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High-resolution dynamic illustrations in soil micromorphology: A proposal for presenting and sharing primary research data in publication

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ABSTRACT

Geoarchaeology, as a significant discipline within archaeology and the geosciences, operates at many different scales and encompasses several analytical methods and techniques, including what we highlight here: (archaeological) soil micromorphology. Communication practices of micromorphological researchers have not evolved significantly or, at least, at the same rate as archaeology as a whole, which has recently experienced an explosion of technological applications related to documentation. This paper aims to explore and illustrate a new methodological proposal for thin section digitalization and for the presentation of micromorphological data in scientific articles. We started from a premise: micromorphology should be a discipline based on images, since they provide the essential data of micromorphological observation and inference. The proposal combines existing tools and techniques, as well as those from other disciplines, to increase the standard quality of images used in scientific publications and produce dynamic and contextualized illustrations of research results in micromorphology. The final goal of the workflow is to provide keys and tools that allow researchers, as *producers* of information, to present their data in a more effective, contextualized and informative way as article enrichments or linked illustrations in their papers. To illustrate the procedure, we use two samples from different archaeological contexts: the Palaeolithic site of Roc de Marsal (France) and the Roman city of *Baelo Claudia* (Spain). The benefits of this proposal are multiple: a) access and objectivity to raw research data, b) improvement in the interaction among micromorphologists, c) spreading of the informative potential of micromorphology to the research community, and, finally, d) making the reader an active participant in the information. Although there are different eligible ways of image scanning and data sharing, the combination of gigapixel thin sections and article enrichments define a step forward in communicating research results and sharing raw data, an opportunity that should be fostered and not be missed.

1. Introduction

Context and contextualized data in time and space are fundamental cornerstones in archaeology, and archaeologists document them in several different ways: photos, profile drawings, field recording sheets, videos, etc. (Green et al., 2014; Benavides López et al., 2016; Remondino et al., 2011). In the last decade, there has been an explosion of technological applications affecting different steps of archaeological work along the way, from fieldwork to the lab, and ultimately to publication (De Reu et al., 2014; Prins et al., 2014; Roosevelt et al., 2015). Good examples are the application of drones, photogrammetry and Structure from Motion (SfM) technologies, GIS and the use of collaborative online databases (Albert et al., 2016; Cerrillo-Cuenca, 2017; Cerrillo-Cuenca and Sepúlveda, 2015; Hendrickx et al., 2011; Howey and Brouwer Burg, 2017; Jorayev et al., 2016; McCoy, 2017; Mozas-Calvache et al., 2012).

Archaeological soil micromorphology (hereafter, 'micromorphology' for brevity) employs thin sections made from undisturbed blocks of soil/sediment collected in the field (Courty et al., 1989). The underlying strategy of micromorphology is it use of intact samples of these materials and thus, it conserves the association, internal geometry, and microcontext of all components (minerals, bones, ceramics, etc.) within the sample (Courty et al., 1989; Goldberg, 1980; Goldberg and Berna, 2010; Goldberg and Macphail, 2006; Macphail et al., 1990). Thus, it is possible to distinguish between original depositional aspects of the sediment — grain size/shape/composition, bedding, or coating of

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grains as in a mudflow — from post-depositional ones associated with diagenesis, as for example, carbonate precipitation/dissolution or phosphatic transformations of the deposits. In addition, features related to large and small-scale human activities (e.g., trampling, sweeping, stabling, agriculture/manuring, and construction) are also discernible in thin sections (Angelucci et al., 2009; Courty et al., 1989; Goldberg and Macphail, 2006; Miller et al., 2010; Wattez et al., 1990). The list of applications of this technique in (geo)archaeology, while not endless, has grown dramatically over the last two decades. Micromorphology is progressively used in combination with other in situ analytical techniques at the microcontextual level, including Fourier transform infrared spectrometry (FTIR), μ-FTIR, SEM/EDAX, μ-XRF, and magnetic susceptibility (Mentzer and Quade, 2013; Shillito et al., 2009; Weiner et al., 1993; Wouters et al., 2016).

Despite this upsurge in use, communication strategies in micromorphological research have not evolved significantly or, at least, at the same rate as other areas in archaeology. Traditionally, scientific papers on micromorphology include dense descriptions of samples accompanied by tables summarizing and commonly semi-quantifying the contents and features in the thin sections (e.g. composition, texture of vertical distribution, quantification of fabric, and significant pedofeatures). These tables are difficult to understand and digest even for micromorphologists. Goldberg and Aldeias (2018) question whether such tables deliver realistically meaningful, diagnostic, or interpretable information. They are based on relative abundance criteria, however, and sometimes the absence of elements can be equally diagnostic. On the other hand, it is common to find mosaics of microphotographs. These images, and their legends, generally refer to singular elements of microfacies, which do not help in the understanding of the thin sections as a whole. Finally, and because of the abovementioned causes, there is no or little connection between the micro evidence and the macroscopical archaeological record, from the profile to the whole site.

In this light, we believe that micromorphology needs to update its resources of analysis, media, and the way it communicates its data and interpretations, which, as we show in the following, can be achieved through the application of information technologies, in the spirit of Digital Humanities. This paper aims to explore a new methodological-digital approach for the presentation of data and the use of images in micromorphology. This pragmatic proposal starts from the premise that images and graphic documentation are a very significant and fundamental part of the data. Methods to scan micromorphological thin sections and produce good quality images of entire thin sections were proposed by Arpin et al. (2002) and more recently by Tarquini and Favalli (2010), Carpentier and Vandermeulen (2016) and Haaland et al. (submitted). However, here we attempt to go one step further by examining new ways to obtain very detailed and accurate scans and to present these high-resolution data in scientific publications. We will focus specifically on one fundamental source of data: the thin sections. The proposal combines existing tools and techniques, also coming from other disciplines, to increase the standard quality of images in scientific publications and produce dynamic and contextualized illustrations of research results in micromorphology. The ultimate goal is to provide keys and tools that allow researchers, as producers of information, to present their data in a more effective, contextualized, and informative way, either as article enrichments or as linked illustrations of papers published in peer-reviewed publications.

To illustrate the proposal, we will use two thin sections from two different archaeological contexts. These examples have been chosen to highlight how the use of this procedure can be relatively straightforward to explain and illustrate different types of complex events and site formation processes from diverse chrono-cultural contexts. One thin section comes from Roc de Marsal (France), a Palaeolithic cave containing both geogenic and anthropogenic processes (Aldeias et al., 2012; Goldberg et al., 2012, 2013; Sandgathe et al., 2011). The lower third of the deposits (Layers through 5 – Fig. 1B2) is characterized by an abundance of imbricated combustion features mostly composed of charcoal and organic matter, burned bone, and calcareous ashes; some post-depositional alteration in the form of calcite dissolution and phosphatization occurs locally (Fig. 3a–c). The second example comes from a classical urban setting, the Roman city of *Baelo Claudia* (Spain), where a suite of human-related micromorphological features is recorded that shows numerous anthropogenic activities and the different usages of a public building through time (Gutiérrez-Rodríguez et al., submitted). The thin section presented here shows a set of microfacies related, firstly, to dumping of glass production by-products later sealed by an *opus signinum* pavement of a public building, and, finally, dumping and storage of penning residues related to secondary use of this space (Fig. 4a–c).

2. Materials and methods

2.1. Soil micromorphology

Undisturbed and oriented samples were collected from stratigraphic profiles at both sites. Blocks were stabilized by plaster of Paris bandages, and later oven dried for several days at 50 °C. Impregnation was carried out under vacuum with polyester resin (Palatal P4-01), styrene monomer, and MEK catalyst. Two thin sections were used for this methodological investigation, and each was examined. They were analyzed under plane-polarized (PPL), cross-polarized (XPL) and oblique incident (OIL) light, as well ultraviolet epi-fluorescence microscopy (UV). Descriptive criteria follow Courty et al. (1989), Stoops (2003), Goldberg and Macphail (2006), and Macphail and Goldberg (2010).

2.2. Microfacies analysis

Archaeological deposits, which contain mixtures of geogenic and anthropogenic inputs, can be quite complex. By their very nature, such deposits include depositional and post-depositional modifications, where lithological changes are common either horizontally or vertically. Thus, it is a methodological advantage to be able to examine them in terms of individually defined lithological packets. Here we use the microfacies concept in the sense of Flügel to refer to the arrangement of sedimentary constituents by distinct and recurrent groups of similar composition and organization within a particular thin section (Flügel, 2004). Thus, through microfacies analysis, similar characteristics of lithological composition, geometric association, and post-depositional changes can be grouped, thus allowing us to recognize patterns in different thin sections. This is based on the principle that distinct actions, depositional environments and post-depositional processes produce a particular set of microfacies units that, in turn, can be associated with a specific microfacies type (Courty, 2001; Flügel, 2004; Goldberg et al., 2009; Karkanas and Van de Moortel, 2014; Aldeias and Bicho, 2016).

2.3. Thin section digitalization

Thin section digitalization is a complex subject, which is only now being taken into consideration. Haaland et al. (forthcoming) have recently summarized in detail many of the current methods that are used to obtain digital images of thin sections, including their respective pros and cons. They principally focus on techniques of acquiring an image and to a lesser extent the use of such photos. This paper follows along this trajectory by illustrating how such products can be treated as primary data resources and how they can be shared among the research community. The concept of sharing has two advantages: it provides access of the virtual thin sections both to micromorphologists and archaeologists. For micromorphologists, the ability to examine independently high-resolution, dynamic images of thin sections permits independent verification of interpretations based on these thin sections; at the same time, it expands the pool of accessible basic data for others in interpreting their own slides with comparative data. Moreover, the