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The Challenges of Digging Data: A Study of Context in Archaeological Data Reuse

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Abstract
Field archaeology only recently developed centralized systems for data curation, management, and reuse. Data documentation guidelines, standards, and ontologies have yet to see wide adoption in this discipline. Moreover, repository practices have focused on supporting data collection, deposit, discovery, and access more than data reuse. In this paper we examine the needs of archaeological data reusers, particularly the context they need to understand, verify, and trust data others collect during field studies. We then apply our findings to the existing work on standards development. We find that archaeologists place the most importance on data collection procedures, but the reputation and scholarly affiliation of the archaeologists who conducted the original field studies, the wording and structure of the documentation created during field work, and the repository where the data are housed also inform reuse. While guidelines, standards, and ontologies address some aspects of the context data reusers need, they provide less guidance on others, especially those related to research design. We argue repositories need to address these missing dimensions of context to better support data reuse in archaeology.

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1 INTRODUCTION
Social and economic dynamics are pushing towards digital publication in archaeology. In the past, archaeologists primarily published books which included not only the interpretation but also selected data. Slowly the data has moved from formal monographs to site reports, which may now be on the web [18]. Publishers currently shy away from printing extensive datasets in paper form, especially since these data are increasingly digital. As a result, new publication venues are emerging in the form of digital repositories. It is in this environment that Open Context[1] was established as a data publisher. Open Context provides web-based data publication for cultural heritage and field research. Consequently, when the U.S. National Science Foundation (NSF) began requiring data management plans with all grant proposals, it named Open Context as a venue for data deposit in the archaeology program. Initially focused on building data supply, more recently Open Context has increased attention on satisfying the demand for data with a major objective to improve standards to support data reuse over the long term. There are two types of standards needed to support data reuse over time: standards focused on the actual research process; and repository standards to support discovery, data manipulation, and integration. Unfortunately no robust set of standards for field archaeology exists and those that do exist are not widely followed. For field archaeology specifically, standards development has been limited, since centralized data curation, management, and reuse is still a fairly new phenomenon.

The existing literature on data reuse informs standards development, but it has shortcomings. Although the data reuse

literature suggests providing access to a dataset's context of production improves the data reuse experience, much of the work has been done in the science and engineering fields. Moreover, there have been no attempts to systematically consider the implications data reuse findings have on the development of standards. Therefore we pose two research questions in this study. 1) How does contextual information serve to preserve the meaning of and trust in archaeological field research over time? 2) How can existing cultural heritage standards be extended to incorporate these contextual elements? More specifically, we will examine archaeologists' current data reuse practices to consider how existing metadata standards might be extended to preserve the meaning of cultural heritage materials related to archaeological field studies.

[1]http://www.opencontext.org

2 BACKGROUND
We begin this section with a discussion of modern archaeological practice and how this influences data collection and management issues related to reuse. We then discuss guidelines and standards attempting to facilitate reuse and end with a discussion of what we know about data reuse in archaeology.

2.1 Archaeological Practice and Data Management Challenges
Archaeology represents an informative domain to explore issues in data management, curation and reuse because of the large amount of documentation generated in carrying out archaeological research as well as the divergence in data practices among different specialties in the discipline. Archaeologists attempt to understand ancient societies and social processes primarily through the documentation and analysis of the material remains of past societies. Investigation of these remains typically requires cross-disciplinary teams where members have different areas of expertise. For example, soil scientists investigate excavation deposits, zooarchaeologists (a sub-discipline with close ties to zoology and the biological sciences) identify and analyze animal remains from archaeological sites, and material scientists analyze the chemical composition of artifacts to identify raw-material sources or to investigate ancient production technologies. Coordinating the efforts of these diverse team members is a tremendous challenge involving complex data management skills.

Effective data management and preservation are particularly pressing for archaeology, because archaeologists often rely upon destructive data collection methods, destroying the very sites they seek to understand [1]. These ancient sites and other critical sources of evidence are limited and non-renewable resources, also damaged or destroyed through development, vandalism, and looting [7]. Archaeologists must carefully document the associations and stratigraphic relationships between finds, architectural remains, soil deposits, and other features as such associations are disrupted and destroyed through excavation. Archaeologists use the term "context" when they refer to such associations, and contextual information is critical to documentation and interpretation [19].

The legal and regulatory regimes governing archaeology are also changing in ways that impact data management issues. Many nations now prohibit the export of artifacts and other finds, even for research purposes. This puts added pressure on researchers to

document objects as comprehensively as possible, since they may have difficulty in securing access to collections in the future. At the same time, public agencies and private granting foundations have adopted "Data Management Policies[2]". While these policies do not explicitly mandate data dissemination or archiving, they make the disposition of data part of the peer-review evaluation of grant proposals.

Research design and documentation are more critical for archaeological research since not only the destroyed sites must be documented but also the artifacts left behind must be analyzed in their countries of origin [28]. Thus, the only records available to archaeologists for future analysis are digital documentation about sites and artifacts now destroyed or inaccessible. Archaeologists describing the documentation process demonstrate that it is anything but straightforward. Many interpretative decisions which affect later reuse are made during the excavation and documentation processes [19, 20]. This represents an important issue for standards and ontology development, since researchers may need to rely upon legacy datasets, often described according to obsolete recording systems.

Finally, archaeology is not a cohesive discipline with universally adopted methods, concepts, or theoretical perspectives [11, 14]. Archaeologists work across the world in many research settings to investigate past societies in all of their diversity. The methods and research questions used by an archaeologist working at a Roman urban site will be very different from those used by an archaeologist working at a Paleolithic cave site. Moreover, research circumstances vary. Some teams will have the time and expertise available to develop more thorough and varied documentation, while other teams must work very rapidly, especially in the context of "salvage archaeology" where development or construction projects impact archaeological sites. This diversity, coupled with the need to reference and adapt legacy data to new research questions, represents a great challenge in developing information standards for the field. The difficulties are only multiplied as archaeologists have transitioned from analog to digital recordkeeping, including sophisticated CAD and GIS modeling techniques which require significant context to communicate meaning:

> *Once the question of format has been dealt with, the archivist must confront questions relating to the use of the model by others. For instance, my model has more than 200 different data segments. In-situ stones of cut marble, with specific date span, and lying in the stair of the entrance structure are in one data segment; the nearby tripod base, also of cut marble and with the same dates, is in another. The particulars of these data segments are not important for this discussion, but the model cannot be used effectively without an understanding of the segments and the way they have been named. That information is not implicit in the model; it must be supplied in a set of documentation that I must have prepared* [14, p. 23].

As we will discuss, an important dimension of context that needs to be captured to inform data reuse centers on the methods, people, and research conditions surrounding data creation.

2.2 The Use of Guidelines, Standards, and Ontologies

Data reuse is more complicated due to the emergent and diffuse nature of guidelines, standards, and ontologies in archaeology. We discuss two categories of these: guidelines and standards aimed at data producers which address data collection, documentation, and deposit; and standards and ontologies aimed at data repositories to facilitate long-term data management, discovery and reuse.

2.2.1 Guidelines and Standards for Data Producers

Various national and professional bodies have developed guidelines for data documentation in archaeology [31, 1, 5, 6, 21]. These guidelines provide information about the types of documentation expected, preferred file formats, and data points desired. However, they often do not accommodate the realities of field work or the interpretation that occurs in the field. More recently, guidelines for data deposit have emerged in the UK and the Netherlands [1, 6, 10, 30]. In other countries, such as Canada, archaeologists are legally expected to deposit research records in repositories, but guidelines for deposit are lacking [28, 31, 38].

2.2.2 Repository-based Standards and Ontologies

Leading archaeologists have promoted data integration as a key motivating factor in data sharing and archiving [27]. However, ontology development in archaeology is in early stages. Most archaeologists have no exposure to formal ontologies or their use. The Digital Archaeological Record[3] (tDAR) is developing tools for researchers to apply ontologies to the datasets it archives. In contrast, Open Context editors increasingly apply ontologies as part of their "data publication" workflow [24]. In the case of Open Context, the technical and conceptual challenges of applying ontologies are taken on by dedicated "data editors," rather than by users or data contributors. As more archaeologists deposit their datasets in repositories, the research rewards and opportunities for computational methods, including development and application of ontologies, will expand. For the time being, the expertise and motivation to use formal ontologies remains rare in archaeology. Furthermore, the standards for data collection, documentation and deposit speak more to the ability to preserve and communicate context while repository metadata and ontologies address access and discovery. In spite of early claims that "metadata also provides a means of reflecting changes in the intellectual and social context in which information exists. Therefore it can enable data collected within one theoretical framework to be reused within another by providing the potential re-user with information about previous recording systems and methods which would allow them to take the original interests and biases of the recorder into account" [32, p. 1059], metadata has not fulfilled this promise in archaeological repositories. Experiments in creating a more "reflexive" repository system to accommodate changing interpretations of data are still largely untested [15].

2.3 Data Reuse Challenges in Archaeology

Much of the data reuse literature, which focuses on the sciences and quantitative social sciences, has found that data reusers need to know the context in which data were produced in order to evaluate the data [e.g. 16, 37, 36]. For instance, information about how data were defined and measured helped quantitative social scientists understand the data, decide whether it met their needs, and trust the data [16]. Knowing how colleagues selected and

[2]http://www.nsf.gov/news/news_summ.jsp?cntn_id=116928

[3]http://www.tdar.org

calibrated data collection instruments allowed habitat ecologists to trust resulting data [37]. Earthquake engineering researchers, who knew both that problems occurred during a laboratory experiment and how they were resolved, were less likely to misinterpret data during reuse [17]. We know much less about the context qualitative social scientists and humanists need to support data reuse.

Archaeologists use other's research data through a variety of venues: person to person sharing, museum archives, and more recently digital repositories. Archaeologists reuse data directly from other archaeologists created in the course of an excavation or survey (e.g., field notes, spreadsheets of finds, photographs) as well as museum collections (for example, comparing a complete figurine in a museum to multiple figurine fragments found in an excavation). In person-to-person sharing, "data sharing (particularly the open dissemination of data not presented in archival publication) is constrained by a variety of factors, including stakeholder interests, the sensitivity of archaeological sites, fear of poaching, concerns about the 'messiness' of data, and the lack of common data standards" [18, p. 70; see also 24 for more discussion of data sharing incentives].

We know little about archaeologists' use of museum collections. In fact, Merriman and Swain concluded that "even within the archaeological profession, archives remain largely unused as reference collections, as support to sites and monuments records or as resources for contractors, even though they represent the prime evidence for the archaeology of an area" [29, p. 259]. More recent evidence suggests that museum metadata is rarely enough for scholarly researchers and that associated documentation on provenance, acquisition, etc. is needed [26]. In her survey of users of archaeological collections in museums, Czyrnyj found that archaeologists were interested in different types of information and less satisfied with that information than other categories of respondents. Overall respondents identified "visual representations of the artefacts and contextual information" as the two major issues for improvement [9, p. 103].

Condrun et al.'s [8] user report for the Archaeological Data Service in the UK is the earliest evidence we have of repository reuse in archaeology. They found that many of the barriers to using digital archaeological data were technological. Still, their recommendations focused on the need for data creation and data archiving standards. More than a decade later, the need for standards remains. Detailed examples of data reuse by archaeologists are scarce. In one example, three zooarchaeologists analyzed 30,000 animal bone specimens in an "orphaned dataset" from excavations during the 1960s at Chogha Mish, Iran. University of Chicago archaeologists transferred the data from punch cards to Excel spreadsheets and made the spreadsheet publicly available, as the only record of the fauna from the site. Each zooarchaeologist analyzed and interpreted the data independently and arrived at different conclusions based on objective measures of the bones as well as conjectures about the original data collection. "They lamented that certain data were not present, specifically contextual and methodological information" [2, p. 5]. In another example of archaeological data reuse, Brody [4] reexamined household artifacts originally excavated between 1926 and 1935 northwest of Jerusalem. He did not dwell on the difficulties of reuse but noted that only certain methodological approaches worked with the data given the original "excavation methods, collection strategies, and records" [4, p. 252]. The consistent themes concerning reuse here are the need for information about the methodological and interpretative contexts in which the original research took place.

3 METHODOLOGY

In this paper, we focus on archaeologists to examine the reuse of research data, particularly digital data. We selected archaeology to study data reuse for two reasons. First, archaeology has an emergent data sharing culture, so data reuse is a relatively new phenomenon and repositories for archaeological data are young. Second, archaeologists use heterogeneous data often triangulating data from multiple sources created using local practices and a variety of de facto standards. Given our interest in exploring a field less experienced in data sharing and reuse, we partnered with Open Context, an open access venue which reviews, documents, standardizes, and publishes archaeological research data, and offers tools and services for archaeologists using that data. Open Context makes use of many available standards (e.g., ArcheoML) and ontologies (e.g., the Encyclopedia of Life) to create a robust platform for data publication [25]. As such, Open Context has gone far to address the need for "consistent standards for data" within archaeology [18].

Between September 2011 and April 2012, we conducted 22 semi-structured, hour-long interviews during which we asked archaeologists about their data reuse experiences. We used both snowball and convenience sampling to recruit participants. Beginning with individuals associated with our collaborators, we moved on to recruit additional participants through workshops, conferences, and by asking interviewees to nominate colleagues. Through our selection process, we recruited a range of archaeologists in terms of research questions, methodology, the centrality of data reuse to their work, and level of expertise. Interviewees were paid $25 US dollars for their participation.

We audio recorded and transcribed the interviews and used NVivo, a qualitative data analysis software tool, for coding and analysis. We based our codes on the topics addressed in our interviews. As a result, the high level categories included context, data reuse, data sharing, and repository codes. We were also open to emergent codes arising from the transcripts. Two project team members coded the interview transcripts and achieved an interrater reliability percentage of 0.73 using Scott's Pi.

4 RESULTS

Most striking about the findings was respondents' reuse of data despite the persistent lack of context. The respondents either found ways to make do with the context they did receive or took action to obtain more. Given the nature of context in field archaeology, data collection procedures and research design were in greatest demand during data reuse. For some respondents, the presentation of documents created in the field also had bearing on data reuse as well as the archaeologists' reputations and scholarly affiliations and the repository where the data were housed. Each of these will be discussed in the paragraphs that follow.

4.1 Lack of Context Was a Persistent Problem during Data Reuse

The lack of context was a persistent problem encountered during the reuse of archaeological data. At issue were the data collection and recording procedures. The lack of context associated with museum collections resulted from the way the objects were collected, whereas some of the early field studies suffered from insufficient recording of context. The lack of context continued for contemporary field studies, given the transition from capturing

context on paper to capturing it digitally and archaeologists' protection of the context that they did record.

4.1.1 Museum Collections

Respondents cited distinct issues when reusing data from museum collections versus data from fellow archaeologists. Respondents explained that there was often less concern and ability to record context for the museum objects. For instance, CCU20 acknowledged that although the museum field was changing, "… oftentimes there's systematic differences almost built in because the way the data was collected … There was less concern about provenance information or context information. So objects are treated as objects and not as objects within their contextual world…" (CCU20). CCU01 explained why even the most basic context was hard to come by with museum objects he accessed from a major university's on-line collection, when asked whether cataloging information about where the objects were found and who found them was provided. "If that was known, yes. This was again the old days when they were just kind of ... They would buy things on the market and not wonder where they came from" (CCU01). Given the way museum collections were acquired in the past, it made sense that context was limited. However, respondents had higher expectations for field archaeology because archaeologists recorded context during data collection. They expected not only cataloging information about who found what objects at which site, but also more detailed information about the objects themselves (e.g. at what strata were the objects found and what was found with them).

4.1.2 Field Archaeology

Even though artifacts were not merely treated as objects in field archaeology, the availability of context was still uneven. For older studies, lack of context was attributed to evolving recording procedures that ranged from meticulous to sloppy. In contrast, contemporary studies were challenged with the transition from paper-based to digital recording procedures and archaeologists' protection of context that was recorded.

4.1.2.1 The Good Old Days

Some respondents discussed the thoroughness of some of the early archaeologists' recording procedures. CCU05 discussed the meticulousness of one excavator's data recording procedures over four decades of research. "[He] … was far ahead of his time in real scientific archaeology and documentation methods. And because of that, we just have so much in the way of material, there are 21,000 glass plate negatives just for [Site Location] alone … There are 45,000 plates all together. And then thousands of pages of register books of logging in the finds and diary pages, noting with daily activities and manuscripts and note cards and all kinds of things" (CCU05). In contrast, others thought early archaeologists were careless recorders of their field work. CCU09 described excavators from the 1950s as the "sloppiest", because they did not include critical context. She recalled her reuse of a series of maps. "…they never put North on their map. They never actually gave me the grid locus of where they were. So I had a really hard time using those maps … I could scan them, but I didn't know where to put them" (CCU09). During CCU16's reuse of a dataset from the 1960s, he recalled missing context as "…one of the most severe problems. So we did not have access to critical information, such as archaeological contexts, excavation methods, sampling methods, even identification methods. We didn't know if the analysts actually used comparative collections or just published manuals to identify specimens or how did she sample... She didn't mention or detail those things." (CCU16). However, the data from these older field studies were valuable and respondents found ways to make it work. Several respondents, including CCU09 and CCU16 described various channels used to search for additional context to enable data reuse, including publications, field reports, accession books, field notes, and visits to museums to talk with staff and the original excavators. In one case, it took CCU09 years to track down the context needed to reuse data, but she did it because she thought it was "…critical to incorporate the data and work with it to the extent that you can. You can't do everything with it, but you can do a lot…" (CCU09).

Although CCU09 blamed archaeologists for the lack of context associated with some of the older field studies, several others attributed archaeologists' shortfall to the era. In explaining why notes from an excavation during World War II were spotty, CCU15 explained "the metadata recording of archaeology has evolved over the last 120 years of its discipline in the [Region Name]. And so the kinds of issues that people were paying attention to and actually 'recording' are very different than today". As the discipline evolved, so did the way archaeologists collected data and recorded context. "… the way things were excavated and the rapidity in which things were excavated, and then just sort of the amount of notes that were taken … as opposed to the amount of stuff that was excavated is almost the inverse today. So we dig a lot less and record a lot more in current times. And back in the good old days, they dug a lot more and recorded a lot less" (CCU20). Likewise others thought "… the general standard and awareness among [today's] archaeologists [vs. those from 20 years ago] is rising, so that they would tend to include more information" (CCU19).

4.1.2.2 Contemporary Field Work

Whether it was an evolution of the discipline or an increased awareness, data collection improved and, over time, archaeologists recorded more contextual information. Yet, respondents still experienced difficulty reusing data from their contemporaries, in part because of limited access. CCU02 actually described this as a "permanent problem", where "the metadata you need is, a lot of the contextual data that you need is not provided". He believed the lack of access stemmed from using paper-based rather than digital data collection and recording procedures in the field. In contrast, CCU21 worried about the move from paper to digital. He thought context would get lost in the absence of more robust recording procedures, especially for terminology, which varied across archaeologists and over time. In order to understand what the data meant he explained needing to know whose vocabulary was being used. "And at least with the paper stuff, what you see is all there and explained or not. With the digital, so much can be left out, if the metadata are inadequate. … okay, I've got this table, or these tables, and I can see how they're related, but gee whiz, I don't know what set of vocabulary they're using. I don't know whether this is Scholar Q's version of Greek geometric pottery, or Scholar Z's version of Greek geometric pottery in terms of the terminology. Where they keep saying Late Bronze I, what did that mean then" (CCU21)? Respondents also discussed challenges around creating data interoperability. In a study of cultural groups across state lines CCU12 needed to combine data from multiple field studies held by different State Historic Preservation Offices. He noted, "You need to do a lot of cleaning and translating to make things work. But the concepts in the archaeological ontologies that are being used to describe are still professionally the same, but they're recorded in various scales. They may use different terminologies, different data types" (CCU12).

For other respondents, the worry was archaeologists who were not providing access to all context that they may have recorded. For instance, CCU08 thought the laboratories she worked with to get metallurgical data were less than transparent. Oftentimes, she had to request information about how samples from the ore bodies were retrieved and received it only occasionally. "They would sometimes just say it was an ore sample, but other times they would say it was taken from an artifact found near an ore. I had to specifically request the latter. It should be given transparently" (CCU08). Many respondents mentioned accessing the documents archaeologists created in the field to understand the interpretations and decisions archaeologists made in situ. Unfortunately, the documents were difficult to access, because they were not being shared or not available online. For instance, CCU10 noted, "A lot of times you don't have access to the notes of another site and it seems... It seems like its relatively territorial that's kind of sensitive information, so lots of times excavators aren't so willing to share their primary notes. Sometimes you have to wait until things come out in print." However, even after print publications came out, critical context was still missing or unclear. Although CCU02 primarily used journal articles to locate data for reuse, he often ended up contacting archaeologists directly to learn details about the field studies. "…it always, always ends up with me contacting the researcher and asking them, 'Well, how did you collect the data? What were your excavation technologies? And then, how did you analyze the data after all this? How did you analyze these animal bones? So, what research question or reference question did you use'" (CCU02).

In sum, field archaeologists provided more context than museum collections, but respondents still wanted more. While some instances of lack were due to poor data recording procedures, others were due to limited access given the transition from paper to digital recordkeeping practices or protection of their work. Despite these challenges respondents still managed to reuse others' data and the primary context they relied on is detailed in the following paragraphs.

4.2 The Role of Data Collection Procedures during Data Reuse

Given the nature of the context encountered during field archaeology research, data collection procedures were most important during data reuse. Not only did archaeologists make interpretations of the context during data collection, context was also destroyed as a result of excavation. In addition, the way archaeologists conducted and recorded their research varied. Having access to data collection procedures helped respondents understand and verify the data against the archaeologists' research objectives and interpretations. Respondents also relied on archaeologists' presentation of documents created during field work, the reputations of the archaeologists, their scholarly affiliation, and the institutions where the data were housed for additional insight into the data.

4.2.1 Accounting for Interpretations of Context Made in the Field

Archaeologists' interpretations of data unfolded in the field during data collection and provided supporting evidence for the conclusions drawn about the data. For instance, the chronology of a site was determined through a series of assumptions an archaeologist made based on the artifacts unearthed. CCU18 described how he might determine the nature and date of a site given the excavation of a floor. "In a perfect world when I excavate the floor and there's a piece of pottery underneath that, and the floor can't have been laid down before that piece of pottery exists …, [and] it's a piece of pottery from a second century AD pot that means the floor was in the second AD or later. … We make a sort of series of interlocking assumptions about the certificate of a finding and the material that I'm processing ..." (CCU18). Our findings indicated respondents needed access to these interpretations as well and looked to access them via documents created in the field. Interested in how landscapes changed over time from 1500-1650 AD, CCU06 wanted to reuse animal remains data and data from zooarchaeological collections. She needed the data to have a certain level of chronological control and looked for stratigraphic information in archaeologists' field reports. "So, I need to be able to say, 'Okay, this particular part of the collection dates from 1490 to 1550. This part dates from 1550 to '60', or that sort of thing. … I can … tell by looking at the [archaeological] report whether there is stratigraphic information so, I can tell whether the site is stratified, and whether it looks like if there's going to be that kind of fine scale of chronological control or not". Archaeologists collected and interpreted stratigraphic information in the field as they excavated and distinguished different strata (i.e. layer of sedimentary rock or soil) to identify time periods. CCU06 looked for stratigraphic drawings that clearly labeled each excavated strata.

4.2.2 Accounting for Context Destroyed in the Field

Archaeologists also thought it was critical to know how the archaeological data were collected, because the context was destroyed as a result of excavation. According to CCU15, "It's this ironic thing in our discipline in which we actually destroy the laboratories in which we recover our data". Since archaeology cannot reproduce results in a laboratory, recognizing the veracity of data depends on the context captured. "… if you dig the majority of an archaeological site and put those materials in boxes, no one can ever go back to that exact site and say, 'Wait a minute, these materials weren't organized that way', because the context is completely lost. They're all put in boxes. … The verification of whether or not the data are real is something that, … it's frequently measured on the metadata about how everything was recovered and whether or not it ultimately corresponds with similar works that have been done and are done later" (CCU12). Data collection procedures were the only means respondents had of understanding how archaeologists obtained evidence that supported the data gathered during field work. Data reuse cannot happen without context: "Every object needs a context; otherwise, it's almost meaningless. I mean, that's the bottom line ... Just knowing an object is there is nothing. You have to know all about it. You need to know where it comes from, how it was acquired, how it was excavated. Everything we know has to be tied to that object, otherwise, it's useless" (CCU11).

4.2.3 Accounting for Different Approaches in the Field

The variety of approaches archaeologists employed in the field was another reason respondents needed to access data collection procedures. In some cases, the variability was a response to a particular research setting, in others it had to do with archaeologists' research interests and objectives. Regardless of the case, being aware of and accounting for the differences helped respondents understand archaeologists' research objectives and intentions and evaluate the data accordingly.

For instance, CCU16 acknowledged that characteristics of a research setting, such as the time period under study and the

nature of a site, impacted his research design, data collection procedures, and strategies. Given his field work in caves and urban sites, he described three aspects of context that were important to know as he worked with data. "… And if I aim to actually rank categorically my data, I would say the first most important aspect would be the archaeological context, where my data is coming from. The second would be recovery that is how we are recovering, actually, data from the grounds. And the third would be sampling … I mean if [it's] complete recovery or whole recovery" (CCU16). Findings indicated that respondents needed similar context during data reuse, given variance in archaeologists' excavation methods. As CCU02 explained, "You can only sort of reconstruct that [the research design] from the field notes and sort of the nature of their observation and there's sort of no standardize features for archaeology. Everybody excavates in a slightly different way…" (CCU02).

Contextual details, such as site location, recovery procedures, and sampling, helped respondents not only understand archaeologists' research design, but also their rationale behind collecting and interpreting the data. Knowledge about archaeologists' rationale was useful in understanding their research objectives and intentions regarding the breadth versus depth of their studies. CCU07's analogy for breadth versus depth was excavating with bulldozers versus tooth picks. "So some people started digging with bulldozers and that's a different kind of resolution than digging with dental picks. And instead of saying that the bulldozer data is bad data, I think you just have to say that's bulldozer data, that's broad data". Similarly, CCU01 was not interested in downgrading broad data collection strategies; rather he wanted to be able to connect the strategies with archaeologists' research intentions and the resulting data. Simply declaring interest in the breadth of a site was not enough for CCU01. He needed to know how the archaeologists conducted their field surveys. "We have to look at their field methods and that's for example, did they walk with spacing close enough so that they were picking up ... [in] a survey that went on in Paphlagonia in northern Turkey where they spread out their survey walkers maybe a 100 yards apart. So, they're walking huge tracts of land, but they're only hitting big things. They'll hit a site, but they'll walk by little tiny sherd scattered things. So you kind of need to know that. I've heard of things like shoulder surveys, where they literally walk side by side and pick those little things, but then, again, you've only, you're doing a very narrow tract. So there are procedures" (CCU01). The data collected in field surveys depended on the density of archaeologists' searches. Knowing more about the methods and research objectives when accessing the data helped CCU01 determine how and why archaeologists restricted their field work.

Archaeologists cited the type of tools used in the field as another aspect of context related to data collection that impacted reuse. For instance, archaeologists often used mesh screens to sift dirt when collecting objects. The screen size was an important element of context, because it determined the size of objects archaeologists found. "…when we excavate sites, we put things... We toss what's called the back dirt, the dirt through a screen. And because I'm so interested in small fauna, the size of the screen that was used is a critical piece of information that is very often left out of reports … To me, whether it's screened or what level of screen it is, it really impacts what I can say from that collection" (CCU06). Archaeologists noted that location information, another aspect of context, was also impacted by the tools used in the field, which meant respondents needed clear specifications. "I have to know what the parameters are in which they gathered those coordinates. So I have to know the type of GPS in this case that with which they collected that data or they collected it from a map, the map systems, et cetera. I need to know the method with which they did collect it. So for example, not just the difference between differential GPS and like a recreation grade GPS but like if you're using a recreation grade GPS, did you average your points ... did you use an Oman dataset, or did you use the WGS 84 data? Those are the pieces of information that have to be entered, because that makes a difference of about 300 meters" (CCU03).

In short, various aspects of context archaeologists recorded during data collection helped respondents account for and link archaeologists' actions and interpretations that occurred in the field. They were particularly important because data collection procedures not only varied given archaeologists' research interests and objectives, but also responded to and destroyed the context as a result.

4.3 The Role Additional Context Plays in Data Reuse

Since data were interpreted in the field and the context was then destroyed, archaeologists had the additional burden of recording their thoughts and actions in situ. Respondents mentioned using additional aspects of context to determine the extent to which data could be trusted, including the documents created in the field, the archaeologists' reputations and scholarly affiliations, and the reputation of the data repository.

4.3.1 Data Recording Procedures

Respondents often relied on documents created in the field not only to access context, but also to assess how diligently archaeologists carried out their field studies and in turn the extent to which the data could be trusted. In looking for data from 1500-1650 AD, CCU06 believed clearly labeled stratigraphic drawings were a sign of an archaeologist's carefulness in capturing context important for chronological control. "And so, if they had labeled stratigraphy, let's say, A, B, C, D, E, and if they're comparing the fauna from E to A, that tells me that when they excavated, they were really careful about preserving that information" (CCU06). Another respondent used sections (stratigraphic drawings) and top plans (horizontal maps of excavated areas), noting if they were good she was more trusting of other data. "And if those were done pretty meticulously and if they adhere to a standard, then I was more trusting of other data, the data that was less standardized" (CCU10). She also paid attention to the words archaeologists used to describe excavations and the ordering of the narrative to determine whether to trust the data. "If somebody was writing about, say, a loci that they were digging and they were talking about some of the major finds before they were talking about the dirt, the matrix, and kind of its relationship to the other squares around it, I was more wary than if it was someone that was talking about kind of following a more standardized pattern, but also talking about the soil itself, the matrix, its relationship to the squares around it, and then the find spots" (CCU10). Similarly, CCU21 believed that archaeologists' organization of data told him a lot about their organization of associated excavations. "…, and I got both tables [from the data repository], the one that has the description of the material, and the actual item-by-item lists of the things they found. And one of the things I discovered was that there are several entries in material that don't exist in the material table. So, maybe it wasn't really a relational database, it really was just two databases that... I mean, I don't know. But from my point of view as a user, I need to know that. I need to be able to have that overall context. In addition to which, it tells you a great deal

about how somebody approaches a site if you see that kind of data organization because it tells you about their excavation organization" (CCU21). Respondents used recording procedures, particularly the supporting documents archaeologists created in the field that provided evidence of their actions and interpretations, as clues into how carefully archaeologists paid attention to and captured the context during data collection.

4.3.2 Reputation and Scholarly Affiliation of the Archaeologist

The reputation and scholarly affiliation of archaeologists also impacted respondents' decisions to reuse data. Scholarly affiliation was a frequent indicator of quality for respondents. They often linked it to assumptions about archaeologists' training and the overarching reputation for quality and reliability of their field work. As CCU06 commented "there are individuals that I have a lot of respect for, and I really respect their training. If it's somebody whose training I don't know about, I'm going to be less likely to use their dataset because I'm not sure how reliable it is" (CCU06). Affiliation and training were also seen as a type of legacy that gave archaeologists an aura of reliability as well. As CCU13 pointed out, "You gravitate towards the people you trust and you trust the people you trust because they come from, sort of, they have a history of a lineage...so, those senior scholars [and] their students are the ones that you trust." This lineage was important for establishing precursory trust in data, because as CCU13 said, "if I don't know their advisor or the program they come from, I would be much more hesitant to put as much weight on, well particularly on their interpretations, but I'd be much more questioning of their data" (CCU13). Therefore, when considering reputation and scholarly affiliation, respondents were much more interested in where and with whom archaeologists trained, not their current institutional affiliation.

4.3.3 Reputation of the Data Repository

Interestingly, knowledge about a data repository's processes, including selection or submission requirements and transparency in repository processes, were reported as important factors in trusting the data housed within them. As CCU02 explained, a repository's metadata requirements signaled higher quality data, because it made it easier to check the data. "They're very keen on producing the comprehensive metadata. And it's not that I trust each research [study]... but I trust that the metadata is there for me to go back and check out each file on my own. I don't give [the repository] a sort of blanket trust that all the data in there is correct, but...I sort of trust going there because I know that I can find the information I need to validate it" (CCU02). A data repository's reputation was also linked to the transparency of the collection and curation methods. As CCU04 pointed out, working with a "famous museum that has a reputation, it does make the source more reliable…knowing that they developed the work and that they were backing up the information" were important indicators of data validity. In addition to validating the content, documenting its actions was also important for establishing trust through transparency. "They are explicit about everything that they did. They tell you all the methods that they use. They tell you every single person who wrote down anything. They tell you all the updates that they did with the material" (CCU04).

In sum, respondents took cues from other aspects of context beyond archaeologists' collection and interpretation of the data when deciding whether to trust the data. In some cases, how context was recorded was as important as what context was recorded, in terms of the diagrams archaeologists created and the wording and ordering of their narratives. In addition, archaeologists' training, particularly their doctoral degree granting institution and advisor, were weighed during reuse. Lastly, the repository where data were stored was considered, with particular emphasis placed on its metadata criteria and the degree of transparency in its processes.

5 DISCUSSION

The results illustrate a number of interrelated challenges for data reuse. With the recent establishment of data repositories in archaeology, the need to consider researcher needs with respect to data reuse becomes all the more pressing.

Some of the results indicate needs already addressed by existing archeological data documentation standards. These include:

- The basic provenance of objects – when and where they were found, and by whom
- The chronology of a site, including stratigraphic information for all objects and relationships between strata

Digital repositories, such as tDAR and the UK Archaeological Data Service (ADS) document basic provenance and chronology information as metadata to describe datasets. Existing archaeological data repositories document data creators, so conceivably, researchers can make their own inferences about data reliability based on their knowledge of the reliability and professionalism of data creators. Open Context recently adopted ORCID to identify individual researchers.[4] By using the ORCID web API to display current biographical and publication information about data contributors, Open Context provides up-to-date information relating to the expertise and credentials of data creators.

While existing repositories document data creators, archaeology faces some surprising challenges for other basic forms of metadata. For instance, there is no universally agreed upon chronology for archaeology. Archaeology lacks an analog to the Global Standard Stratigraphic Age used in geology[5]. The lack of disciplinary-wide consensus on chronological designation reflects common concerns researchers identified in data-reuse:

- Differences or changes in terminology/vocabulary – whose terminology is being used, what do certain phrases mean at the time of a field study (e.g. Late Bronze I)?

Addressing the challenges inherent in comparing datasets described according to different vocabularies represents a common research priority for many informatics initiatives in archaeology [27].

5.1 Emerging Data Standards

Research efforts in archaeological data integration often center on the development and application of ontologies. Nevertheless, such efforts are typically small in scale and experimental [22]. Only a few large-scale applications, such as the ADS's "ArchaeoTools" project [23, 33] currently use formal ontologies in archaeology. Thus far, the most successful attempt to integrate multiple collections of archaeological (and related historical) data uses less

[4]http://www.orcid.org
[5]http://www.stratigraphy.org/GSSP/index.html

formalized (and less complicated) approaches. The UK-based (JISC-funded) Pelagios[6] project uses a Linked Data approach to integrate several archaeological, museum, and ancient history collections. These collections are aggregated and indexed according to references to place concepts in the Pleiades Gazetteer[7], but semantics of place references have little formal semantic modeling.

The most widely used and recognized formal ontology relating to archaeology is the CIDOC-CRM[8] [12, 13]. However, its main focus and area of application is in the context of museums and museum collections, not directly with field archaeology. The CIDOC-CRM's complexity and orientation toward enabling inferences on data as developed by museum curators makes it somewhat difficult to apply directly to field archaeology. The landscape is rapidly evolving however. A research group at English Heritage recently extended the CIDOC-CRM to include more concepts specific to field archaeology[9] [3].

In addition, some groups have developed machine-readable (and open) controlled vocabularies that supplement the abstract classes and properties defined by the CIDOC-CRM. Whereas the CIDOC-CRM focuses on abstracted concepts defining cultural heritage events, such as the discovery of an object, or transfers in its custody [e.g. 35], archaeologists often focus their attention on the classification and description of objects and archaeological contexts. The controlled vocabularies recently released by the British Museum as Linked Open Data (accessible via a Web API and SPARQL endpoint) may facilitate large-scale alignment of artifact typologies and classification systems. The British Museum has a vast collection of objects from across the globe, making its controlled vocabulary potentially valuable for many chronological and regional specializations in archaeology. The recent Open Context data publication of Murlo[10] (an Etruscan site) used the British Museum's controlled vocabulary for annotation of the project's internal classification system.

In addition to the development of ontologies and controlled vocabularies specific to archaeology, data integration efforts in archaeology can borrow from ontology developments in related disciplines. This is especially the case for zooarchaeology. Zooarchaeology already has many common (informal) conventions in recording, especially with regard to biological taxa, bone element, and to a lesser extent measurements and characteristics related to age determinations [2]. In both the tDAR digital repository and the Open Context data publishing system, efforts to align datasets to formal ontologies focus on zooarchaeology. However, application of ontologies in zooarchaeology varies in these two systems:

- tDAR is developing features to enable zooarchaeologists to select and apply ontologies on collections held in tDAR [34]. It currently has about 34 "ontologies" (many of which can be better defined as controlled vocabularies) relating to zooarchaeology.
- For zooarchaeological data, Open Context mainly uses ontologies / vocabularies developed outside archaeology by other bioinformatics research communities. These include the Encyclopedia of Life[11] for annotation of biological taxa and now UBERON[12] for annotation of anatomical entities.

Besides having more widely used recording conventions, zooarchaeologists sense more clear and immediate research applications and uses for using shared ontologies. Ontology enabled data integration can facilitate larger scale analysis of data exploring regional and chronological variation across many zooarchaeological bone assemblages.

5.2 Gaps in Archaeological Data Standards

The previous discussion reviews recent developments in archaeological data standards. The recent introduction of increasingly comprehensive and open (in an intellectual property and interoperability sense) controlled vocabularies may help to address frustrations about terminologies identified in our study. Nevertheless, we note that archaeology's emerging ontologies address only part of the data reuse challenges identified in our study. Besides vocabulary and terminology alignment, our results show researcher interest in the following issues:

- Methodological procedures for excavation and/or survey, including specifications of field tools e.g. maps and map systems, type of GPS used, including hardware and software specifications and how data were collected (i.e. were points averaged, Oman or WGS84), excavation strategy, including mesh screen size if contexts were sieved. Well-documented procedures for sampling, recording, and analysis, including use of comparative collections for identifications, use of standards, data validation techniques, and carefully-written narratives.

- Information about the archaeologist who conducted the work: The training and previous work of this person (i.e. their reputation) are important in assessing data quality.

- Information about the repository holding the data: The overall reputation of the repository, the amount of metadata it provides, and transparency in its collection and curation procedures, all help increase the perceived quality of a dataset.

These points indicate researcher interest in the entire data lifecycle, from excavation to deposit in a repository. Details of the methods and participants involved in excavation and analysis of the material increases researcher trust in the quality of datasets. However, most of ontology development in archaeology centers on classification (e.g. British Museum thesaurus) and semantic inference (CIDOC-CRM). Existing archaeological ontologies provide less guidance for modeling the methods and research conditions at the point of data creation. As noted by our interviews however, researchers expressed concern that methodological differences may make certain datasets incompatible. Our results show that the conditions and methods

[6] http://pelagios-project.blogspot.com/
[7] http://pleiades.stoa.org/
[8] http://www.cidoc-crm.org/
[9] http://crmeh.files.wordpress.com/2011/10/arch_ontological_modellingv4.pdf
[10] http://opencontext.org/projects/DF043419-F23B-41DA-7E4D-EE52AF22F92F
[11] http://www.eol.org
[12] http://www.uberon.org

that shaped data creation therefore needs much greater elaboration in archaeological ontologies so that archaeologists can make more informed judgments about the suitability of datasets for different forms of reuse.

Finally, archaeological ontologies, even if more fully developed to describe the conditions of data creation can only address part of archaeology's data management challenges. Our results illustrated complex records management and inventory control needs, as artifacts and samples move through several steps from the ground to museum storage facilities. Each step introduces new chances for mishaps that may alienate the artifacts from or garble key contextual information. As archaeologists increasingly come to use shared datasets, there will be increasing need for better managed and reliable data creation processes throughout the entire research cycle.

6 CONCLUSION

A major objective of Open Context is to improve standards to support data reuse over the long term. An examination of data reuse practices in field archaeology showed that context surrounding the research methods, people, and repository processes were particularly important, but often not readily available. For instance, the methodological procedures for field studies, such as specifications of field tools, excavation strategies, and sampling, recording, and analysis procedures were used to understand, verify, and trust the data. In addition, the reputation and scholarly affiliation of the archaeologists, the phrasing and structure of the narratives created during field work, and information about the repository where the data were held were used to assess data quality. However, examination of current data documentation guidelines, standards and ontologies showed much of the context needed for reuse was not being incorporated into practice. For instance, basic forms of context, such as chronology, lack disciplinary consensus on chronological designation. CIDOC-CRM, a well-established formal ontology, is oriented to meet the needs of museum curators, not producers and reusers of archaeological field data. On a positive note, there are several small scale, experimental data integration projects developing and applying formal ontologies. In addition, data repositories and data publishing systems have stepped in to implement tools and recruit data editors to align datasets with formal ontologies and controlled vocabularies in the meantime. As experimental projects, data repositories, and data publishing systems continue work in the area, our examination of data reuse practices has highlighted critical aspects of context that must be considered to facilitate long term data reuse.

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