

A Rejoinder on the Value of Archaeomagnetic Dating Integrative Methodology Is the Key to Addressing Levantine Iron Age Chronology

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The Earth's magnetic field is dynamic, with fluctuations that range from minute daily variances to massive polar field reversals that occur with a frequency on the order of one million years. Magnetic minerals in heat-treated archaeological materials have the ability to store a record of these past field changes, which can be measured using modern superconducting rock magnetometers. For example, artifacts such as fired pottery or slag from metal production contain magnetic minerals that record the Earth's field strength and direction as they are cooled from high temperatures (such as those typical in ceramic kilns), providing a fixed record of the ancient field at the time of their manufacture. Compilations of well-dated sequential field measurements can act as reference curves, which can be used to estimate the age of other heat-treated archaeological materials. This is the basis for archaeomagnetic dating, an important chronological method that is powerful even at sites that do not preserve materials suitable for radiocarbon analysis.

A recent article by Streit and Höflmayer (2016) calls into question the reliability of archaeomagnetic dating as a potential method to address the Levantine Iron Age chronology debate. We felt compelled to reply to ensure their criticism of the method does not dissuade archaeologists from utilizing this valuable dating tool in their research. While most of Streit and Höflmayer's comments appear to agree with and repeat all the information presented in Stilling, Hardin et al. 2016, they question the data used to construct and calibrate the archaeomagnetic model presented and state that archaeomagnetism is "hampered by circular reasoning" (233), thus implying that the authors do not recognize this issue. They also suggest that the authors intended archaeomagnetic dating to "surpass radiocarbon dating and Bayesian analysis" (234).

The archaeomagnetic model, as presented in figure 10 of Stilling, Hardin et al. (2016: 97), clearly distinguishes magnetic data calibrated with absolute (in this case radiocarbon) versus relative-dated materials and how the reference curve is altered when controversial radiocarbon dates are removed. In an effort to present an article without excessive methodological detail, Stilling, Hardin et al. 2015 refer the reader to Stilling,

Feinberg, and Frahm 2015 for details regarding data selection for the curve. To clarify here, the data used for model construction were obtained from recent archaeomagnetic studies¹ incorporating specific techniques, error corrections, and acceptance criteria recognized by the geophysical community. These data are similar to those used by the Levantine Archaeomagnetic Curve (LAC), which has been employed successfully to address the chronology of several important sites in the region.² The LAC and other regional archaeomagnetic models represent nearly three decades of global research refining methodologies and modeling techniques better to understand the Earth's field variability during the Holocene.

In the absence of radiocarbon (the preferred radiometric dating technique for most archaeological studies), historical evidence, or other absolutely dated materials for calibration points, archaeomagnetic models must rely on relative dating information, such as typological seriation, stratigraphy, and cultural association. Stilling, Hardin et al. (2016: 91) recognize this problem of "circular logic" when archaeomagnetic curves are constructed, particularly when based on subjective pottery seriation alone. In their concluding remarks, they state that refining archaeomagnetic dating "will require the incorporation of additional absolute dating techniques to firmly calibrate the curve" (104). They then offer several examples of how this can be accomplished, such as uranium series dating and dendrochronology.

Herein lies the goal of the original article: to reintroduce archaeomagnetism (a method that has been around since the 1960s) to the archaeological community in the hopes of garnering more interdisciplinary cooperation and collaboration between geoscientists and archaeologists. Archaeomagnetism is an established discipline that is crucial for understanding the rate of change of the Earth's magnetic field and related natural phenomena. The continuing debates over various absolute chronologies and the problem of plateaus on the radiocarbon calibration curve demonstrate the need for the integrative application of several dating methods to achieve higher resolution in absolute dating of archaeological contexts. In this regard, we would like further to stress the strengths of archaeomagnetism in advancing this goal.

While the ascribed age of archaeomagnetic data in current reference databases is primarily based on radiocarbon or

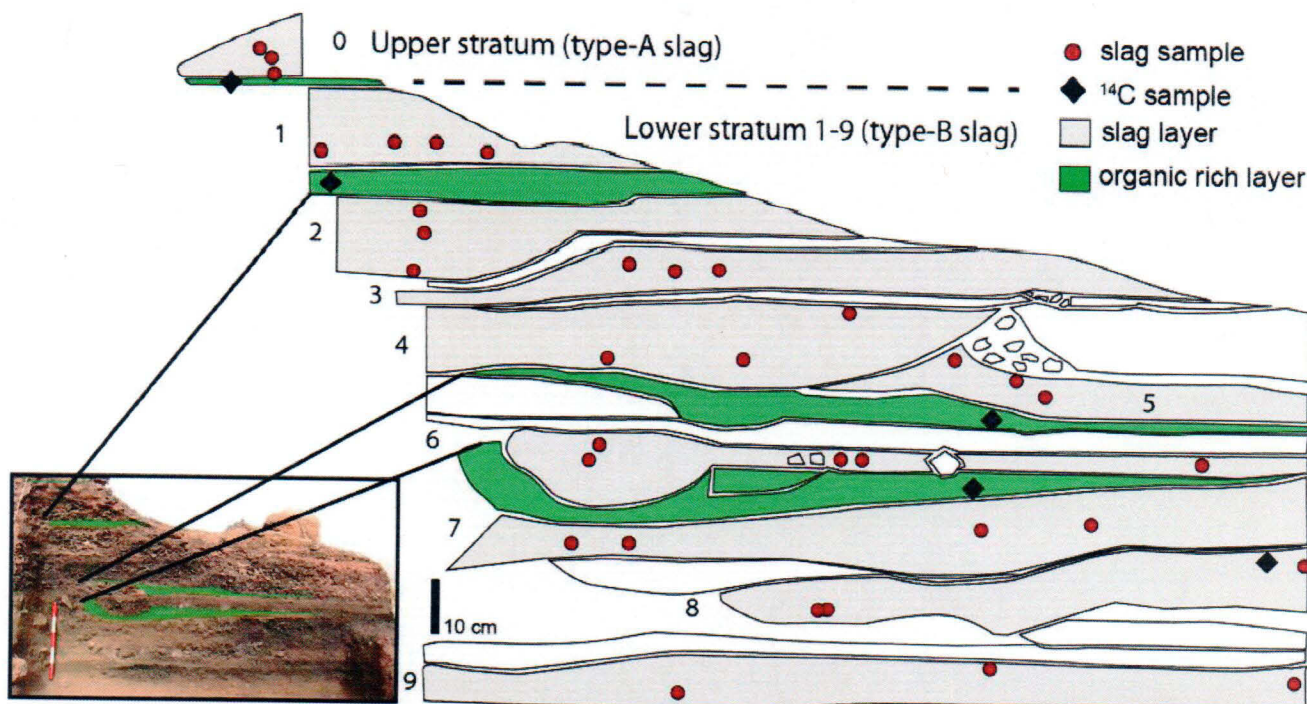


Figure 1. Cross section of stratigraphic slag debris from Timna-30. Modified from Shaar et al., 2011: fig. 3. Inset photo of section. Archaeomagnetic and radiocarbon samples that yielded reliable magnetic results are shown. The relative stratigraphic order of ten depositional sequences provides further constraints on the age of archaeomagnetic data recovered from the slag material. See original article for further details.

typological seriation, it is also constrained by three additional sources of information that in many cases can significantly increase time resolution, which follow here.

1. Historically Dated Archaeomagnetic Materials

Materials such as cylinder seals, bullae, ostraca, and other artifacts that have inscribed dates (such as names of historical figures) can be used as calibration anchors in regional databases and potentially provide annual resolution that surpasses the resolution achievable by radiocarbon and other radiometric methods (see recently the study on Judean stamped jar handles, Ben-Yosef, Millman et al. 2017). In addition, materials from destruction layers of historically documented military campaigns can further constrain archaeomagnetic chronologies, sometimes to the year (e.g., destruction layers of the 701 Assyrian conquest of Judah), or even to the day (e.g., Saladin's campaign on Vadum Iacob on 24 August 1179 C.E. (Segal, Marco, and Ellenblum 2003)).

2. Continuous Sedimentary and Archaeological Sequences

Sequenced stratigraphy that represents largely uninterrupted deposition can further constrain the age of archaeomagnetic data. For example, Ben-Yosef, Tauxe, Levy et al. 2009 and Shaar, Ben-Yosef et al. 2011 dated two contemporaneous, rapidly accumulating waste mounds of the early Iron Age ancient copper production industry of the Arava Valley and conducted archaeomagnetic intensity experiments on associated slag samples (e.g., fig. 1). The absolute chronology of magnetic data from these two sections was determined by using both Bayesian-modeled

radiocarbon ages and the relative position of each sample in the sequence, thereby providing a more precise absolute age than what was possible using the associated radiocarbon dates alone. Similarly, sedimentary sequences (such as lake deposits) hold the potential to provide continuous records of the geomagnetic field (Shaar and Ben-Yosef 2017). Although researchers have explored this approach in the past (e.g., Frank, Schwab, and Negendank 2002), such studies for the Holocene in the Levant still require a more systematic effort.

3. Intersite Correlation and Synchronization of Geomagnetic Field Intensity

At the core of many chronological debates in archaeology, including that about the Iron Age, lies the challenge of correlating stratigraphic sequences between sites. Based on the principles elaborated in Stiller, Hardin et al. 2016, a comparative archaeomagnetic study can be used to confirm or reject synchronization of stratigraphic contexts at key sites, regardless of the reference datasets and models (see, e.g., Shaar et al. 2016 for synchronization between Megiddo and Hazor). In the example above, further refinement of the curve was achieved by correlation between several slag deposit sites (Shaar, Ben-Yosef et al. 2011). Additionally, a large increase in field intensity at ~2600 B.C.E., followed by a monotonic decline in field strength until ~1600 B.C.E., has now been identified at several Near Eastern sites. This pattern in field variability was used to correlate stratigraphic features and site chronology during the Early Dynastic II period at Mari in Syria (Gallet and Butterlin 2015). This method is particularly useful if a site includes a massive destruction event. Since the geomagnetic field should have the same properties

over a limited geographic region, discrepancies in field records between sites that have similar destructions would necessarily indicate different events. However, similarities should be treated cautiously as periods of static geomagnetic variation do occur (in a way, similar to radiocarbon plateaus).

As mentioned in Stillinger, Hardin et al. (2016), archaeomagnetism provides a complementary, affordable dating method using materials that are often abundant at most sites in the Levant. An additional advantage should also be noted: the possibility to date artifacts of interest directly, thus avoiding issues of stratigraphic ambiguity or contextual contamination. For example, archaeomagnetism can provide chronological insights into certain types of pottery by conducting direct measurements on the pottery itself. As key pottery types are often at the center of chronological debates, archaeomagnetism has the potential to make an important contribution to seriation studies.

Stillinger, Hardin et al. 2016 was not meant to solve the Iron Age chronological problem or dispute the value of Bayesian analysis or radiocarbon dating, but rather to serve as an introduction to archaeomagnetic dating for nonpractitioners. The example results presented were included to illustrate how the method works. Archaeomagnetic reference curves are not static; they change (and improve) as new high-quality data become available. These data serve both Earth scientists, who are interested in better understanding the planet, and archaeologists, who are interested in exploring more ways to address chronological issues. It is worth noting that studying the Earth's magnetic field is important also to those invested in radiocarbon dating, as the former influences the production rate of ^{14}C , and therefore radiocarbon calibration curves.

So how shall we move forward with the absolute dating of the Iron Age? We believe that an integrative approach is the only way to proceed. Reliance on one particular dating technique will not resolve the Levantine Iron Age chronology debate. Instead, researchers must integrate observations from radiocarbon, archaeomagnetism, and various other complementary techniques (e.g., dendrochronology, luminescence dating, Th-series, and more) in order to achieve the highest possible temporal resolution. We must also recognize the shortcomings and advantages of each geochronological method. Collaboration with specialists across all fields will not only produce a rigorously detailed chronology for the Near East Iron Age, but will also help mutually improve each of these methods for studies in this region and beyond.

Notes

1. E.g., Genevey and Gallet 2003; Gallet and Le Goff 2006; Ben-Yosef, Tauxe, Agnon et al. 2008; Ben-Yosef, Tauxe, Levy et al. 2009; Gallet, Le Goff et al. 2008; Gallet, D'Andrea et al. 2014; Shaar et al., 2011; Shaar et al. 2015; Ertepinar et al. 2012; Stillinger, Feinberg, and Frahm 2015.
2. Ben-Yosef, Gidding et al. 2016; Ben-Yosef, Millman et al. 2017; Ben-Yosef, Tauxe, and Levy 2010; Peters, Tauxe, and Ben-Yosef forthcoming; Shaar et al. 2015; Shaar et al. 2016; Shaar et al. 2017.

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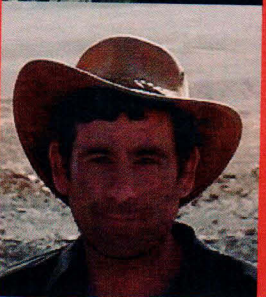
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