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RADIOCARBON AND THE ARCHAEOLOGICAL RECORD: AN INTEGRATIVE APPROACH FOR BUILDING AN ABSOLUTE CHRONOLOGY FOR THE LATE BRONZE AND IRON AGES OF ISRAEL

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ABSTRACT. The establishment of an absolute chronology for the Late Bronze and Iron Ages in the southern Levant would make it possible to use changes in material culture in order to study the impact of trade, dissemination of knowledge, and the impact of climate on historical processes. To achieve this, a detailed absolute chronology is needed for individual sites and on a regional scale with a resolution that can differentiate events within a century. To realize this challenging goal, only samples from well-established primary contexts ought to be studied. Such primary contexts (with "dating assemblages") can be identified by combining macroscopic with microscopic observations. Chronological studies at the sites of Qubur el-Walaydah, Tel es-Safi, and in particular, Megiddo, demonstrate that high-resolution dating can be achieved, with very few outliers in the data sets. The major limitation on applying this approach is the fact that we are currently constrained to dating short-lived samples (charred seeds and olive pits) and collagen from bones. Thus, an immediate goal of radiocarbon research is to develop the ability to date other short-lived materials, such as organic material occluded in siliceous plant phytoliths, wood ash, and possibly organic residues preserved in pottery vessels.

INTRODUCTION

During the Iron Age, between about 1200–1150 and 600 BCE, major historical events and changes in material culture took place in the southern Levant. The basis for reconstructing either "snapshots" of the historical picture or documenting gradual cultural changes is a reliable regional absolute chronology. In archaeological research, changes in material culture (e.g. pottery types, architecture) are the basis for interpreting past events. These changes can be an invaluable source of information if linked to absolute chronology. In the Iron Age, changes in ceramic typology usually correspond to roughly an event per century or century and a half (Mazar 1992). This resolution is achievable using radiocarbon, but to date, a consistent absolute chronology for the southern Levant is still not available.

Absolute dating is also important for paleoenvironmental research. There is a relatively well-documented climatic record for the southern Levant (e.g. Bar-Matthews et al. 1999; Orland et al. 2012). Yet, as humans can adapt to environmental transformations, it is difficult to identify a direct cause and effect between climate and the macroarchaeological record; hence, absolute dating is critical in order to link between them. If possible, the environmental signals preserved at a given site, such as the carbon isotopic record in botanical remains, must be ^{14}C dated and in this way used in order to link between climate and human behavior.

An important issue in chronology research is resolution. A good example for the Iron Age in the southern Levant is the arrival of the Sea Peoples. Their first appearance represents a moment in time, but it probably took a while before their presence had a detectable impact on the material culture (Stager 2003). Identifying this event with a resolution of a few decades requires good stratigraphic control and is a challenging chronological project from the point of view of current ^{14}C methods. Once a research question such as this is defined, it is necessary to determine whether or not the precision of ^{14}C dating is sufficient to actually provide an answer. In the timespan covered by the Late Bronze and Iron Ages, there are periods (e.g. 1150–1050 BCE) for which the ^{14}C calibration curve has a very poor resolution or has several wiggles (e.g. 1230–1100 BC) (Reimer et al. 2013); hence, the time resolution is low irrespective of the number of samples measured or their measurement precision. Still, even when the curve is relatively flat, there are ways to alleviate (but not eliminate)

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the resolution problem (Manning 2006–2007; see the example below of dating the Late Bronze/Iron Age transition at Qubur el-Walaydah, Asscher et al. 2015).

Another difficulty involves the selection of sites for obtaining datable materials that can resolve a research question. Multilayer sites are ideal for documenting changes in material culture. However, they vary in terms of settlement history: whether all periods are represented, the rates of sediment accumulation, preservation (versus disturbance) of the layers, etc. Single layer-occupation sites are much easier to date, even if they are relatively more bioturbated or disturbed during later periods.

Beyond all this stands the question whether datable materials can be obtained from primary contexts that relate to the given research theme. Thus, addressing a chrono/archaeological question requires a well-designed research program and sampling strategy.

ABSOLUTE CHRONOLOGY OF THE IRON AGE IN ISRAEL: PERSPECTIVES

Isolated ^{14}C dates for the Iron Age were obtained from samples that were extracted from different sites, often with the aim of confirming the timeframe of the associated material culture assemblage. Following Finkelstein's (1996) challenge regarding the traditional dating of the 11th–9th century layers, samples for ^{14}C dating were analyzed systematically at the sites of Tel Dor (Gilboa and Sharon 2001) and Tel Rehov (Bruins et al. 2003). A central aim of these projects was to determine the date of the Iron I/IIA transition. These projects represent the first orderly studies of a chronological question involving absolute dating of Iron Age layers in the southern Levant. Yet, their conclusions were at odds: Tel Rehov documented the transition in the early 10th century BC and Tel Dor in the very late 10th century BC (Levy and Higham 2005; Sharon et al. 2007; Finkelstein and Piasetsky 2011; Mazar 2011).

The Iron I/IIA transition is a crucial moment in history since it documents not only a change in material culture; in the hill country it represents a transformation from a relatively egalitarian rural society in the Iron I to a more hierarchical society, urbanism, and the emergence of territorial kingdoms in the Iron IIA. In order to resolve the problem of conflicting dates provided by Tel Rehov and Tel Dor, a comprehensive absolute chronology study was undertaken, encompassing a large number of sites in Israel (Boaretto et al. 2005; Sharon et al. 2007). ^{14}C has the resolution necessary to resolve this issue provided that suitable samples are available before and after the transition. This is a formidable challenge. The detailed Iron I/IIA transition project involved the ^{14}C dating of short-lived materials from post-excavation collections from 21 sites in the region. Approximately 105 samples and over 380 dates were obtained. After modeling, the transition was determined to have occurred at the end of the 10th century BC (Sharon et al. 2007)—in line with the "Low Chronology" for the Iron Age strata in the Levant.

This enormous project, as well as later studies (Mazar and Bronk Ramsey 2008; Garfinkel and Ganor 2009; Toffolo et al. 2014), did not manage to reach a consensus. One problem was that in certain cases the precise depositional contexts of the samples and the associated pottery were not well defined, leaving open the possibility of interpreting the significance of the transition date in different ways. Increasing the number of samples in order to achieve the required subcentury resolution would not have resolved a poor context problem. One operative conclusion that I have drawn from this situation is that detailed excavation, including sediment analyses (both in composition and depositional mode), is invaluable for identifying primary contexts, and that only samples from such settings should be dated.

This conclusion has subsequently dictated my mode of research. A chronological project begins in the field using on-site analyses and all the available stratigraphic information. For this purpose, we exploit not only the widely used macroscopic archaeological record but in particular the microscopic record that allows us to characterize materials as the excavation progresses (Weiner 2010). This capability significantly increases the chances of identifying and then carefully excavating key primary contexts. If the contexts are secure, then the date should be correct, provided that the material dated is sufficiently well preserved to be cleaned and chemically characterized. Only under such conditions can absolute chronology change prevailing concepts.

DEFINING A PRIMARY CONTEXT FOR DATING: A "DATING ASSEMBLAGE"

A primary context for dating is a feature that is directly related to the research question. Macroscopic primary features that can be dated (all must be well stratified) are, for example, a pottery vessel of distinctive typology that contains short-lived charred materials, skeletons in articulation that have preserved collagen, pyrotechnological installations such as ovens or hearths that have associated charred short-lived materials, or silos with charred grains. Lenses of sediments may also be considered as primary deposits, but ensuring this requires the use of additional microscopic techniques, such as micromorphology, or material compositional analyses. The key issues here are (1) comparing the supposed primary deposit with the layers above and below (controls) and (2) determining if the components in the primary deposit are the products of a unique process (such as a burning event or a layer of what was once animal dung). This information can identify what we define as a "dating assemblage." For example, a locus that contains a cluster of charred seeds associated with burnt phytoliths, ash, and high phosphate concentrations is likely to be a primary dating assemblage resulting from a burning event *in situ*. A micromorphological analysis of the sediment textures may also help to differentiate between primary and secondary deposition and hence clarify if the given layer had been redeposited from somewhere else. For specific examples of dating assemblages, see Toffolo et al. (2012) and Asscher et al. (2015).

Figure 1 A locus dating to the Late Bronze Age in Area F at Tell es-Safi/Gath in Philistia. The small vials contain samples of sediments related to features from an archaeological surface, collected in order to characterize the surface and its anthropogenic activities. These sediments were analyzed in the field using Fourier transform infrared spectroscopy in order to identify the associated materials and from the environment of the deposition.

This approach was used to construct the Early Bronze Age chronology at Megiddo (Regev et al. 2014). In this case, we analyzed only "dating assemblages" that were still preserved in a last remaining baulk in a widely exposed excavation field. This method helped to (1) achieve a good understanding of the quality of the context and the "actual" precision (not only the analytical precision) and (2) define good contexts for dating, in addition to the rarely found macroscopic *in situ* pottery with seeds, or clusters of seeds.

A word of caution is needed here. The operation of an on-site laboratory, which enables the components of potential "dating assemblages" to be identified while the site is being excavated (Weiner 2010), significantly increases the chances of finding datable primary assemblages (Figure 1). But even exercising multiple macro- and microscopic techniques does not guarantee that every primary context is identifiable, or that a primary context does not contain materials from other periods. Our study of a macroscopically easy-to-define Late Bronze Age floor at Tell es-Safi included detailed micromorphology and the identification of finely laminated microstrata, including phytolith-rich layers and high concentrations of phosphate. These properties all pointed to a primary context. Despite this, the ^{14}C dates of the charcoal samples were generally younger than the dates of the short-lived olive pits from the same floor (Toffolo et al. 2012).

DATING PROJECTS CARRIED OUT IN THE FRAMEWORK OF THE ANCIENT ISRAEL PROJECT

Figure 2 presents short-lived Late Bronze Age IIB-to-Iron Age IIB ^{14}C dates available from sites in Israel, most of which were not studied by us in the field (Toffolo et al. 2013a). Subperiods (in different colors) are based on ceramic typology. Only those dates which, from our reading of the literature and discussion with the excavators, appear to be in primary context, are included. There is a general trend in the results that follows the relative chronology, but there are also many inconsistencies with samples from a given ceramic phase providing dates that "fall" together with dates of an earlier or later phase. There are many possible reasons for these contradictions, including diverse excavation methods, inclusion of samples from secondary contexts, different terminologies used to define the same phase, misidentification of the given pottery assemblage typology, and variable quality of ^{14}C analyses carried out using different preparation procedures.

Only three sites provided a large number of ^{14}C dates from a stratigraphic sequence: Tel Dor (Sharon et al. 2007), Tel Rehov (Mazar and Bronk Ramsey 2008), and Tel Megiddo (Toffolo et al. 2014) (the latter was in part studied in the framework of the Ancient Israel project). At all three sites, a clear-cut progressive change in the absolute dates was obtained, which for the most part correlates with the relative chronology. Other sites provided a smaller number of ^{14}C dates, some in clear contradiction with the overall trends.

Using Bayesian theory, it is possible to evaluate the agreement of the relative archaeological time model with the absolute ^{14}C data, and to identify outliers (Bronk Ramsey 2000, 2009). This is more successful when applied to a single site than to a vast region. The reasons are many, as mentioned above, and it should be considered that synchronization based only on cultural material could lead to a rather simplified model, as transition between ceramic phases could have occurred at different times at different locations.

Within the framework of the Ancient Israel project, we dated several sites for various reasons: the relatively long stratigraphic record at Megiddo, which includes the entire sequence of the Late Bronze and Iron Ages; three sites in Philistia, which include layers representing the Late Bronze/Iron Age transition; and various sites in Greece, which were explored in order to try correlate the chronologies of the Levant and the Aegean Basin.

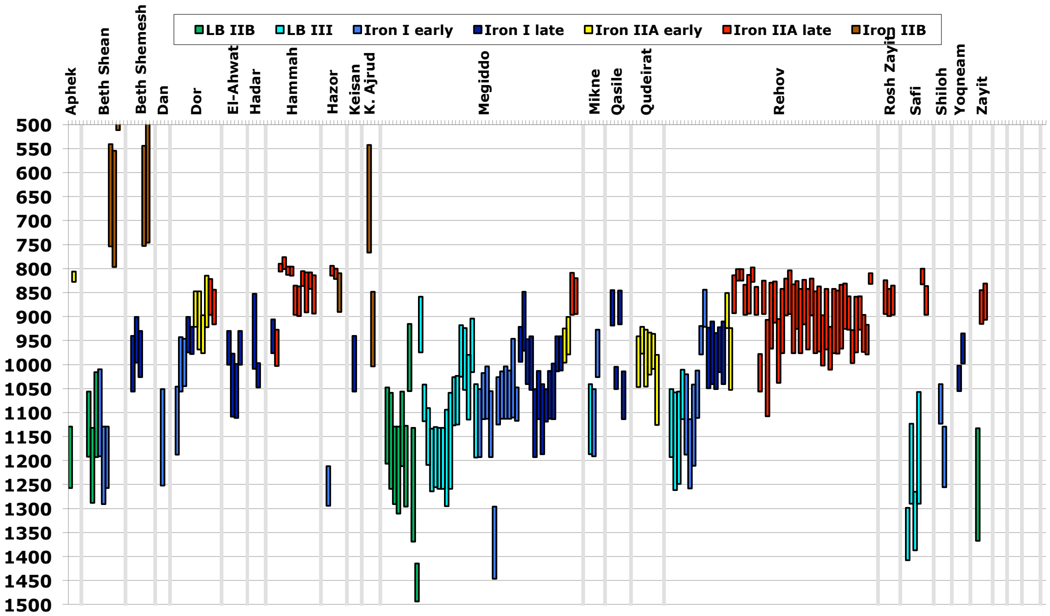

Figure 2 Radiocarbon dates obtained from short-lived samples for Late Bronze and Iron Age layers at sites in the southern Levant. Each segment shows the calibrated range ±1σ (Toffolo et al. 2013a).

High-Resolution Dating at Tel Megiddo

The Late Bronze and Iron Ages sequence at Tel Megiddo provided some 80 ^{14}C dates from two excavation areas (Toffolo et al. 2014), among them only two outliers. This is currently the best dated sequence for this period in the southern Levant. One of the highlights of this study is the detection of statistically significant differences in the dates of the Late Bronze III/Iron I, and early/late Iron I transitions between two excavation areas (H and K). These observed differences are <100 yr apart but still raise a series of methodological questions if one assumes that pottery makes a precise time proxy. Is it possible that the stratigraphic records are not identical, e.g. some strata are not represented in one of the areas and thus a bias in the sampling is introduced? If this is not the explanation, then what are the broader implications of this observation? One implication of the Megiddo study is that the determination of the absolute chronology of a single site should be based on as many dated samples from primary contexts as possible. In contrast, a site with a large number of samples, but not all from primary contexts, introduces intolerable noise that makes it almost impossible to understand the results.

The Late Bronze Age/Iron Age Transition at Qubur el-Walaydah

The project we carried out at Qubur el-Walaydah—a rural site on Israel's southern coastal plain—was aimed at dating the Late Bronze/Iron I transition and shedding light on the arrival of the Sea Peoples in the southern Levant (Asscher et al. 2015). This is a particularly challenging project for absolute dating, as the calibration curve in the period from the 12th to the end of the 11th century BC is relatively flat, and every date, irrespective of the quality of the ^{14}C analysis, has a large calibrated interval. The strategy to minimize this flat calibration effect is to date a series of superimposed strata. This means making every effort to obtain datable material from well-defined, *in situ* cultural assemblages (Figure 3), and then using Bayesian modeling to minimize the uncertainty imposed by the calibration curve. We characterized the macroscopic and microscopic contexts from which every sample was obtained using an on-site analytical laboratory and additional analyses were carried out off-site. After modeling, we concluded that the transition date is 1140–1095 BC (Asscher et al. 2015).

Figure 3 Early Iron Age pit at Qubur el-Walaydah showing a sequence of dark colored lenses containing charred materials, burned clay, aragonite formed at high temperatures, and short-lived charred materials. All these were associated with a well-defined assemblage of pottery. Thus, each lens constitutes a dating assemblage, even though the burning probably occurred elsewhere (Asscher et al. 2015). The samples for dating were taken from the dark lenses.

Three Sites in Greece

The chronological links between the Aegean region and the southern Levant in the Late Bronze and Iron Ages are particularly important to better understand the archaeology of the Eastern Mediterranean. ^{14}C is however not used frequently at Greek sites dating to these periods. Furthermore, very few of these sites are well stratified, which presents a further complication for constructing a ^{14}C-based chronology. In a preliminary survey, we identified three possible sites for ^{14}C dating: Lefkandi, Kalapodi, and tombs in Corinth. From these three sites, we were able to obtain only 16 samples of datable short-lived material in what we considered primary contexts. Tombs are in principle ideal contexts, provided that they were used for a short period of time (single burial), that the bones still have preserved collagen, and that the associated pottery assemblage represents a single relative-chronology phase. The results obtained allowed us to determine that the transition from the Sub-Mycenaen to the Protogeometric periods took place in the second half of the 11th century BC. This result supports one of the proposed alternatives for the absolute chronology of the Aegean (Toffolo et al. 2013b).

Attempted Dating of Iron Age Layers at Ashkelon

Not all sites can be dated. We worked extensively at the site of Ashkelon, also in Philistia, using all the tools available to us, including an on-site laboratory, but we were not able to find short-lived Late Bronze and Iron Age materials in primary contexts. Still, the study of the sediments and their deposition mechanism produced results on bead production during the Iron Age (Toffolo et al. 2013b) and on the identification of aragonite as a pyrotechnological material (Toffolo and Boaretto 2014). The latter might have broader implications for ^{14}C dating (see below).

FUTURE PERSPECTIVES

The ultimate goal is to establish an absolute chronological time framework for every site excavated, and for the various regions of the Levant. With this information at hand, many exciting issues could be addressed, such as the diffusion of technologies, trade networks, the determination of whether or not major regional events, such as destruction events, were synchronous, and whether climatic changes impacted whole regions. Even if all the necessary resources were made available, however, this goal is currently not viable. The major reason is that for high-resolution (subcentury) chronologies we are only able to date charred short-lived plant remains and bones that contain collagen.

Furthermore, these short-lived materials must be found in clusters in a primary context so that there is minimal danger that they have been redeposited. At most archaeological sites I am familiar with, such primary contexts are rare. A major goal is therefore to develop the capability of obtaining high-resolution dates from other materials, preferably those that are frequently found in primary contexts.

Phytolith-Rich Layers

Phytoliths are silicified deposits produced by many plants, in particular by grasses. This includes cereals, whose phytoliths (mainly from stalks and husks) are often found in large amounts at archaeological sites, in grain storage containers or animal fodder and/or dung accumulations. The latter are usually found within animal enclosures. Phytolith-rich layers, some of which are even visible to the naked eye, are frequently encountered at sites in Israel (Shahack-Gross et al. 2005; Albert et al. 2008). Such layers would be ideal for dating, as phytoliths contain occluded organic materials (Elbaum et al. 2009). Indeed, a few reports on ^{14}C dating based on phytoliths have been published (Wilding 1967; Piperno and Stothert 2003; Santos et al. 2010; Corbineau et al. 2013). To date, however, there is no known methodology that can provide accurate dates from phytoliths. Significant progress is being made in this field, and hopefully phytolith dating will soon become a reality.

Plaster and Ash

Plaster and ash both form via the uptake of atmospheric carbon dioxide that includes ^{14}C. It has thus long been recognized that the calcite of these materials can potentially be dated. Yet, despite major efforts over the last 20 years, these materials do not produce accurate and precise dates. The major reason, besides the presence of original calcite from the limestone, appears to be the instability of the calcite crystals that readily undergo exchange with carbon dioxide in the humid atmosphere or the water in the sediments. Efforts to identify one well-preserved fraction by differential dissolution (Ringbom et al. 2014) using a cryosonic technique (Marzaioli et al. 2011) and analyzing pristine lime lumps in the mortar (Pesce et al. 2012) are still far from being systematic. Another approach, used by us, is to identify plaster that still contains well-preserved calcite crystals based on a newly developed assay for atomic disorder using infrared spectroscopy (Regev et al. 2010; Poduska et al. 2011). When this approach was applied to the Early PPNB site of Yiftahel in the Lower Galilee, the dates obtained were close to the known age of this period, but still not close enough to be used as an independent dating method (Poduska et al. 2012).

We have recently discovered that small but significant amounts of aragonite, the second, less stable polymorph of calcium carbonate, also form during plaster production (Toffolo and Boaretto 2014). It is conceivable that if this aragonite can be isolated, it might provide reliable ^{14}C dates on the assumption that it is still a primary deposit that has not undergone exchange (that would cause it to transform into the more stable calcite).

Pollen

Pollen is widely used for paleoclimatic reconstructions. A recent study within the framework of the Ancient Israel project has identified a link between the cultural crisis at the end of the Late Bronze Age and a dry climate event (Langgut et al. 2013). The chronological scheme is based on ^{14}C dates of macrofossils found in a core from the Sea of Galilee. With considerable effort, pollen can be purified from a sediment and ^{14}C dated (Langgut et al. 2014). Yet the method is not widely applicable since the recovered quantity of pollen is very small and it might represent a mixture from different ages. Hence, in the case of pollen, direct dating is still not possible. Efforts should be made by the ^{14}C and pollen communities to develop a "single pollen grain" dating method that would provide the absolute chronology of the signal, independent of the depositional location. If this becomes possible, then intrusive or residual pollen can be identified and placed in its correct chronological sequence.

Organic Residues in Ceramics

Organic residues are sometimes preserved within the pores of ceramic vessels. They can be extracted and at least one attempt has been made to ^{14}C date specific molecules (Hedges et al. 1992; Stott et al. 2003). In general, however, the residues are extractable only by organic solvents (which can introduce contamination) and are available only in small amounts. A recent study reports a new method for prescreening ceramics for the presence of preserved organic residues; it shows that organic solvents only extract a small fraction of the organic material that is present (Goldenberg et al. 2014). We are currently developing different extraction procedures with the aim of being able to ^{14}C date this organic material.

CONCLUSIONS

Building a reliable absolute ^{14}C-based chronology requires the integration of different methods both in the field and in the laboratory. The variety of questions that can be addressed by ^{14}C in archaeology is well represented in this volume. There can be no compromise on the quality of the context from where the samples are selected. The identification of a "dating assemblage" is essential to ensure reliable dating and any sample should, in the end, provide information about the event and site formation processes.

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