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Ole Stilborg*, Mattias Sjölander**, Philip Buckland**/§

* SKEA Ceramics AB, Rosengatan 17, 784 65 Borlänge, Sweden.
** Environmental Archaeology Lab., Umeå University, Sweden.
§ Corresponding author: philip.buckland@umu.se

UPSCALING CERAMIC THIN SECTIONS THROUGH A DATABASE: A MULTI-SITE ANALYSIS OF ORGANIC TEMPERS IN SWEDISH PREHISTORIC POTTERY

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Abstract: The inclusion of ceramic thin section data from multiple sites in the SEAD environmental archaeology database provides an opportunity for not only examining the distribution of organic temper in Sweden, but also for an analysis of the pros and cons of research using a large-scale data infrastructure. This paper uses an extract of over 40 years of semi-quantitative data, primarily collected at the now disbanded Ceramics Research Laboratory in Lund, to examine the evidence for the use of organic tempers in Swedish pottery. These observations are interpreted in terms of the craft traditions in the region's prehistory, discussed with respect to their potential implications, and put in the context of similar traditions in Asia. The discussion points to a limited, selective transference of organic tempering technology from the east to Sweden. The experience of the authors in digitising and working with these data is then used as the basis for a discussion on the challenges and potentials of using large-scale multi-site databases for synthesis research. The conclusion is that the potential for creating and exploring new lines of enquiry into the material outweighs the difficulties.

Keywords: Ceramic thin sections, organic temper, database, pottery, synthesis, prehistory, Sweden, Eastern craft tradition

1. Introduction

Portals to other worlds is a much-used concept in Science Fiction; they are often used to instantly transmit people, objects and information from one place to another whilst saving vast amounts of time (and energy). They present fascinating possibilities, but also a clear risk that the transmission from one side to the other will not work perfectly – something may be lost in the transition. Open databases also promise "portals" to rich but otherwise dispersed information, as well as much sought after tools for effectivization, as well as expanding and enriching archaeological research. They also represent points of entry to past research, where data collated over a considerable span of time may become instantly available through an online interface. The capacity for accessing and aggregating data from multiple sites, with multiple lines of evidence, through a single web portal is both time saving and powerful in its potential for facilitating innovative research.

As information passes through these digital portals, however, they risk losing some of the nuances of the original data. This is especially true where complex, human-made, materials such as ceramics are concerned; and there is a risk that standardisation required by a database excludes details that are important for interpretation. These exclusions are sometimes necessary compromises in large-scale synthesis research, where the aim is to examine broad scale spatio-temporal patterns. It is still the duty, however, of the database hosts or managers to make the character and structure of the data as clear as possible to users, raise awareness of any limitations to how the data should be used, and ensure they know where to find any missing information that might be needed for interpretation.

This article draws on our experience of building and using a database which includes the complexity of semi-quantitative data from ceramic thin sections. It represents the first study of the ceramic thin sections data in SEAD, relating these data to the current state of knowledge on the use of organic temper in a broader geographical perspective. The case study is used to demonstrate both potential and limitations, and discuss some of the implications of undertaking multi-site synthesis research using a large scale data infrastructure.

The SEAD database

The Strategic Environmental Archaeology Database (SEAD) is a multi-proxy database and research infrastructure (Buckland et al., 2018), hosted by the Environmental Archaeology Lab (www.umu.se/forskning/infrastruktur/mal) and the Humanities Computing Lab (HUMlab) (www.umu.se/humlab) at Umeå University, Sweden. The system is a relational PostgreSQL (www.postgresql.org/) database with a custom web-interface through which users can filter, aggregate, access and visualise data (https://browser.sead.se/).

Despite its title, SEAD is designed to store almost any kind of archaeological science data, and it has an extensive capacity for storing reference data and information that can help in the interpretation of archaeological materials (i.e. any material of use to archaeologists)(Buckland et al., 2022). It was primarily designed to hold quantitative and semi-quantitative data – in effect, anything that can be counted or measured. The benefits of including the results of multiple forms of analysis in a single database include a simplification of multi-proxy data retrieval and analysis (i.e. more than one type of analysis from the same site), and comparing overviews of the state of knowledge within different fields, time periods and geographical regions. It also allows for the efficient construction of different data portals through a common web based architecture, with a single Application Programming Interface (API) feeding data from the database to the user interface. SEAD's online browser uses the now common "portal" concept to provide user group oriented points of entry for well-defined sets of data. The interface is always connected to the entire scope of the database, but when the Ceramics portal is selected, a particular set of filters are made available and the map visualisation is restricted to only sites for which ceramics data are available.

Ceramic thin sections and craft focus

Ceramic thin sections are slices cut through the fabric of a vessel or other ceramic object for microscopic analysis of the material composition and its formation through ceramic craft (Lindahl, 2002, pp. 47-50; Worley, 2009; Quinn, 2013, p. 23; Rose 2013). A pre-modern ceramic fabric always consists of a once plastic (shapeable) clay matrix and naturally occurring or added non-plastics. The thin section is cut and subsequently ground so thin (ca. 30 microns) so as to be able to transmit polarised light shined from below in a petrographic (geological) microscope. This allows the optical characteristics of the crystalline grains to be analysed and other materials to be identified.

When analysing complex composite materials like ceramics, there is more information to be extracted from a thin section than just the mineralogical composition (fig. 1). Looking at the material, the grain size distribution and particle shape, one or more groups of non-plastics can be identified as added temper – in addition to the naturally occurring amount of non-plastics acting as temper for the clay (Stilborg, 2002, p. 18; Quinn, 2013, pp. 153-156). The amount and fineness (grain size) of the added temper may then be calculated. In addition, the homogeneity

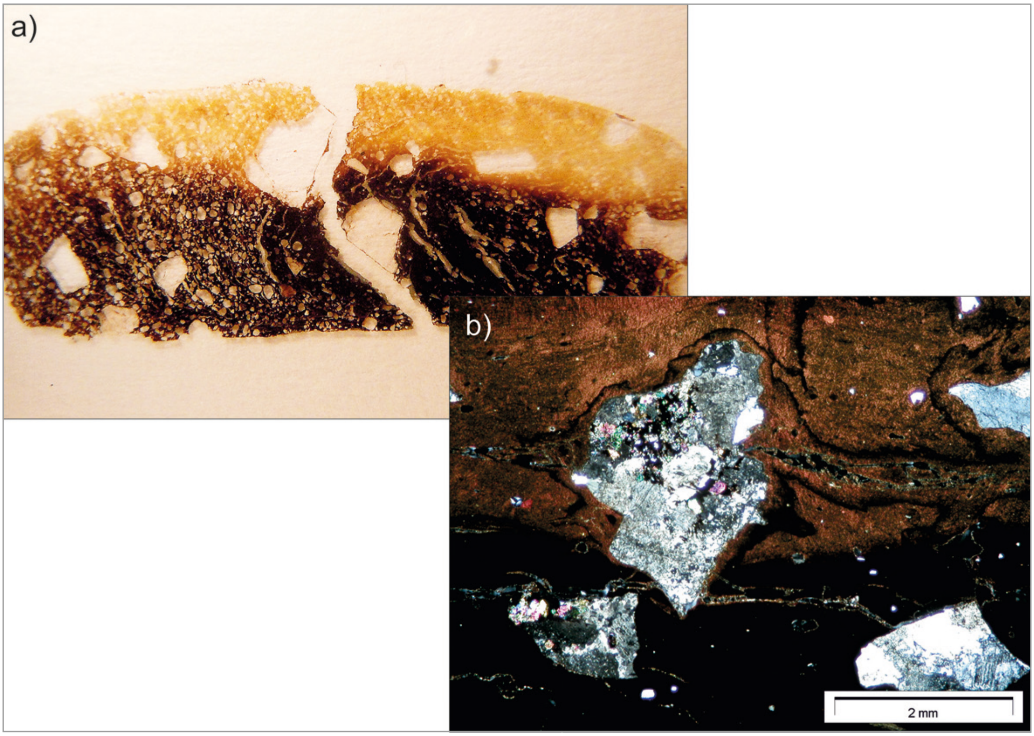

fig. 1. a) Photograph of a whole thin section sample of a sherd that shows the curved cracks from the so called U-type coiling technique used to build the vessel wall (sample from Northern Germany, site of Hamburg-Boberg). b) Microscope photograph of a granite tempered fabric from Sweden, Uppland (site Gödåker), which shows the large angular stone grains added to a fine grained clay.

of the non-plastics (natural and added) in the clay provides information on the quality of the kneading of the clay mixture (primarily the time invested). Structures in the matrix and the orientation of larger temper grains may reveal different types of coil building and differences in the coarseness of the clay, and structural shifts may show slip layers on the surface (Quinn, 2013, pp. 180-184). Changes in the optical performance of minerals like mica show if the firing temperature was above or below 700 °C, and materials absorbed in cracks and cavities of the vessel wall/sherd provide information on use and post-depositional influences.

Ceramological analyses provide valuable insights into human activities, including pottery production techniques, material and resource use, and food preparation. Large parts of the craft process are preserved in every sherd and thus possible to analyse using the petrographic microscopy of thin sections. For this reason, starting in the late 1970's, the now disbanded Laboratory for Ceramic Research (KFL) at Lund University developed an analytical protocol for work on thin sections, focusing on the craft information that could be gleaned from the samples. From a pre-modern ceramics perspective, there has been little interest in provenance studies in Sweden, and this is reflected in the data available from KFL. The level of detail (e.g. the frequency of specific dark minerals or diatom species in the clay) required for provenance research is not present in the recorded material stored in SEAD. This omission is in part a consequence of the low level of detail in the geological mapping of Sweden's Quaternary deposits, which restricts possibilities for matching fabrics with source materials. The mineralogical variation both in raw clays and temper materials in Middle and Northern Scandinavia is also quite limited (with a few marked exceptions), and the small amount of variation often spread in a way that does not easily allow for the pinpointing of a source on the basis of geological mapping. However, it is most often possible to make a satisfactory argument for local production on the basis of the small mineralogical variation among the samples from a site, by matching this to the variation in samples of the local clays. However, it is very difficult to provenance clearly deviating fabrics. There is always a possibility that a local potter used an unusual *local* clay and/or tempering recipe for one special pot, deviating from that normally used for the production of household ceramics in the area.

KFL's focus on craft factors means that the recorded thin section data contains more information on temper material and quality (fineness and amount) than on the mineralogy of the natural sand content (for example). The contents of calcium, mica, iron oxide, metal ore etc. are given as estimations rather than accurate measurements. Minor differences in the composition of the raw clay were not considered relevant for reconstructing and comparing ceramic craft traditions. The variation (in quality and mineralogy) seen in raw material samples of the prevailing moraine clays in Scandinavia is both broad and indistinct; and the clays used to make the same types of pots at the same site show similar variation. Together, these variations form a compelling argument that the mineralogical variation holds little significance for understanding differences in ceramic craft in the past (Hulthén, 1977; Stilborg, 1997). In this context, the types of raw materials chosen, and how they were treated and mixed, are the most important characteristics of the ceramic fabric. Forming technique and firing atmosphere are likewise important, but vessel shapes and decorations are considered secondary since the potter may, in principle, make almost any shape and decoration with any fabric. The dataset presented in this paper derive from decades of recording from this point of view, and thus consists mainly of categorised information on the type and quality (amount and fineness) of added temper.

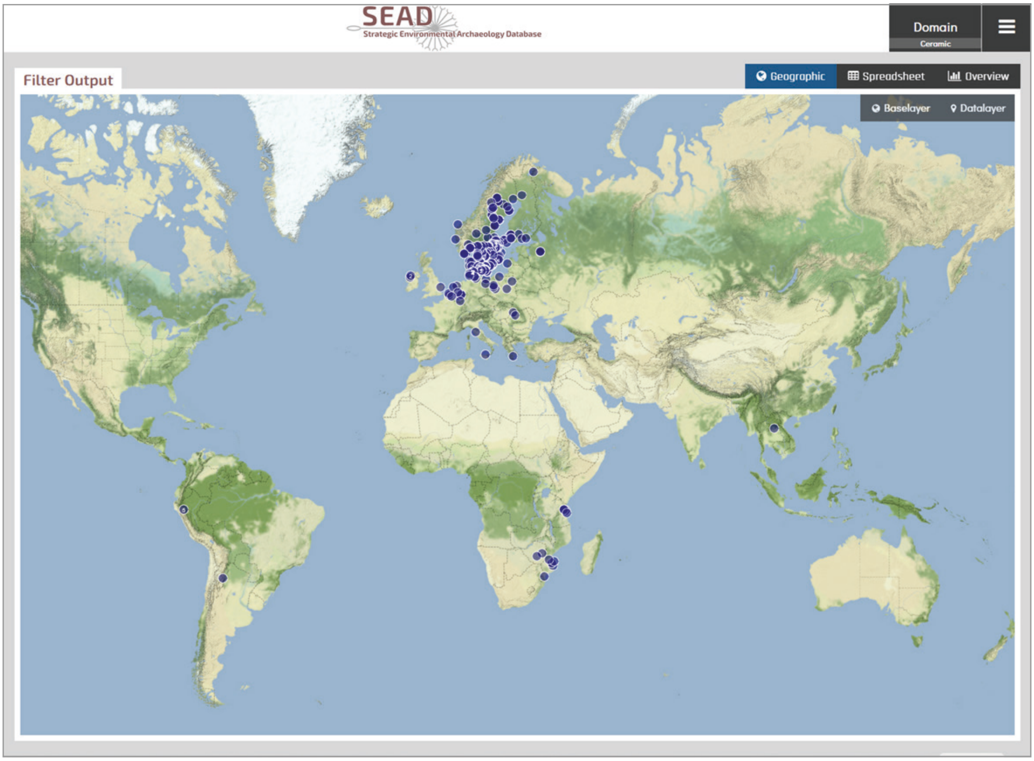

fig. 2. Screenshot of the SEAD online browser showing all of the data available through the Ceramics portal. (Image captured 25th May 2022 from https://browser.sead.se/ceramic).

Thin sections in SEAD

Data from a total of 3499 thin sections analysed at KFL are currently stored in SEAD (fig. 2). The database has been prepared for ceramics data from other sources, and work with the SKEA ceramic consultancy (https://www.stilborg.se/) to further facilitate the addition of new data, as well as ensuring a smooth user experience for all potential users. KFL undertook the analysis of ceramics, for both research and contract archaeology, for more than five decades, work that now only continues in Sweden in private consultancies such as SKEA. The data generated over this considerable amount of time represents a valuable, and somewhat underused, resource for archaeology. Most of the data was previously only available via printed publications, ranging from consultation reports to doctoral theses and scientific journals. Through SEAD, these data are now considerably more findable and accessible as individual datasets. However, the most powerful benefit of integrating the data into an infrastructure like SEAD, is the ease with which data aggregation tasks can be performed, and the possibilities for synthesis research this offers (Buckland et al., 2022; Stilborg, 2021a).

The ceramics data in SEAD provides a good overview of fabric variation and its geographical distribution in Sweden. A subset of this can be used to investigate whether eastern influences can be seen in the use of organic temper in neolithic or later fabric traditions in Sweden Currently, these data include 85 thin-sections collected from organic tempered objects found at 38 different sites.

The tools used to examine these data were developed for extracting and analysing the fossil insect data contained within the same database (Pilotto et al., 2021; Pilotto et al., 2022). Numerous other examples from palaeoecology (e.g. mammals: Andermann et al., 2020; vegetation: Githumbi et al., 2021) also demonstrate the enormous potential for any field when making data from multiple sites available through a single portal. An overview of the scope of the ceramics data in SEAD has been presented by Stilborg (2021a), and an exposé of the Iron Age pottery data was provided (prior to import into SEAD) by Eriksson & Lindahl (2013).

Organic tempering traditions in Swedish prehistory

An early major Eastern ceramic craft tradition (from ca 20,000 BP) incorporates organic tempered fabrics – mostly plant material but even eggshells, bird feathers, bone, mussel shells and fish scales (Stilborg, 2017; Jordan & Zvelebil, 2009; Stilborg & Holm, 2009). The eastern tradition is intermixed through time and space across northern Asia with various stone tempered fabrics (mostly so in the western parts). However, as far west as the Baltic countries, Late Mesolithic/Early Neolithic pottery (from 6,000 BP) was dominated by organic temper (shell, fish scales, plant material; Dumpe et al., 2011). Until now, there has been no investigation as to whether this tradition continued into Sweden, or whether it can be seen to have influenced tempering traditions in this region. In the Baltic organic tempered

fig. 3. Photograph of an Early Neolithic sherd from Latvia, with the markings of a comb tool used in the building of the vessel wall, and characteristic of an Eastern ware tradition with roots in the Far East.

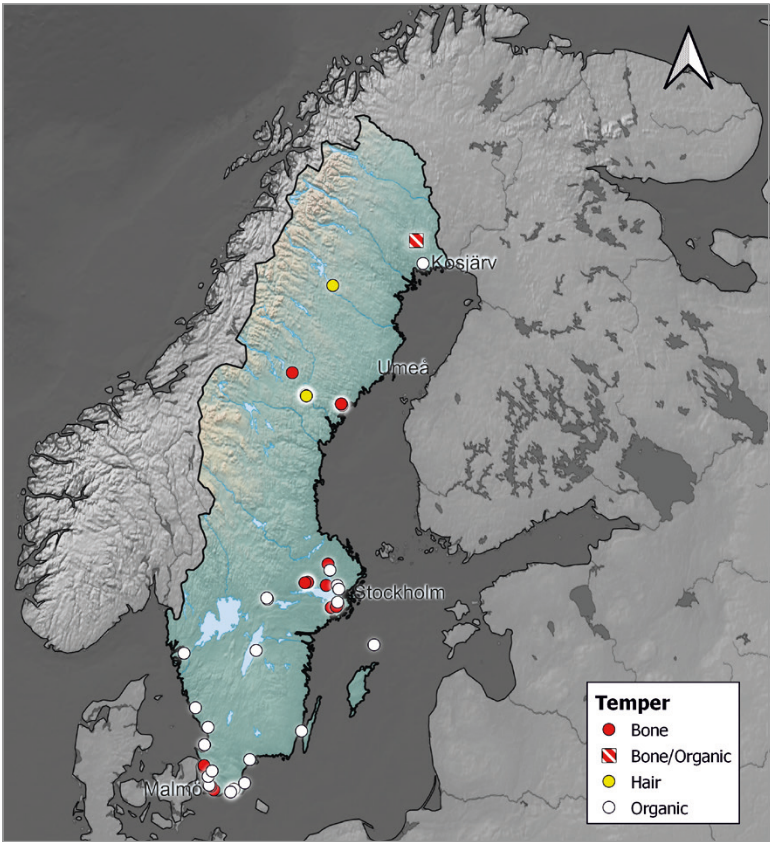

fig. 4. Distribution of 38 sites with vessels with organic tempering in Sweden. With the exception of Lillberget (striped square) in the north, all points represent sites with temper identified through thin section analysis. (Basemap: Natural Earth).

vessels we also see the use of a comb-tool for shaping the vessel walls, leaving fairly deep striations where the tool traces have not been smoothed over (fig. 3). This is most often the case on the inside of the pot. Similar traces are seen on older Far Eastern pottery (11-15,000 BP; Mckenzie, 2009, p. 177) and it seems to belong to the same craft tradition as the organic temper spreading slowly and unevenly from East to West. These special kinds of comb traces (which should not be confused with the comb-ornamented Comb Ceramic tradition) have so far not been found on pottery from Scandinavia. However, they are also missing from some of the other groups of organic tempered pottery in West Asia which are contemporary with the combed Baltic pottery. There is thus a possibility that organic temper influences from the east may have occurred in Swedish prehistoric pottery without the tell-tale comb traces expected from the neighbouring Baltic region. It is therefore important to take a closer look at the fabric variation to see if complex tempering recipes of eastern origin may be found in Swedish pottery.

In order to check for eastern influences in the Neolithic or later fabric traditions in Sweden, SEAD can be used to investigate the type, frequency and spread of organic tempering (fig. 4). In addition to the data on ceramic objects with organic temper in SEAD, another 3 recent datasets, not yet entered into the database, have been included. For this article, a few additional points of interpretation have been made on the basis of macroscopic observations that have not yet been verified by thin section analysis. These interpretations are, however, based on comparisons with previously analysed fabrics. The following sections will examine the evidence by temper type, and discuss their implications with respect to craft traditions and connections over space and time.

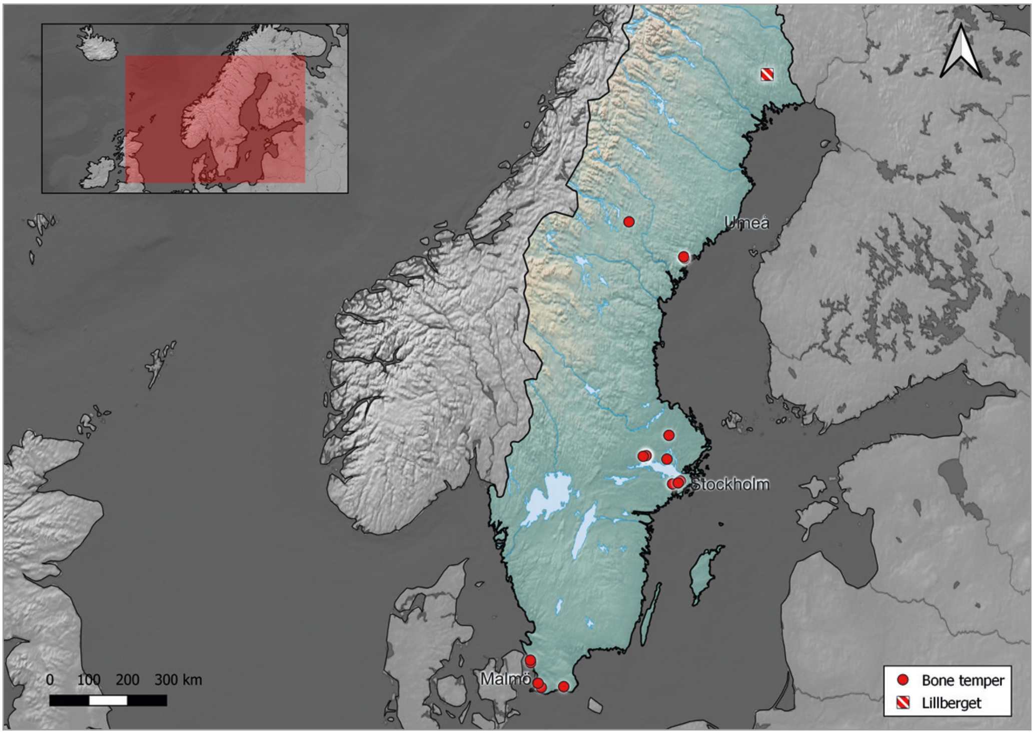

fig. 5. Distribution of sites with vessels with bone tempering in Sweden, as identified through thin section analysis, with the addition of Lillberget (striped square) where bone tempering has been analysed macroscopically. (Basemap: Natural Earth).

Shell, fish scales, feathers, hair and bone

In determining any kind of non-plastic material as intentionally added by the potter as temper, both the type, amount, grain size variation and the distribution within the fabric in relation to the naturally occurring constituents of the clay must be recorded. To identify a stone temper, the grains/pieces should have the same origin (i.e. crushed fragments of the same kind of rock) and have a grain size variation that sets the material apart from the natural non-plastics. For organic materials, more or less the same applies; amount and size range are important parameters. As plant fragments often occur naturally in the clay, background information on the natural variation in the local clays is required through raw clay samples (although the potential for use of non-local clays complicates this picture). For other organic materials (e.g. bone), the possibility of contamination from the environment where the pots were made must always be considered.

Shell fragments and *fish scales* may be found in the clay beds of dried out rivers, but most likely not in the amounts seen in some of the Baltic Early Neolithic (EN) fabrics analysed so far (Stilborg, 2017). On the other hand, individual feathers, as seen in Russian pottery fabrics (Kulkova & Gusentsova, 2012) and macroscopically observed in one fabric from the Comb Ceramic site of Lillberget (ca 5,000-4,600 uncal. BP; Bennerhag & Färjare, 2001) (fig. 4), may rather be contamination from the ceramic production environment. Likewise, small pieces of bone or larger singular pieces in a ceramic fabric could be unintentionally incorporated rather than purposefully added. Tempering with marine material such as shell and fish scales has so far not been identified in fabrics from Sweden.

True *bone* tempering has been ascertained in neolithic fabrics from across Sweden (fig. 5), from the Middle Neolithic settlement at Karlsfält in Scania (Hulthén, 1985) to the EN

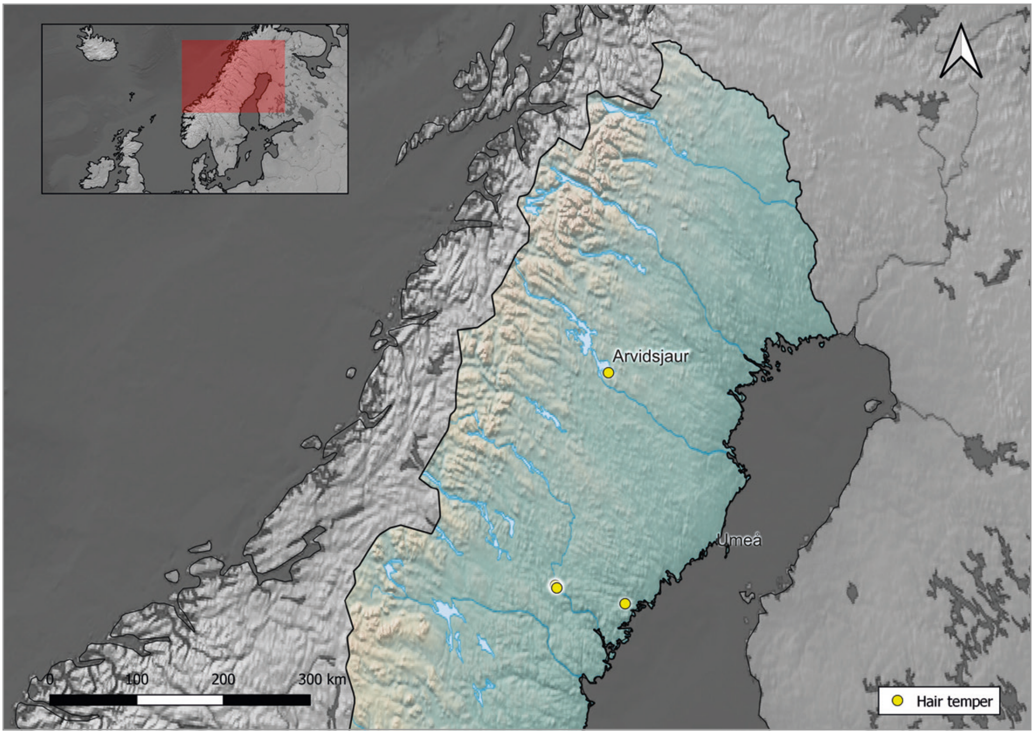

fig. 6. Distribution of sites with hair tempered pottery in Sweden. (Basemap: Natural Earth).

Comb Ceramic site at Lillberget, Överkalix, in the North – although the latter so far only macroscopically (Bennerhag & Färjare, 2001) (fig. 5). Even other types of organic tempering including plant temper have been identified in the same way in other sherds from the latter site. Across time, the spread of bone temper stretches from the Lillberget site (Bennerhag & Färjare, 2001) as the oldest to the Early Iron Age phases of minor settlements in Scania as the latest examples (Stilborg, 2006a; Stilborg, 2003). In between these extremes in time and space (within Sweden), there are various minor finds of bone tempered pottery. The later phase of the Pitted Ware Pottery tradition (ca 4,600-3,500 uncal. BP; Artursson et al., 1996; Larsson, 2009, p. 15 & pp. 72-80) in the middle of Sweden presents the most frequent use of crushed, burnt bone as temper. Even here, however, it represents a limited anomaly to the much more common use of crushed limestone (Artursson et al., 1996; Larsson, 2009, p. 15 & pp. 72-80), which is strange and remarkable given the very good technical properties of bone as a temper (Stilborg, 2001 with references). Bone tempering leads to a lighter ware that may have a lesser physical strength but functions well under the thermal stresses that a cooking vessel is exposed to. During the Iron Age in Scania, bone tempered vessels occur as singular incidents on some sites (Stilborg 2006a) sometimes clearly attached to metalcraft environments (Stilborg, 2003, pp. 126-129). Contemporary bone-tempered vessels in Denmark occur in graves (Stilborg, 1997, p. 258).

Hair has been identified in ceramic fabrics from Northern Sweden, both through microscopy of thin sections, identified as small round holes, often with a charred remnant of the hair straw (Hulthén, 1991, pp. 29-31), and macroscopically, where hair temper is revealed by very thin straw cavities in the vessel wall surface (Hulthén, 1991, fig 35). The bulk of the finds of hair tempered pottery seems to date to the Bronze Age and so far hair tempered fabric has only been found in the Northern part of Sweden (fig. 6). Normally, the fabrics analysed contain around 30% hair (volume), but another fabric group, referred to as either “asbestos- and hair-tempered” or “hair-tempered asbestos-rich” fabric adds to the complexity of hair tempering (Hulthén, 1991; Stilborg, 2017). Whether the asbestos in these fabrics is added as a temper, or the potters have chosen a naturally asbestos-rich clay is subject to current debate, but the hair – often occurring in small concentrations – must have been added as temper. It is, furthermore, interesting that the asbestos/hair-vessels (as well as the purely hair tempered vessels) most often have so called textile impressions on the surface. Hulthén has pointed out that this type of impression has some resemblance to the rope patterns found on Jomon culture pottery in Japan (Rice, 1999; Hulthén, 1991, pp. 21-22). These impressions could have been made by rolling a braided string – macramé – over the surface, and certainly the experiments conducted produce a surface very similar to the textile-impressed pottery of Northern Sweden (Hulthén, 1991, p. 21). That there could be a Far Eastern origin for the textile-impressed surfaces on the Swedish vessels dated to the Bronze Age (ca 4050-3350 BP) is suggested by similar textile-impressed vessel surfaces on hair-tempered pottery from the Yakutia area in northeastern Siberia (Okladnikov, 1970, p. 164; Hulthén, 1991, p. 28) from the Kola peninsula (Gurina, 1953, p. 76) and northern Finland (Carpelan, 1979, pp. 15-20), forming a possible east-west connection (even including some finds in Norway, Hulthén 1991, p. 32). However, other textile-impressed vessels from Estonia (Kriiska et al., 2005) and central Russia (Patrushev, 1992) were apparently tempered with crushed rock and shell, not hair or asbestos. More finds, research, and precise primary dating, is needed to confirm this theory, but this ware is a strong indication of craft connections with deep Eastern roots.

Plant temper

Similar to bone and hair temper, an admixture of plant fragments makes a vessel considerably lighter than the equivalent stone tempered pot. The ware will, however, be more fragile and have a poorer thermal stress resilience. For the fabric analysis, plant material poses some specific problems that the user of data from databases like SEAD should be aware of. It is quite normal that clay extracted from the ground just below the soil, or from a stream bank, contains a certain amount of plant fragments (e.g. roots) while wetland or lake clays may be naturally rich in fresh and decaying plant detritus. Other plant materials may enter the clay naturally during a longer storage period (e.g. wintering of the clay; Möller, 1999, p. 215). Thus a potentially plant tempered ceramic fabric should be compared with accessible local clays to see if the plant content in the ceramic clearly differs from any natural content in type, amount or size range. Small and well distributed fragments are generally more likely to be a natural component. However, with a temper of well-burnt dung, the potter may achieve almost as homogenous a fabric as Nature can, although this production technique takes both skill and a good deal of time investment. On the basis of Occam’s razor, the investment of such time to achieve something which is already present in nature seems unlikely, despite the human tendency to introduce unnecessary complexity into tasks for reasons of ritual or symbolism (see for example Rice, 1984, p. 241).

The Swifterbant pottery in Belgium and Holland provides a good example of the problems associated with identifying natural or anthropogenic plant based tempers. In contemporary pottery found in Northern France and Belgium, small rounded plant fragments in the fabric have been identified as pieces of a specific type of moss (Jan & Savery, 2017, pp. 163-168). In experiments, moss-fragments that are quite similar to the original inclusions (tested by thin section analysis) can be achieved by pulverising dried moss branches (Constantin & Kuijpers 2002, p. 776), but while the singular, charred fragments of moss are indeed very similar to the fragments in the prehistoric pottery (Jan & Savery 2017, fig. 7), it is very difficult to achieve the very homogenous distribution of the fragments seen in the prehistoric fabric (see the photos in Constantin & Kuijpers, 2002,fig. 7). This speaks in favor of a natural origin, something which would also be a much simpler solution from a ceramic craft perspective. We also know from geological surveys that organic rich clays are not uncommon around the Swifterbant sites in the Netherlands (Raemaekers & Stilborg, in press).

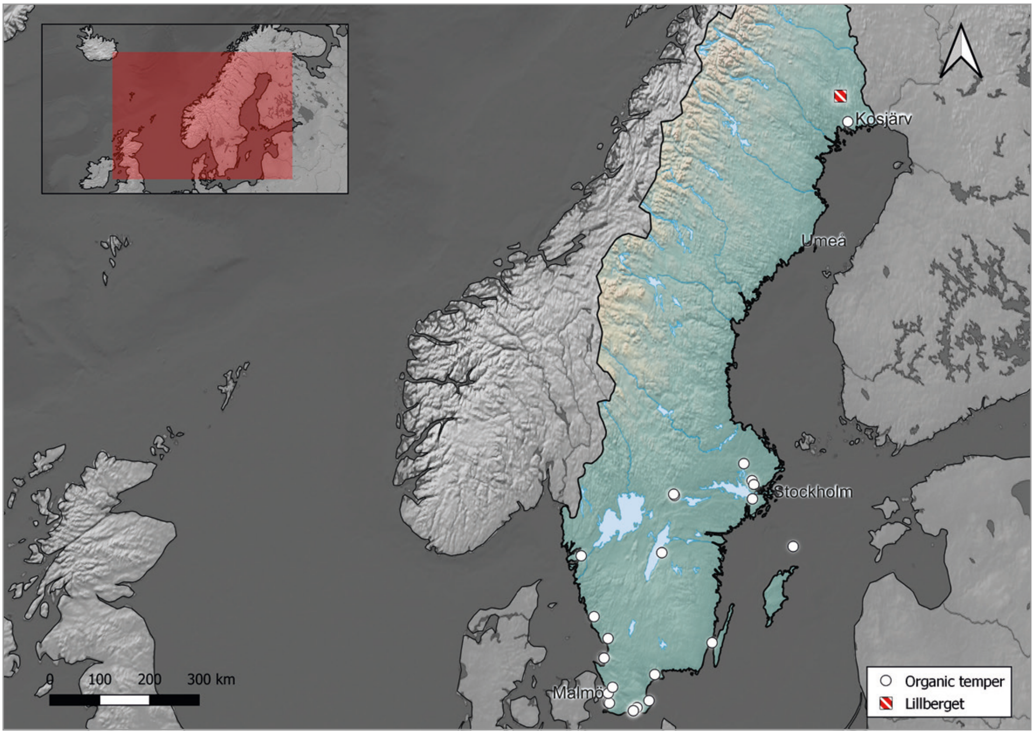

fig. 7. Distribution of sites with various types of organic temper identified from thin section analyses, with the addition of the Lillberget site where organic temper was identified through macroscopic observation.

In addition to this interpretative problem, another observational problem also hampers our ability to identify plant temper. Fragments of charred plant material and even the cavities they occupy in the ceramic matrix may have disappeared entirely in a well-fired, oxidised ceramic ware.

Plant temper occurs sporadically across time and space throughout Sweden (fig. 7). During the Neolithic, plant tempered fabrics appear (macroscopical observation) to be part of the fabric variation in the phase Typical Comb Ware (ca 4,200-3,800 BP) at some sites in the far North of Sweden (e.g. the Lillberget settlement; Bennerhag & Färjare, 2001; Stilborg, 2021b). In a petrographically analysed find of Late Neolithic Pöljä ceramics from the Kosjärv site, we see what could be a mixture of asbestos and organic (plant?) temper. As we cannot exclude that the few large fragments represent an accidental contamination, the fabric is not marked as plant tempered in the database (Stilborg, 2006b). Similar Pöljä fabrics have been found in Finland (Pesonen & Leskinen, 2009, p. 311) but so far not further east (Stilborg 2017, p. 662 with references). Among the fabrics of the Ertebölle culture pottery in the far South of Sweden (ca 6,200-5,500 BP), the fabrics of one vessel and two seal blubber lamps contain combinations of plant and crushed rock temper, and of grog (crushed fired ceramics, also called chamotte) and plant temper (Dumpe et al., 2011, p. 434; Stilborg & Holm 2009, p. 336; Hulthén, 1977, p. 26). A mixed crushed rock and plant temper has also been used sporadically for Middle Neolithic funnel beaker culture pottery in Scania (Karlsfält site; Hulthén, 1985) and Pitted Ware Culture pots in Eastern Sweden (Alvastra site; Hulthén, 1998). A very special and so far unique grain tempered fabric has been found in a Late Neolithic/Early Bronze Age-pot in Scania. No analysed sherds from the Bronze Age have been undisputedly interpreted as plant tempered, and the examples from the Iron Age are very rare (Stilborg, 2009, p. 160). From macroscopical studies, we also know of a few examples of chaff (straw and husks of grain) tempered pottery

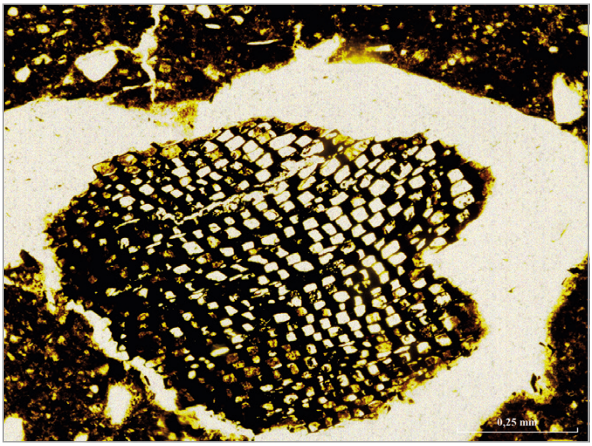

fig. 8. Charcoal in a ceramic thin section.

on sites in Scania (Stilborg, 2001). In the same period, it is very common to find daub and technical ceramics – such as the shafts of iron production furnaces, hearth lining and casting moulds – to be tempered with plant material (sometimes chaff).

Plant tempered fabrics subsequently occur in the Viking Age in Southern Sweden, without any known external influence (fig. 7). With one notable exception, all plant tempers in this group are combined with added crushed rock, grog or both rock and grog. The exception, a find from Old Uppsala in the county of Uppland (Bäck et al., 2017, p. 55), is peculiar in that it represents the only known vessel fabric tempered with charcoal (and granite) (fig. 8). It may well be a temper choice influenced by the local presence of activities using charcoal (e.g. smithing), rather than one based on ceramic fabric requirements.

Judging from the vessel fabrics analysed and some macroscopic observations, there may well have been a neolithic plant-tempering tradition in the northern and middle parts of Sweden, but otherwise the use of plant temper seems to have occurred very sporadically and almost always in combinations with other types of temper – mostly rock or grog – across Sweden and scattered through time.

Transmission or limited selective dialogue?

The fabric analysis data available through SEAD, with a few supplements from macroscopical observations, makes it possible to discuss the distribution of organic tempered pottery in Sweden and their potential relationships with influences from craft traditions in the east. In the data, we see a small number of Swedish parallels to the Late Mesolithic/Early Neolithic fabrics analysed from westernmost Russia and the Baltic countries. One of the clearest parallels is the hair-tempered, textile-imprinted pottery in the northern part of Sweden, which may have followed a northern trajectory with roots as far East as Japan. Even the macroscopically determined fibre-tempered (plant?) pottery at Lillberget and a few other northern sites might be seen as the result of eastern influences, while the rare incidences of plant temper in the southern Ertebølle pottery are too few to be proof of any contact. More importantly, the use of the comb tool (for the vessel construction – see fig. 3), which is connected with the organic tempering tradition across Asia from Central China to Latvia, has so far not been seen on any Scandinavian vessels. Thus, if the evidence available is reliable, something may have happened between the Baltic countries and Scandinavia to break off the Asian tradition or at least modify it strongly. While the comb-tool seems to stop in Latvia, the plant temper tradition could have transformed into the asbestos-temper tradition which predominates in Finland, and is important in the North of Sweden (Pesonen, 1996; Hulthén, 1991; Stilborg, 2017). In which case, at least this part of the tradition reached the Norwegian Atlantic coast in the West.

The more special temper choices of hair or bone seem to have histories which are both different from the other organic tempers and each other. The hair tempered wares in Norrland make up a significant but well delimited group both in time and space (probably with eastern roots); but this is still a group that needs more research. During the Iron Age, both the bone tempered and the plant tempered vessels are usually isolated finds or few in number, and so far we have no well-founded explanation for their occurrence. An avenue for future research would be to investigate whether these are special vessels used for making medicine. From ethnographical accounts we know that pots with this kind of function may have been made from special materials and in special ways (Roberts, 2000). Vessels used for making medicine must have been present in prehistory, but they have yet to be identified in the Scandinavian archaeological record. Such work could be enhanced by combining the methods described here with the identification of residues on the surface of the vessels (see e.g. Guerra-Doce, 2006), and potentially archaeobotanical analyses from the same sites.

Ceramic temper data in an environmental archaeology database – Round pegs into square holes?

The case study described above builds on the inclusion of semi-quantitative and qualitative data in a database which was primarily designed for handling quantitative data. Whilst the technicalities of this solution are outside the scope of this paper, the implications of, and lessons learned from both the process of digitising the data and using it in a "real world" research exercise are worth discussing. When working with quantitative data (e.g. macrofossil counts, uncalibrated radiocarbon dates), uncertainty can often be specified numerically (e.g. 5000 BP±50 years) or calculated from the numerical values stored in the database (e.g. mean and standard deviation of number of individuals of a species in samples from a region). Some forms of qualitative uncertainty are relatively simple, such as an uncertain identification (e.g. plant?, *Hordeum* c.f. *vulgare*), and are based on definitions supplied by accepted definitions of taxonomy and syntax. These are easily incorporated into a database as modifications that can be applied to ontologies. This is, however, not without its risks, as automated text matching or ontology parsing (i.e. comparing lists between databases) may strip these uncertainties when linking data – creating a false sense of certainty which is then transmitted into new conclusions.

The need for standardised lists of terms or ontologies in (archaeological) databases is now more or less universally accepted. These both help the research process by streamlining queries and international comparisons, and facilitate understanding (through definitions) for researchers unfamiliar with a discipline's terms. Examples abound, and include https://perio.do/en/ for defining cultural or chronological periods with respect to their geographical relevance (Rabinowitz et al., 2016), and the numerous lists created around the ARIADNE+ EU infrastructure for archaeological data (e.g. Doerr et al., 2016; Meghini et al., 2017). Translation between ontologies is not without its problems, however, as exemplified by disagreements on the equivalence of "grog" and "chamotte" (Quinn, 2013, p. 58). Considerable work has been put into systems for mapping between databases and ontologies, including through the expansive CIDOC Conceptual Reference Model (CRM) (Doerr et al., 2016). Type descriptions can also become problematic in international contexts, such as 'Selling type A1' designated a Western type (Selling 1955, p. 42) having different geographical connotations depending on where the material is from. Similarly, stylistic nomenclature is not always intuitive, and a Finnish-Ugric "design" can be made with clay from and in Uppsala (Bäck et al., 2017). Another problem with including interpreted results in a database is that of accepted interpretations changing over time. Asbestos, for example, was identified in our material as an added temper for over 40 years. Ongoing research, however, suggests that at least some of these fabrics are made from a clay with naturally occurring asbestos content ("natural temper"). This does not, however, exclude the possibility that some ceramic objects had asbestos added as a temper, and each object in the database will thus need to be re-evaluated individually. This could require a change in the database's metadata classifications to allow for different kinds of "natural temper".

No matter how comprehensive the database, there is no escaping the need to consult the literature around the phenomenon being investigated. This is not only to make certain that the data is relevant (in scope and level of detail) for the current research question but also for acquiring the nuances of interpretation and uncertainty that are perhaps not saved in the database.

Some other uncertainties are deceptively simple, but with fuzzy implications, such as locations (e.g. 5 km west of Umeå, or an unspecified distance from the nearest named settlement), chronological assumptions or open-ended interpretations (e.g. Iron Age, probably pre-Roman), or possible origins (e.g. most likely natural; probably non-local). Whilst these descriptive items can be easily entered into a text field in a database, they are more difficult to consistently display in an interface or use in a synthesis. Standard data formats such as DarwinCore inevitably rely heavily on notes fields or flexible object types to transmit these anomalies (if at all), but there is a strong possibility of the user overlooking their presence when mapping data in Geographic Information Systems (GIS), or when obtaining data through API's and linked data. There is also a qualitative aspect in catering for dataset modifications to incorporate "expert opinion" when describing distributions, such as the decision to include two seal blubber lamps (which could be classified as technical ceramics) in the narrative on Ertebölle culture pottery fabrics above.

Describing uncertainty for text based data may also be more complicated, and take the form of a narrative in publications. When the results of analyses are inconclusive, or open to interpretation at the present level of research, a decision must be made as to whether to include or exclude the uncertain interpretation in the database. For example, the fabric from Kosjärv was not marked as plant tempered in SEAD as this has not conclusively been proven with the currently available finds. However, it is still potentially true, and so included on figure 7 to indicate the *potential* spread of plant tempering should a positive conclusion be reached for this material. The authors have judged the uncertainty to be less substantial than the significance of including the point in the distribution map and discussion, and highlighted the different nature of the evidence through map symbology (the site is named). Whilst it is possible to build a system which specifies the degree to which any piece of data, be it numerical or text based, is reliable, this would be prohibitively complex (especially for data entry) if it was applied throughout the >30 analysis methods currently stored in the SEAD database. Users must therefore bear such limitations in mind when exploring and using the data, just as data managers must make and document decisions on the cut-off points between useful data and speculative interpretations. The future reproducibility of research based on these data is dependent not only on the persistence of the data, but also the documentation of its provenance and any modifications made during digitisation (e.g. Kansa & Kansa, 2013; Marwick et al., 2017).

It is perhaps natural to hold a database, or its creators and managers, accountable for any mistakes contained in the data. However, when, in this case, the data have been collated from over 40 years of research, and digitised from a variety of analogue sources authored by numerous authors, this may be unreasonable. The portal to the past inevitably includes mistakes made by the original data providers, and there is a good chance that records which would allow for a more thorough quality control (e.g. raw data files, analogue photographs, notebooks) are now lost. Synthesis research, such as that presented here, may, however, help identify any mistakes as anomalies in the expected distribution of sites and materials. In the research process behind this paper a number of mistakes were identified which have now helped ensure a better data quality for future researchers. For example, the samples of Iron

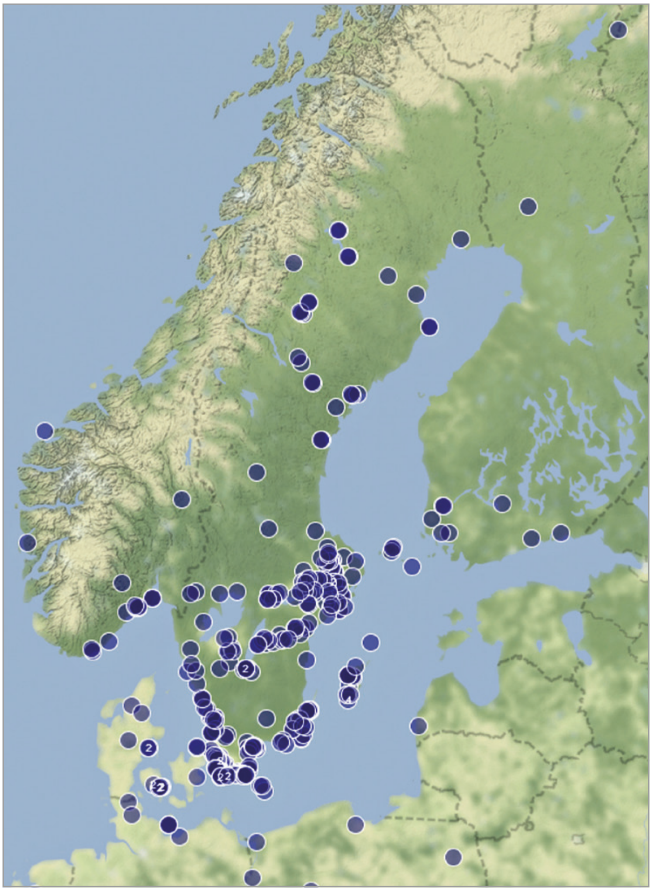

fig. 9. Screenshot of the Scandinavian sites in the ceramics portal in the SEAD online browser. (Image captured 29th May 2022 from https://browser.sead.se/ceramic).

Age pottery from Säby, Scania, were listed as plant tempered fabrics in SEAD due to data on the natural occurrence of plant fragments having been entered into the wrong Excel column during the digitisation process. This omission was only identified by the ceramics expert among the authors when a distribution map was produced. The act of using the database in a research context is essentially a proof-reading of the data, and appears to be as functional as teaching using case studies rather than using abstract examples (e.g. Mahdi et al., 2020). This has parallels within archaeology, such as the use of experiments instead of simply theorising about the production of an object.

Sampling and representativity

A cursory examination of the maps presented above may lead the reader to conclude that the use of organic tempers in Scandinavian prehistory was, with the exception of five sites, a coastal phenomenon (fig. 2). Comparison with the full Scandinavian distribution map (fig. 9) does little to dispel this deduction, although the almost linear tracks of sites across both northern and southern Sweden should raise the suspicion of any experienced field archaeologist; these are the paths of rivers (= hydroelectric plant construction), roads and railways. The latter two are also responsible for much of the sites located along the coasts, and it is a testimony to the importance of transport infrastructure, and thus contract archaeology, in the production of excavation data and thus most of the archaeometric data available. The spatial distribution of sites is clearly biased (Stilborg, 2021a), and thus conclusions on the regional variation of ceramic crafts should only be drawn in terms of broad spatial comparisons.

Similarly, there are chronological biases in the data which are based on regional and individual interests in particular periods or cultures (Stilborg, 2021a). In fact, the largest number of ceramic thin section analyses (in SEAD) comes from the Middle Neolithic of Southern Scandinavia (1369 records), followed by Viking Age (589) and Medieval (573) sites. Such background information is essential when interpreting site distributions over any region, as conclusions are always limited by the extent of the available sample. In this paper, we have examined the question of eastern influence on the use of organic tempers on the basis of published research. The inclusion of data from more sites east of Sweden into SEAD would increase the capacity of the database for supporting or testing these conclusions. However, the same issues of sampling bias would have to be considered, and probably on a considerably larger scale. Naturally, the involvement of experts on those regions would be beneficial.

Data versus metadata for ceramic thin sections

Whilst the database has a fixed relational structure, the contents of individual tables and columns are flexible and possible to repurpose as new needs arise. SEAD has a hierarchical structure, with the "site" (place of sample retrieval) representing the highest level, and analysis results representing the lowest level of recorded data. An abstract database entity called an "analysis entity" (in SEAD) for each individual analysis result (e.g. temper classification or radiocarbon date) represents the lowest common denominator, and connects all data and metadata from the same object (e.g. ceramic sherd, soil sample). This entity also allows the same type of data or metadata from multiple objects to be aggregated, thus facilitating the type of synthesis work presented in this paper. The boundary between what is considered "data" or "metadata" can become fuzzy in interdisciplinary research and the multi-purpose databases designed to support it (Buckland et al., 2022, p.19). "Data" is most usefully defined in the eyes of the research community which created and uses it. In SEAD, the quantification and classification of the contents of ceramic thin-sections are considered "data", as these elements provide the basis for research on the fabric composition of the ceramic object. Any notes made on the superficial aspects of the ceramic object itself (e.g. glaze, decor, form, stamps, design), although relevant to any inferences made, are considered "metadata". In another context, such as a typology or form oriented database (e.g. Smith et al., 2014) or other dedicated ceramics database (e.g. http://potsherd.net; Tyers, 2015), these metadata might be considered primary data. This differentiation, whilst important and non-trivial when describing the FAIRness of the data (Wilkinson, 2016), also has practical implications for how the database can be queried. While the "data" will be stored in a way that enables more efficient and complex computational tasks, the "metadata" might instead be represented as descriptive texts not easily reduced into searchable terms. The aggregation of "metadata" across multiple sites may also be more problematic, as the use of standard ontologies cannot be guaranteed over multiple decades and data creators. These issues are not necessarily an effect of digitisation, but may be traced back to the lab procedures for recording data, and fundamentally a consequence of these determinations being cultural historical interpretations rather than categories created to facilitate efficient database storage or connectivity.

Upscaling ceramic thin section research with the help of multi-site databases

Synthesis research using large-scale online databases and research infrastructures has much in common with working with small-scale personal databases (e.g. single site or desktop systems). Both workflows may rely on similar tools for analysis and visualisation (although not necessarily applied in the same way), and interpretation is dependent on the character of the underlying data and the scope of the research questions. Research transparency, including the provenance of raw data and metadata, as well as method descriptions, are equally important for conducting open science at any scale. There are, however, some important differences which both limit and enable in the research processes. A personal database (using e.g. MS Access, Excel) may be more flexible in terms of entering data and creating custom queries for data extraction or processing. Ad hoc solutions (e.g. task specific code modules or temporary data tables) and limited documentation are usually more viable when there is only one or a few users. This flexibility may enable both rapid changes and enhance productivity. The same flexibility is not available in ~~a~~ large-scale (centrally managed or distributed) infrastructures. In order to ensure high data quality, reproducibility and FAIRness, an infrastructure benefits from a stable database structure, consistently available API's, and standardised routines for data entry, ingestion, quality control and updates. A rigorous testing of new code prior to deployment is not conducive to rapid solutions to new user needs.

There are also a number of important caveats to using large databases, for which any user must ensure that they are prepared. Data portals and infrastructures, while powerful data-discovery, exploration and synthesis tools, are most often not designed to provide the complete picture. Compromises are regularly made with respect to the finer details of manually recorded data, especially text notes or notations of uncertainty, to ensure adherence to the database structure or commonly accepted formats or ontologies. The design thinking and original or primary purpose behind any database system, although the project may develop over time, may still influence the scope, detail and presentation of data. As SEAD was primarily designed as an environmental archaeology database (Buckland et al., 2018), unintentional biases may arise in the digitisation of thin section data, especially considering SEAD's focus on quantitative data. The database structure was modified to accept the ceramics data types, and a new portal was created (https://browser.sead.se/ceramic). At the time of writing, however, the API for machine access to the ceramics data is still at the planning stage, and this severely restricts the flexibility for use in GIS and statistical software. The user must either have database access or download the database for more advanced analyses, drawing on database querying skills or cooperation with those who have them.

Whatever the access route to data, the expert must always exercise due diligence when aggregating and interpreting data from multiple investigations, undertaken by multiple analysts. Some of these challenges are compounded in an interdisciplinary database such as SEAD, where different types of data from different fields require different data management approaches (e.g. data entry forms, export formats, visualisations). The benefits of being able to query, visualise and extract multiple lines of evidence in a single system, however, hopefully outweigh the difficulties involved in maintaining such a system. This does not, however, in any way negate the importance of experts in each of the fields covered by the database. Only the domain experts can provide insights into the nuances of the data, as well as feedback on the analysis and visualisation facilities required for current and future research.

Future directions

There is still a tendency in archaeology for each expert to author their own section of a report with little cross-reference of the other lines of evidence available. Ceramological analyses provide valuable insights into an array of human activities (e.g. pottery techniques, trade, material use, food preparation). These interpretations could potentially be better understood in the context of palaeoenvironmental reconstructions for the same period, and the use of a common database has enormous potential for multi-proxy analyses. If more data from different proxies (e.g. archaeobotany, fossil insects, pollen, geoarchaeology) from the same sites is available, then the scope for establishing statistical significant connections between human activities could increase dramatically.

In the future, with more data entry, the SEAD database could allow for the coupling of information from thin sections and geochemical analyses on the same objects. Geochemical analyses, such as the use of X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS), have increasingly been used in parallel to the mineralogical examination of the thin sections forming an even more encompassing data set (Maritan, 2019; Rose, 2013). Whilst geochemical data may be quantified as spectra, the dataset presented in this paper consists mainly of categorised information on the character of the natural non-plastics in the clay and the type and quality (amount and fineness) of added temper. These data types are not easily compared, and, coupled with the difficulties in comparing the results from different XRF analysers, there are considerable challenges to making such a variety of data accessible in a meaningful way. Thought, rather than blind use, is always needed when making such comparisons.

Despite the pitfalls, large-scale databases nudge researchers to think along larger, general lines. The most immediate benefit of collating dispersed data in a single database is the rapid overview which it provides, but it also challenges us to critically evaluate the data and the reliability and meaning of these overviews. It stimulates the creation of new research questions to deal with overarching issues which (in our experience) are often dismissed as less relevant from the perspective of single site-level interpretations. To return to our initial metaphor, the portal is not only a point of entry to an amassed storage of data, but also a way to level-up our approach to the analysis of archaeological data itself.

Authors' statement

Conceptualization and methodology: Ole Stilborg and Philip Buckland; Data collection and curation: Ole Stilborg and Mattias Sjölander; Data analysis: Ole Stilborg and Mattias Sjölander; Writing and review of the Original Draft: Ole Stilborg, Mattias Sjölander and Philip Buckland; Visualization: Mattias Sjölander.

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