Introduction: Ceramic Studies and Petrographic Analysis in Levantine Archaeology, the Limitations of Current Approaches

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Keywords: Northern and Central Levant; ceramics; petrography; geochemical fingerprinting of ceramics; large-scale data integration

Abstract
By way of an introduction to this volume, we seek here to provide a brief review of recent approaches to ceramic studies in Levantine Archaeology, and to the way that the results of laboratory-based investigations have been integrated within these. As we are interested in using ceramic data to address questions that extend beyond single-site studies, we pay particular attention to the information potential offered by the large-scale integration of ceramic and petrographic data from multiple archaeological projects. We will begin by highlighting some of the weaknesses of traditional approaches to pottery in Levantine archaeology and how these have continued to limit the interpretive potential of ceramic data. The strengths and weaknesses of petrographic research in the region to date will be discussed, and observations made regarding the use of petrography and geochemistry to address wider issues. The question of how new approaches, and the large-scale integration of ceramic data, might be used to address key social and economic questions in Levantine archaeology will form the subject of the concluding paper of this volume.

Introduction

Ceramic studies have long been a core element of archaeological research in the Near East. Pottery became ubiquitous in the archaeological record of the region from the Ceramic Neolithic onwards, and in combination with its resistance to post-depositional processes, it, (along with lithics) might be viewed as the most reliably preserved aspect of the regional material culture. Yet, with regard to the utilisation of ceramic data over the past 40 years, in the main, researchers in the Levant have focused upon a few basic themes: chronology, typological development, and the identification of regional associations of style/fabrics. The latter offer a basis for understanding ceramic distributions, but as they often take the form of individual case-studies, they may struggle to address wider regional perspectives. These themes are interconnected of course, in that they are all intended to support the definition of coherent analytical units, which will aid subsequent understanding and interpretation. Various commentators have questioned the validity and usefulness of these approaches and therefore that of the resulting organisational units (Badreshany *et al*. this volume, Philip 2014; Philip and Baird 2000; Dessel and Joffe 2000). While work on these core themes is foundational and necessary, it is ultimately intended to serve as the basis for new and ambitious studies of economic and political organisation, inasmuch as these can be addressed through ceramic data. Despite an ever-increasing volume of ceramic data, with a few notable exceptions, attempts to understand the evidence in social and economic terms are rather less common that one might hope (but see Roux 2015; Baldi and Roux 2016; Samet and Yasur-Landau 2016). This might in-part explain the rather limited interest among younger researchers (in the UK at least) in the study of ceramics, as opposed to, say, isotopic analysis, GIS-based studies, or the various sub-fields of environmental archaeology. As the immensity of ceramic data makes it an exceptionally valuable resource, we must ask why scholars working in the Levant have generally failed to realise its full explanatory potential? The contrast with the Aegean is striking; changes in scholarly approaches to pottery in that region over recent decades have been usefully summarised by Sherratt (2011). Key differences in approach include the much greater scale of petrographic research in the Aegean and the related efforts to integrate ceramic data at a regional level (e.g. Gauss and Kiriatzi 2011). The region has also witnessed the exploration of a range of research questions that address ceramic production and distribution (Day *et al*. 2010), vessel usage (Day and Wilson 2004), and in recent years both the spread of technology (Jeffra 2013; Knappett 2016) and the development of learning networks (Gauss, Klebinder-Gauss and von Ruden 2015).

Two decades ago, Philip and Baird (2000: 1-2) assessed the situation with specific reference to the southern Levant, though their remarks were applicable to the Near East in general. They concluded that variations among field projects in the treatment of ceramics (recording systems, attitudes to quantification, etc.), adherence to generalised terminologies that emphasised region-wide unity over localised detail, and the lack of direct inter-assemblage comparisons, itself a result of the hectic pace of fieldwork and contemporary political realities, restricted efforts to integrate work across projects, and thus maintained a focus on more traditional themes and approaches. If we add to these the great time commitment required to fully digest and extract information from ceramic datasets, and the practical limitations imposed by both geography and time (in particular increasing academic workloads in the university sector and the sheer volume of salvage excavations undertaken by local antiquities staff), we can begin to identify some of the barriers to meaningful engagement with multiple assemblages.

The result has been a climate the serves to encourage project-specific studies and research agendas, while restricting the potential for inter-assemblage comparative work. There exists a marked focus on localised themes (e.g Burton *et al.* 2018, Badreshany and Genz 2009) and, in a Levantine context, a lack of significant integration between information derived from ceramics and that from other data classes. For example, few regional surveys routinely undertake petrographic studies on their ceramics, while the application of organic residue analysis to excavated pottery remains unusual (but see Assaf-Landau *et al*. 2018).

While rich localised datasets from good contexts are essential if we are to move beyond overly-generalised and normative models, their lack of accessibility to others has hindered a move towards robust region-wide interpretive frameworks, and restricted the ability of ceramics to be address 'big picture' questions. Philip and Baird (2000: 9) also raised the potential of petrographic and fabric data to contribute to the formulation of new questions, and the current authors believe the key steps required, if we seek to move ceramic studies forward, include:

1. a greater the number of datasets treated using a combination of macro and microscale analysis;
2. these being integrated with a *chaîne opérotoire* based approach to vessel production (Jeffra 2015; Roux and Courty 2019);
3. that the resulting data are made widely accessible to other researchers.

In the time since Philip and Baird's (2000) assessment, a range of technologies has made the digitisation and communication of large-scale datasets possible. We believe that these can be used to reinvigorate interest in ceramics and situate them within broader research frameworks. So doing will allow us to correct the imbalance between the effort expended on ceramic analysis and the relatively modest level of information that this often provides (Philip 2014: 36). This will necessarily require new integrated approaches and the mobilisation of new technologies to facilitate a much increased degree of communication and connectedness between researchers, along with the addition and development of new theoretical perspectives for our interpretive 'toolkit'.

The papers in this issue (with the exception of Sowada *et al*. which was included because it addressed closely related issues) originated in a workshop entitled '*Towards an Improved Integration of Ceramic and Petrographic Datasets in the Prehistoric and Bronze Age Levant'* which was held at Durham University in July 2015. This formed part of the project Computational Research on the Ancient Near East (CRANE), funded by the Social Sciences and Humanities Research Council of Canada. The aim of the workshop was to bring together those working specifically in the Central and Northern Levant, and who were actively engaged with ceramic petrographic research, to discuss ways in which we might better understand and communicate data with each other. The workshop provided a forum for discussing ways to integrate the diverse pottery, petrographic, and geochemical datasets with which we deal and that is essential if we are to understand long-term developments in the production and distribution ceramics across the Levant. The resulting volume thus provides the first substantive set of archaeometric papers dealing with the Prehistoric and Bronze Age archaeology of the northern Levant.

Moving Forward

Ceramic petrography has a long history in the region, with the Northern Levant the context for some of the earliest work, that focused on the Amuq plain (Matson 1945, Braidwood & Braidwood 1960). In recent decades, however, most substantive petrographic and analytical research projects on ceramics have been focused upon the Southern Levant. However, the Central / Northern Levant offers an excellent focal point for developing new integrative approaches. There are comparatively few scholars conducting petrographic research, but their work is spread over a wide geographical area. In addition, traditional frameworks, of the kind that have held back work in the south by forcing new data into outdated analytical categories (Dessel and Joffe 2000: 36-44), are less evident in the north. This is partly because there is a smaller quantity of legacy data, and thus of the widely propagated inaccuracies that arise from such material (see below).

An opportunity, therefore, exists to develop analytical protocols and frameworks from the ground up relevant to localised archaeological datasets, with workshop participants taking the lead in establishing these across the area through the publications in this volume. Their work will serve as a solid basis for future development. The papers presented here establish approaches and perspectives that are relatively new to the region, certainly on this scale, and the volume as a whole seeks to set an agenda for work on ceramics in the Near East. We do this by using this new data to address questions relating to modes of production, the economy, and the sharing of ceramic technology, work that should point towards a new research framework. The volume will also serve as reminder of the great potential of archaeology in Syria, and that its rich artefactual datasets will continue to reward research despite the impossibility of fieldwork.

But how can we manage the large-scale integration of ceramic data? In our view, the key to utilizing these resources effectively is to facilitate ease of accessibility, integration, and communication, despite a lack of standardization. Discussions at the workshop considered ways in which we might accomplish integration in ceramic and petrographic data in practice, and so increase their accessibility to a wide community of scholars. These were centred on three main areas.

Firstly, we agreed that efforts to impose a prescriptive system for recording and describing data would fail; no ‘one-size-fits-all’ system could be established and adapted to the needs of every project without favouring the creation of generalized datasets at the cost of localized nuance. We agreed that any widely accepted system could be employed, as long as the parameters were made clear, or referenced in the publication, as has been done throughout this volume. In practice, this is easier for petrographic work than macroscopic analysis as thin-sections offer fewer miscellaneous parameters when compared to macroscale ceramic data where attributes are to some extent dictated by varied notions of style. Here, the authors suggest that a loose performance-based, rather than prescriptive, framework could serve to marshal groups of scholars towards shared objectives. To give one example of our intent, every petrographic description should clearly describe grain-size and shape as two among a number of parameters. The terminology and specific descriptors used, however, can be decided by the individual, as long as the system is clearly referenced. Of course, in the vast majority of cases, the use of a commonly accepted well published descriptive system would be most appropriate, and is recommended. For petrographic data, Quinn (2013) has established itself as a standard reference among petrographers, and we suggest that the example descriptions in his Appendix A.1-A.3, can function as a basic framework for the types of information that should be included in a petrographic description. The parameters can, of course, be adapted to suit the needs of individual sites and projects.

Secondly, we believe that we can capitalize on new technologies to build higher quality digital datasets and create online appendices, and thus provide the wider research community with access to data on an unprecedented scale and level of detail. A key issue raised by workshop participants is that while petrographic descriptions from various projects could be utilised to certain extent to compare samples and integrate datasets, good images are at least as important as written descriptions for comparative analyses and efforts to reduce uncertainty. Typically, it has been normal practice in publications, to include one or two plates of photographic images of ceramics or thin section micrographs (mostly in black and white). However, with more journals now published online and a growing number that offer facilities for online appendices, it is now possible to include a much greater number of high-quality colour images with a publication. An array of software options now exist for stitching together images of thin-sections, providing unprecedented level of detail of ceramic surface features (e.g Reflectance Transformation Imaging), and for building high-quality 3D models (e.g agisoft metashape). The potential now exists for giving a community of scholars unprecedented accessibility to the entirety (or a large subset) of a dataset. For example, two recent studies which include ceramic petrography, Schmitt *et al.* (2018) and Badreshany *et al.* (this volume) provide an online appendix representing the complete dataset. This includes detailed images and drawings of every sherd, stitched extensive micrographs with scale (measuring at least 1 x 1 cm^2) of every thin-section analysed, geochemical data, and in the former, 3D models representing every type. A number of contributions to this volume have made use of the online appendix, or included a large number of good colour images. We encourage scholars interested in ceramics and artefact studies in general to keep in mind the greatly increased level of accessibility and integrative potential afforded by digital media when publishing new data, and to endeavour to make use of online facilities where possible.

Thirdly, good links and communication should be established and maintained by groups of like-minded scholars. Since 2015, a great deal of cooperation has developed between those who attended the workshop, greatly benefiting ceramic research in the region through the production of number of publications (Vacca *et al* 2018.; D'Andrea *et al. in press.*; Genz *et al. in press*, with others planned (Badreshany *et al.* in prep). Advances in digital technology affords scholars worldwide the ability to share data and establish dialogue. There are practical limitations, of course. The sharing of unpublished or raw data for previously published studies may make some uncomfortable, and the political realities of the region renders direct contact between some scholars impossible, but it is our view that widespread cooperative engagement is essential to progress in the field, and should be established and encouraged where possible. A hopeful sign is the trend in towards greater interconnectedness and data sharing demonstrated through initiatives such as CRANE and the Levantine Ceramic Project (https://www.levantineceramics.org).

Our hope is that following the guidelines presented here will allow for the creation of flexible descriptive systems and terminologies capable of communicating effectively the nuance and complexity of individual datasets and this, along with the use of new forms of digital media, will serve to enable the integration of ceramic data in such a way as to encourage the development of robust 'big picture' narratives in the Levant. The current situation is almost the opposite with overly generalized classificatory systems having been adopted across large regions; "Dark-Faced Burnished Ware" and "Caliciform Ware" are two such examples. Such schemes may serve to classify material at a very general level, but often lack sufficient detail to enable the evidence to be interrogated in a range of ways, by a wide community of scholars.

The Strengths and Limitations of Current Approaches to Ceramics Utilising Petrographic and Geochemical data

It will be useful to survey a selection of previous approaches and suggest how we may improve the integration of petrographic and geochemical data with ceramic evidence obtained at the more traditional macroscale, to increase their explanatory potential. The focus here will be petrographic and geochemical approaches utilised in the Levant, but the issues discussed are applicable to the whole region. As most petrographic work carried out in the Near East has been undertaken on material from the southern Levant, this serves as an indicator for the potential of microscopic ceramic datasets in broader research. Influential authors such as Yuval Goren, Naomi Porat, and Shlomo Shoval who have been publishing on the topic since the 1980s have led the way, by both training a new generation of scholars directly, and encouraging others through numerous publications (e.g Goren *et al.* 2004; Porat 1989; Greenberg and Porat 1996; Shoval 1988) that have underscored the potential of petrographic research to address archaeological problems in the region.

As a result, petrography has proliferated through the southern Levant and is (in part through the CRANE project) gaining a stronger foothold in the Northern Levant and elsewhere in the wider Near East (Boileau 2005; Daszkiewicz *et al*. 2012; Fragnoli, and Palmieri, 2017; Maritan *et al*. 2005; Santarelli 2013). As a ceramic petrography element is found on a number of projects throughout the Southern Levant, a comprehensive survey is beyond the scope of this article. Therefore, we will organise the research conducted into thematic and methodological groups. In addition to Goren and Porat, several recent authors have been notably prolific in this regard, and alongside the now-traditional production of short reports, have used ceramic analysis to address significant cultural questions (Ben-Shlomo 2006; Boness *et al*. 2015; 2016, Cohen-Weinberger and Goren 2004; Cohen-Weinberger *et al.* 2017; Gilboa, *et al*. 2015, Iserlis 2009, Iserlis et al. 2015, 2019; Maeir, et al. 2019; Waiman-Barak *et al.* 2014). However, it is worth stating that despite great interest in petrography, the vast majority of research has been published by a relatively small number of scholars.

The great strength of the dataset from the southern Levant is the sheer range of fabrics that have been described in the literature, and which can be mobilised for comparative analysis. An example of this is *Inscribed in Clay,* Goren's petrographic study on the Amarna tablets (Goren, Finkelstein, and Na'aman 2004), which while found at Amarna in the Nile Valley, ostensibly originated from locations across the Near East. Although the work is focused on the Late Bronze Age and on tablets rather than ceramics, it usefully highlights the types of clays and material utilised in the LBA in various parts of the Levant, and can serve as an indicator of the kind of clay/temper combinations that we might expect within a given area across much of the pre-classical Near East.

Despite the availability of so much data, the substantive integration of multiple petrographic datasets (even within the Southern Levant) to address 'big-picture' research questions remains rare. Scanning the literature, one obvious factor is the existence of great variation in the quality and detail of publication. In some cases, only a sentence or two including fairly vague descriptions are provided to the researcher. An example is the initial assessment of the production location of Black Wheelmade Ware (which occurs in the Early Bronze Age IV in northern Palestine and Lebanon) by Goren which ascribed this type of vessel to Lower Cretaceous formations in Lebanon. The basis of this claim is not clear, however, as only a couple of lines of qualitative description were provided in support (Greenberg *et al.* 1998: 23) and this largely unsupported conclusion was to become a 'factoid', that was repeated in the literature until disproven by more recent investigations (Bechar 2015, Genz *et al* in press). This case illustrates the importance in literature of developing conclusions based on well-presented and well-supported evidence, rather than a reliance on 'expert opinion', both for enabling critical independent assessment by the reader and for supporting the progression of future research.

If the guidelines for the description of petrographic data laid out above, are followed moving forward, we hope that published data can be more easily verified and utilised by other researchers. This example, however, raises another issue that has negatively impacted upon both ceramic and petrographic analyses. This is the point that even where the data itself was not usable because of a lack of published detail, scholars still accepted and propagated the conclusions, because of their trust in 'expert opinion'. In ceramic petrography, this situation no doubt was more problematic in the past because of the difficulty of accessing published or unpublished data; it will hopefully recede as digital technologies allow the large-scale presentation of primary data. A limited understanding or engagement with the pertinent geological literature, and/or a lack of geoprospection has also been problematic, resulting in generalisations, or overly confident interpretations of, petrographic data, often by scholars who may never have visited a particular area, and so have no first-hand understanding of its geography. A number of inaccuracies thus exist in the published literature and it is our view that some published petrographic studies from the region should be utilised with caution, in particular those where descriptions are vague, images unclear, and reference to the published geological literature poorly integrated. One solution for legacy and newly published data is the consultation of primary geological/geographical sources and discussion, where possible, with researchers familiar with particular areas.

Inscribed in Clay, showed that the clays and tempers used and treatments favoured by potters were employed in multiple regions which may render some fabrics petrographically indistinct (see Kennedy *et al* this volume for an example). Levantine geology can indeed be distinctive and representative of specific areas, but large formations of similar composition also extend across the whole region. The presence of Globigerina, or microfossils, associated with chalks (see Dubertret 1955) is often cited as evidence of a Lebanese origin by those working on South Levantine material. However, similar outcrops containing Globigerina and other planktonic foraminifera exist throughout the Eocene series of the southern Levant (Hall *et al.* 2005: 438 fig 18G1; Sneh 2016).

These geological similarities should facilitate data integration, but the rock types, formations, and members often carry different names. To use a well-known example, the term 'Ramleh' in Lebanon and Syria, is equivalent to 'Kurkar' in Israel, with both describing the well-known calcareous sandstone found along the eastern Mediterranean seaboard, materials that are often indistinguishable as they were formed under similar conditions. The situation can be more complicated for other types of geological formations and their associated clays. We must accept, therefore, that petrographic data alone can only take us so far in terms of provenance. This is exemplified by the two studies in this volume dealing with coastal Lebanon in the EBA (Badreshany *et al* and Jean) where the petrofabrics utilised for combed wares at Arqa, and in the area of Byblos, are indistinguishable by standard optical microscopy.

A number of scholars have turned to geochemistry (e.g. Badreshany *et al* this volume; Iserlis *et al.* 2019), which should provide distinct chemical fingerprints and has been shown capable of distinguishing between pots made of similar clays originating in different areas. For example, recent work on samples of EBA combed ware originating at Arqa, in the region of Byblos, and in Egypt (Badreshany *et al* in preparation) has demonstrated that samples composed of quite similar petrofabrics can be distinguished using geochemistry. Geochemical methods present great possibilities, but a range of issues regarding their proper use should be addressed (see below) to help guide the current proliferation of applications towards the establishment of genuinely useful datasets. What remains abundantly clear is that a macro/microscale *chaîne opératories* approach is required to get the best out of ceramic data (e.g. Jean this volume).

Thematically, ceramic petrography has overwhelmingly been focused on provenance, no doubt conditioned by a desire to establish or reinforce regional associations of style/fabrics, and establish interregional patterns of exchange. Necessarily perhaps, most studies focus detailed attention on one-site/area (e.g. Badreshany and Genz 2009; Burton et al. 2018; Greenberg and Iserlis 2014, Iserlis et al. 2012; Schmitt et al 2018; Waiman-Barak et al. 2014). Such datasets are essential for further research, but the data can be mobilised towards broader aims, if it can be incorporated into more geographically extensive datasets. There have been some recent studies that draw upon multi-site interregional datasets

(Badreshany 2013, *Badreshany et al.* this volume, Bettles 2003, Graff 2006). These tend to be more ambitious in their use of the ceramic data to explore important socio-economic themes, such as long-term changes in modes of production and distribution, and understanding the role of ceramics (and what they contain) in social practices.

Here, we have argued a true integrated *chaîne opératoires* approach is needed to make the most of the ceramic data, but it is often the case that studies betray a lack of integration between those studying the macroscale ceramic data and employing microscale data. The complex relationship between the numerous fabric types created by the excavators, and the far smaller number of fabrics identified through petrographic analysis (Maritan *et al*. 2005) is well illustrated by Iamoni's (2012: 94-5, Table IV-3) work on the Bronze Age pottery from Qatna. This case is far from being unique, and too often, in practice, petrofabrics are weakly linked to the typological information, and/or may significantly cross-cut macroscale ware classifications. A lack of integration between petrographic and macroscale data severely limits the explanatory potential of ceramic analysis. Studies might focus on technological development, for example, but fail to make the connections to major changes in morphology and style, all of which may be interlinked, and when taken together provide a greater appreciation of the social role and significance played by pottery. The majority of the papers in this volume are the product of very close work between specialists that have studied the macroscale data, and those focused on the microscale (if they are not the same person) and show that successful integration is possible, beneficial, and should be prioritized.

A cautionary word on Geochemistry

We have already noted the potential that geochemistry offers for augmenting petrographic data. Ceramic projects utilizing SEM-EDS, ICP-AES and -MS, lab-based XRF, portable -XRF (pXRF) or other forms of elemental analysis are still relatively rare in the Levant though increasing rapidly (Badreshany 2013, *Badreshany et al. this volume,* Bettles 2003, Burton et al. 2018; Frahm 2018, Iserlis, et al. 2019, Kennedy *et al. this volume,* Schmitt *et al.* 2018,). A number of earlier works utilized NAA and PIXE/PIGME (Esse and Hopke 1986, McGovern 2000), as have some more recent projects (Zuckermann et al. 2010; Gilboa et al. 2015) (see Sowada 2009 for a comprehensive overview). This list is not meant to be exhaustive, but seeks to cover key studies, and give a sense of the range of techniques applied.

Two of the works in this volume (Badreshany *et al.* and Kennedy *et al.*) utilise ICP - AES and –MS, while two others use laboratory-based WD-XRF (Mouamar and

Neiuwenhuyse *et al.*). All four contributions demonstrate the richer interpretive potential gained by the inclusion of geochemistry. Both techniques are capable of providing data for about 40-50 elements, although ICP has the advantage of providing the best trace element data, and might be viewed as a 'gold standard' for trace element geochemistry. The per sample cost is relatively high (though not exorbitant). WD-XRF is generally lower in cost and can provide the very best data for the Major elements, when fused beads are used (see Mouamar), and very good trace element data if samples are pelletized. Both techniques require dedicated laboratory facilities and a level of expertise sufficient to operate the equipment, so the associated data is often reliable.

For all the great potential of geochemistry to enrich our current datasets, there is, likewise, quite some potential for the creation of invalid interpretations based on erroneous data. Our discipline will benefit as a whole if scholars improve their understanding of the proper use of such techniques, and thus the production geochemical data. The major issues lie with the generation, and interpretation of data by those lacking the experience necessary to do so. This is especially problematic with the proliferation of pXRF, which tends to encourage, through its ease of operation, misuse/misinterpretation by inexperienced analysts. Availability, portability, and low per-sample cost, has fuelled the adoption of pXRF by archaeologists. However, with regard to ceramics, pXRF results can suffer from issues around their reliability and validity, through factors such as the inherent limitations of the machines, poor maintenance and a lack of proper sample preparation. These points have been discussed in detail by a number of authors, but we direct the reader to Killick (2015) and Speakman and Shackley (2013) for particularly useful critiques.

To be clear, the issues raised by them, including the poor performance of portable instruments for light and trace elements, and a need to destructively homogenize ceramic samples by powdering (at a minimum) to obtain reasonably accurate data are rooted fundamentally in the physics of XRF and cannot be overcome. Furthermore, to maintain accuracy, all XRFs need to be recalibrated with some regularity to account for drift as the source ages (usually done with drift correction monitors developed at the time of calibration) and, in our experience, few manufacturers of pXRFs provide an easy way to accomplish this task. Gauging by the published literature, it seems unlikely that regular 'drift corrections' are being conducted on their instruments by a majority of analysts, and it is often the case that they rely on inbuilt proprietary standardless calibrations, the accuracy of which, in our experience, varies greatly from sample type to sample type and element to element. Drift on these calibrations will have an especially acute impact on the light elements (typically Na-Si) which are already difficult to quantify using pXRFs. As an indication, a typical lab-based unit might require drift correction monthly. With this in mind, unless a methodology is provided detailing the homogenization of samples (e.g. powdering and pelletizing) and including data for standards similar in composition to those being analysed, it is reasonable to assume that that the data published is inaccurate and is probably not suitable for integration into larger datasets. As a discipline we should aim to ensure the adoption of these two principles when utilising pXRF data to ensure quality and suitability for integration.

To reiterate, the error and uncertainty generated through non-destructive pXRF analyses are significant and cannot be overcome. A good demonstration of this point is a recent multi-disciplinary treatment of ceramics from Chalcolithic Shiqmim (Burton *et al.* 2018), that integrates thin-section analysis, nano-fossils, and pXRF analysis. This study, highly commendable for its high-quality, detailed analyses, and for providing a detailed methodology, distinguishes itself from other pXRF approaches by utilising an 'in-house calibration that was developed using a set of homogeneous fired clay samples, spiked with four different concentrations of each of the eight elements Fe, Ga, Nb, Rb, Sr, Ti, Y and Zr' (Burton *et al.* 2018: 242 cf. Wilke *et al*. 2017). Despite incorporating a purpose-built calibration best simulating heterogeneous non-homogenised samples, the authors are honest in reporting errors of 12-15% for the relatively limited number (8) of elements they employed in the study. Error was much higher (20-50%), however, for an almost equal number of remaining elements. Given the fundamental limitations of the technique, it is possible that this study may represent the best we can achieve utilising a pXRF with non-homogenised samples. The resulting data might be 'internally consistent' and thus be utilised to distinguish between groups of archaeological materials, but with such error, these techniques lead to the establishment of a dataset that, as Killick (2015: 244) remarks, is 'an island unto itself'.

The real consequence is that data of this kind cannot be integrated into wider regional-level databases, thus limiting the scope for its inclusion in high-level synthesis. Of course, there are some cases in ceramic studies where we have no alternative to non-destructive analyses, and the great value of studies such as those of Wilke *et al.* (2017) and Burton *et al.* (2018) is that they outline the best possible way forward. In such cases, we must be encouraged to understand, accept, and clearly communicate the limitations of our analyses, following their example by providing good information on the estimates of standard error, and, even if producing useful outcomes, the research community must understand that the results are at best semi-quantitative.

pXRF analyses are often an add-on to thin-section based studies, where destructive analyses were apparently permitted, as thin-sections were made of the samples. We argue it would be better in cases such as these that at least a proportion of the sample set is homogenised. Homogenisation for geochemical analysis will provide better and more useful data, and perhaps with less effort than, for example, the custom calibrations developed for non-destructive analyses by Burton *et al.* (2018) and Wilke *et al.*(2017). The utility of these recent non-destructive studies could have been enhanced at a modest cost (< $600), by conducting ICP analysis (which would utilise no more 100 mg of material) on two or three thin-section ‘off-cuts’ from each fabric group, thus providing an indication of real geochemical values.

Here we suggest guidelines for the use pXRF instruments: the homogenisation of samples where possible (powdering at least, and preferably pelletizing and/or bead fusion) and the publication of the analysis of appropriate Certified Reference Materials (CRM) standards, in a format similar to the samples analysed to provide the reader with an indication of analytical performance. If the instrument is not capable of providing values similar to those given for the CRM, it should be calibrated, or if performance is poor for particular elements, these should be omitted.

Ceramic Data: Future Directions

This volume shows that projects drawing upon large-scale, multi-site ceramic datasets are being established and mobilised to generate a deeper understanding of key archaeological themes. It is hoped that the utilization of technology to improve practices in the recording and sharing of data will improve accessibility, and result in the construction of ceramic and petrographic datasets of a size and quality that can address new and more ambitious research questions. In the concluding section of the volume (Philip and Badreshany) we suggest a few strategies, and touch upon new theoretical frameworks, that would help revitalise the way in which ceramic data is interpreted and thus underpin future work.

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