*, S- | granite, grog? | B2 | ++ | other clay |
| 809 | S3 | 25164 | Si-, Fs*, S* | rock** | A4 | + | clay most like S3-26 (clay 2) |
| 8046 | S3 | 49920 | Si*, Fs- | granite | B1 | -- | large cp, other clay |
| 8047 | S3 | 910005 | Si+, Fs+, S-- | granite | C2 | * | other clay |
| 8047 | S3 | 21188 | Si*, Fs- | grog? | F1 | * | other clay (quality = S3-03) |
| 8043 | S11 | 226 | Si+ | grog*** | A6 | | other clay |
| 8043 | S11 | 12736 | Si*, Fs-, S- | grog? | F1 | + | clay like S3-03 but no fossils |
| 8043 | S11 | 3520 | Si*, Fs*, S-- | rock** | F3 | + | clay like S3-03 but no fossils |
| 8019 | S23 | 348 | Si*, Fs*, S-- | granite | B2 | + | clay like S3-26 (clay 2) |
| 8020 | S23 | 942 | Si+, Fs - | granite | A1 | + | clay 1a |
| 8020 | S23 | 1375 | Si*, Fs+, S* | granite | A5 | + | clay like S3-19 (clay 2) |
| 8132 | | clay | Si*, Fs-- | grog, org | experimental | | |

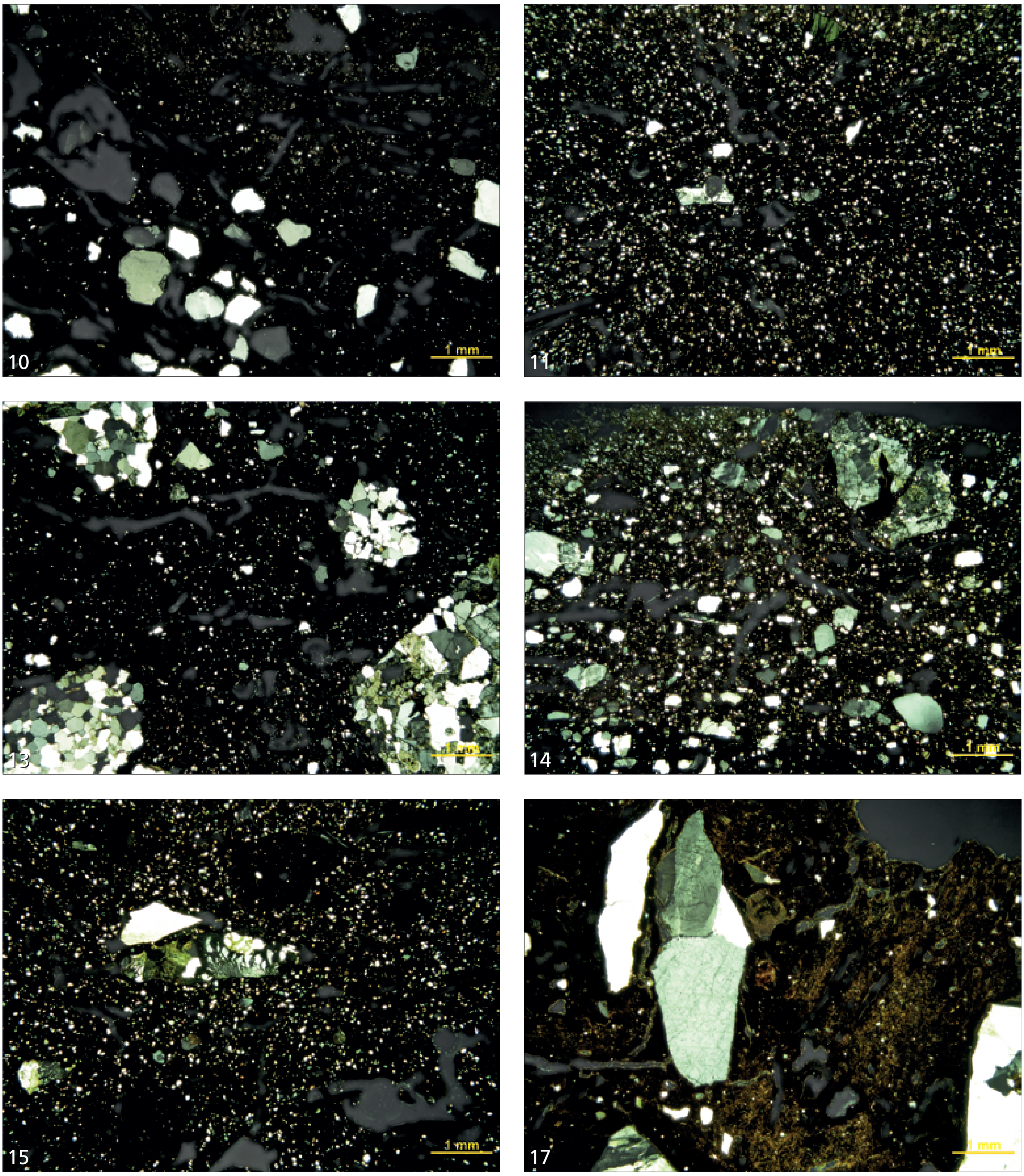
**Appendix Table 2** presents the petrographic data on the sherds analysed by J. P. de Roever (2004) and re-examined by O. Stilborg, for comparison. Fabric grouping by de Roever. – Legend: ** = quartzite-rich. – *** = grog tradition. – Si = silt. – Fs = fine sand. – S = sand. – -- = very few. – - = sparse. – * = common. – + = rich.

| vessel | clay | | | | | | | | | | | | | temper | | | | ware structure | comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coarseness | sorting | slit | fine sand | sand | calcium | mica | iron oxide | other minerals | plant fragments | diatoms | spongia needles | type | type | amount (%) | maximum grain size (nn) | average maximum (mm) | | |
| 2 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu, Z, Iso | rich | rich | Sparse | 1a | granite (+plant?) | 15 | 5 | 1.3 | suffficiently homogenised | intruded pyrite |
| 3 | fine | unsorted | common | sparse | very few | | rich | common | A/P, Mu, Z | rich | | | | granite? | 12 | 3.1 | 2.2 | suffficiently homogenised | |
| 5 | medium | sorted | rich | sparse | | | sparse | common | O, A/P?, Mu | rich | common | common | 1a | amphibolite | 12 | 3.3 | 2.0 | suffficiently homogenised | intruded pyrite |
| 6 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu, Z | rich | common | sparse | 1a | granite? | 13 | 5.8 | 3.0 | suffficiently homogenised | intruded calicium #Moos?# |
| 7 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu, Z | common | rich | common | 1a | granite | 26 | 6.4 | 3.2 | well homogenised | |
| 9 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu | rich | rich | common | 1a | rock | <10 | 2.0 | 1.2 | suffficiently homogenised | intruded pyrite, calcium |
| 10 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu | rich | rich | sparse | 1a | Sand | 16 | 1.6 | 1.3 | suffficiently homogenised | intruded pyrite, calcium |
| 11 | medium | sorted | rich | sparse | | | common | common | A/P, Mu | common | rich | common | 1a | rock | <10 | 1 | | well homogenised | |
| 13 | medium | sorted | rich | sparse | | | common | rich | O, Mu | rich | common | common | 1a | granite (+plant?) | 17 | 5.5 | 4.0 | well homogenised | intruded vivianite, gypsum (?) |
| 14 | medium | unsorted | rich | rich | sparse | | rich | common | O, A/P, Mu, Z | common | common | common | 1b | granite (+plant?) | 22 | 4.5 | 2.3 | well homogenised | intruded pyrite |
| 15 | medium | sorted | rich | common | | | common | common | A/P, Mu | rich | rich | common | 1a | granite (+plant?) | <10 | 2.9 | 1.6 | well homogenised | intruded siderite? |
| 17 | fine | sorted | sparse | very few | | | sparse | rich | A/P | common? | | | | rock (+plant?) | 27 | 7.1 | | well homogenised | larger plant fragments temper? |
| 19 | coarse | unsorted | common | rich | very few | | sparse | rich | O, A/P, Mu | common | | | 2 | amphibolite | <10 | 4.3 | 1.6 | well homogenised | intruded pyrite, temper poorly homogenised |
| 20 | medium | sorted | rich | sparse | | | rich | common | O, A/P, Mu | rich | rich | sparse | 1b | granite | 11 | 4.3 | 2.7 | well homogenised | intruded pyrite, calcium, temper fairly homogeneous |
| 23 | medium | sorted | rich | sparse | | | common | common | O, Mu | rich | rich | sparse | 1a | natural | | 3.7 | | well homogenised | intruded pyrite |
| 26 | coarse | unsorted | common | rich | sparse | | common | rich | A/P, Mu | rich | | | 2 | plant? | 24? | 4.5 | 3.4 | well homogenised | intruded Pyrite, sand natural temper |
| 28 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu, Z | rich | rich | common | 1a | granite | 10 | 5.2 | 2.2 | well homogenised | intruded pyrite and siderite (?) |
| 32 | medium | sorted | rich | sparse | | | common | common | O, A/P, Mu | common | rich | common | 1a | sandstone | 21? | 5.4 | 3.4 | well homogenised | intruded pyrite and siderite (?) |

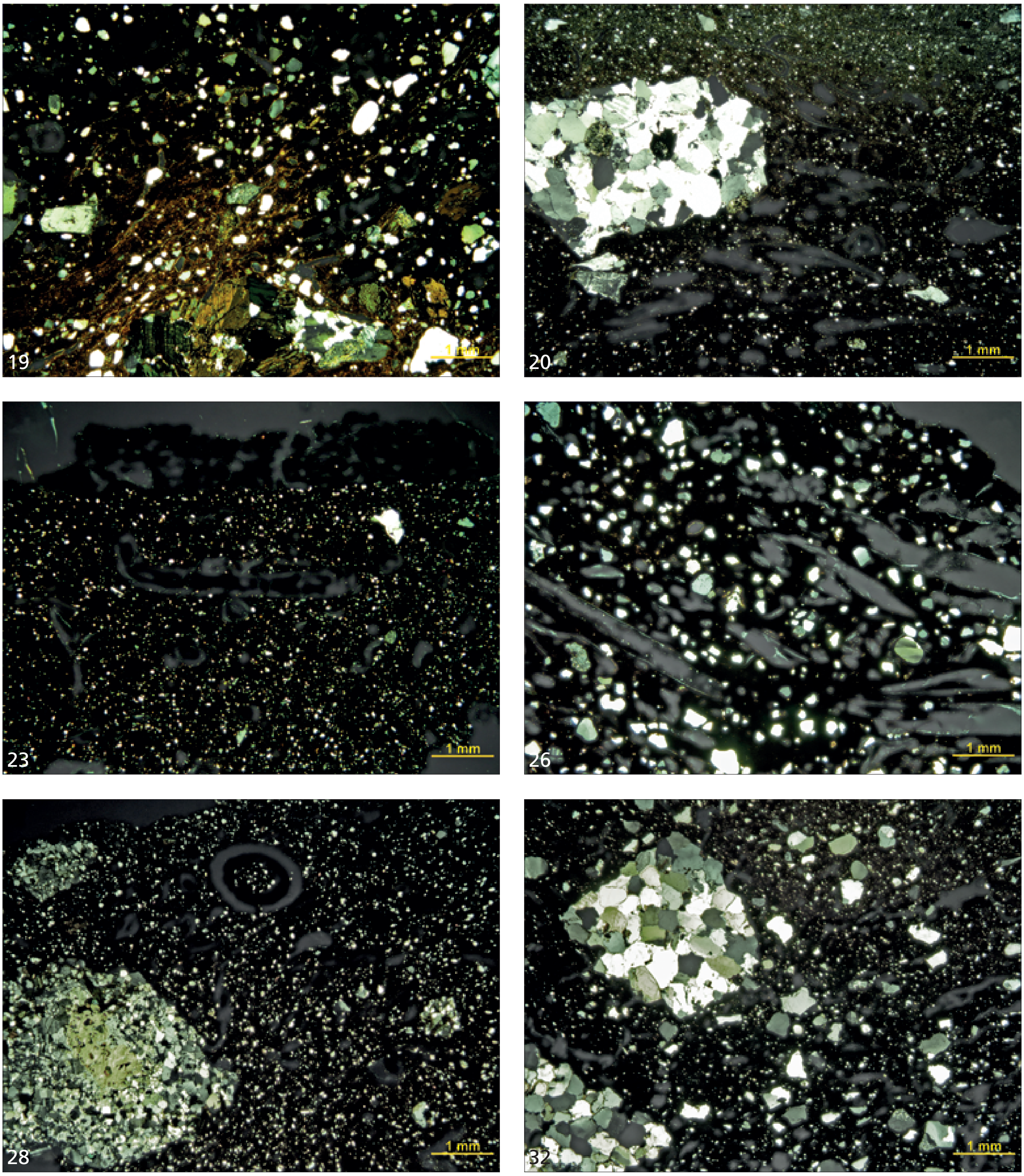
**Appendix Table 3** presents the description of the ceramics analysed in our study. The column »other minerals« presents O = ore. – A/P = amphibolite/pyroxenes. – Mu = muscovite. – Z = zircon. – Iso = isotropic mineral. – The column »average maximum« presents the average maximum grain size based on the five second-largest grains.




**Appendix Fig. 1a** Cross-polar microscopic photos of the samples.




**Appendix Fig. 1b** Cross-polar microscopic photos of the samples.




**Appendix Fig. 1c** Cross-polar microscopic photos of the samples.

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## *Zusammenfassung / Summary / Résumé*

**Petrografische Analyse von Keramik aus Swifterbant S3 (prov. Flevoland/NL) (ca. 4300–4000 cal BC)**

In diesem Artikel wird eine petrografische Analyse von 18 Keramikscherben aus Swifterbant S3 vorgestellt. Die Swifterbant-Keramik ist recht homogen. Die meisten Gefäße wurden aus einem Ton hergestellt, der Kieselalgen, Schwammnadeln und Glimmer enthält, und wurden mit Steinstückchen gemagert, die möglicherweise vor Ort gesammelt wurden. Wir vermuten, dass es sich bei den Pflanzenfragmenten in unseren Proben hauptsächlich um natürliche Einschlüsse handelt. Die aktuelle Probe wurde mit Scherben verglichen, die von de Roever (2004) aus S3 und benachbarten Fundorten untersucht wurden. Diese Scherben enthalten einige mit Schamotte gemagerte Tone. Dies bedeutet, dass die Stichprobengröße der vorliegenden Studie nicht ausreicht, um die Variabilität von Ton und Magerung zu erfassen. Unsere Analyse hat auch deutlich gemacht, dass die vorgeschlagene Korrelation zwischen Magerung und Funktion nicht so eindeutig ist, wie früher von Raemaekers et al. 2013 vorgeschlagen, und dass Emmer in Gefäßen aus allen Tonen und mit fast allen Magerungen gefunden wurde. Die petrografische Analyse unterstreicht die Unterschiede in der Keramiktechnologie zwischen der Swifterbant-Kultur und der Ertebølle-Kultur. Die Verwendung von Tonen, die reich an Pflanzenmaterial sind, ist typisch für die Swifterbant-Keramik.

**Petrographic Analysis of Ceramics from Swifterbant S3 (Prov. Flevoland/NL) (c. 4300–4000 cal BC)**

This article presents a petrographic analysis of 18 ceramic sherds from Swifterbant S3. The Swifterbant pottery is rather homogeneous. Most vessels were made from a clay containing diatoms, spongia needles and mica and were tempered with stone material that may have been collected on-site. We suggest that the plant fragments in our samples are primarily natural inclusions. The current sample was compared with sherds studied by de Roever (2004) from S3 and neighbouring sites. These sherds include some grog-tempered fabrics. This implies that the sample size of the present study is insufficient to cover the variability in clay and temper. Our analysis has also made clear that the proposed correlation between temper and function is not as clear-cut as proposed earlier by Raemaekers et al. 2013 and that emmer was found in pots from all clays and with almost all tempers. The petrographic analysis underlines the differences in ceramic technology between the Swifterbant Culture and the Ertebølle Culture. The use of clays rich in plant material is typical for the Swifterbant pottery.

**Analyse pétrographique de la céramique de Swifterbant S3 (prov. Flevoland/NL) (env. 4300–4000 cal. BC)**

Cet article traite de l'analyse pétrographique de 18 tessons provenant de Swifterbant S3. Cette céramique présente une certaine homogénéité. La plupart des récipients furent modelés avec une argile contenant des diatomées, des aiguilles de spongiaires, du mica et dégraissée par des fragments lithiques ramassés peut-être sur place. Nous pensons que les fragments organiques présents dans nos échantillons sont avant tout des inclusions naturelles. Cet échantillon fut comparé à des tessons de S3 et de sites voisins étudiés par de Roever (2004), dont certains présentent une pâte dégraissée avec de la chamotte. L'échantillon actuel n'est alors pas assez grand pour couvrir la variabilité de l'argile et des dégraissants. L'analyse a également révélé que la corrélation proposée entre la fonction et les dégraissants n'est pas aussi nette que l'avait proposé Raemaekers et al. 2013. On a trouvé en plus de l'amidonnier dans des pots faits avec toutes les sortes d'argiles et presque tous les dégraissants observés. L'analyse pétrographique souligne les différences technologiques entre la poterie de la culture de Swifterbant et celle d'Ertebølle. L'utilisation d'une argile riche en inclusions organiques est typique pour la poterie de Swifterbant. Traduction: Y. Gautier

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