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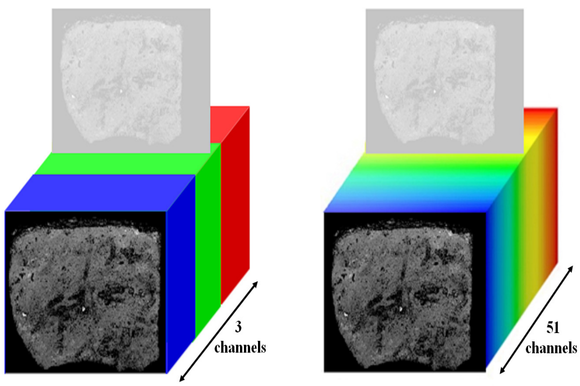

RECONSTRUCTING ANCIENT (BIBLICAL) ISRAEL
THE EXACT AND LIFE SCIENCES PERSPECTIVE

A European Research Council funded project Directors: **Israel Finkelstein & Steve Weiner**

Guest Editors Israel Finkelstein, Steve Weiner, and Elisabetta Boaretto

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The Iron Age in Israel: The Exact and Life Sciences Perspectives

Edited by Israel Finkelstein, Steve Weiner, and Elisabetta Boaretto

Special issue, Radiocarbon, Vol 57, Nr 2, 2015

CONTENTS

ARTICLES

Radiocarbon, Vol 57, Nr 2, 2015, p 197–206 DOI: 10.2458/azu_rc.57.18566

PREFACE—THE IRON AGE IN ISRAEL: THE EXACT AND LIFE SCIENCES PERSPECTIVES

Israel Finkelstein[1] • Steve Weiner[2] • Elisabetta Boaretto[2]

In the original proposal entitled Reconstructing Ancient Israel – The Exact and Life Sciences Perspective, two of us (Israel Finkelstein and Steve Weiner) wrote, "If the microscopic data are well integrated into the macroscopic (archaeological) record, they will undoubtedly provide new insights into the study of Ancient Israel." And this was what this 5-year (2009–2014) European Research Council (ERC) sponsored program (details below) was all about. New ground was broken on three fronts: conceptual, methodological, and in the generation of new data that indeed provide novel insights into the history and material culture of Ancient Israel in particular and the Iron Age Levant in general. The reviews presented in this special volume synthesize some of these new insights. The findings have been published in about 70 papers (see Appendix).

CONCEPTUAL BREAKTHROUGHS

The archaeological record is, for the most part, fragmentary in that rather little of what existed originally is buried, what is buried undergoes change over time, and when excavated not all the interesting information is retrieved. We cannot do anything about the first two processes, but where we can improve and innovate is during the excavation. The approach we use is to explore as much as possible the entire archaeological record of a site, from the level of atoms to the levels of architecture and site organization, and to try to do this as much as possible during the excavation itself. An excavation is destructive; the more information that is obtained while excavating, the more informed can the excavation team (macro- and microarchaeologists) be, and the more they can use this information to adapt the excavation strategy and extract as much valuable data as possible. The macroscopic record can be seen with the naked eye down to a submillimeter level, but the remaining record, which spans no less than 10 orders of magnitude down to the atomic level, requires instrumentation. This integrated on-site approach is referred to by us as "microarchaeology."

Another conceptual breakthrough is that the archaeological finds need to be mapped in four dimensions, with the 4th dimension being time. Albeit great improvements are being made with the mapping of the three spatial dimensions (use of total stations, 3D reconstructions, laser scanners, etc.), the 4th dimension, time, is still mapped, for the most part, using traditional means (stratigraphy, material culture assemblages, and links to supposed historical events and figures), even though for the last 65 years, a precise and accurate method for determining absolute time is available—radiocarbon. In our project, a great effort was made to place every site and find into an absolute chronological framework using radiocarbon dating (e.g. Toffolo et al. 2014 in the list below). By so doing, we opened up questions regarding the dynamics of the spread of ideas, materials, and people in the past, and made it possible to obtain reliable snapshot views of what was transpiring in a given region at a specific point in time (Boaretto in this issue).

One of the reasons we think it most appropriate to publish these reviews on the achievements of this project in many diverse fields in the journal *Radiocarbon*, is because we feel that absolute chronology really does "set the stage," or define the framework for the essential 4th dimension of time. Obtaining accurate and precise dates, it turns out, depends to a great extent on using both the

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macroscopic and the microscopic records. So radiocarbon dating really permeates through many of the topics we addressed.

Eventually, archaeology is all about reconstructing history. Indeed, the history of the Levant in the Bronze and Iron Ages has traditionally been drawn according to three sets of evidence: macro-archaeological finds, the biblical record, and ancient Near Eastern textual material. The introduction of the microarchaeology "philosophy" (to differ from the usage of a single method at a given site) is another conceptual change in the way we work.

METHODOLOGICAL BREAKTHROUGHS ("PUSHING THE ENVELOPE")

Traditionally, many of the "micro" methods used in archaeology were developed in the earth sciences, with the one glaring exception of ^{14}C dating, which was first applied to archaeology. With the new agenda of revealing as much as possible of the archaeological record in real time during the excavation (Figure 1), a method has an added value if the information can be obtained within a few minutes on site, or even from one day to the next, still during the active excavation. This is a unique requirement for archaeology, and thus new methods have to be developed specifically for these purposes. In our project, we developed several methods to enhance the on-site tool kit.

Figure 1 The on-site microarchaeological laboratory in operation in Area Q, Megiddo.

Immediate turnaround for on-site analysis: the key tool for the on-site analysis is Fourier transform infrared spectroscopy (FTIR), where just 5 to 10 min are required for each analysis. We developed two valuable tools using FTIR. The first assesses the atomic disorder of calcites that, if well preserved, enable us to differentiate between geogenic, biogenic, and anthropogenic calcite (plaster and wood ash). The same approach can be used for the carbonated hydroxyapatite mineral of bone, dentin, and enamel, in which the key issue is usually assessing state of preservation. By careful calibration of standard mixtures, we can use FTIR to assess proportions of quartz and clay, a tool that is often helpful for differentiating sediment sources and uses.

From one day to the next: We reported a new rapid method for counting phytoliths in sediments that has broad application in mapping past activities involving plants. In one application, we used this method to define the boundaries of a small archaeological site that extend well beyond its architecture (Cabanes et al. 2012). A new prescreening method was established (Goldenberg et al. 2014) for determining whether ceramics of interest have preserved organic residues, which could then be extracted and analyzed. This requires the availability of an XRF on site. A relatively simple method was developed for producing small thin sections within 24 hr in order to examine the micromorphology of particularly important areas.

Home laboratory methods: elegant methods for revealing ink inscriptions on sherds were developed using spectral imaging (Faigenbaum et al. 2012 and in this issue; Sober et al. 2014). This alleviates the problem of the writing fading once the sherd is extracted from the sediments, and allows for a more objective interpretation of the text (Shaus et al. 2010). Raman spectroscopy was deployed in order to produce automated facsimiles of ink inscriptions (Shaus et al., forthcoming). In addition, we developed algorithms for comparing letters in order to identify different handwritings (articles in progress). In another field, a chemical method was developed for assessing phytolith preservation (Cabanes et al. 2011), which has now become a key issue in reconstructing the archaeobotanical record.

NEW INSIGHTS INTO THE IRON AGE IN THE LEVANT

The eight reviews in this volume each address different topics, and synthesize the various observations, placing them into a broader framework.

A major contribution, which resonates far beyond ancient Israel, is our input on the absolute chronology of the entire Mediterranean region in the Iron Age (Toffolo et al. 2013). This issue has been fiercely debated and ours was an attempt to resolve it by ^{14}C dating secure samples from several sites in Greece, representing a sequence of relative phases of the Iron Age.

One of the declared aims of this project was to integrate observations from more than one site, using different methods. A good example is the work in the Negev Highlands, which was aimed at better understanding the mode of life in this southern desert region during the Iron Age, as well as broader issues related to the history of the marginal areas of the southern Levant. Geoarchaeological studies, together with extensive archaeobotanical work on phytoliths, were all placed in an absolute chronological framework using ^{14}C dating (Shahack-Gross et al. 2014; Shahack-Gross and Finkelstein, this issue). The project established that the predominant lifestyle during the Iron IIA involved livestock management. This is inconsistent with past theories regarding the importance of seasonal dry farming in the subsistence economy of the groups that inhabited the region. We also discovered an active trade route through this area, which involved the production of ceramics in the copper-production sites of Timna and/or Feynan (Martin and Finkelstein 2013; Martin et al. 2013). Our dating established a new paradigm regarding the historical setting of the wave of settlement in the Negev in the 9th rather than 10th century BCE.

Based on a comprehensive database of livestock frequencies and mortality profiles, we examined synchronically and diachronically conventional assumptions regarding animal husbandry in the southern Levant in the Late Bronze and Iron Ages (Sapir-Hen et al. 2014). Contrary to past assumptions, we proposed that changes in animal-husbandry strategies were dictated by historical factors rather than by environmental ones. The main shift in livestock husbandry reflects enhanced social complexity during a period of transformation in the territorial-political system from local kingdoms to imperial rule.

Destruction events are important in the archaeology of the southern Levant, both because of their historical significance and as they are well-defined marker horizons in multilayer sites. A detailed macro- and microarchaeological study of a late 9th century destruction horizon at Tell es-Safi (Namdar et al. 2011) revealed information about the manner in which the space was used prior to the destruction, aspects of the destruction itself, and the postdestruction processes that may have continued for decades. A similar study, but on a much larger scale, focused on the huge so-called "red city" destruction layer at Megiddo, and is still ongoing.

Regarding the environment, our study of the pollen record in sediments extracted from the Dead Sea and the Sea of Galilee was carried out at an unprecedented resolution of a sample per 25–40 yr (Langgut et al. 2014 and this issue). This, and the study of Dead Sea levels (Kagan et al., this issue), shed light on the climatic history of the Levant, and in fact the entire eastern Mediterranean and Near East. Our work reveals a major dry event at the end of the Late Bronze Age, which seems to have played a major role in the "Bronze Age Collapse" in the late 2nd millennium BCE (Langgut et al. 2013). The pollen results are supported by two other records that relate to the same timespan (~1250–1100 BCE): a wave of destructions in many major sites and ancient Near Eastern texts that speak about drought, famine, movement of displaced people, and as a result destruction of cities. The pollen investigation also illuminated a "mini-crisis" in the early 2nd millennium BCE (~2000–1800 BCE), which affected the sedentary fringe areas from southern Israel and Jordan to northern Syria (Finkelstein and Langgut 2014).

The Philistines were a group among the Sea Peoples, who were on the move in the transition from the Late Bronze to the Iron Age, probably as a result of the climate crisis referred to above. Investigations of early Iron Age faunal assemblages from their urban centers in southern Israel indicate the importance of pig culture—far beyond the usual in the Levant. This fact drew much attention to the role of culinary practices in establishing ethnic boundaries and more specifically the pig taboo in biblical Israel. We carried out two pig-related studies (Sapir-Hen et al., this issue). Our archaeozoological investigations revealed a relatively large number of pig bones in lowland Iron II sites related to the Northern Kingdom (Israel). Based on this, we suggest that the pig taboo was a result of the Israel–Judah relationship in the later phases of the Iron Age more than the supposed Israel–Philistine conflicts in the early Iron Age (Sapir-Hen et al. 2013). Because of the cultural importance of pigs, and past clues that wild boars in Israel carry a European (to differ from Middle Eastern) genetic signature, we turned to ancient DNA of pigs (Meiri et al. 2013). Our first step verified that, indeed, the modern wild boar population in Israel is of European origin. We then checked pig bones from different archaeological periods and discovered that the first significant appearance of European pigs took place in ~900 BCE. We suggest associating the early arrival of European pigs with the migration of the Sea Peoples.

One of the biggest surprises in our work came from the analysis of molecules preserved in small rounded Phoenician flasks that date to ~1000 BCE (Namdar et al. 2013 and this issue). This study showed the presence of a molecule called cinnamaldehyde, which is only produced in large quantities in cinnamon tree bark. These trees grow in the Indian subcontinent and the Far East. The finds indicate the existence of long-distance trade from India and beyond to the southern Levant and further to the west in an early phase of the Iron Age.

Regarding trade, our study of shape and volume of trade containers (storage jars) from different phases of the Late Bronze and Iron Ages demonstrated that standardization in production of ceramics occurred in the Iron IIB (the 8th century BCE)—the period of Assyrian domination in the Levant and prosperity of Phoenician-led trade in the eastern Mediterranean (Finkelstein et al. 2011).

A major achievement of the project is the study of various aspects of bronze and iron industries in the Iron Age (Yahalom-Mack et al., this issue). First and most important for future fieldwork, we demonstrated the possibility of identifying metallurgical activity not only according to objects found in a dig, but also in the residues it leaves in the sediments (Eliyahu-Behar et al. 2012). The metallurgy track shed new light on the gradual transition from bronze to iron, which culminated in the Iron IIA, in the 9th century BCE. And it illuminated two highly important facts—continuity in metal industry over a long time in the same quarters in multiperiod sites and the fact that iron production emerged from the bronze workshops (Yahalom-Mack et al. 2014 and forthcoming).

LONG-TERM IMPACT

Long-term outcomes are usually not easily measureable or identifiable so soon after the completion of a research program. We hope that what will be said about this project in, say, 10 years from now, is that this was the turning point when archaeologists working in the Levant redefined excavation modes and research goals, taking into account the potential of integrating the microscopic and macroscopic archaeological records.

MODE OF OPERATION

The project discussed here was supported by the European Research Council Advanced Grant no. 229418, titled Reconstructing Ancient Israel: The Exact and Life Sciences Perspective (RAIELSP). Principal and Co-Principal Investigators were Israel Finkelstein of Tel Aviv University and Steve Weiner of the Weizmann Institute of Science. The project was administered by Shirly Ben-Dor Evian and Yuval Gadot.

The project was organized into five main tracks, which included 10 subtracks (names of researchers in parentheses, name of track leader underlined) (Figure 2):

1. The time of Ancient Israel: focused on developing a detailed absolute chronology for the Iron Age in the Levant, and correlating Iron Age chronology in the southern Levant with that in Greece in particular and the Mediterranean in general (<u>Elisabetta Boaretto</u>, Michael Toffolo, and Alexander Fantalkin).

2. The genesis of Ancient Israel: (a) focused on the genetics of the local pig population from the Bronze Age through the Iron Age (<u>Meirav Meiri</u>); (b) tracking subsistence economy using mainly geoarchaeological approaches both in the Negev and in sites in central Israel (<u>Ruth Shahack-Gross</u>, Dan Cabanes, and David Friesem); (c) relating paleoclimate to settlement patterns by studying pollen in samples from the Dead Sea and the Sea of Galilee (<u>Daphna Langgut</u>, <u>Thomas Litt</u>, <u>Mordechai Stein</u>, Elisa Kagan, and Frank Neumann).

3. The life of Ancient Israel: (a) reconstructing trading patterns in the Negev using ceramic petrography (<u>Mario Martin</u>); (b) tracking trade networks and technological advances based on bronze and iron metallurgy (<u>Adi Eliyahu</u> and <u>Naama Yahalom-Mack</u>).

4. The mind of Ancient Israel: (a) the study of daily mathematics of dimensions in Iron Age pottery (<u>Itzhak Beneson</u> and Lena Zapasky); (b) the use of advanced imaging capabilities to decipher writing in Israel and Judah (<u>Eli Piasetzky</u>, Shira Faigenbaum, David Levin, Murray Moinester, Arie Shaus, Barak Sober, and Eli Turkel).

5. The identity of Ancient Israel: (a) study of preserved organic residues in pottery to reconstruct ancient trade routes (<u>Dvory Namdar</u>, Ayelet Gilboa, and Larisa Goldenberg); (b) study of animal bones to better understand subsistence economies and diet (<u>Lidar Sapir-Hen</u>, <u>Guy Bar-Oz</u>, and Lior Weissbrod).

Figure 2 Reconstructing Ancient Israel project retreat (Neve Ilan, 2013). Standing in the upper row, left to right: Michael Toffolo, Steve Weiner, Lidar Sapir-Hen, Ruth Shahack-Gross, Elisabetta Boaretto, Maayan Mor, Dvory Namdar, and Meirav Meiri; standing, middle row, left to right: Lior Weissbrod, Shira Faigenbaum, Zach Danseth, Mathilde Forget, Yuval Gadot, Na'ama Yahalom-Mack, Adi Eliyahu-Behar, Shirly Ben-Dor Evian, Dafna Langgut, Israel Finkelstein, Mario Martin, Larisa Goldenberg, Barak Sober, Arie Shaus, and Thomas Litt; sitting: Eli Piasetzky.

Fieldwork, including sampling, was conducted in the following sites (in the case of ongoing excavations, the name of the director appears in parentheses) (Figure 3):

Ashkelon (Dan Master, Harvard University), Tel Burna (Itzhak Shai and Joe Uziel, Bar Ilan University), Tel Eton (Avraham Faust, Bar Ilan University), Hazor (Amnon Ben-Tor and Sharon Zuckerman, the Hebrew University), Izbet Sartah, Megiddo (Israel Finkelstein and David Ussishkin, Tel Aviv University; Eric H. Cline, George Washington University), Moza (Shua Kisilevitz, Anna Eirikh-Rose, and Zvi Greenhut, Israel Antiquities Authority), Qubur el-Walaydah (Gunnar Lehmann, Ben-Gurion University), Ramat Rahel (Oded Lipschits and Yuval Gadot, Tel Aviv University; Manfred Oeming, University of Heidelberg), er-Ras (Yuval Gadot, Tel Aviv University), and Tell es-Safi/Gath (Aren Maeir, Bar Ilan University).

Samples were also taken from the following sites:

Israel: Acco (Danny Syon and Edna Stern, Israel Antiquities Authority), Azekah (Oded Lipschits and Yuval Gadot, Tel Aviv University; Manfred Oeming, University of Heidelberg), Beer-sheba (Zeev Herzog, Tel Aviv University), Tel Dor (Ayelet Gilboa, Haifa University; Ilan Sharon, Hebrew University), Gezer (Steve Ortiz, Southwestern Baptist Theological Seminary; Sam Wolff, Israel Antiquities Authority), Tel Halif (Oded Borowski, Emory University), Jerusalem (Doron Ben-Ami and Shlomit Weksler-Bdolah, Israel Antiquities Authority), Kinneret (Stefan Münger, University of Bern; Juha Pakkala, University of Helsinki; Jürgen Zangenberg, University of Leiden), Tel Malhata (Itzhaq Beit-Arieh, Tel Aviv University), Negev Highlands sites, Patish (Pirhiya Nahshoni, Israel Antiquities Authority), Tell Qasile (Amihai Mazar, Hebrew University), Khirbet Qeiyafa (Yosef Garfinkel, Hebrew University), Tel Rehov (Amihai Mazar, Hebrew University), Tel Rekhesh (Akio Tsukimoto, Rikkyo University Tokyo; Hisao Kuwabara, Tenri University; and Yitzhak Paz, Ben-Gurion University), Beer Sheva, Horvat 'Uza, and nearby Horvat Radum (Itzhaq Beit-Arieh, Tel Aviv University) and Tel Yokneam (Amnon Ben-Tor, Hebrew University).

Cyprus: Idalion (Pamela Gaber, Lycoming College).

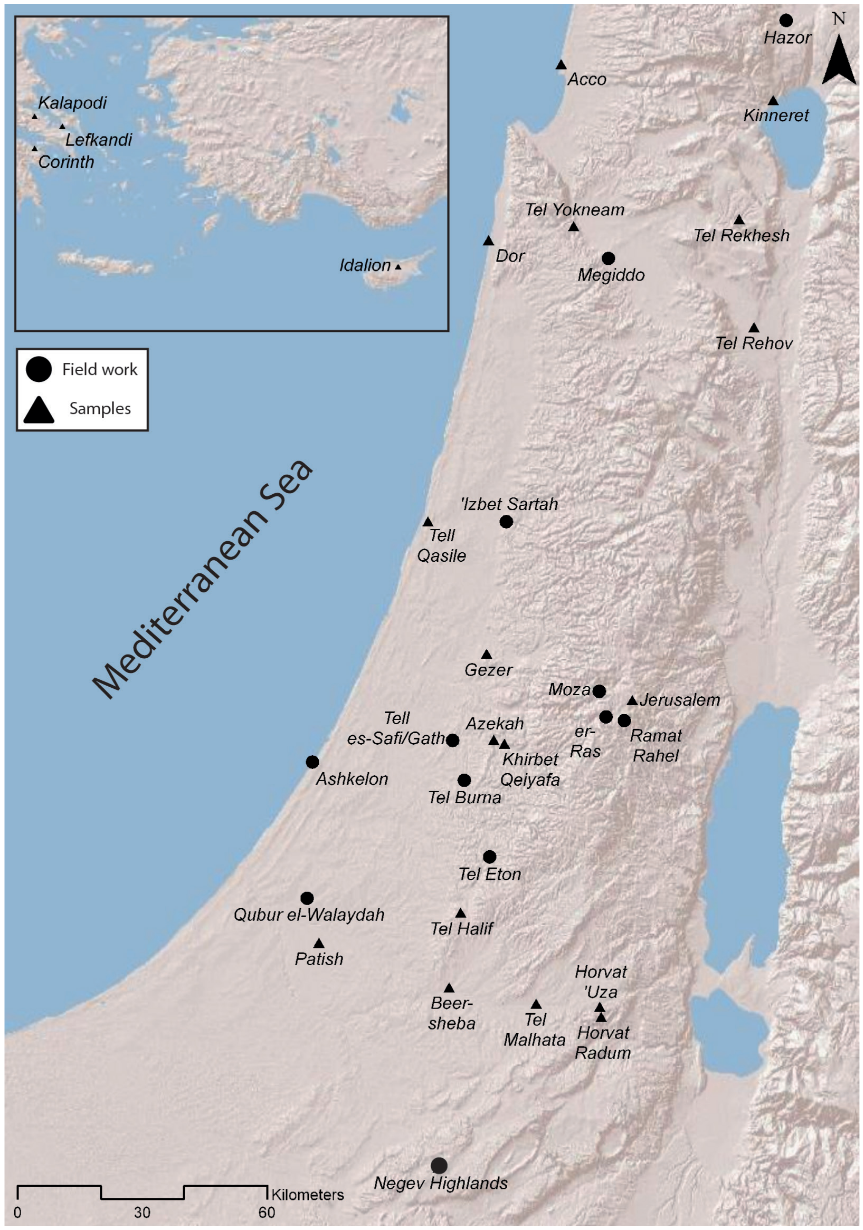

Figure 3 Reconstructing Ancient Israel project: sites where actual fieldwork was carried out and sites sampled.

Greece: Corinth (Guy Sanders, American School of Classical Studies in Athens), Kalapodi (Wolf-Dietrich Niemeier and Rainer C.S. Felsch, German Archaeological Institute in Athens), and Lefkandi (Irene Lemos, Oxford University).

Laboratory work was carried out at Tel Aviv University, the Weizmann Institute of Science (Rehovot), and the University of Bonn (Germany).

APPENDIX: LIST OF PUBLICATIONS

Published and accepted for publication

Asscher Y, Lehmann G, Rosen SA, Weiner S, Boaretto E. 2015. Absolute dating of the Late Bronze to Iron Age transition and the appearance of Philistine culture in Qubur el-Walaydah, southern Levant. *Radiocarbon* 57(1):77–97.

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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)

The Iron Age in Israel: The Exact and Life Sciences Perspective
Edited by Israel Finkelstein, Steve Weiner, and Elisabetta Boaretto

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.

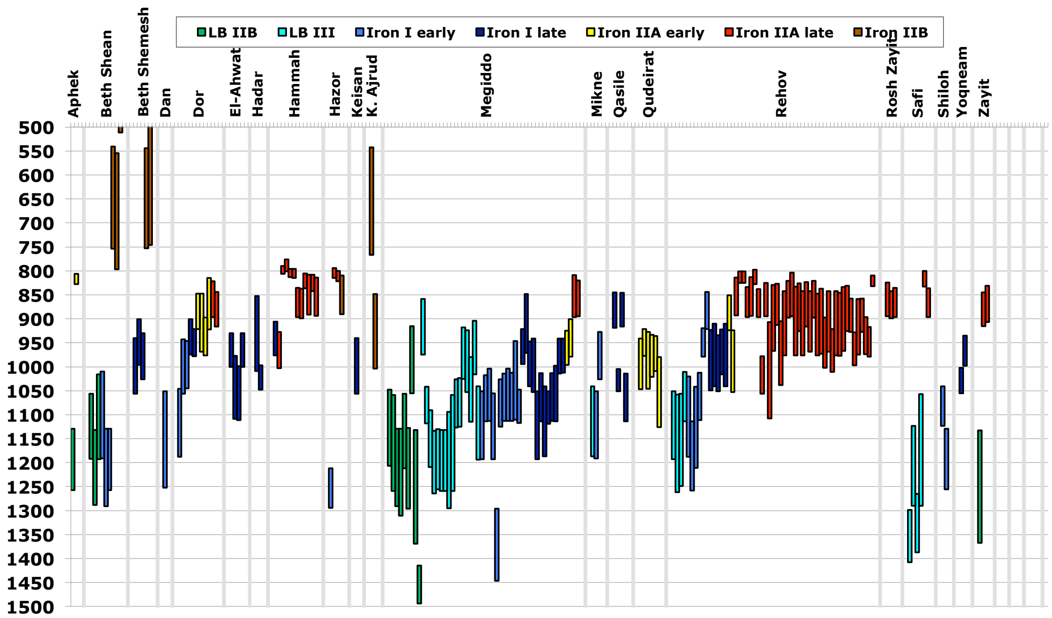

Figure 2 Radiocarbon dates obtained from short-lived samples for Late Bronze and Iron Age layers at sites in the southern Levant. Each segment shows the calibrated range ±1σ (Toffolo et al. 2013a).

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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VEGETATION AND CLIMATE CHANGES DURING THE BRONZE AND IRON AGES (~3600–600 BCE) IN THE SOUTHERN LEVANT BASED ON PALYNOLOGICAL RECORDS

Dafna Langgut[1] • Israel Finkelstein[2] • Thomas Litt[3] • Frank Harald Neumann[4] • Mordechai Stein[5]

ABSTRACT. This article presents the role of climate fluctuations in shaping southern Levantine human history from 3600 to 600 BCE (the Bronze and Iron Ages) as evidenced in palynological studies. This time interval is critical in the history of the region; it includes two phases of rise and decline of urban life, organization of the first territorial kingdoms, and domination of the area by great Ancient Near Eastern empires. The study is based on a comparison of several fossil pollen records that span a north-south transect of 220 km along the southern Levant: Birkat Ram in the northern Golan Heights, Sea of Galilee, and Ein Feshkha and Ze'elim Gully both on the western shore of the Dead Sea. The vegetation history and its climatic implications are as follows: during the Early Bronze Age I (~3600–3000 BCE) climate conditions were wet; a minor reduction in humidity was documented during the Early Bronze Age II–III (~3000–2500 BCE). The Intermediate Bronze Age (~2500–1950 BCE) was characterized by moderate climate conditions, however, since ~2000 BCE and during the Middle Bronze Age I (~1950–1750 BCE) drier climate conditions were prevalent, while the Middle Bronze Age II–III (~1750–1550 BCE) was comparably wet. Humid conditions continued in the early phases of the Late Bronze Age, while towards the end of the period and down to ~1100 BCE the area features the driest climate conditions in the timespan reported here; this observation is based on the dramatic decrease in arboreal vegetation. During the period of ~1100–750 BCE, which covers most of the Iron Age I (~1150–950 BCE) and the Iron Age IIA (~950–780 BCE), an increase in Mediterranean trees was documented, representing wetter climate conditions, which followed the severe dry phase of the end of the Late Bronze Age. The decrease in arboreal percentages, which characterize the Iron Age IIB (~780–680 BCE) and Iron Age IIC (~680–586 BCE), could have been caused by anthropogenic activity and/or might have derived from slightly drier climate conditions. Variations in the distribution of cultivated olive trees along the different periods resulted from human preference and/or changes in the available moisture.

INTRODUCTION

Due to the occurrence of different vegetation zones that follow steep north-south and west-east precipitation gradients, the southern Levant is a sensitive region for tracing links between climate and cultural changes, featuring Mediterranean (precipitation >400 mm/yr), semi-arid steppe Irano–Turanian (~400–200 mm/yr), and desert Saharo–Arabian (precipitation <200 mm/yr) zones (Zohary 1973, 1982; Figure 1). The region went through significant changes in climate patterns during the Late Holocene. These changes were accompanied by transformations in settlement and demographic patterns (e.g. Migowski et al. 2006; Neumann et al. 2007a; Kaniewski et al. 2010; Litt et al. 2012; Langgut et al. 2013). The question of how environmental changes affected human activity in this area in antiquity has been debated (compare Rambeau 2010). This article includes the results of recent research efforts to establish the vegetation history of the Bronze and Iron Ages (~3600–600 BCE) based on high-resolution and well-dated fossil pollen records. This time interval features cycles of rise and fall of urban cultures, the emergence and collapse of the territorial kingdoms documented in the Hebrew Bible and other Ancient Near Eastern records, and periods of imperial rule. It also features sharp settlement oscillations, including human movements between the Mediterranean, semi-arid, and desert environments that could have resulted from climate fluctuations.

The study of fossil pollen grains is a powerful tool in the reconstruction of past vegetation and climate history (e.g. Bryant 1989). Several palynological records that cover the Bronze and Iron Ages are available for the southern Levant. Four of them are presented and discussed below (Figure 1):

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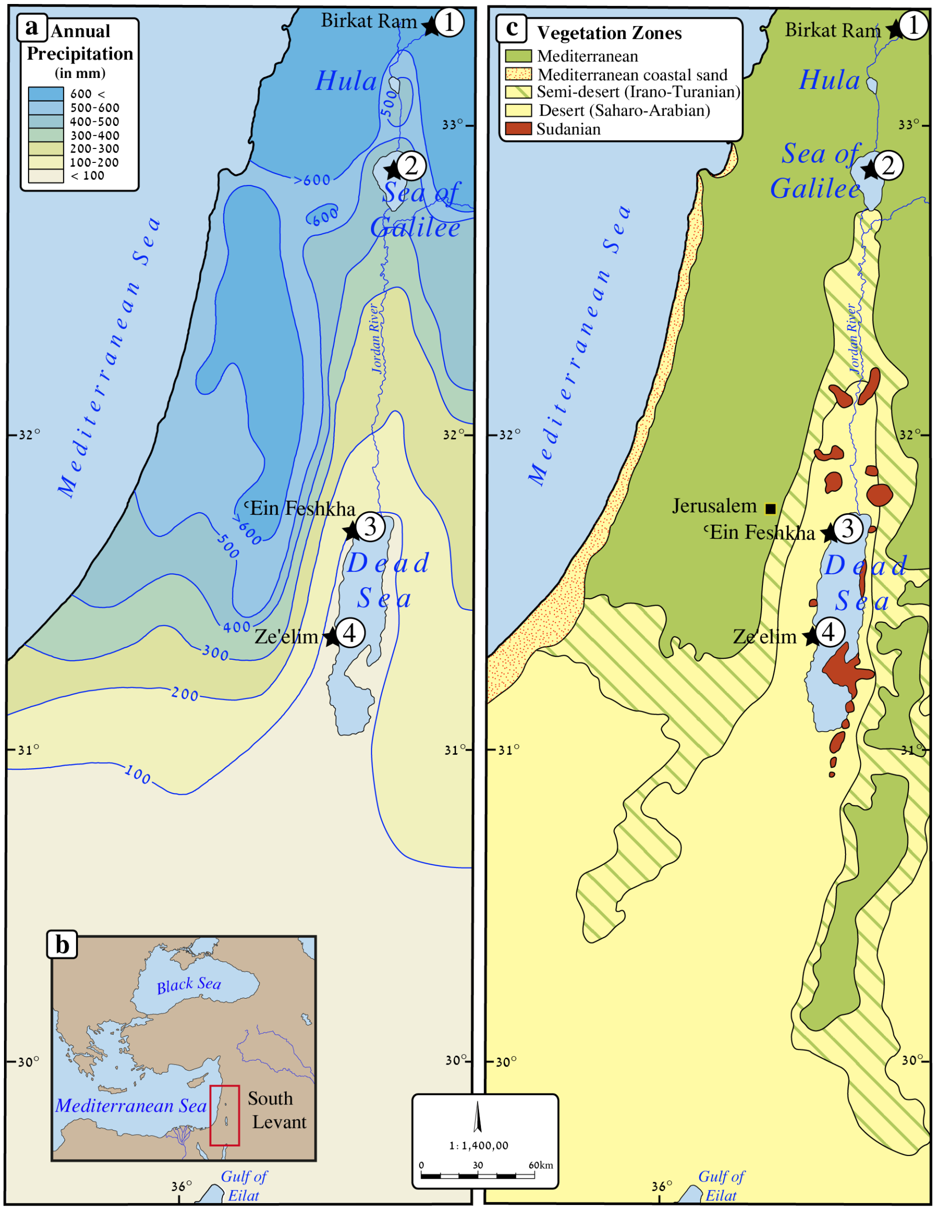

Figure 1 (a) Rainfall isohyets of the south Levantine region (after Srebro and Soffer 2011), with the location of the four fossil pollen records discussed in this paper: 1. Birkat-Ram (Schwab et al. 2004; Neumann et al. 2007b); 2. Sea of Galilee (Langgut et al. 2013; this study, Figure 3); 3. Ein Feshkha (Neumann et al. 2007a, 2009), and 4. Ze'elim Gully (Neumann et al. 2007a; Langgut et al. 2014a); (b) the position of the southern Levant in the Eastern Mediterranean; (c) phytogeographic zones.

Birkat Ram (Schwab et al. 2004; Neumann et al. 2007b), Sea of Galilee (Langgut et al. 2013; this study), Ein Feshkha (Neumann et al. 2007a, 2009), and Ze'elim Gully (Neumann et al. 2007a; Langgut et al. 2014a). These records were chosen because of their relatively robust chronological framework and high pollen sampling resolution (only a few decades interval between samples). Other pollen diagrams from the region are not presented here since they were either sampled in lower resolution [e.g. Litt et al. (2012) at the Dead Sea analyzed samples in ~180/200-yr intervals between samples], and/or because they suffer from chronological uncertainties (Baruch 1986, 1990, 1993; Baruch and Bottema 1999; van Zeist et al. 2009; several studies discuss the chronological problems of some of the pollen diagrams from the region, e.g. Cappers et al. 1998; Meadows 2005; Neumann et al. 2010).

This study therefore spans a north-south transect of 220 km of the southern Levant, which features a north-south precipitation gradient of ~1000 mm of annual rainfall as well as a sharp topographic gradient. While Birkat Ram, located in a volcanic maar, is located at 940 m above msl (mean sea level), the Sea of Galilee and the Dead Sea—which comprise morphotectonic depressions along the Dead Sea Transform (Neev and Emery 1995; Stein 2001, 2014a,b)—are situated at 200 and 400 m below sea level (m bsl), respectively.

In addition to paleoclimate reconstruction, this research also aims at tracing evidence of human interference in natural vegetation as reflected in the pollen curves: agricultural activity, grazing, deforestation, abandonment of fields, and soil erosion.

CURRENT CLIMATE AND VEGETATION

Annual rainfall in the southern Levant is high on the coast and in the north, and diminishes to the south and east (Ziv et al. 2006; Dayan et al. 2007), where the north Sinai coastline forms the southern limit in which rain clouds can form in large masses (Zangvil and Druian 1990). East of the Mediterranean, the influence of the Mediterranean humidity drops sharply, also due to the orographic effect of the mountain ranges, which create a rain shadow, the Judean Desert. As a result, the southern Levant is composed of three main phytogeographical zones (Zohary 1962, 1973) (Figure 1b): (1) the Mediterranean, (2) the Irano–Turanian, and (3) the Saharo–Arabian (which also includes some tropical plants that belong to the Sudanian vegetation).

1. The Mediterranean region runs along the coast and its adjacent mountainous areas (Galilee, Carmel Ridge, Samaria, and Judea). This vegetation zone features Mediterranean maquis/forest with typical evergreen trees such as *Quercus callipprinos*, *Olea europaea*, and *Pinus halepensis* and some deciduous trees (e.g. *Quercus boissieri*, *Q. ithaburensis*, and *Pistacia palaestina*). In the understory of forests or in open fields, dwarf-shrubs as well as many herbaceous species are common. This territory receives more than 400 mm rainfall annually and is generally influenced by the Mediterranean climatic system together with some regional orographic phenomena. The Israeli coastal plain occupies a mix of Mediterranean and desert plants due to its sandy soil and saline environment. This sandy strip is dominated by different species of Poaceae, Chenopodiaceae, *Artemisia monosperma*, and *Ephedra.*
2. The Irano–Turanian phytogeographic region runs from the coastal plain near Gaza to the Negev Highlands and the southern edge of the Judean Highlands and then continues northward via the central Jordan Valley to the Sea of Galilee. This is an almost tree-less landscape with semi-arid vegetation, often described as steppe. Different species of Poaceae and Chenopodiaceae are the main vegetal components of this region as well as *Artemisia herba-alba.* The annual rainfall is 200–400 mm on average and is due mainly to western Mediterranean depressions. The region is also characterized by relatively broad seasonal and daily temperature distributions.
3. The Saharo–Arabian territory occupies most of the Negev Desert, which lies within the world desert belt (30°N). The vegetation is typified by relatively low species diversity and is dominated by many members of the Chenopodiaceae, *Zygophyllum dumosum*, grasses, and *Tamarix* spp. This region has a typical desert climate: the mean annual rainfall does not exceed 200 mm

and is usually lower than 100 mm. Seasonal and daily temperature distributions are broad. This zone is influenced by southern and southeastern synoptic systems, which are widespread in the spring and autumn, as well as by the western Mediterranean depressions, which mainly influence the northern part of the Negev Desert. Within these desert plants' geographical area, the Sudanian territory with tropical elements occurs along the shores of the Dead Sea, in the Arabah Valley and in the central Jordan Valley (up to ~80 km north of the Dead Sea). Some of the tropical plants are linked to freshwater springs or wadi beds; they include *Acacia*, *Ziziphus spina-christi*, and *Salvadora persica* (Zohary 1962; Shmida and Or 1983; Al-Eisawi 1996).

SOUTHERN LEVANT POLLEN RECORDS

Birkat Ram

Birkat Ram, in the foothills of Mount Hermon, comprises a small maar lake that has occupied this volcanic depression since the last interglacial period (the TAHAL borehole, which was performed in 1968, penetrated 120 m and reached the basaltic flow at the bottom of the lacustrine sequence; Singer and Ehrlich 1978). The paleohydrological importance of Birkat Ram stems from its being a "sampler" of the Mount Hermon hydrological system; in general, maar lakes comprises a "delicate" regional tracer because of the lack of input water from major river and streams (e.g. Lamb et al. 2000; Lamb 2001). In 1999, a joint team of GFZ-Potsdam and the Hebrew University carried out several drills under water at a depth of 1.5 m (Schwab et al. 2004). This very shallow depth could not support deep drilling and the expedition yielded cores that were only several meters long. They were used to prepare a 543-cm-long composite profile. Correlations between the cores were established by high-resolution magnetic susceptibility, which was independently improved by palynological observations (Schwab et al. 2004; Neumann et al. 2007b). The compiled sedimentary record is characterized by a relatively homogenous lithology of detrital marls and diatoms. Eighteen samples of organic debris were accelerator mass spectrometry (AMS) radiocarbon dated and a chronological framework was established from ~4500 BCE to modern times (Schwab et al. 2004; Neumann et al. 2007b). The palynological investigation was conducted at an average sample interval of ~4 cm from the Bronze to the Iron Ages. Considering a uniform sedimentation rate in the composite core, this would imply that every sample represents on average 75 yr.

Sea of Galilee (Lake Kinneret)

The Sea of Galilee receives its water from the Jordan River and some other shorter rivers running from the Galilee Mountains and the Golan Heights (Figure 2). The southern part of the lake comprises a shallow body of water, a few meters deep, while the northern part (where Research Station A is located) reaches a water depth of 40 m. During most of the Holocene, the Sea of Galilee stood at ~212 m bsl, yet there were periods when the lake level declined and the shallower southern part was exposed (Hazan et al. 2005; Stein 2014a). However, no evidence exists for a full desiccation of the lake during the past 10,000 yr. Thus, it appears that sedimentation in its northern part has been continuous.

The drilling campaign performed during the spring of 2010 recovered an 18-m core from the bottom of the lake near Research Station A. Details on the description of the compiled cores are given by Schiebel (2013). ^{14}C dating of organic debris from the core indicates that the drilled sediment sequence covers almost the entire Holocene (Schiebel 2013). The time interval of the Bronze to Iron Ages comprises 5.5 m of the 18-m profile, and is characterized by a relatively homogenous lithology. This specific interval (composite depth of 458.8–1006.6 cm) was sampled for palynological analysis at 10-cm intervals (a total of 56 samples). A concise palynological diagram of the Bronze and Iron Ages was presented by Langgut et al. (2013); a more detailed diagram is given in Figure 3 and the online Appendix. Six samples of terrestrial, short-lived organic debris were extracted from the Bronze and Iron Age sediment section and were AMS ^{14}C dated. The chronology (age-depth model) is presented in Langgut et al. (2013), which covers the time interval of 3150–500 BCE. Assuming a uniform sedimentation rate in this interval, the resolution of the palynological sampling would be a sample per ~40 yr.

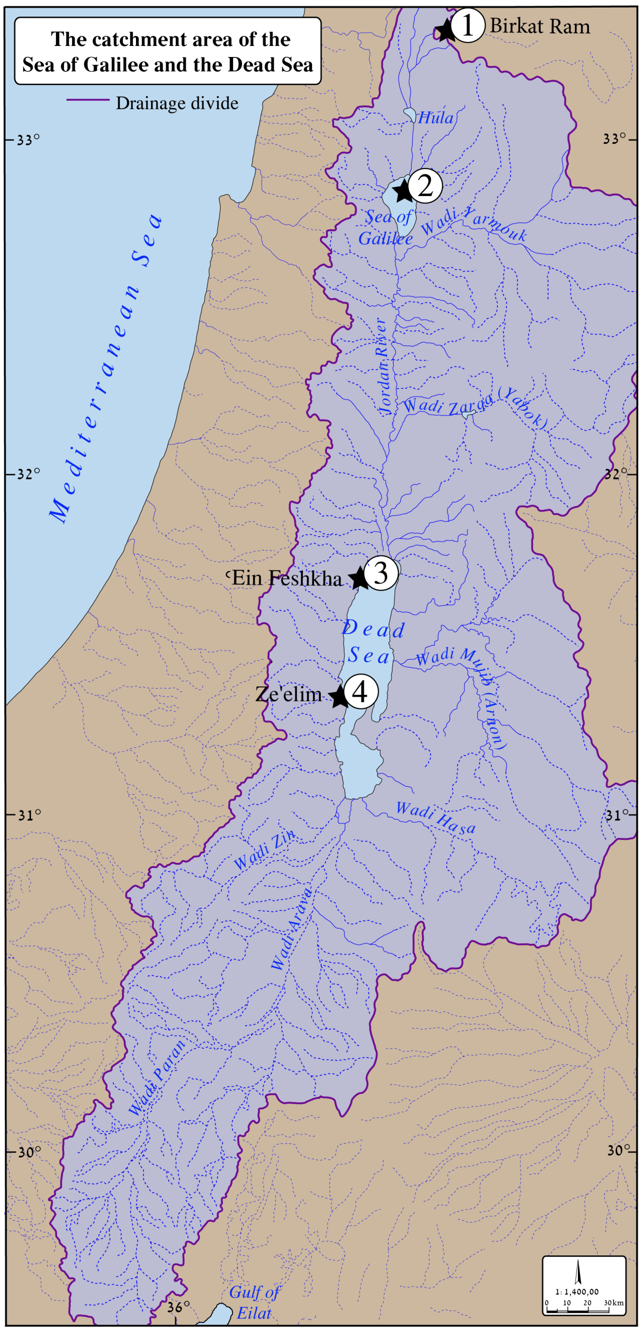

Figure 2 The catchment area of the Sea of Galilee and the Dead Sea with the watershed divide line of the region.

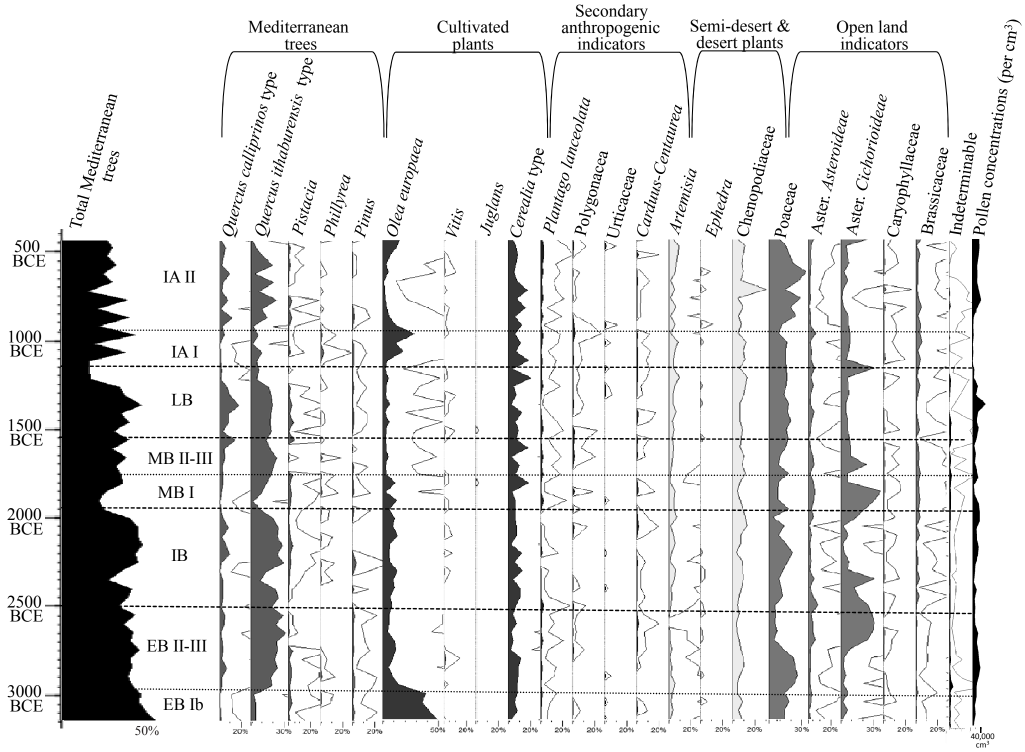

Figure 3 Simplified pollen diagram of the Sea of Galilee record during the Bronze and Iron Ages. A 10-fold exaggeration is used to show changes in low taxa percentages. The palynological diagram was divided into five main groups based on taxa geographical origin and on ecological and cultural characteristics (see online Appendix). EB = Early Bronze Age; IB = Intermediate Bronze Age; MB = Middle Bronze Age; LB = Late Bronze Age; IA = Iron Age.

Ein Feshkha

A 5.85-m-long outcrop was sampled at the Ein Feshkha National Reserve from the gully's wall (Neumann et al. 2007a, 2009). The site is located at the northwest side of the Dead Sea and is affected by water and sediments that flow from the central part of the Judean Hills. The profile is predominantly lacustrine, composed mainly of fine detrital particles and sequences of laminated couplets of aragonite and silty detritus or triplets of detritus, aragonite, and gypsum (described in Neumann et al. 2007a). The chronological framework of the section (an age-depth model) was obtained by AMS ^{14}C dating of organic debris (Neumann et al. 2007a) that was later integrated with ages of historical earthquakes that were correlated to disturbed sedimentary structures in the section described as seismites (Kagan et al. 2011). The record begins at about 1400 BCE, that is, in the middle of the Late Bronze Age, and was sampled for pollen investigation in resolution of 10 cm or less, which represents ~30 yr between samples.

Ze'elim Gully

The Ze'elim terrace is located east of the Masada plain on the southwestern side of the northern deep basin of the Dead Sea, very close to the sill that separates the southern and northern basins [at the elevation of 402–403 m bsl, Bookman (Ken Tor) et al. 2004]. The Ze'elim Gully, the origin of the outcrop, dissected the terrace. It has been the focus of ongoing investigation since 1992, following the continuous anthropogenic retreat of the lake (currently >100 cm/yr). The Ze'elim River (Nahal Ze'elim) that enters the Dead Sea at the Ze'elim terrace drains the southern part of the

Judean Desert, carrying waters and sediments that originate on the eastern flank of the central highlands ridge. Description of the stratigraphy, sedimentology, ^{14}C chronology and palynology of the Ze'elim sections is given in several papers [Ken-Tor et al. 2001; Bookman (Ken-Tor) et al. 2004; Neumann et al. 2007a; Kagan et al. 2011, 2015; Langgut et al. 2014a]. Within the framework of the current project, we returned to the Ze'elim Gully exposures in 2010 and described several new sediment wall-profiles, each 50 cm long, focusing on the section that covers the Bronze and Iron Ages (Langgut et al. 2014a). The 2010 sediment outcrop is located near the section studied previously by Neumann et al. (2007a), who analyzed the pollen record in lower and irregular resolution. Yet, the proximity to this older profile (which has since collapsed) enabled us to perform a stratigraphic and chronological correlation (Langgut et al. 2014a; Kagan et al. 2015). The chronology of the entire integrated sediment sequence (the ZA-Pcomp Ze'elim section) is based on 11 ^{14}C AMS dates of short-lived organic material and on the identification of a seismic event dated to the 8th century BCE (the "Amos earthquake") (Kagan et al. 2011). The ZA-compiled profile covers the time interval of ~2500–500 BCE—from the beginning of the Intermediate Bronze Age to the end of the Iron Age and beyond. It was sampled for pollen analysis at ~5-cm intervals, which represents a few decades between samples (Langgut et al. 2014a).

Pollen Indicators

Four main pollen curves were chosen in order to compare the palynological records (Figure 4):

1. *Quercus* (oak): This group includes two oak pollen types: evergreen and deciduous. While *Q. calliprinos* is the only evergreen oak tree in Israel, among the *Q. ithaburensis* type some may have been *Q. boissieri*, which is a deciduous oak species of the upper elevations of the highlands, and some *Q. ithaburensis*, a tree typical of lower elevations (Zohary 1973). However, the two deciduous oak species are palynologically indistinguishable.
2. *Pinus halepensis* (Aleppo pine) is the only naturally occurring pine species in Israel (Weinstein-Evron and Lev-Yadun 2000). In historical periods, pine was the first tree of the Mediterranean maquis/forest that established itself naturally in areas disturbed by human activities where it colonizes abandoned fields (Baruch 1986, 1990; Lev-Yadun and Weinstein-Evron 2002; Danin 2004). Pines have excellent pollen dispersal efficiency; especially in non-forested landscapes, they are often over-represented due to long-distance transport (e.g. Sivak 1975; Faegri and Iversen 1989). Pollen of *P. halepensis* cannot be differentiated from pollen of other *Pinus* species (e.g. Eastwood et al. 1998).
3. *Olea europaea* (olive) was among the most important cultivated plants in the region since the Early Bronze Age (Zohary et al. 2012). It grows today in the southern Levant in the Mediterranean territory mostly as a cultivated tree (Zohary 1973; Zohary et al. 2012). The wild olive is a minor component of the native Mediterranean *Quercus calliprinos–Pistacia palaestina* association as evident by Pleistocene and Early Holocene pollen diagrams (Horowitz 1979; Weinstein-Evron 1983; Kadosh et al. 2004; van Zeist and Bottema 2009; Langgut et al. 2011). Based on both palynological evidence (Baruch 1990; Neumann et al. 2007a,b; van Zeist et al. 2009; Litt et al. 2012) and archaeological finds (e.g. Zohary and Spiegel-Roy 1975; Epstein 1978, 1993, 1998; Gophna and Kislev 1979; Neef 1990; Eitam 1993), it is obvious that by the Early Bronze Age *Olea* had already been intensely cultivated in the southern Levant. This evergreen wind-pollinated tree has a very efficient pollen dispersal system (e.g. Baruch 1993) and has a strong response to cessation and resumption of orchard cultivation (resulting in dramatic fluctuations in pollen production following abandonment or rehabilitation of olive orchards). It is therefore considered as a reliable marker for identifying agricultural activities in antiquity (Langgut et al. 2014b).

4. Mediterranean arboreal pollen: This group sums up all the Mediterranean trees and shrubs and is dominated by evergreen and deciduous oaks while other Mediterranean trees appear in lower percentages (e.g. *Phillyrea*, *Pistacia* spp., *Pinus halepensis*, and *Ceratonia siliqua*). Cultivated olives were combined within the natural elements of the Mediterranean forest (the Mediterranean arboreal pollen; gray pollen curves in Figure 4), which evidently includes wild olive trees, while desert trees such as *Acacia* and *Tamarix* were excluded. In general, the Mediterranean trees and shrubs require at least 350 mm of annual rainfall in order to thrive (e.g. Zohary 1973). Therefore, fluctuations in the Mediterranean arboreal pollen curve can provide information on climate, especially in the climate-sensitive areas located on the fringe of the Mediterranean zone.

VEGETATION HISTORY, CLIMATE CHANGES, AND HUMAN IMPACT

Each of the periods is discussed below for its paleoenvironmental reconstruction (both natural and anthropogenic) (Figure 4), integrating the relevant archaeological and textual evidence. The dating of the periods follows the ^{14}C results for Levantine sites from the last decade (Regev et al. 2012 for the Early Bronze Age and the transition to the Intermediate Bronze Age; Finkelstein and Piasetzky 2010; Toffolo et al. 2014 for the Iron Age); the transition from Middle to Late Bronze Age, currently broadly fixed in the mid-16th century BCE, is yet to be ^{14}C dated (Bietak 2002 for the beginning of the Middle Bronze Age). Within our north-south palynological transect, decreasing percentages of the total Mediterranean trees indicate the shrinkage of the Mediterranean maquis/forest and the shifting of the semi-arid boundaries to the north and west due to less available moisture (Figure 1c); increasing values of the Mediterranean pollen tree indicate the opposite. The pollen records from the Sea of Galilee and the Dead Sea are sensitive to the conditions in both the Mediterranean area and the Irano–Turanian vegetation belt, as the two lakes collect wind-driven pollen from these two adjacent zones. In addition to airborne pollen, they receive fluvially transported pollen from large sectors of the southern Levant—mainly through the Jordan River, but also via local streams (Figure 2). Therefore, the southern pollen records (Sea of Galilee, Ein Feshkha, and Ze'elim; Figures 4b–d) are more sensitive recorders of climate fluctuations than the northernmost pollen record from Birkat Ram (Figure 4a), which is located in an area that receives more than 1000 mm of annual rainfall (Srebro and Soffer 2011). While the Birkat Ram and the Sea of Galilee records begin during the Early Bronze Age, the Ze'elim profile begins in the Intermediate Bronze Age (~2500 BCE) and the Ein Feshkha record begins only in the middle of the Late Bronze Age (~1400 BCE). In addition to climate fluctuations, changes in vegetation distribution can result from human interference, such as the spread of agriculture, grazing, clearance of wood, and soil erosion. Therefore, in interpreting the palynological transect we are taking into account pollen grains that may point to the occurrence of these activities.

Early Bronze Age (~3600–2500 BCE)

Two palynological diagrams are available for this period (Figures 4a,b)—Birkat Ram and the Sea of Galilee (the latter begins only in ~3150 BCE, corresponding to the later phase of the Early Bronze Age I). The Mediterranean arboreal pollen curve, including olive trees, appears in its highest percentages, indicating that the Early Bronze Age I (~3600–3000 BCE) was the most humid phase in the Bronze and Iron Ages. This period also features the highest frequencies of olive trees (in Birkat Ram ~10% and in the Sea of Galilee up to 50%), representing the development of a specialized economy focused on olive orchards and their secondary products (Neumann et al. 2007b; Langgut et al. 2013). Settlement activity in northern Samaria and the western Jezreel Valley reached a peak during the Early Bronze Age I (Finkelstein and Gophna 1993; Finkelstein et al. 2006, respectively). The settlement pattern in the highlands represents dramatic intensification of the olive culture. Evidence from the southern Coastal Plain and the Nile Delta attests to strong trade relations with Egypt

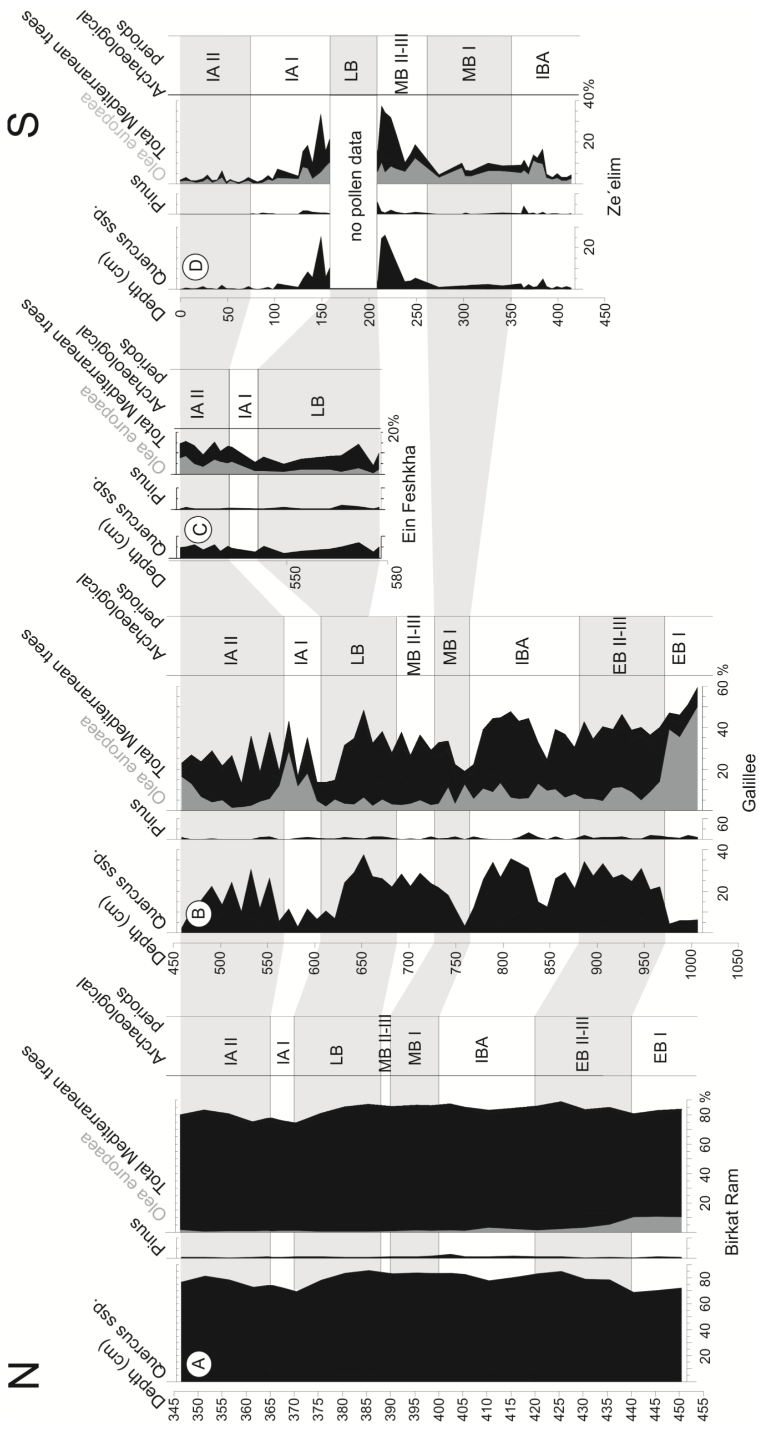

Figure 4 A north-south transect of 220 km along the southern Levant during the Bronze and Iron Ages composed of the pollen records from Birkat Ram, Sea of Galilee, Ein Feshkha, and the Ze'elim Gully (references in Figure 1a). Four main pollen curves are given: *Quercus* (oak), *Pinus halepensis* (pine), *Olea europaea* (olive), and total tree pollen of the Mediterranean maquis/forest.

(various articles in van den Brink and Levy 2002). Secondary products of the highlands' olive horticulture activity must have played a major role in this network (e.g. Finkelstein and Gophna 1993; van den Brink and Braun 2002).

The highest olive frequencies characterizing the Early Bronze Age I were followed by a dramatic decline in olive pollen percentages during the transition to the Early Bronze Age II, as evident in both pollen records (Figures 4a,b), although this decrease is much more pronounced at the Sea of Galilee, where it is accompanied by strong increase of deciduous oak (the *Quercus ithaburensis* type; Figure 3). In the Early Bronze Age II–III (~3000–2500 BCE), a minor increase in oak pollen was also documented in the Birkat Ram record, signaling a slight spread of the natural Mediterranean forest/maquis (Figure 4a). Since the decreasing olive percentages were not accompanied by a reduction of arboreal pollen, this decline in olive pollen was probably linked to changes in geopolitical (rather than climatic) conditions in the region. We refer to the weakening of overland connections with Egypt and the rise of maritime links with the coast of present-day Lebanon (Marcus 2002), which may indicate that the main area of export of olive oil to Egypt shifted to the north. The relatively humid period characterizing the Early Bronze Age II–III saw the rise of important urban centers in the southern Levant (e.g. Tel Bet Yerah in the north and Tel Yarmuth in the south).

Intermediate Bronze Age (~2500–1950 BCE)

At both Birkat Ram and the Sea of Galilee, this period shows no major change in the distribution of the Mediterranean arboreal vegetation in comparison to the previous period (Figures 4a,b). Therefore, it seems that the crisis in the urban system, which started at the end of the Early Bronze Age (~2500 BCE, Regev et al. 2012) and lasted through the entire Intermediate Bronze Age, was not a result of climate change. Yet, during this relatively climatically stable period, two short events pointing to drier conditions were recorded: at ~2350 BCE (based on the Sea of Galilee record) and at the end of the Intermediate Bronze/beginning of the Middle Bronze Age I (the Sea of Galilee and Ze'elim; Figures 4b,d). These dry events were also documented by the declining level of the Dead Sea (Kagan et al. 2015). The Intermediate Bronze Age features evidence for strong settlement activity in the Negev Highlands (Cohen 1999); the latter dry event may be one of the reasons for the decline of this settlement system.

The Intermediate Bronze Age is a period traditionally associated with a more pastoral mode of subsistence in the southern Levant. However, the northern pollen records (Birkat Ram and the Sea of Galilee) show that no major shift took place in human exploitation of the environment; that is, olives were still probably cultivated to the same extent as during the previous period, the Early Bronze Age II–III. Since *Olea* pollen production has a strong response to cessation (a dramatic decrease in pollen production was documented in deserted orchards after several decades of abandonment; Langgut et al. 2014b), the olive pollen that was identified during the Intermediate Bronze Age represents well-maintained orchards.

In the southern record of Ze'elim, an olive pollen peak of maximally 10% of the total pollen was identified around the second part of the Intermediate Bronze Age (~2200–2000 BCE), which probably indicates expansion of olive horticulture in the southern Judean Highlands (Figure 4d). A pronounced rise in *Olea* pollen percentages was also documented around the same time in the Ein Gedi core (13 km north of Ze'elim; Litt et al. 2012). We suggest that the high distribution of olive probably reflects human influence in the Judean Highlands rather than increased precipitation, since this *Olea* peak was not accompanied by any significant rise in other Mediterranean trees. Settlement activity in the Judean Highlands in the Intermediate Bronze Age was limited (Ofer 1994), so the pollen record may attest to possible transhumance links between the Negev Highlands and Hebron Hills (e.g. Dever 1980), that is, to pastoral groups that moved between winter and summer camps and engaged in opportunistic horticulture in the wetter southern Highlands.

In addition to the drier climate conditions that were prevalent at the end of the period based on the decline in the Mediterranean trees, a slight decrease of *Olea* pollen and somewhat increase in pine values were identified in two out of the three pollen diagrams available for this period: Birkat Ram and Ze'elim (Figures 4a,d). In historical periods, pine was the first tree of the Mediterranean maquis/forest that established itself naturally in large numbers in disturbed areas (Baruch 1986, 1990; Lev-Yadun and Weinstein-Evron 2002). We therefore suggest that some olive orchards were abandoned at the end of this period in certain parts of the southern Levant (probably not in the Sea of Galilee area).

More arid conditions at the end of the Intermediate Bronze Age are also evident by the lithology of the Ze'elim section, which points to accumulation of sediments in a shore environment (sands and a thin beach ridge were deposited from ~2000 to ~1800 BCE) (Langgut et al. 2014a; Kagan et al. 2015). Drier climate conditions were also documented by (A) the declining level of the Dead Sea (from 380 to 400 m bsl; yet, the drop began slightly earlier ~2200/2100 BCE and lasted about 200–300 yr) (Migowski et al. 2006; Kagan et al. 2015) and (B) the isotopic composition of tamarisk wood from the Mount Sedom Cave (southern Dead Sea), which also points to a prolonged drought (of >100 yr) at the end of the Intermediate Bronze Age (Frumkin 2009). The Soreq Cave speleothems isotopic record also points to a decrease in precipitation during ~2200–1900 BCE (Bar-Matthews and Ayalon 2004, 2011).

Middle Bronze Age (~1950–1550 BCE)

From the beginning of the period and until about 1800 BCE, Mediterranean tree values remain low, as evidenced by the more "climate-sensitive" pollen records—the Sea of Galilee and Ze'elim—while Birkat Ram does not point to any pronounced climate change. It therefore seems that the dry period that began at the end of the Intermediate Bronze Age lasted about 2 centuries (~2000–1800 BCE). In the Ein Gedi pollen diagram, a reduction in Mediterranean elements was documented in the same time interval, pointing to a decrease in humidity (Litt et al. 2012). During the Middle Bronze Age I, in both records (Sea of Galilee and Ze'elim), olive tree percentages appear in the same magnitude as in the Intermediate Bronze Age, representing olive production probably only for local consumption.

The wetter climate conditions, which were recognized by the increasing percentages in Mediterranean trees around 1800 BCE, continued through the Middle Bronze Age II–III and probably led to re-expansion of the Mediterranean maquis/forest in the region; note, for example, in the Sea of Galilee record (Figure 3) the maximum pollen percentages of evergreen oak and *Pistacia* towards the end of the Middle Bronze Age, which may point to a well-developed *Quercus calliprinos–Pistacia palaestina* association in the Mediterranean maquis/forest.

Evidence for dry climate conditions in the beginning of Middle Bronze Age and more humid conditions in the later phases is also provided by the lithology of the Ze'elim record, which points to the accumulation of sediments in a shore environment (sands and beach ridge) during the Middle Bronze Age I, and therefore indicates relatively low Dead Sea stands. During the Middle Bronze Age II–III, sediments accumulated in a lacustrine environment (mainly detritus), representing an increase in Dead Sea levels (Langgut et al. 2014a; Kagan et al. 2015). Indeed, according to the reconstruction of the Dead Sea levels, during the Middle Bronze Age II–III, the lake reached its highest level in the last 4 millennia—up to 370 m bsl (Migowski et al. 2006; Kushnir and Stein 2010). These paleoclimate data (sedimentological and Dead Sea levels reconstruction) are also indicators of high moisture in the northern parts of the Dead Sea drainage basin (Figure 2). They also confirm the palynological observation of regional dryness (rather than human-induced changes) during the Middle Bronze Age I.

The archaeological finds indicate that the low settlement activity at the end of the Intermediate Bronze Age continued in the Judean Highlands into the Middle Bronze Age I, before an increased presence in the Middle Bronze Age II–III (Ofer 1994; Finkelstein 1995). The dry phase in the very late Intermediate Bronze Age and the Middle Bronze Age I had significant impact on settlement patterns in the entire Levantine region. During that time, the 400-mm rainfall isohyet, marking the boundary between the Mediterranean and Irano–Turanian vegetation zones, seems to have shifted to the north and west. As a result, permanent settlements withdrew from the southern margins of southern Canaan and population in northeastern semi-arid zones, such as the Beq'a of Lebanon and the Jezirah in Syria, shrank in size (Finkelstein and Langgut 2014). For this reason, significant numbers of people may have moved to "greener" parts of the Levant. Wetter conditions in the Middle Bronze Age II–III (~1750–1550 BCE) caused the settlement system to recover and re-expand in the south (in areas such as the Beer Sheba Valley in the northern Negev).

Late Bronze Age (~1550–1150 BCE)

According to the northern pollen diagrams (Birkat Ram and Sea of Galilee; Figures 4a,b) during the beginning of the period, the Mediterranean arboreal vegetation values remain relatively high, representing the continuity of a well-developed Mediterranean forest/maquis. Indeed, very high percentages of evergreen oak (*Quercus calliprinos* type) and *Pistacia* characterize this time interval in the Sea of Galilee diagram (Figure 3). The Ein Feshkha record begins in the middle of the Late Bronze Age; it features high arboreal percentages, which decrease towards the end of the period, signaling drier climate conditions (Figure 4c). No pollen data for the Late Bronze Age are available from the Ze'elim record (Figure 4d) due to some sedimentary erosion and unfavorable conditions for pollen preservation in sandy sediments (Langgut et al. 2014a).

During the 14th century BCE, high frequencies of total Mediterranean pollen trees were recorded in the Sea of Galilee pollen diagram, most probably indicating relatively wet climate conditions (Figures 3 and 4b); this is consistent with the fact that the Amarna tablets, dated to ~1360–1330/35 BCE, do not mention droughts or famine in the Levant. Yet, the values of olive pollen remain in their low frequencies, indicating a limited spread of olive horticulture (Figures 4a–c). The Ein Gedi palynological record (Litt et al. 2012) is consistent with this picture.

The Late Bronze Age was marked with a dramatic decrease in the settlement activity in the hill country of the Galilee, Samaria, and Judea (Bunimovitz 1994; Ofer 1994; Finkelstein 1995). The relatively high frequencies of the arboreal pollen indicate that in much of the period the settlement crisis was human-induced rather than a result of environmental change.

Yet, according to all four pollen records, the most striking feature in the Bronze and Iron Age pollen transect appeared at the end of the Late Bronze Age. This phase is characterized by extremely low arboreal vegetation percentages (both Mediterranean trees and olive trees) in the Sea of Galilee and Ein Feshkha, while in the less-sensitive Birkat Ram record only a slight reduction in arboreal pollen was documented. Based on the Ein Gedi (Litt et al. 2012) and Sea of Galilee pollen records, it is assumed that the decline in Mediterranean elements began during the mid-13th century BCE. However, it seems that in the former record the dry event lasted longer (down to the early stage of the Iron Age I), while according to the Sea of Galilee, the arid event occurred from the mid-13th century BCE until the end of the 12th century BCE. The dramatic drop in the reconstructed Dead Sea levels (from 370 to 418 m bsl) was dated slightly earlier, to ~1400–1200 BCE (Kagan et al. 2015). Litt et al. (2012) also report that around 1300 BCE a thick sand unit accumulated in the Ein Gedi core and Neumann et al. (2007a) describe a sedimentological unconformity in the Ein Feshkha record about the same time. At the Ze'elim Gully, a beach ridge was deposited in a shore environment around

1200 BCE (Langgut et al. 2014a; Kagan et al. 2015). The occurrence of a shore depositional environment in these western Dead Sea margin sites (Ein Gedi, Ein Feshkha, Ze'elim) represents a drop in the Dead Sea lake levels that was most probably the result of reduced precipitation at the end of the Late Bronze Age, mainly in the area of the northern sources of the Dead Sea drainage basin.

It is noteworthy that the decrease in tree percentages was not accompanied by an increase of secondary anthropogenic palynological indicators (e.g. *Plantago lanceolata* [ribwort plantain] pollen type—Baruch 1990; Danin 2004) in the Birkat Ram (Neumann et al. 2007b), Sea of Galilee (Figure 3), or Ein Feshkha records (Neumann et al. 2007a); therefore, the decline in the arboreal vegetation was probably not as a result of deforestation. In the Sea of Galilee record, a dramatic reduction in evergreen oak and *Pistacia* percentages was documented, with almost total disappearance of other Mediterranean trees such as *Phillyrea* and with an increase in of the semi-desert and desert plants Chenopodiaceae and *Artemisia* (Figure 3). Because of low settlement activity at that time, shrinkage of the Mediterranean forest was most probably not the result of human pressure. The decline in arboreal percentages was therefore a result of climate rather than human-induced change; this is also supported by the sedimentology and configuration of the Dead Sea as described earlier.

A dry event during the end of the Late Bronze Age and into the transition to the Iron Age I was detected in three other high-resolution pollen records from the Levant: the northern Syrian coast (Kaniewski et al. 2010), Cyprus (Kaniewski et al. 2013), and the Nile Delta (Bernhardt et al. 2012). These data suggest that the dry spell at the end of the Late Bronze Age took place across a vast geographical area.

Harsh, long-term droughts may be the prime mover, then, for the sociopolitical collapse in the eastern Mediterranean basin during the "crisis years" at the end of the Bronze Age (Carpenter 1966; Weiss 1982; Neumann and Parpola 1987; Alpert and Neumann 1989; Ward and Joukowsky 1992; Issar 1998). Archaeological evidence indicates that the crisis in the eastern Mediterranean took place from the mid-13th century to the end of the 12th century BCE—during the same time interval when drier climate conditions were prevalent in the region. In the Levant, the crisis years are represented by destruction of urban centers, shrinkage of other major sites, hoarding activities, and changes in settlement patterns. Textual evidence from several places in the Ancient Near East attests to drought and famine starting in the mid-13th century BCE and continuing until the second half of the 12th century BCE (Astour 1965; Klengel 1974:170–4; Na'aman 1994:243–5; Zaccagnini 1995; Singer 1999:715–9, 2000, 2009:99).

Iron Age I (~1150–950 BCE)

All four pollen records for the Iron Age I time interval display a rise in oaks, total Mediterranean trees, and olive pollen percentages. In Birkat Ram, where only two samples fall within the Iron Age I, a minor peak of Mediterranean trees is visible at the transition from the Late Bronze Age to the Iron Age I (Figure 4a). In the Sea of Galilee, a pronounced *Olea* peak is notable; a similar peak appears in the Ein Feshkha and Ze'elim records together with an increase in oak pollen (Figures 4b,d). Thanks to the increase in available moisture following the severe dryness at the end of the Late Bronze Age, both the Mediterranean forest/maquis and olive orchards expanded. This is evident also in the Ein Gedi pollen record starting at ~1000 BCE (Litt et al. 2012) and by the moderate rise in the Dead Sea level (Migowski et al. 2006; Stein et al. 2010). The improved climate conditions during the Iron I enabled the recovery of settlement activity. This is evident in the revival of the urban system in the northern valleys (Finkelstein 2003) and in the settlement wave in the highlands, including areas that are amenable to olive orchards (Gal 1992; Finkelstein 1995; Frankel et al. 2001; Zertal 2004, 2007). Evidence for better water availability for plants was also found by

Riehl (2009) as well as archaeobotanical indications for an increase in olive cultivation during this period (Liphschitz 2007; Riehl 2009:Figure 7).

The growth of settlement activity in the highlands is the backdrop for the rise of Ancient Israel and other Iron I Age groups—the Arameans, Ammon, and Moab (Finkelstein 1995; Joffe 2002). Especially noteworthy are settlement developments on the margin of the settled lands: the spread of activity in the Beer Sheba Valley (Herzog 1994), the rise of an early Moabite territorial polity south of the Arnon River (Finkelstein and Lipschits 2011), and the appearance of Iron Age I sites on the Edomite plateau (Finkelstein 1992).

Iron Age II (~950–586 BCE)

In the Iron Age IIA (~950–780 BCE), Mediterranean trees retain their values, representing a developed Mediterranean forest/maquis and relatively humid climate conditions, while the Iron Age IIB (~780–680 BCE) and the Iron Age IIC (680–586 BCE) are characterized by a slight decrease in Mediterranean trees as evident in all three northern pollen records (Birkat Ram, Sea of Galilee, and Ein Feshkha). The slight reduction in arboreal percentages may represent moderate climate conditions but could also result from anthropogenic activity such as tree clearing for building purposes and spread of agriculture and grazing activities. Indeed, a surge in human activity that had started in the Iron Age I and increased in the late Iron IIA reached its zenith during the Iron Age IIB–C (e.g. Ofer 1994 for the Judean Highlands).

The picture is less clear in the southernmost record (Ze'elim), where Mediterranean arboreal pollen appears in relatively low values starting with the end of the Iron Age I and through the entire period of the Iron Age II, while the lithology of this sequence shows that at that time the sediments were deposited in a lake environment, and therefore represent relatively high Dead Sea lake levels (~408 m bsl). The reconstructed Dead Sea levels for this period indicate moderate climate conditions [the level still stood beneath the sill separating the northern and southern basins of the Dead Sea; Bookman (Ken-Tor) et al. 2004; Migowski et al. 2006; Kushnir and Stein 2010; Kagan et al. 2015].

CONCLUSIONS

This paper presents the role of climate fluctuations in shaping southern Levantine human history ~3600–600 BCE (the Bronze and Iron Ages) as evidenced in four palynological archives. Three out of the four pollen records presented in this study show similar vegetation fluctuations (Sea of Galilee, Ein Feshkha, and Ze'elim), indicating that at least in the Bronze and Iron Ages different regions of the southern Levant were characterized by similar climate patterns. Most vegetation changes presented in this study occurred in the Mediterranean and semi-arid vegetation zones. The Birkat Ram record does not point to any dramatic vegetation and climate fluctuations because of its northern location within an area that receives more than 1000 mm of annual rainfall, which makes it a less sensitive climate recorder.

The climate history of the southern Levant during the Bronze and Iron Ages, derived from the high-resolution pollen diagrams, can be summarized as follows (Figure 5): The wettest period was identified during the Early Bronze Age I (~3600–3000 BCE). Though a reduction in the arboreal pollen percentages was documented during the Early Bronze Age II–III (~3000–2500 BCE), the region was still typified by humid climate conditions. The Intermediate Bronze Age (~2500–1950 BCE) was characterized by moderate climate conditions. Since ~2000 BCE and during the Middle Bronze Age I (~1950–1750 BCE), drier climate conditions were prevalent, while the Middle Bronze Age II-III (~1750–1550 BCE) was somewhat wetter. During the early phases of the Late Bronze Age, humid conditions continued. The driest conditions in the entire Bronze and Iron Age timespan were

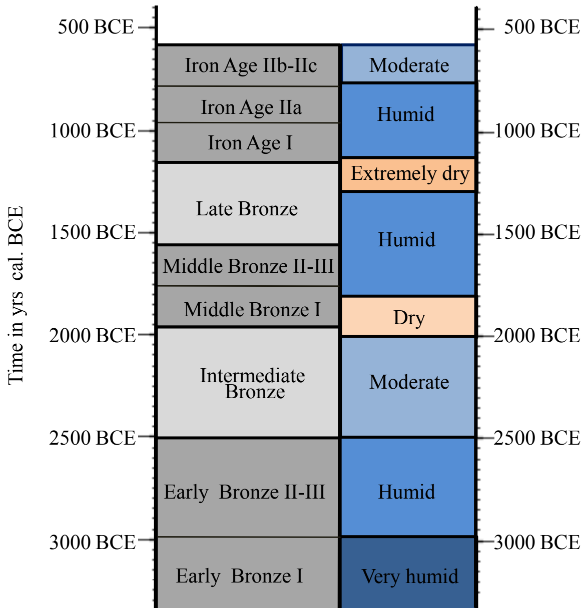

Figure 5 Summary of the climate history of the southern Levant during the Bronze and Iron Ages based on the palynological evidence.

recorded towards the end of this period and down to the end of the 12th century BCE. An increase in arboreal percentages was documented between ~1100–750 BCE, which therefore covers most of the Iron Age I (~1150–950 BCE) and the Iron Age IIA (~950–780 BCE), representing humid conditions after the severe dryness. During the Iron Age IIB (~780–680 BCE) and IIC (~680–586 BCE), the region experienced moderate climate.

Two relatively profoundly dry periods were identified based on the significant decrease in oaks and the total Mediterranean arboreal pollen. The first dry episode was dated to ~2000–1800 BCE and resulted in the shift of the border between the Mediterranean and Irano–Turanian vegetation zones to the north and west. Permanent settlements withdrew from the southern margins of southern Canaan. The second, more severe event occurred at the end of the Late Bronze Age and lasted until the end of the 12th century BCE. This arid phase, characterized by the lowest arboreal percentages in the Bronze and Iron Ages, probably represents long and severe droughts. The dry climate conditions at the end of the Late Bronze Age seem to correspond to references in Ancient Near Eastern texts to a period of droughts and famine and thus political instability, which is also reflected in the archaeological record (destruction of cities, etc.). All this helps to better understand the "crisis years" in the eastern Mediterranean at the end of the Bronze Age.

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DEAD SEA LEVELS DURING THE BRONZE AND IRON AGES

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ABSTRACT. The history of lake-level changes at the Dead Sea during the Holocene was determined mainly by radiocarbon dating of terrestrial organic debris. This article reviews the various studies that have been devoted over the past 2 decades to defining the Dead Sea levels during the Bronze and Iron Ages (~5.5 to 2.5 ka cal BP) and adds new data and interpretation. In particular, we focus on research efforts devoted to refining the chronology of the sedimentary sequence in the Ze'elim Gully, a key site of paleoclimate investigation in the European Research Council project titled Reconstructing Ancient Israel. The Bronze and Iron Ages are characterized by significant changes in human culture, reflected in archaeological records in which sharp settlement oscillations over relatively short periods of time are evident. During the Early Bronze, Intermediate Bronze, Middle Bronze, and Late Bronze Ages, the Dead Sea saw significant level fluctuations, reaching in the Middle Bronze an elevation of ~370 m below mean sea level (bmsl), and declining in the Late Bronze to below 414 m bmsl. At the end of the Late Bronze Age and upon the transition to the Iron Age, the lake recovered slightly and rose to ~408 m bmsl. This recovery reflected the resumption of freshwater activity in the Judean Hills, which was likely accompanied by more favorable hydrological-environmental conditions that seem to have facilitated the wave of Iron Age settlement in the region.

INTRODUCTION

The Dead Sea, a hypersaline (currently 340 g TDS/L) terminal lake located at the lowest elevation on Earth [water level at 427 m below mean sea level (bmsl) in 2014], is the modern remnant of a series of lakes that filled the tectonic depressions situated along the Dead Sea transform during the late Quaternary (Neev and Emery 1995; Stein 2001, 2014a,b). The watershed of the lakes that filled the Dead Sea Basin (Figure 1) is located between the desert belt and the Mediterranean climate zone and receives water and sediments from both regions. Thus, the Dead Sea, which is considered a "terminal trap" of these waters and sediment fluxes, is regarded as a regional gauge that records in its sedimentary archives the late Quaternary climate-hydrological history of these regions [e.g. Stein 2001, 2014a,b; Bookman (Ken-Tor) et al. 2004; Migowski et al. 2006; Kushnir and Stein 2010; Haliva-Cohen et al. 2012; Langgut et al. 2014; Neugebauer et al. 2014].

In this review, we focus on the lake-level history of the Dead Sea during the Bronze and Iron Ages (~5.5 to 2.5 ka cal BP). This period saw dramatic changes in the regional climate and in the development of human cultures. During the Early Bronze Age, cities such as Jericho, Bab edh-Dhra', and Arad prospered and olive horticulture spread in the Samaria and Judean highlands (Neev and Emery 1995; Rosen 2007). Numerous settlements flourished in the Judean Hills and in the northern Negev Desert as well as in the entire circum-Mediterranean (Finkelstein and Gophna 1993; Finkelstein 1995; Offer and Goossens 2004; Issar and Zohar 2007). In general, the climate was significantly more humid than in modern times (Litt et al. 2012). The Intermediate Bronze Age is described as a nonurban interlude, with low settlement activity, between the urban civilizations of the Early Bronze and the Middle Bronze Ages (Dever 1980). At that time, moderate climate conditions prevailed (Langgut et al. 2015). This low settlement scenario continued into the beginning of the Middle Bronze Age I. Settlement activity increased in the Middle Bronze Age II–III, with re-expansion to more southern areas (Gophna and Portugali 1988; Finkelstein and Langgut 2014).

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The Iron Age in Israel: The Exact and Life Sciences Perspective
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Figure 1 The catchment area of the Dead Sea (~40,000 km^2) (brown line), the maximum extent of the Pleistocene paleo-Dead Sea (blue shading), and main sites on the western shores of the Dead Sea mentioned in the paper. Note that the Sea of Galilee is also referred to as Lake Kinneret. The Hula Lake is depicted as it was before its desiccation in the 1950s (due to human interference).

The Late Bronze Age is characterized by low settlement activity with a collapse of the entire settlement system towards the end of the period, when many sites were abandoned altogether. This collapse is largely contemporaneous with a drop in Dead Sea level and increasing aridity (Litt et al. 2012; Langgut et al. 2014). This period features a decrease in olive cultivation in the Samaria and Judean highlands (Litt et al. 2012). Aridity also affected the northern regions of the Dead Sea watershed (Schwab et al. 2004; Langgut et al. 2013, 2014, 2015), as well as other large regions all over the eastern Mediterranean, where prominent civilizations had previously thrived, e.g. the Hittite Empire in Anatolia, Cyprus, the Syrian coast, and Egypt (Ward and Joukowsky 1992; Drews 1993; Kaniewski et al. 2010, 2013). Immigrants from the Aegean Basin—the Sea Peoples—settled along the coastal regions of the Levant at the time of transition to the Iron Age (Stager 1995). A contemporary wave of settlement, representing the (proto)-Israelites, characterizes the Samaria and Judean Hills (Finkelstein 1995). This time period saw an increase in humidity in the Dead Sea area (Neumann et al. 2007; Litt et al. 2012; Langgut et al. 2014) as well as in northern Israel (Schwab et al. 2004; Langgut et al. 2013).

The focus of this review is the reconstruction of the Dead Sea level during the Middle Bronze to Iron Ages. In particular, we focus on research efforts devoted to refining the chronology of the sedimentary sequence in the Ze'elim Gully, a key site of paleoclimate investigation in the ERC Reconstructing Ancient Israel project. We compile the chronological data, mainly radiocarbon ages along with the information on shoreline elevations, and link it with the cultural history in the southern Levant. The sedimentological and chronological data were derived from wadi (ephemeral stream) exposures and boreholes at several sites along the retreating western shores of the modern Dead Sea: mainly at the Ze'elim, Ein Gedi, and Ein Feshkha shores (Figure 1).

LIMNOLOGICAL SETTING OF THE HOLOCENE DEAD SEA

The Holocene Dead Sea evolved from Lake Lisan, its Pleistocene precursor, which filled the tectonic depressions along the central Dead Sea transform during the last glacial period ~70–14 ka cal BP (Haase-Schramm et al. 2004; Torfstein et al. 2013a,b). At its maximum elevation of ~160 m bmsl, Lake Lisan extended over the entire Dead Sea–Jordan–Kinnarot Basins from Hazeva in the south to the Bethsaida (Beteicha) Valley in the north, converging with the Sea of Galilee (Lake Kinneret; freshwater) (Bartov et al. 2003; Hazan et al. 2005; Stein 2014b). At ~14–13 ka cal BP, Lake Lisan declined from its high stand to below 450 m bmsl, rose back during the Younger Dryas, then declined again at ~11–10 ka cal BP (depositing a thick sequence of salts), and recovered in the Neolithic period (Stein et al. 2010). During the Holocene, the lake evolved through a complex limnological history with surface levels fluctuating between ~430 and 370 m bmsl [Bookman (Ken-Tor) et al. 2004; Migowski et al. 2006; Kushnir and Stein 2010]. The surface levels reflect the net freshwater influx (precipitation minus evaporation) into the lake that in turn mainly reflects the precipitation over the larger watershed regions. At the beginning of the 20th century, the lake stood at ~390 m bmsl and covered the southern shallow basin of the Dead Sea. Yet, during significant parts of the Holocene the southern Dead Sea was dry or precipitated salts (Neev and Emery 1995). A topographic sill at ~402–403 m bmsl separates the relatively deep northern basin and the shallow southern basin of the Dead Sea. When the lake level is high enough for the water to cross the sill, additional water is subjected to evaporation (similar to the current situation at the evaporation ponds of the Dead Sea Works potash plant). Thus, a significant increase in the water supply to the lake is required for the lake to rise above the sill and additional evaporation at the southern basin buffers lake-level rise (Bookman [Ken-Tor] et al. 2004).

It is noteworthy that during the past few hundred years the Dead Sea was characterized by salinity-driven stratification and only in 1977 did the lake overturn and attain its current configuration. The layered configuration reflects enhanced freshwater input to the lake. This is accompanied by supply of bicarbonate and sulfate ions that result in the precipitation of primary carbonate and gypsum in the lake (Stein et al. 1997; Barkan et al. 2001). When the supply of freshwater loaded with carbonate is limited, almost no aragonite precipitates into the lake (e.g. Waldmann et al. 2007; Stein 2014a).

RECONSTRUCTION OF DEAD SEA WATER LEVELS – BACKGROUND

General

The reconstruction of water-level curves of the ancient lakes that occupied the Dead Sea Basin in the past hundreds of thousands of years has been a major objective of Dead Sea researchers over the past decades, reflecting the potential of this curve to serve as a regional hydrological gauge [e.g. Bowman 1971; Neev and Emery 1995; Machlus et al. 2000; Frumkin et al. 2001; Bartov et al. 2002; Bookman (Ken-Tor) et al. 2004; Torfstein et al. 2009, 2013a; Waldmann et al. 2009]. The changes in the supply of water and sediments to the lake reflect the hydroclimate history of the watershed during Quaternary times and in turn are reflected in the lakes' limnology (composition and water levels) and sedimentology (sedimentary facies, Figures 2a,b) (Stein et al. 2001; Stein 2014a,b and references therein). A positive correlation exists between precipitation from 1870 until 1964—just before human intervention in the flow of the Jordan River—and recorded Dead Sea levels (Klein and Flohn 1987; Enzel et al. 2003). This is so despite all potential complexities that are involved in the "transfer" of the hydroclimate configuration of the watershed into the lakes' limnological and sedimentological properties. The lake rose when annual precipitation in Jerusalem exceeded ~650 ± 100 mm and receded when the annual precipitation dropped to ~450 ± 100 mm (Enzel et al. 2003). The most significant lake rise of the past decades (since the beginning of human intervention in the regional water balance) occurred in the winter of 1991/2, when anomalous amounts of rain fell in the watershed (e.g. ~1500 mm in Jerusalem compared to the annual mean of 550 mm). That winter the Degania Dam, which prevents the flow of the Jordan River out of the Sea of Galilee, was opened and the Dead Sea level rose by more than 1.5 m.

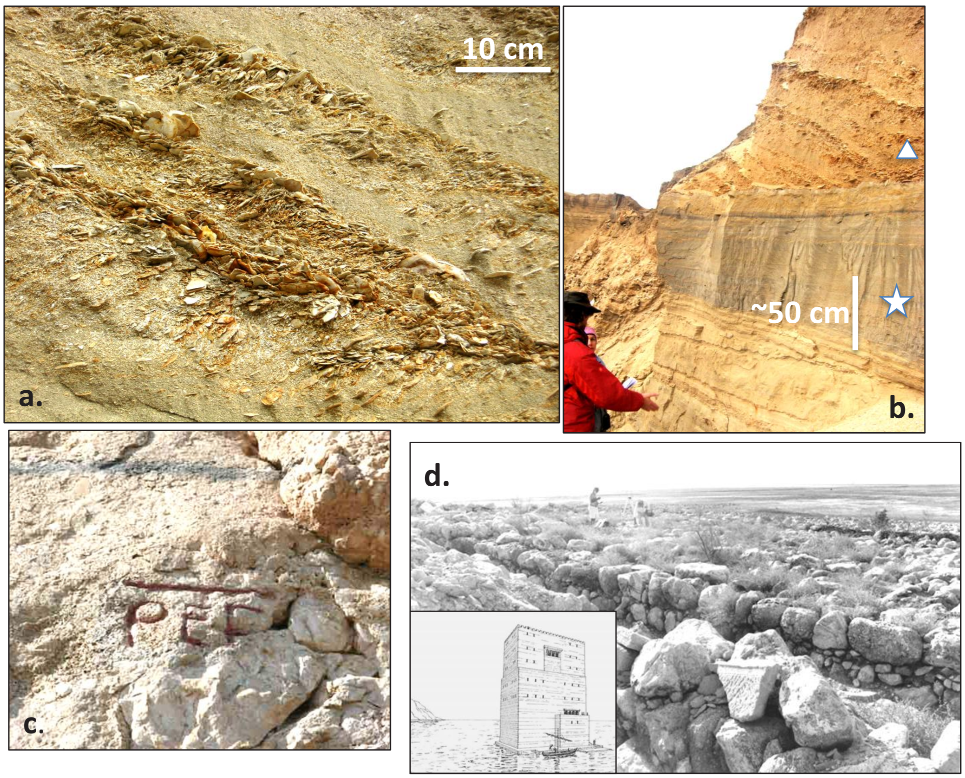

Figure 2 (a) Fragments of aragonite crusts in the Late Bronze Age beach ridge at the Ze'elim Gully outcrop; (b) transition from lacustrine fine clastics and aragonite laminae (star marking the Middle Bronze Age) to beach deposition (triangle marks the Late Bronze Age); (c) the PEF (British Palestine Exploration Fund) rock that marked the levels of the Dead Sea at the turn of the 20th century (~390 m bmsl); (d) Rujm el-Bahr Late Hellenistic–Early Roman anchorage site on the northern Dead Sea shore (in the inset: reconstruction of the anchorage and tower by Hirschfeld 2006).

At the turn of the 20th century, the British Palestine Exploration Fund (PEF) expedition began a 14-yr program to measure the level of the Dead Sea. A baseline level was established on a rock located above the modern road (No. 90) on the western coast near the Ein Feshkha Nature Reserve (Figure 2c). The marker is ~31 m above the current (2014) level—a difference that reflects the human intervention in the watershed. Yet, the high stand at the end of the 19th century was at a uniquely high level, since the lake stood at lower levels during most of the previous 400 yr.

The reconstruction of earlier lake levels requires identification and dating of ancient shorelines. Historical features such as piers or harbors can also be used for this purpose. At the Dead Sea, classic examples are the Late Hellenistic–Early Roman anchorage piers at Rujm el-Bahr (Figure 2d) (at 393.1 m bmsl, placing the lake level of that time at ~394 m bm) and at Khirbet Mazin (390–394 m bmsl) (Hirschfeld 2006). A pioneering investigation into Dead Sea levels was attempted by measuring and dating wide versus narrow cave passages in the Mt. Sedom salt diapir (Frumkin et al. 1991, 2001; Frumkin 1997). Precise lake-level elevation reconstruction using salt cave data was hampered by uncertain rates of diapir rise (Frumkin et al. 2001). Beyond the historical data and cave evidence, the lake-level reconstruction is based on sedimentological features such as shoreline markers or near-shore sediments (Figures 2a,b). Comprehensive descriptions and reviews of methods of identification of the shoreline deposits characteristic of the Dead Sea Basin are given by Machlus et al. (2000), Bookman (Ken-Tor) et al. (2004), and Bookman et al. (2006). For the purpose of this review, we use the following criteria: (1) laminated detritus, laminated primary aragonite and detritus, indicating a few meters or more water depth; (2) silty-sandy detritus, indicating very shallow near-shore depths; and (3) sand, small pebbles, aragonite crusts, and wave-related structures (e.g. beach ridges, ripple marks), indicating former shorelines. Note that primary aragonite laminae precipitation, whether as lacustrine aragonite laminae or encrusted aragonite at the shore, require continuous supply of freshwater loaded with bicarbonate to the lake (Stein et al. 1997; Barkan et al. 2001; Torfstein et al. 2013a).

The dating of the shoreline markers is accomplished by several methods such as ^{14}C (discussed in the following sections) or the U-Th dating method, which is applicable for the primary aragonites deposited from the lake waters or encrusting pebbles and organic debris (Figure 2a). Based on these principles, level curves were reconstructed for the lakes that occupied the Dead Sea and Kinnarot basins during the past ~140 ka. These reconstructions included works by Neev and Emery (1995), Machlus et al. (2000), Frumkin et al. (1991, 2001), Bartov et al. (2002, 2003), Bookman (Ken-Tor) et al. (2004), Hazan et al. (2005), Waldmann et al. (2007, 2009), Stern (2010), and Torfstein et al. (2013a). Over this time interval, which encompasses the last interglacial period (Lake Amora–Samra), the last glacial (Lake Lisan), the post-glacial, and the Holocene (the Dead Sea), lake level fluctuated between 160 m bmsl and lower than 450 m bmsl. Recent studies of a core drilled in the deep basin of the Dead Sea suggest a possible extreme low stand of the last interglacial Lake Samra (the ICDP drilling project, Stein et al. 2011; Torfstein et al. 2015). Here, we focus on the chronology of the mid- to late-Holocene Dead Sea levels, when the Bronze and Iron Age cultures, which feature processes of settlement expansion and collapse, developed in the region.

RADIOCARBON DATING OF THE HOLOCENE DEAD SEA

The sediments comprising the Holocene sections deposited from the Dead Sea are termed the Ze'elim Formation [Yechieli et al. 1993; Bookman (Ken-Tor) et al. 2004]. The formation comprises sequences of laminated detritus (transported to the lake by seasonal floods) and primary aragonite, gypsum, and salt (details in Migowski et al. 2004, 2006; Haliva-Cohen et al. 2012; Neugebauer et al. 2014).

The chronology of the Ze'elim Formation is essential for the reconstruction of the Dead Sea level curve. Paleoclimate, paleoseismology, and palynology studies have been carried out using these indispensable outcrops (e.g. Enzel et al. 2000; Ken-Tor et al. 2001a,b; Neumann et al. 2007; Kagan et al. 2011; Langgut et al. 2014). The sediment exposures are rich in organic debris of seeds and wood that were transported from the surrounding mountains or the close marginal terraces by runoff and winter floods [Ken-Tor et al. 2001a,b; Bookman (Ken-Tor) et al. 2004; Migowski et al. 2006]. Early ^{14}C dating of Holocene sediments from cores drilled at the southern (shallow) basin of the Dead Sea was undertaken by D Neev and W C Broecker (published in Neev and Emery 1995). Yechieli et al. (1993) dated organic debris from a core (DSIF) drilled at the western side of the Ze'elim Plain (Figure 1), and reported several ^{14}C ages of post-glacial to early Holocene times. These researchers also dated driftwood from the Ze'elim Gully floor near the Dead Sea shores in order to examine the residence time of wood at the shore environment and to estimate any delay between time of organic matter demise and incorporation into the sediment. All five driftwood samples yielded percent modern carbon (pMC) between 102 and 155, signifying that modern shore driftwood is post-bomb (younger than 40 yr old at time of sampling) and that transport time is insignificant for dating of geological and paleolimnological events (Yechieli et al. 1993). Ken-Tor et al. (2001b) also demonstrated a short lag period between the beginning of ^{14}C decay and the deposition of the organic debris (usually less than a few decades, and no more than 2 centuries). In most of the chronological studies, researchers aimed to date "short-lived" organic debris (seeds, twigs) where equilibrium with the atmosphere and short transport time to the shoreline sediments can be assumed. We suggest that lacustrine sediments incorporate organic fragments recently washed off-shore, while near-shore lithologies, such as beach ridges, tend to also accumulate recycled organic remains.

The Ze'elim Gully has been a major site of study of the limnological and sedimentological history of the mid- to late-Holocene Dead Sea. This stems from its location at the Ze'elim Plain on the fringe of the fan delta of Nahal Ze'elim, a major wadi (ephemeral stream) that drains the southwest regions of the Dead Sea watershed, and from its rapid incision into the Ze'elim Plain (the previously submerged part of the fan delta), which comprises lacustrine and fluvial sedimentary facies. In the 1990s, the exposed gully walls were only 4 m deep beneath the plain surface. Ken-Tor et al. (2001a,b) and Bookman (Ken-Tor) et al. (2004) provided a detailed chronology of the sedimentary sections in two of the southern gullies that dissect the Ze'elim Plain. In their reconstruction of the paleoseismic history from these sections, through identifying and ^{14}C dating of the seismites, Ken-Tor et al. (2001a) produced an age-depth model based on 24 ^{14}C ages of short-lived plant remains. Remarkable correlation of all historically documented earthquakes to either sediment deformations or to depositional hiatuses supports Ken-Tor et al.'s (2001b) argument for a short (<50 yr) interval between plant death and burial in the sediment. Bookman (Ken-Tor) et al. (2004) used the chronological information from the Ze'elim Gully and from Nahal David outcrop (near Kibbutz Ein Gedi) (Figure 1), as well as identification and measuring of elevation of shoreline indicators, to produce a lake-level curve for the late Holocene (past 3000 yr) Dead Sea.

In December 1997, a joint team from the GFZ-Institute in Potsdam, Germany, and the Hebrew University, Israel, carried out a drilling campaign along the Dead Sea shores, with the aim of recovering the entire Holocene sedimentary record. Migowski (2001) and Migowski et al. (2004) presented a detailed sedimentary description and ^{14}C chronology of the 20-m-long core recovered at the Ein Gedi spa shore, covering the past 10,000 yr. Migowski et al. (2006) combined the lithological and ^{14}C-chronological information from three cores—Ein Gedi (DSEn), Ein Feshkha (DSF), and Ze'elim (DSZ)—to produce a lake-level curve for the entire Holocene Dead Sea. The DSEn core was dated by 20 ^{14}C ages and by laminae counting of ~1500 yr, from 200 to 1300 CE. Migowski et al. (2004) reported the appearance of various types of seismites along this core and a laminae-counted floating chronology of the seismites was matched with the historic earthquake catalog. The best-fit gave model ages younger than their calibrated ^{14}C ages, and thus in the time interval of ~3.0 to 0.2 ka BP the authors shifted the age-depth curve by 50–200 yr. At the interval discussed herein, there is only a small 50-yr shift. Other studies found no significant reworking time of the organic debris in the Ze'elim Formation (Ken-Tor et al. 2001a,b; Kagan et al. 2011; Langgut et al. 2014; Neugebauer et al., in press).

Ongoing gully incision at Ze'elim and Ein Feshkha alluvial fan plains, responding to the continuous anthropogenic drop of the Dead Sea, exposed new outcrops (Figure 3) previously only observed in cores. Neumann et al. (2007) and Kagan et al. (2011) took advantage of these new outcrops and provided additional insight into the chronology, palynology, paleoclimate, and paleoseismology of the Late Holocene.

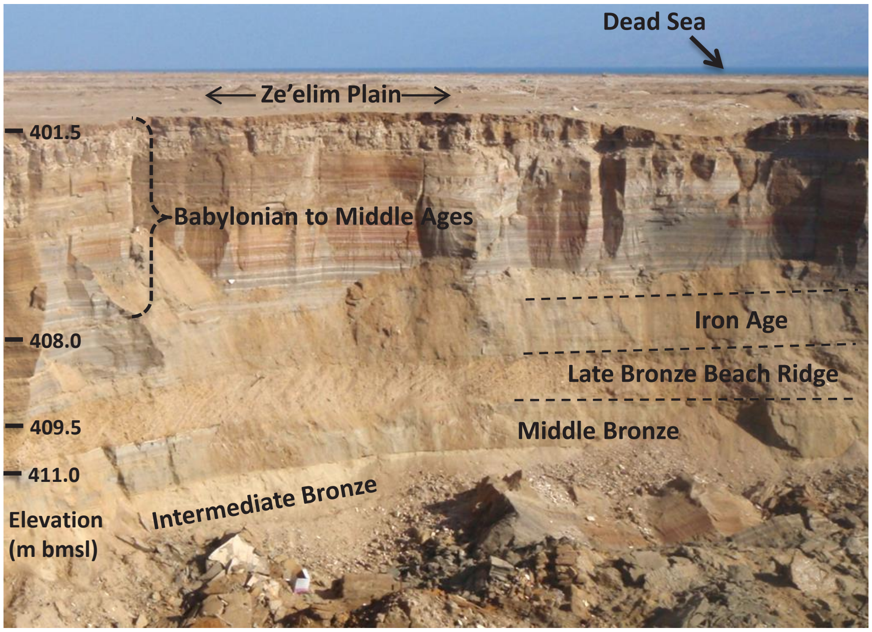

Figure 3 ZA3 outcrop section, with main archaeological periods and elevations

^{14}C dating of the more lake-ward Ze'elim Gully outcrop (ZA2) was established down to 10.5 m below the plain surface (12 ages) in the palynological study of Neumann et al. (2007) and the paleoseismic study of Kagan et al. (2011). The ZA2 section is a few hundred meters east of the Ze'elim A section (ZA1) [Bookman (Ken-Tor) et al. 2004], making it more lacustrine, but interfingering with shore facies. The section showed mostly continuous deposition, with perhaps minor hiatuses not identified by dating and one long hiatus (~7–4 ka BP). This hiatus is, at least in part, only local since at the nearby ZA3 section part of this time interval is represented. At the Ein Feshkha Gully, Neumann et al. (2007) and Kagan et al. (2011) dated nine horizons along an almost 6-m section (from about 3300 to 550 yr cal BP), showing essentially continuous lacustrine deposition. In an effort to improve the chronology of the Ze'elim and Ein Feshkha sections, Kagan et al. (2010, 2011) produced Bayesian age-depth deposition models using the OxCal P_sequence model (see Bronk Ramsey 2008). In this manner, the Bayesian package provides a model age for every depth in the section, such as the earthquake marker depths, with a narrow uncertainty envelope. The application of this model allowed correlation of seismites to tens of historic earthquakes and an intrabasin correlation and comparison of seismite occurrence and characteristics at three sites. In a palynological-sedimentological study carried out as part of the Reconstructing Ancient Israel project, more than 10 ages were reported covering the Bronze and Iron Ages time interval in the Ze'elim Gully (ZA3 section) (Langgut et al. 2014).

LAKE LEVELS DURING THE BRONZE AND IRON AGE INTERVAL

General

This section summarizes the chronological and shoreline information established for the Bronze to Iron Age time interval in the Ze'elim Gully. The sedimentary sections were also studied for palynological investigation as reported by Langgut et al. (2014), and reviewed in this issue by Langgut et al. (2015). A stratigraphic, mineralogical, and isotopic study of this interval is given by Kagan and colleagues in a forthcoming publication.

For the purpose of establishing a lake-level curve, the shoreline elevations and their ages obtained from the Ze'elim gullies were integrated with ^{14}C ages from other lacustrine and off-shore exposures from various sites: the Ein Gedi core (Migowski et al. 2006), the Ein Qedem outcrop (Stern 2010), the Ein Feshkha core (Migowski et al. 2006), the Ein Feshkha outcrop (Neumann et al. 2007; Kagan et al. 2011), the Arugot outcrop (Bartov et al. 2007), and the Darga outcrop (Kadan 1997; Enzel et al. 2000; Bartov et al. 2007). ^{14}C ages relevant to this discussion are listed in Table 1.

Late Chalcolithic Period and Early Bronze Age (~6000–2500 BCE; ~8 to 4.45 ka cal BP)

The time interval of the Chalcolithic period through the Early Bronze Age (Table 2) is not exposed in the Ze'elim Gully, where deposition was discontinuous at that time. Lake level was therefore estimated from drilled cores in the Ze'elim Plain, Ein Gedi spa shore, and Ein Feshkha (Migowski et al. 2004, 2006; Litt et al. 2012). Migowski et al. (2006) reconstructed an "approximate" level curve for the time intervals that lack direct shoreline evidence (Figure 4). Integrated with the evidence from the Nahal Darga exposure (Bartov et al. 2007) it appears that the Dead Sea rose from its early Holocene low stand (~8–6.5 ka cal BP) to its mid-Holocene high stand at ~6.3 ka cal BP. The low-stand period is characterized by gypsum and sand layers in the cores and supported by evidence from a salt tongue revealed in a core from the southern Dead Sea Basin (Neev and Emery 1995). At ~6.3 ka cal BP, laminated lake sediments exposed at the Darga and Arugot terraces mark a significant lake transgression to ~370 m bmsl (Bartov et al. 2007). Neev and Emery (1995) report on a lacustrine transgression at ~6.3 to 6.0 ka BP that interrupted the salty south basin of the Dead Sea. The transition to the Early Bronze Age is marked in the Ein Gedi core by deposition of laminated aragonite, indicating the onset of a significant lake rise at ~5.2 ka cal BP (Migowski et al. 2006). This rise was sufficient to cause the lake to cross the sill at ~4.9 ka cal BP (Neev and Emery 1995). This rise is corroborated by data of wide and high cave passages at Mt. Sedom, dated by wood fragments embedded in flood deposits from the caves (Frumkin et al. 1991; Frumkin 1997) and by pollen archives indicating especially high arboreal pollen percentages (Litt et al. 2012; Langgut et al. 2014). The humid period was characterized by the rise of large urban centers in the southern Levant (de Miroschedji 1999; Greenberg et al. 2011).

Intermediate Bronze Age (~2500–1950 BCE; ~4.45 to 3.9 ka cal BP)

At ~4.4 ka cal BP, the lake dropped sharply based on gypsum deposition in the Ein Gedi core (Migowski et al. 2006) and microconglomerate, pebbles, and abundant gypsum precipitation at ~415–416 m bmsl at the Ein Qedem spring system outcrop (Stern 2010). This low stand is also indicated by narrower cave passage morphology at Mt. Sedom (Frumkin et al. 1991).

At the Ze'elim Gully (ZA3 section), in the middle of this time period, there is a 40-cm sequence of lacustrine detrital sediment representing a short lake rise. This event is also reflected in the Ein Gedi core lithology (at 5.8 m depth; Migowski et al. 2006), but was not noted in previous lake-level curves. A significant increase in olive pollen in the Ein Gedi core (Litt et al. 2012) and the Ze'elim Gully (Langgut et al. 2014) corroborates this event. Then, at ~4.1 ka cal BP, the lake level dropped, depositing gypsum and pebbles at the Ein Qedem site (415.5 m bmsl; Stern 2010) and shore sediments at the Ze'elim Gully section. A drought of more than 100 yr at the end of the Intermediate Bronze Age is also recorded in the isotopic composition of tamarisk wood from the Mt. Sedom Cave (southern Dead Sea) (Frumkin 2009). Carbon isotopes measured in speleothems from the Soreq Cave (Judean Hills) indicate a sharp rise in desert vegetation at this time (Bar-Matthews and Ayalon 2004).

Table 1 ^{14}C age data for eight outcrop and core sites reviewed in this paper. Organic debris, e.g. leaves, twigs, and thin branches, were used for ^{14}C dating. ^{14}C ages are reported in conventional ^{14}C yr (before present = 1950), in accordance with international convention (Stuiver and Polach 1977).

Lab #	Sample name	Location	Elevation‡	^{14}C age yr BP ± 1σ	Calibrated 2σ age range	Reference	Sampling location
RTT 5188	ZA-20	ZA2	409	2345 ± 40	2503–2289 BP*	K11	lacustrine, above BR
RTT 5189	ZA-18	ZA2	410	2820 ± 40	2935–2775 BP*	K11	lacustrine, above BR
RTT 5688	ZA-1071	ZA2	411	3320 ± 55	3690–3415 BP	this study	within BR
ZA871	ZA-871	ZA2	411	3175 ± 30	3453–3352 BP	N07,K11	within BR
RT 5191	ZA-51	ZA2	411	3500 ± 75	3974–3584 BP	N07,K11	silt & ac, within BR
RTT 5192	ZA-5	ZA2	412	3540 ± 45	3965–3695 BP	N07,K11	lacustrine, below BR
RTT 5193	ZA-10	ZA2	413	3475 ± 45	3863–3636 BP	N07,K11	sandy, ac, beach sediments, below BR
RTK 6325-1	FDd I(230)	ZA3	411	2895 ± 50	3210–2881 BP	LG14	lacustrine, above BR
RTK 6325-2	FDd II(230)	ZA3	411	2935 ± 50	3320–2963 BP	LG14	lacustrine, above BR
RTK 6324	FDd (164)	ZA3	411	3070 ± 50	3394–3084 BP	LG14	lacustrine, above BR
RTK 6323	FDa I (-5)	ZA3	413	3780 ± 50	4383–3985 BP	LG14	lacustrine, below BR
RTK 6323-2	FDa II (-5)	ZA3	413	3800 ± 50	4410–4000 BP	LG14	lacustrine, below BR
RTK 6459-2	FDa (-22)	ZA3	413	3790 ± 50	4410–3990 BP	LG14	silty lacustrine, below BR
AA42807	Ze'elim 27	ZA1	408.5	2775 ± 37	2960–2790 BP	BM04	above BR
AA42809	Ze'elim 28	ZA1	410	3130 ± 44	3470–3240 BP	BM04	youngest within BR
AA42806	Ze'elim 29	ZA1	410	3220 ± 36	3550–3360 BP	BM04	lacustrine, directly below BR
AA42810	Ze'elim 30	ZA1	410	3703 ± 37	4150–3920 BP	BM04	lacustrine, below BR
AA43160	Ze'elim B 8	ZB	408	2977 ± 48	3330–2990 BP	BM04	youngest within BR
RT5183	EFW-530	EFE	418	2850 ± 65	3065–2789 BP*	K11	lacustrine, 40 cm above gypsum domes
R.I.C.H.B.	Eh2	AR	374	5630 ± 40	6310–6450 BP	BT04	shore marker
R.I.C.H.B.	Eh3	AR	372	3330 ± 50	3630–3480 BP	BT04	shore marker
KIA32726	DS-F-B6o-73	EFC	418	2873 ± 88	3211–2862 BP*	K11	above sand and aragonite crusts
KIA11629	DS-En A5o-7	EGC	419	3065 ± 40	3377–3084 BP	M06	lacustrine, above sand
KIA9123	DS-En B4-78	EGC	419	3545 ± 35	3956–3701 BP	M06	sand in core
982G	Mi-15	MSd		3100 ± 55	3446–3172 BP	F91	wide cave passages
AA75250	N-2-240	EQ	415	3188 ± 35	3562–3435 BP	OS10	conglomerate
Mi12	982E	MSd		3030 ± 50	3442–3077 BP	F91	wide cave passages
810D	SN5	MSd		3580 ± 80	4141–3646 BP	F91	narrow cave passages
886C	MM2	MSd		4250 ± 95	5214–4451 BP	F91	wide cave passages
886F	Me3	MSd		4350 ± 75	5286–4745 BP	F91	wide cave passages
810E	Qo1	MSd		4360 ± 140	5440–4570 BP	F91	wide cave passages
848D	MS1	MSd		4440 ± 120	5465–4823 BP	F91	wide cave passages

Notes: All dates from wood pieces and plant fragments. BP = before present, calculated as AD 1950, as customary. BR = Late Bronze Beach Ridge at Ze'elim Gully. ZA2 = Ze'elim Gully A, south side, lakeward; ZA3 = Ze'elim Gully A, north side, lakeward; ZA1 = Ze'elim Gully A, south side, landward; ZB = Ze'elim Gully B, south side; EFE = Ein Feshkha Nature Reserve Gully; AR = Arugot River; EFC = Ein Feshkha core; EGC = Ein Gedi core; EQ = Ein Qedem; MSd = Mount Sedom salt caves. References: LG14 = Langgut et al. 2014; BT04 = Bartov 2004; BM = Bookman (Ken-Tor) et al. 2004; M06 = Migowski et al. 2006; N07 = Neumann et al. 2007; K11 = Kagan et al. 2011; F91 = Frumkin et al. 1991; OS = Stern 2010. Calibration of ZA2 previously published ages, as in K11. Ages marked with * are model ages (Bayesian age-depth modeling, see Kagan et al. 2011). ‡ Absolute elevation m below main sea level, rounded to 1 m. The elevations of the MDd (Mt Sedom salt caves) samples are not given since they were measured upstream from the relict cave outlets and due to uncertainties in diaper uplift corrections (Frumkin et al. 1991; Frumkin 1997).

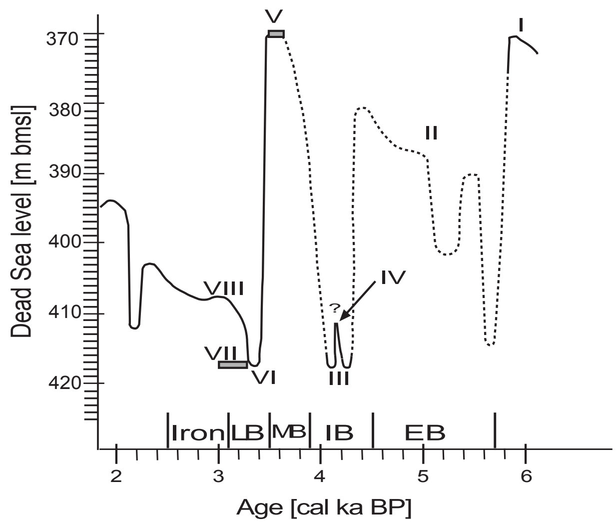

Figure 4 Dead Sea levels during the Bronze and Iron Ages. Lake levels are based on previous works by Bookman (Ken-Tor) et al. (2004) [Ze'elim and Nahal David (Ein Gedi) outcrops], Bartov (2004) [Arugot and Darga outcrops], Migowski et al. (2006) [DS cores], Stern (2010) [Ein Qedem outcrop], Kushnir and Stein (2010)'s interpretation, and on new data (Ze'elim outcrops) and interpretations from this study. References for some specific parts of the curve: I - Bartov et al. 2007; II - Frumkin et al. 1991; Migowski et al. 2006; III - Stern 2010; IV- this study; V - Bartov 2004; VI - Stern 2010; VII - beach ridge, this study and Bookman (Ken-Tor) et al. 2004; VIII - Bookman (Ken-Tor) et al. 2004. For ages, see Table 1. Dashed part of the curve is based on relative lake-level fluctuations.

During the Intermediate Bronze Age, large settlements were abandoned and the population moved towards a more rural way of life (Dever 1980). Increased settlement in the Negev Desert with possible transhumance links with the highlands in the Dead Sea catchment area is discussed by Langgut et al. (2014).

Middle Bronze Age (~1950–1550 BCE; ~3.9 to 3.5 ka cal BP)

Establishing the history of the Dead Sea watershed hydrology during the Middle to Late Bronze time interval is crucial for understanding the environmental background of the Late Bronze archaeologically attested settlement fluctuations. Thus, we devoted efforts to establishing in great detail the lake-level structure during this period. Data, however, as the discussion below shows, are limited.

The low lake levels of the Intermediate Bronze Age continued for a short time into the Middle Bronze Age, but then the Dead Sea rose, reaching the high stand of ~370 m bmsl (Figure 4). The shoreline that marks this elevation was documented in both the Arugot and Darga valleys; however, it was dated only at the former, to 3630–3480 yr cal BP (Table 1; Bartov et al. 2007). This high stand is consistent with evidence for a relatively high lake stand from subaqueous deposition at the Ze'elim Plain (Neumann et al. 2007; Kagan et al. 2011), Ein Qedem (Stern 2010), Ein Gedi and Ze'elim cores (Migowski et al. 2006), deep Dead Sea cores (Neugebauer et al., in press), and the southern subbasin cores (Neev and Emery 1995). Mt. Sedom Cave data indicate a high lake level at 3446–3172 cal BP (Frumkin et al. 2001). Since the age and identification of the high shoreline is essential for reconstructing the level fluctuations at this time, in this study we revisited the Arugot and Darga exposures, documented them in detail, and verified the existence of the pebbly shore marker at ~370 m bmsl, dated by Bartov et al. (2007).

According to pollen archives, these wetter conditions are indicated by a significant increase in Mediterranean trees; they have been attributed to the expansion of Mediterranean forest into the Judean Highlands (Litt et al. 2012; Langgut et al. 2014, 2015). Archaeology presents a picture of low settlement activity in the Intermediate Bronze Age, continuing into the Middle Bronze Age I, and then increased settlement activity in the Middle Bronze Age II–III, with re-expansion to more southern areas (Gophna and Portugali 1988; Finkelstein and Langgut 2014).

Table 2 Summary of archaeological periods, Ze'elim Gully sedimentary environment, and lake-level conditions.

Period	Date	Environment at Ze'elim Gully site	Comments regarding lake level
Iron Age	1150–586 BC (~3100–2536 BP)	*lacustrine*	Rise in LL to moderate/low level
Late Bronze Age	1550–1150 BC (~3500–3100 BP)	*lacustrine*	Slight LL recovery
		shore (beach ridge)	
		probably short hiatus	Drastic drop in lake level
Middle Bronze Age	MB II–III, 1750–1550 BC (~3700–3500 BP)	*lacustrine*	Very high lake level
	MB I, 1950–1750 BC (~3900–3700 BP)	*shore*	Low lake level
Intermediate Bronze Age	2500–1950 BC (~4450–3900 BP)	*shore, lacustrine, shore*	Low lake level, with short lake rise in the middle of the period
Early Bronze Age	3500–2500 BC (~5450–4450 BP)	*hiatus/truncated*	High lake level

Notes: Lake-level interpretation from this study and from Frumkin et al. (1991), Bartov (2004), Bookman (Ken-Tor) et al. (2004), and Migowski et al. (2006). The dating of the archaeological periods follows, as far as possible, ^{14}C results of Levantine archaeological sites from the last decade [Regev et al. (2012) for Early Bronze and Intermediate Bronze Ages; Bietak (2002) for beginning of Middle Bronze Age; the transition from the Middle to the Late Bronze Age, now broadly fixed in the mid-16th century BCE, is yet to be verified; Finkelstein and Piasetzky (2010) and Toffolo et al. (2014) for the Iron Age].

Late Bronze Age (~1550–1150 BCE; ~3.5 to 3.1 ka cal BP)

The Late Bronze Age begins with a severe lake drop, well documented in many geological archives: the Ze'elim Plain, Ein Qedem, Ein Feshka Gully, and Ein Gedi cores. The lowest stand was identified at the Ein Qedem shore (415 m bmsl) and was ^{14}C dated to 3562–3435 yr cal BP by Stern (2010). The uncharacteristic lithology of this period in the Ein Gedi core (Migowski et al. 2006; Neugebauer et al., in press), displaying sand and gypsum, also indicates a very low stand (at ~3.5–3.3 ka cal BP). Within the uncertainties in the ^{14}C calibration (Reimer et al. 2009), the ages of the Nahal Arugot high stand (3630–3480 yr cal BP) and the Ein Qedem low stand (3562–3435 yr cal BP) seem very close. We suggest that the high stand occurred towards the beginning of that range (late Middle Bronze Age) and the low stand towards the end of it (Late Bronze Age). The Ze'elim Gully displays a thick (>1 m) beach ridge during the Late Bronze Age. The lower constraint for this low stand is given by an age of 3550–3360 cal BP (Bookman [Ken-Tor] et al. 2004) taken from lacustrine sediment directly below the beach ridge. Organic matter from lacustrine sediment ~80 cm below the beach ridge in the ZA-2 section yields an age of 3965–3695 cal BP, which, based on approximate sedimentation rate, would give an age of ~3.7–3.4 ka cal BP directly below the beach ridge (Kagan et al. 2011). There is possibly a short sedimentary hiatus between this lacustrine sediment and the beach ridge.

The pollen data from the Late Bronze Age interval recovered from the Sea of Galilee and Ein Feshkha sedimentary sections is characterized by extremely low arboreal vegetation percentages (Langgut et al. 2014, 2015), in agreement with the arid conditions inferred from the Ze'elim Gully sediments.

The recovery of the Dead Sea began towards the end of the Late Bronze Age, with evidence seen in the existence of aragonite crusts in the beach ridge. The beach ridge is a prominent sedimentary feature of a sequence of recycled aragonite crusts comprising a foresets-backsets structure (Figures 2a,b). The aragonite crusts, at various stratigraphic levels in the Ze'elim Formation, were formed along the shoreline marking enhanced supply of freshwater rich with bicarbonate (e.g. Bookman [Ken- Tor] et al. 2004); on the shoreline they were subjected to wave action, which constructed the foresets and backsets. Thus, the beach ridge structure marks the time of resumption of freshwater activity in the Judean Hills (after the extreme dry event of the Late Bronze Age) and the elevation of the shoreline where the structure was formed. Along with the aragonite crusts, the waves collected and amalgamated wood fragments that were incorporated within the aragonite crust layers of the beach ridge. ^{14}C dating of the youngest group of wood remains in the beach ridge yielded ages that lie in the interval of ~3.4 to 3.2 ka cal BP (Table 1). The youngest of these dates (3470–3240 cal BP; Bookman [Ken-Tor] et al. 2004) marks the approximate time of formation of the beach ridge structure, slightly preceding the end of the Late Bronze Age. Lacustrine subaqueous sediments indicating further lake rise were deposited above the beach ridge. They include organic matter dated to 3394–3084 yr cal (Table 1; chronology from Langgut et al. 2014). The younger part of this calibration range is at the transition to the Iron Age.

At the Ein Feshkha site, the Ze'elim beach ridge structure is correlated with a layer containing gypsum domes that were probably deposited in shallow waters (Neumann et al. 2007). ^{14}C ages of organic debris recovered from a laminated section ~40 cm above the gypsum dome horizon yielded an age of 3258–2788 BP (Neumann et al. 2007; Kagan et al. 2011), indicating lake-level recovery earlier than that. The Ein Feshkha sediments support the scenario described above, with the lowest stand being represented by the gypsum domes and resumption of lacustrine deposition above that, but still within the Late Bronze Age.

Continuous speleothem growth at the Soreq Cave in the Judean Hills throughout the Holocene (Bar-Matthews and Ayalon 2004) indicates that rainfall there was always >300–350 mm/yr (Vaks et al. 2010); nonetheless, slower speleothem growth during the Late Bronze Age (Bar-Matthews and Ayalon 2004; Vaks et al. 2010) may signify drier conditions. Sampling resolution is uncharacteristically low in this interval of the Soreq Cave stable isotope record, where each data point represents ~102 yr, meaning that rapid events may not be apparent (Bar-Matthews and Ayalon 2004).

Severe, long-term droughts may be the main reason for the sociopolitical collapse in the eastern Mediterranean area during the "Crisis Years" (Carpenter 1966; Weiss 1982; Neumann and Parpola 1987; Alpert and Neumann 1989; Ward and Joukowsky 1992; Issar 1998). In the Levant, the Crisis Years are represented by destruction of urban centers, decline of village life, and changes in settlement patterns. Textual evidence from several places in the Ancient Near East attest to drought and famine starting in the mid-13th century BCE and continuing until the second half of the 12th century BCE (see in this issue, Langgut et al. 2015 and references therein).

Our reconstruction of the Dead Sea levels indicate that the recovery of the hydrological system occurred at ~3.2 ka cal BP, slightly before the time indicated by the palynological, archaeological, and historical findings. Possibly the conditions leading to the recovery of the hydrological system of the Dead Sea watershed heralded the recovery of the regional settlement system.

The global climatic reasons for this catastrophic drop of the Late Bronze Dead Sea and its recovery during the end of the Late Bronze Age and Early Iron Age are complex and beyond the scope of this paper. Other similar abrupt lake drops occurred throughout the Holocene and were correlated by Kushnir and Stein (2010) with times of global abrupt climate events referred to as the Holocene

Rapid Climate Change (RCC, Mayewski et al. 2004). Kushnir and Stein (2010) argued that these abrupt events were the result of extreme cold temperatures in the North Atlantic and extreme cold air outbreaks over the Mediterranean that caused cooling of the deep seawater layers, resulting in cold summer sea temperatures and weakening of the winter Mediterranean cyclones.

Iron Age (1150–586 BCE; ~3.1–2.5 ka cal BP)

By ~3.1 ka cal BP, the Dead Sea had somewhat recovered, rising from its low stand of below 414 to ~408 m bmsl. Although the lake recovered from its extreme minima, low lake-level deposition continued at the Ze'elim site, with silty detritus and some aragonite laminae. The Ein Gedi core shows enhanced primary aragonite precipitation, indicating more stable lake conditions (Migowski et al. 2004; Waldmann et al. 2007). Deeper lacustrine conditions returned to the Ze'elim site only about a millennium later, at the end of the Hellenistic period to beginning of the Roman period, when lake levels rose significantly [Bookman (Ken-Tor) et al. 2004; Migowski et al. 2006].

The resumption of hydrological activity in the Dead Sea watershed that led to the recovery of lake level is expressed in the development of Iron Age settlements in the Judean Hills. This required not only freshwater supply but also soil development, which was perhaps made possible by the transport of desert dust from the Sahara Desert and leaching of the carbonates to the Dead Sea when more precipitation and vegetation were available (Haliva-Cohen et al. 2012; Belmaker et al. 2014; Stein 2014a). While the movement of the Sea Peoples over the Mediterranean possibly reflects environmental stress such as severe droughts in their source regions during the Late Bronze circum-Mediterranean crisis, the Iron Age settlement recovery was most likely supported by the resumption of freshwater activity, recovery of the vegetation, and formation of mountain soils.

SUMMARY

The terminal and hypersaline Dead Sea stores in its sedimentary archives the climate-hydrological history of its large watershed. The reconstruction of level curves for the lakes that occupied the Dead Sea Basin during the late Quaternary requires information on the shoreline elevations and their ages. This information is obtained by sedimentological and geological means and by radiometric dating methods. Here, we reviewed the studies that established the lake-level curve of the late Holocene Dead Sea, including new data. In particular, we focused on the time interval of the Early Bronze to the beginning of the Iron Age that is characterized by dramatic changes in the regional climate and human culture history. In the mid-Holocene, the lake rose several times to its highest Holocene stand of ~370 m bmsl, but also displayed abrupt declines. The most dramatic decline occurred in the Late Bronze Age when the lake level dropped by more ~50 m to below 414 m bmsl. This was shortly followed by a rapid but limited rise to ~408 m bmsl, close to the transition to the Iron Age. The resumption of freshwater activity was likely accompanied by vegetation recovery and soil production in the Judean Hills terrain. These hydrological-environmental developments made the Iron Age settlement and demographic growth in the region possible.

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SETTLEMENT OSCILLATIONS IN THE NEGEV HIGHLANDS REVISITED: THE IMPACT OF MICROARCHAEOLOGICAL METHODS

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ABSTRACT. Microarchaeological methods, especially those focused on geoarchaeology and radiocarbon dating, have revolutionized the manner in which the Iron Age settlement peak in the Negev Highlands is interpreted. We review here results from field and laboratory studies conducted at two Iron Age sites (Atar Haroa and Nahal Boqer) compared to one Byzantine/Early Islamic site (Wadi el-Mustayer)—all located near Sede Boqer. We present our methodology, which is based on small-scale but detailed excavations, study of sediments, and identification of livestock dung remains and their utility as indicators of past subsistence practices. To this we add meticulous ^{14}C dating, ceramic petrography, and identification of botanic and zoological remains. We conclude that subsistence during the Iron Age included tending livestock but did not include agriculture. We further propose that the long-distance trade of copper from the Arabah Valley under Egyptian auspices and possibly the trading of cinnamon, dates, and other Arabian/Indian commodities were the driving force in the initiation (and later decline) of the Iron Age settlement system. We hypothesize that the agricultural settlement peak during the Byzantine/Early Islamic period was also influenced by an imperial power from outside of the Negev and that large-scale agriculture was enabled due to the adoption of new agricultural techniques, including terracing of ephemeral streams along with water diversion systems and possibly water storage facilities such as advanced cisterns. Future studies are expected to shed additional light on the complexity of settlement oscillations in the Negev Highlands region in key periods such as the Early and Intermediate Bronze Ages.

INTRODUCTION

Intensive archaeological explorations—surveys and excavations alike—have identified four main settlement periods in the Negev Highlands, an arid zone in southern Israel. Using ceramic typology, these periods were assigned to the Early Bronze Age II, Intermediate Bronze Age (also known as Early Bronze IV), Iron Age IIA, and Byzantine/Early Islamic Period culture-historical complexes. Other periods in the same region that span long eras, such as the Middle and Late Bronze Ages and most of the Iron Age, are not represented archaeologically. Sharp settlement oscillations thus characterize the history of the Negev Highlands (Rosen 1987; Finkelstein 1995 and references therein).

Possible reasons for these settlement oscillations have been discussed at length. Because the Negev Highlands is an arid region (~100 mm of annual rainfall), one theory proposed that, among other factors, populations moved in and out of the area in relation to changing environmental/climatic conditions (e.g. Rosen 1987). Water availability in the region is indeed a limiting factor for human subsistence, with low potential for agriculture and even for animal husbandry. Others considered these demographic oscillations to be related to socioeconomic opportunities and geopolitical changes (e.g. Finkelstein 1995; Haiman 1996 and references therein). A third explanation is that periods of settlement took place in relation to improved economic opportunities. One example is participation of local groups in copper production in the Arabah Valley and transportation of copper to Egypt and other places in the ancient Near East (e.g. Levy 2009; Martin et al. 2013). Another example is the transportation of lucrative south Arabian commodities, such as myrrh and frankincense, through the region in the same direction (e.g. Finkelstein 1988; Jasmin 2006). These activities were at least partially related to the balance of power between empires and kingdoms that surrounded the Negev, e.g. Egypt, Assyria, Rome, and Byzantium as well as Israel, Judah, and Edom.

Still, a key question is the daily mode of subsistence of the Negev Highlands inhabitants during the peak settlement periods: Were they engaged in primary production of agricultural and herd

The Iron Age in Israel: The Exact and Life Sciences Perspective
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products, did they rely on exchange (and/or purchase) of commercial goods, or conduct a complex regime of both? Determining the subsistence mode is crucial for understanding each of the historical peaks of human activity in the region, as well as the broader phenomenon of settlement oscillations over time. Related issues that may influence the interpretation of the settlement oscillations and their historical background are the exact dating of the sites and past climate/environmental conditions.

Most previous studies in the Negev Highlands inferred subsistence practices using traditional archaeological methods, focused on macroscopically visible remains only (systematic studies of faunal and botanical remains were not conducted). Researchers deduced herding from stone structures interpreted as animal pens, agriculture from stone walls along ephemeral streams (i.e. wadi terraces) as well as grinding stones and sickle blades, and copper trade from occasional finds of copper ingots or objects. The prevailing assumption has thus been that the Negev Highlands inhabitants in the Iron Age and later periods engaged in animal husbandry and small-scale seasonal agriculture (e.g. Haiman 1989; Finkelstein 1995; Cohen 1999; Cohen and Cohen-Amin 2004). With the exception of wadi terraces (Goldberg 1984; Bruins 1986; Bruins and van der Plicht 2005; Avni et al. 2006, 2012), none of these features has been studied in detail. Also, all sites and features representing a given settlement peak were described as belonging to a single wave of activity, although in most cases these remains could not be accurately dated. Hence, minute chronological differences within the peak periods (for the Early Bronze Age, see e.g. Sebbane et al. 1993) and the relationship between remains (e.g. associating datable pottery from a built site with undated wadi terraces in its vicinity; see an example of such a mistaken association in the Nahal Zena "fortress" site in Avni et al. 2009) could not be traced. In addition, cases where terraces were dated based on reworked charcoal associated with terrace fill sediments (e.g. Bruins and van der Plicht 2005) is highly questionable. Therefore, both the period-by-period interpretation and the overall, long-term, socioeconomic reconstruction of human activity in the Negev Highlands have been based on partial data.

With the development of research into the microscopic archaeological record (hereafter microarchaeology, *sensu* Weiner 2010) it became clear that crucial data required for connecting subsistence economy, specific time periods, and environment in the Negev Highlands sites may be obtained by deploying these methods.

THE MICROARCHAEOLOGICAL PROJECT IN THE NEGEV HIGHLANDS

Research of the microscopic record in various locations and chronological contexts has shown that certain materials hold information that allows identifying the subsistence base of ancient groups, as well as subsistence interrelationships between ancient groups. For example, identification of thick accumulations of dung deposits indicates presence of livestock enclosures and thus herding of animals (Shahack-Gross et al. 2003; Shahack-Gross 2011), and use of elemental analysis in lithic, ceramic, and metal object studies enables identification of traded items and trade routes (see Weiner 2010:36–40 on "provenience and procurement strategies"; Segal et al. 1996–1997; Martin et al. 2013 for the Negev Highlands). Here, we review the contribution of microarchaeological studies to deciphering the nature of the Iron Age settlement peak in the Negev Highlands. Our project, ongoing since 2005, focuses on full retrieval of information related to subsistence and chronology—macroscopic and microscopic—and is designed to incorporate the aspect of paleoclimate/environment in the near future as well.

The first stage of the project focused on the Iron Age settlement peak, which is restricted to a short phase in this period, mainly in the Iron IIA (e.g. Herzog and Singer Avitz 2004). We worked at two sites—Atar Haroa and Nahal Boqer—both located in the area of Sede Boqer, ~50 km south of Beer Sheba (Figure 1). Our work included two aspects of microarchaeological research: geoarchaeology and radiocarbon dating. We attempted to answer the question of subsistence strategies by employing methods that examine microscopic remains indicative of animal dung. This material, if properly identified, holds a wealth of information about the foddering practices of ancient herdsmen, and is especially useful in differentiating pastoral from agropastoral groups (see Shahack-Gross 2011 for a review of additional types of information that can be obtained from archaeological remains of livestock dung). The geoarchaeological aspect was thus composed of two parts: methodology development and archaeological application. The former included building a database of the phytolith component in selected Negev Highlands fodder plants and a database of the phytolith and dung spherulite components, as well as $\delta^{15}N$ and $\delta^{13}C$ values in dung from various modern Negev Highlands wild and domestic herbivores (Shahack-Gross and Finkelstein 2008). In addition, we tested the state of preservation of phytoliths in the Negev Highlands (Shahack-Gross et al. 2014). The archaeological application segment of the project was achieved through fieldwork at the two Iron IIA sites, where systematic sampling of sediments for studying subsistence practices and charred botanical remains for ^{14}C dating were conducted (Shahack-Gross and Finkelstein 2008; Boaretto et al. 2010; Shahack-Gross et al. 2014). Fieldwork was carried out via small-scale excavations. Two rooms and three courtyard contexts were opened at Atar Haroa, while at Nahal Boqer the contexts of one room and one courtyard were investigated (for location of excavation contexts, their sizes and types and numbers of samples, see Shahack-Gross and Finkelstein 2008; Shahack-Gross et al. 2014). We have been criticized in the past for sampling in the courtyard contexts; however, these contexts are exactly those where remains of animal corralling, and the information they include about foddering practices, were expected (and found; see below). Additionally, we tested our results against two control situations in the same region: (a) an abandoned, pre-modern Bedouin rockshelter and (b) a Byzantine/Early Islamic site (see details in Shahack-Gross et al. 2014).

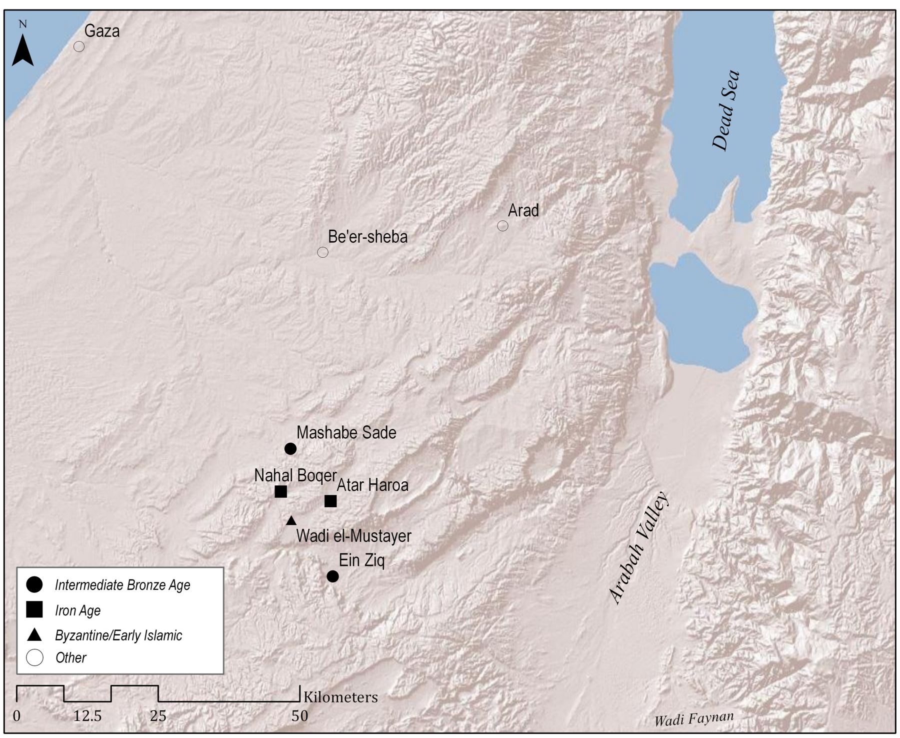

Figure 1 Location of sites mentioned in the text (open circles: Bronze and Iron Age urban sites close to the study region); note the location of the studied sites in relation to the Arabah Valley and Wadi Faynan.

All of this work provided a set of new and surprising insights on animal husbandry practices, on the date of the sites, and on commercial ties with neighboring regions, resulting in several significant paradigm changes:

1. It was found, using micromorphology and phytolith analysis, that the inhabitants of the Iron Age sites were herding animals but did not engage in cereal cultivation, contrary to previous "common wisdom" (Shahack-Gross and Finkelstein 2008; Shahack-Gross et al. 2014). We discuss critiques of this conclusion in greater detail below.
2. While previous studies promoted the idea that the Iron Age sites were 10th century BCE Judahite royal fortresses that were destroyed by Pharaoh Shoshenq I in his campaign to Canaan ~925 BCE (e.g. Cohen 1979; Haiman 1994), our ^{14}C assays have proven that the sites were occupied mainly after this campaign (late 10th to late 9th centuries BCE; Figure 2). This indicates that the settlements flourished rather than declined following this event, during a period of Egyptian domination in the region, which was probably related to the copper industry in the nearby Arabah Valley (Boaretto et al. 2010; Shahack-Gross et al. 2014; for Egyptian influence in the Arabah copper sites see Ben-Yosef 2010:971–8).

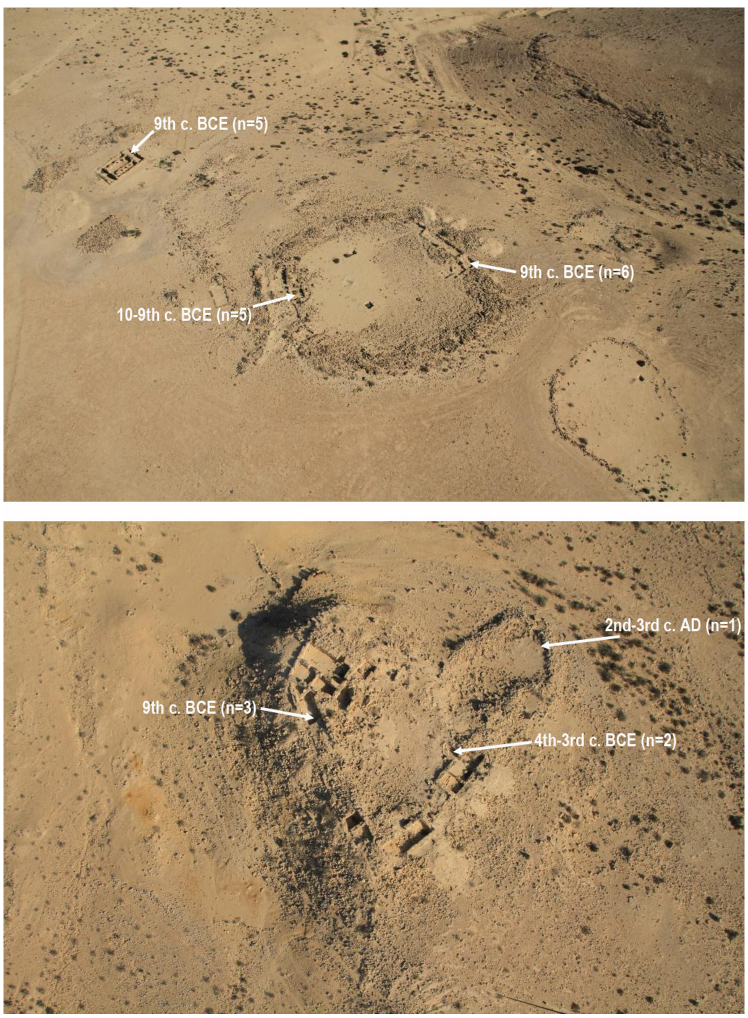

Figure 2 Aerial photographs showing the two Iron Age sites studied, with reference to location and number of ^{14}C samples and to the general results. Top: Atar Haroa; bottom: Nahal Boqer. The Iron Age activity at both sites is limited to the late 10th to late 9th centuries BCE.

3. We have shown that the sites studied by us were not destroyed by fire, as suggested in past research (Cohen 1979); rather, the black-gray dusty layer of sediment on floors originated from partially degraded livestock dung (Shahack-Gross and Finkelstein 2008). Additionally, we identified fragments of mudbrick, revealing information thus far unknown on the construction technology of these settlements.
4. We identified that fuel materials for hearths within rooms were local, including wood from trees and shrubs (e.g. *Tamarix* and *Retama* species) as well as livestock dung (Shahack-Gross and Finkelstein 2008). The latter component is another support for the pastoral nature of the settlements. Additionally, we identified charred seeds of date palm, barley, grape, and chickpea (Boaretto et al. 2010).
5. Despite the lack of macroscopic copper remains, ceramic petrography identified copper slag that was incorporated as temper into the typical "Negebite" pottery that is found in abundance in the Iron IIA sites in the Negev Highlands. This finding provides evidence for a link between the Negev Highlands and the copper production areas in the Arabah (Martin et al. 2013).

Our first conclusion, about lack of evidence for cereal cultivation in the Iron Age, has been criticized in the past, in personal communication following presentation of results at international and national scientific meetings and through comments made by the two readers of this review article. The evidence produced in our studies is based on the identification of thick accumulations of degraded dung deposits at Atar Haroa (about 10–20 cm thick, indicating that the organic component formed much thicker deposits) and Nahal Boqer (Shahack-Gross and Finkelstein 2008; Shahack-Gross et al. 2014). Phytolith analysis in these dung deposits yielded very low concentrations (mostly below 0.3 million in 1 g of sediment) and phytolith morphotype analysis showed that most phytoliths originate from shrubs and wild grasses. Taken together, these lines of evidence indicate long-term corralling of livestock in the courtyards of the two studied sites with foddering based on free grazing only. Domestic cereals clearly did not form part of the herds' diet (data in Shahack-Gross et al. 2014). Below, we relate to each point of criticism with which we have thus far been confronted.

First, colleagues suggested that the phytolith indicator may not be well preserved, i.e. that phytoliths may have been dissolved with time. We addressed this possibility by carrying out a chemical test whose results unequivocally showed that phytoliths in the study area are well preserved (Shahack-Gross et al. 2014; see also Cabanes et al. 2011, 2012 for basic explanation of the chemical procedure). This is expected under the dry conditions in the Negev Highlands. Other lines of criticism relate to "common wisdom" notions:

(a) The location of the Iron IIA sites in an area with more water (Negev Highlands) than its surroundings indicates that settlements were established in areas that ensured success in dry farming (i.e. cultivation based on rain without need for irrigation). The fact that the study area receives only ~100 mm of rainfall per year (in unpredictable patterns), while barley and wheat require at least 200 and 300 mm of water per growth season, respectively, in order to obtain economically successful yields (Arnon 1986), indicates that the only way to ensure successful yields would require growing these crops using irrigation systems such as wadi terraces. However, recent independent evidence based on optically stimulated luminescence (OSL) dating of wadi terraces demonstrates that irrigation systems were not present in the area prior to the late Roman period (Avni et al. 2012).

(b) The Iron IIA sites are located where later (Byzantine/Early Islamic) farmers built their settlements, indicating these were areas suitable for agriculture. This geographical observation is indeed correct, but in the absence of irrigation systems to intensify water availability to crops during the Iron IIA, this suggestion is irrelevant.

(c) The Iron IIA sites are scattered, and with often only one or two buildings, which arguably indicates a settlement pattern that provides wide areas for cultivation on wadi beds. This critique, however, does not take into account the investment of labor required for cultivation and processing of crops. It is difficult to imagine one or two families being able to manage the labor needed for economically justified yields. Only microarchaeological work in the future at such small sites will be able to resolve this point.

(d) Grinding stones and small amounts of sickle blades have been found at Iron IIA sites, and these together with the few charred seeds of edible plants we found (see Shahack-Gross and Finkelstein 2008) indicate to some scholars that cultivation was conducted during the Iron IIA. We have already discussed this point in the past (Shahack-Gross and Finkelstein 2008), explaining that these items do not necessarily point to local cultivation as they can also indicate consumption of grains bought/exchanged from neighboring areas.

(e) We have been asked whether herds could survive the lean months of the year if they are not foddered by a supplement, arguably through grazing on field stubble or stored cereals/grasses. We have previously reported, based on our own ethnoarchaeological work among Bedouins in the Negev Highlands, that the black goat, which is highly adapted to survival in this arid region, can feed on lichens during the lean months of the year (Shahack-Gross and Finkelstein 2008).

(f) Certain studies used pre-modern and modern Bedouin agricultural activities in the Negev Highlands as ethnographic analogs to archaeological societies of the area in historical periods (e.g. Bruins and van der Plicht 2007:492; Haiman 2012:46). We argue that Bedouins have used pre-existing irrigation systems available in the Negev Highlands since the Byzantine/Early Islamic period and hence their involvement in cereal cultivation cannot be used uncritically for archaeological inference.

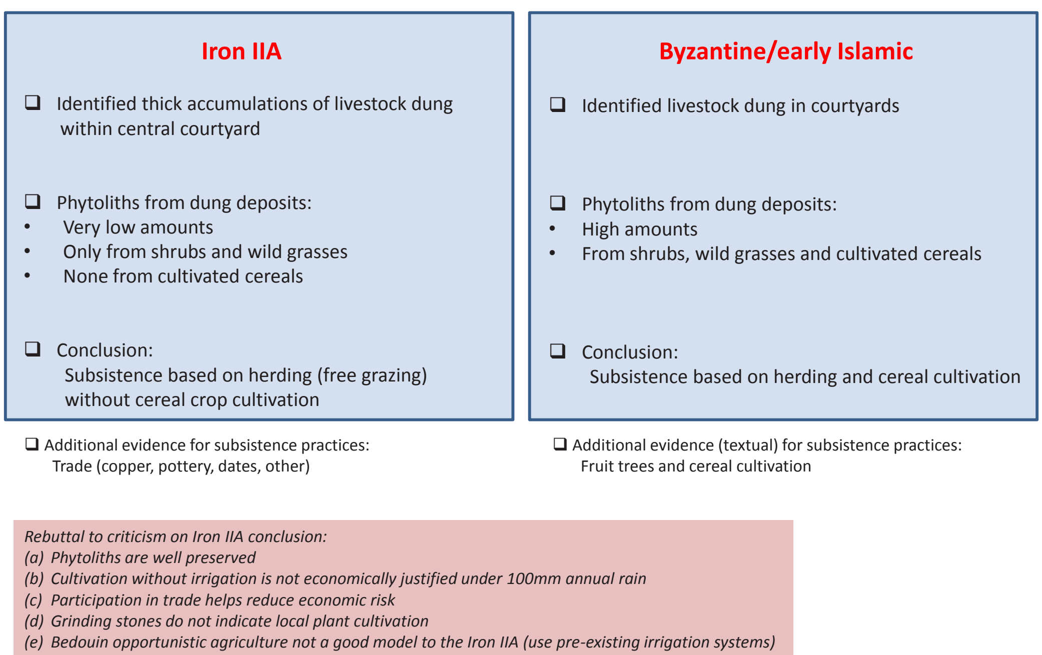

Figure 3 Summary of georchaeological evidence and the conclusions derived from them regarding subsistence practices in the Negev Highlands in the Iron IIA and Byzantine/early Islamic periods (boxes; the georchaeological evidence is presented in detail in Shahack-Gross and Finkelstein 2008; Shahack-Gross et al. 2014). Additional evidence for subsistence practices is given below the "Conclusion" points. At bottom, our rebuttal to the various points of criticism that our conclusion regarding subsistence practices in the Iron IIA has attracted.

In conclusion, all lines of evidence point to absence of large-scale, and most probably even small-scale, cereal cultivation in the Negev Highlands during the Iron Age IIA settlement peak.

Results obtained from the study of two room and three courtyard contexts at a Byzantine/Early Islamic site—Wadi el-Mustayer—included evidence for cereal cultivation preserved in the concentrations and morphotype identities of phytoliths from degraded livestock dung deposits (details in Shahack-Gross et al. 2014). These results show the importance of using such sites as methodological controls, i.e. that phytolith analysis of well-preserved assemblages from dung indeed reflects human subsistence economy. The expected conclusion from this control study is therefore that cereal cultivation was carried out by the Byzantine/Early Islamic inhabitants in the Negev Highlands. The data, conclusions, and rebuttal to criticism are summarized in Figure 3.

ADDITIONAL INFORMATION ON TRADE CONNECTIONS DURING THE IRON IIA

Analysis of organic residues in late Iron I and Iron IIA pottery flasks found in Israel identified remains of cinnamon (Namdar et al. 2013). This commodity, which originated in India or another region of Southeast Asia, could have been transported to the Levant via several routes, including the one from Arabia and the Hejaz to southern Jordan, the Negev, and then the Mediterranean coast. The use of this route depended on availability of beasts of burden. Donkeys were utilized as burden animals as early as 5000 BP (Rossel et al. 2008), while recent work in southern Israel seems to indicate that the introduction of domestic camels to the region took place in the early Iron IIA—contemporary with the activity at the Negev sites (Sapir-Hen and Ben-Yosef 2013). In addition, in both Iron IIA sites studied by us, we identified many charred date palm pits, while palm phytoliths, produced in large quantities in palm leaves, were absent. A recent study by Cabanes and Shahack-Gross (forthcoming) shows that palm phytoliths are especially resistant to postdepositional dissolution. The absence of palm leaf phytoliths thus indicates that palm trees were not abundant in the Negev Highlands landscape or used for construction (e.g. roofing) at these sites. Based on these observations, we tentatively suggest that the relative abundance of charred date palm pits indicates that dates were not cultivated in the vicinity of the sites; rather, they were brought from afar via the desert trade routes, possibly from Arabia, where date palm trees have been cultivated in oases since the Bronze Age, ~3000 BCE (Tengberg 2012). This suggestion requires further testing.

SITING OF SETTLEMENTS IN THE IRON IIA NEGEV HIGHLANDS

Past research suggested that the stone-built courtyard sites represent fortresses because most are located on topographic highs above wadi beds. Based on our familiarity with many Iron Age sites across the Negev Highlands, we suggest that the location of sites on topographic highs is not related exclusively to defense or other strategic considerations. We noted that almost all sites are built from limestone of the same geologic (Netzer) formation, which is characterized by thin beds (20–50 cm thick) that naturally weather and crack into rectangular blocks (Figures 4a–b). We propose that site location was determined, at least in part, based on the availability of this raw material for construction. We note that Atar Haroa is exceptional in the rock type used for construction, namely flint from the geologic Mishash Formation, but this too is abundant in the site's proximity where it naturally weathers into large slabs (Figures 4c–d). While many consider stone-built structures as evidence of year-round settlement, we propose that the Iron IIA sites could have been built with rather low work investment and that the possibility that they served as seasonal/ephemeral habitation localities cannot be ruled out.

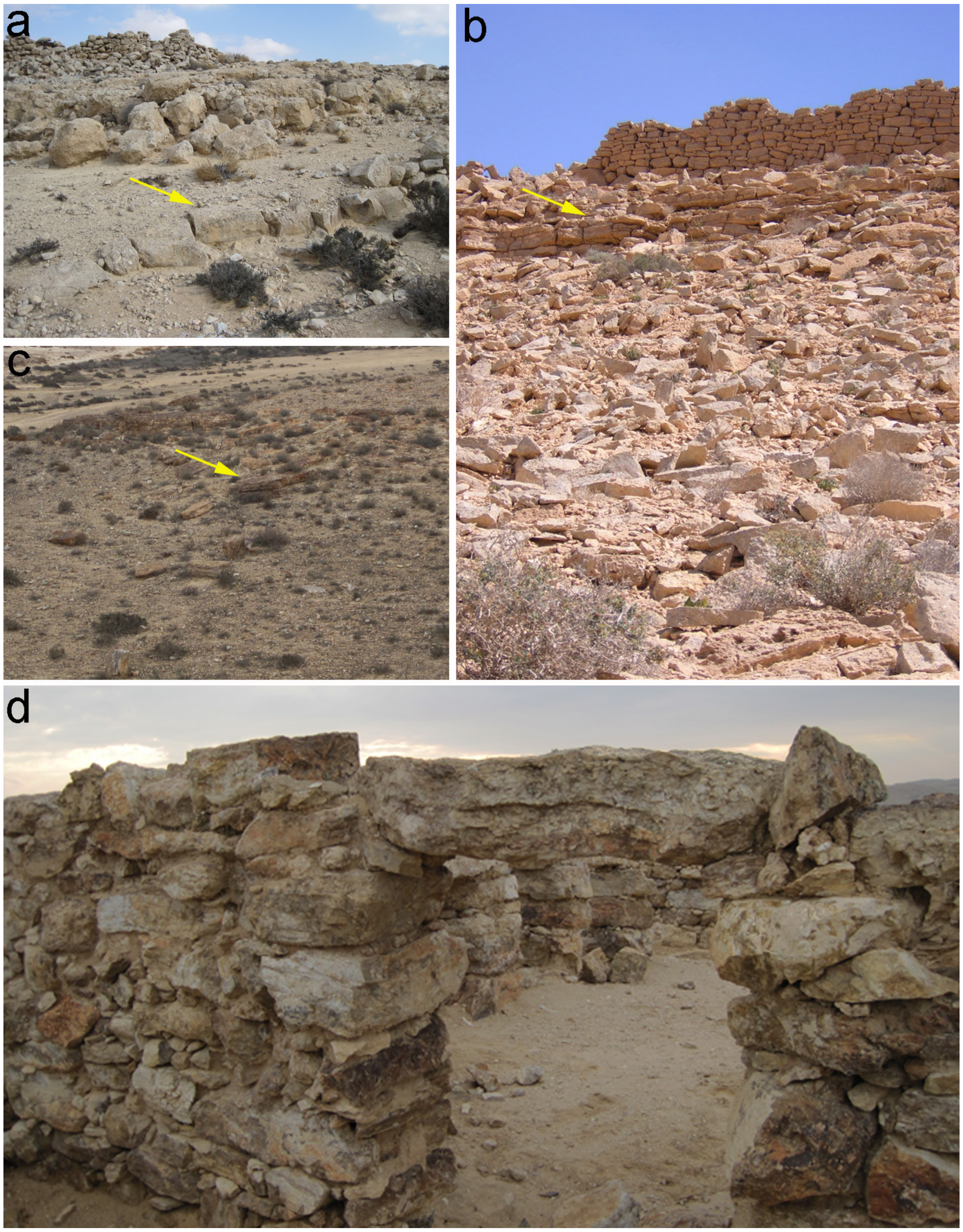

Figure 4 Construction materials in relation to their availability and accessibility: (a) well-bedded Netzer limestone showing natural weathering into blocks (arrow); in the background the site of Nahal Zena "fortress"; (b) well-bedded Netzer limestone (arrow) in the vicinity of Nahal Aqrab "fortress"; note the weathered limestone blocks along the slope; (c) weathered blocks of flint of the Mishash Formation along the slope adjacent to Atar Haroa; (d) well-preserved house at Atar Haroa constructed of local flint blocks.

SYNTHESIS

The new data obtained in our microarchaeological project provides evidence of a complex subsistence system that operated in the Negev Highlands during the Iron IIA and reached a peak following

Shoshenq I's campaign to Canaan, which seemingly boosted a complex international trade system. Viewing the settlement oscillations in the Negev Highlands as solely representing ephemeral, limited-in-scale activities of small groups of pastoral nomads is somewhat misleading; the evidence presented here indicates that the Iron IIA settlement system was part of a larger apparatus that included copper production, possibly long-distance transportation of exotic spices, and perhaps trade of other commodities (e.g. seashells, asphalt/bitumen, ochre). It seems logical, then, to seek intervention of a major political power as a factor in the creation of such an international trade system. We emphasize that we do not contend that Shoshenq I ushered pastoralists to participate in an international trade system. Ethnographic studies of pastoralists consistently emphasize the flexibility of this subsistence strategy as one that readily adopts changes as a response to shifting social, political, and economic opportunities (e.g. Cribb 1991; Frachetti 2009). We suggest that Iron IIA pastoral groups actively participated in the international trade system as part of their risk-reducing, flexible survival strategy. Pastoralists may have taken part in copper production and trade. We note that participation in long- or short-distance trade can potentially be easy for nomadic pastoralists to adopt, as it can be conducted with accompanying herds, i.e. take advantage of involvement in trade while herds are being driven to various pasture lands. Or, certain members of the families/clans could have taken part in the copper industry in the Arabah and in transporting copper to the north, while other members of the same groups practiced short-range animal husbandry in the vicinity of their settlements in the Negev Highlands.

The Byzantine/Early Islamic wave of settlement in the Negev Highlands, too, was supported by strong out-of-the-desert political powers. A major unresolved question is why cereal cultivation was conducted during the Byzantine/Early Islamic period but not in the Iron Age IIA. Two possible answers may be posited, both understudied: (a) climate change and (b) technological innovation. The first option has not been well studied, at least not for the Negev, and future paleoclimatic research may lend insight into this question. The second option, and the more plausible one in our mind, is the advent of technological innovations in dry farming, which facilitated higher agricultural yield. The building of terraces along wadi beds is probably the best example of such technological innovation that penetrated into the Negev Highlands. Direct OSL dating conducted in the Negev Highlands indicates that terraced fields first appeared in the region during the late Roman or Byzantine/early Islamic period (Avni et al. 2012). This phenomenon may be tied to the prosperity of the Roman–Byzantine empires and later Arab polity, when the expansion of eastern irrigation techniques, such as the *qanāt* (identified in the southern Arabah, for example), across arid zones of the Middle East is evident (e.g. Watson 1974; Kamash 2012). Thus, a working hypothesis for future research may be that for the arid zones of the Levant—even in an improved ecological niche such as the Negev Highlands—sedentarization was a result of opportunities created by economic powers centered outside of the desert. In the Iron IIA, stimulation came from international trade, including the demand for Arabah copper following the decline of production in Cyprus (Knauf 1995:112–3), while in the Byzantine/Early Islamic period expansion of settlement into semi-arid margins (extensification *sensu* Porter et al. 2014) was probably related to population growth, intensification of production, and thus expansion of dry farming into marginal areas utilizing agrarian technological innovations such as terraces. Future research should thus focus on gaining a deeper understanding of other waves of settlement in the Negev Highlands, as well as a better understanding of the available agricultural and water management installations.

STUDYING THE INTERMEDIATE BRONZE AGE WAVE OF SETTLEMENT

The Intermediate Bronze Age in the Negev Highlands features a dense settlement system, including hundreds of sites of different size and nature, a large number of which were excavated in the late-

20th century and produced primarily macroscopic data (Cohen 1999). Settlement during this period is characterized by both large central sites and smaller ephemeral sites. Scholars (e.g. Haiman 1996) interpreted the IBA settlement system in the Negev Highlands as part of a larger phenomenon distributed geographically between the Nile Delta, northern Sinai, the Negev Highlands, Wadi Arabah, and southern Transjordan, suggesting that it was driven by an external power (Egypt) interested in copper extraction, production, and trade, supplemented by limited pastoral nomadism (in the ephemeral sites) and marginal agriculture.

A recent radiometric project indicates that the Early Bronze Age came to an end ~2500 BCE (Regev et al. 2012), 200–300 yr earlier than the conventional opinion. This means that the Intermediate Bronze Age spans about 550 yr (~2500–1950; for the latter datum see e.g. Bietak 2002), with the first 300 yr or so corresponding to the Old Kingdom in Egypt—a developed empire, characterized by intensive trade, pyramid building, etc., and the last 250 yr corresponding to the First Intermediate Period in Egypt, a time when Egypt disintegrated, and the very beginning of the Middle Kingdom. Based on this data, one could suggest that the central sites flourished as a result of copper trade with Egypt during the period of the Old Kingdom (for copper implements in these sites see Cohen 1999:260–5; for production in the area of Wadi Faynan see Levy et al. 2002), while the ephemeral sites coincide with the decline of this system and withdrawal of the Negev population to traditional pastoral activities during the First Intermediate Period. This hypothesis could be tested if a large data set of radiometric dates from this period would be available for the Negev Highlands; however, only a few such dates have been published thus far (Avner and Carmi 2001).

Based on the above, for this period, too, a microarchaeological approach is expected to yield new information regarding chronology and subsistence practices. A pilot test excavation at two IBA sites—the large, central site of Mashabe Sade and a small ephemeral site located ~300 m east of it (Cohen 1999:117–30)—was conducted in 2013. Initial results designate that microscopic remains indicative of subsistence practices are meager in sediments sampled within and outside rooms at the central site (Dunseth 2013). New excavations are also being conducted at the site of Ein Ziq (Cohen 1999:137–88). Work is ongoing in order to gain a deeper understanding of the Intermediate Bronze Age settlement phenomenon.

STUDYING AGRICULTURAL AND WATER MANAGEMENT INSTALLATIONS

Agricultural and water management installations in the Negev Highlands include wadi terraces, built and rock-cut water cisterns, dams, canals, wells, silos, stone piles (*tuleilat el-anab*), and threshing floors (Evenari et al. 1982; Rubin 1990, 1991). Most research thus far has focused on macroscopic descriptions of these installations, and their chronological assignment was determined based on assumptions drawn from proximity to settlements datable through pottery finds. Systematic study so far has focused on terraced fields only (Avni et al. 2006, 2009, 2012). In the future, we intend to explore evidence for chronology and construction methods of water cisterns, as well as evidence for construction, tillage, manuring, and crops in field terraces. The ultimate goal is to integrate all lines of evidence with past climate and environmental conditions, political circumstances, and subsistence practices.

CONCLUSION

The Negev Highlands project described herein produced a significant impact on the archaeology of the south Levantine deserts. It demonstrated how integration of field archaeology and natural science-based methods can result in important new evidence related to interpretation of archaeological remains and historical reconstruction. It initiated a change of paradigm, including a change from the suggestion presented by one of us (Finkelstein 1995) regarding subsistence economy in these regions and hence their history.

ACKNOWLEDGMENTS

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ON THE BEGINNINGS OF SOUTH ASIAN SPICE TRADE WITH THE MEDITERRANEAN REGION: A REVIEW

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ABSTRACT. When did the trade in lucrative spices from South Asia to the West commence? Recent organic residue analyses performed on small early Iron Age (11th–late 10th century BCE) Phoenician clay flasks provide the first concrete archaeological evidence that such sustainable trade took place much earlier than hitherto suspected. The analysis shows that several of the flasks contained cinnamon, which in this period could only have originated in South/Southeast Asia. Here, we first summarize the rationale and results of that study. Subsequently, we provide an updated review of all sources of data relevant to the question at hand—archaeological, analytical, and textual. Finally, we offer suggestions for future research on the Asian spice trade with the West.

INTRODUCTION: SOUTH ASIAN SPICE TRADE WITH THE WEST

South/Southeast Asian spices have fired the imaginations of European historians, poets, and travelers, and whetted the appetites of elites and rulers ever since the "West" became aware of their existence (Keay 2006). Starting in the 16th century, the quest to dominate the spice trade became a major factor in European colonialism, the development of maritime technologies, and more, and dictated the fate of many of the spice-producing regions and societies (e.g. Corn 1998). But when did the spice trade begin?

Based on Greek literary evidence, discussions of the South Asian (mostly Indian) spice trade to the West usually begin with the late 6th/5th centuries BCE, when European acquaintance with cinnamon and cassia was recorded by Herodotus (3.107–111; 5th century BCE) and by his more-or-less contemporary Melannipides of Melos (Athenaus 14.561F; e.g. Barnstone 2010:157).[1] Herodotus' fanciful account (3.107–111) demonstrates that even in this period Europeans had only a vague idea regarding the origin of these spices; cassia and cinnamon were said to be procured by the Arabs (alongside myrrh and frankincense). On the other hand, Herodotus proclaimed that the origin of cinnamon is in fact unknown and that it was brought from Nysa "where Dionysus was reared." For him, this probably meant Ethiopia (2. 146).[2] Per Herodotus (2.86), cassia was used by the Egyptians, alongside myrrh, for embalming.[3]

The association of cinnamon/cassia with Arabia suggested by Herodotus (and later writers), and their affiliation with Trogodytica or Somalia in East Africa by Pliny the Elder (*NH* XII, 42.19; 1st century CE) led some scholars to suggest that these terms, rather than referring to South Asian spices, denote African or Arabian plants, yet unidentified botanically [esp. De Romanis 1996; Crone 2004:36–7 and Appendix I (first published in 1987)]. These suggestions, however, did not gain much support (for critiques, e.g. Amigues 1996; Goyon 1996; additional endorsements of the South

1. Other commodities traveling between South Asia and the Mediterranean in the Persian period are summarized in Salles 1996:257; Van Alfen 2002:299–300, Table 2A and passim (for cinnamon and cassia, see pp. 47–53).
2. And that Greek tradition variously identified in the Aegean, Africa, or Asia (from Hellenistic times this was specifically India; see Herrmann 1937 and references in Amigues 1996:660). For Herodotus' quite fuzzy acquaintance with both Arabia and India, see e.g. Dihle (1990) and Casevitz (1995). The notion that Indian spices actually originated in Africa remained widespread in Europe until early modern times, for example in Garcia de Orta's famed *Colóquios* (16th century; Pearson 1996:1–50 for an English version).
3. This brings to mind 19th century Egyptologists, including the famous Thomas ("Mummy") Pettigrew, who strangely reported encountering cinnamon, or its odor, when treating New Kingdom mummies (Lucas and Harris 1989:354).

The Iron Age in Israel: The Exact and Life Sciences Perspective
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Asian hypothesis are cited further below). As pointedly noted by Van Alfen (2002:50): "…those arguing for non-Far Eastern origins [are in] the unenviable position of first trying to find an African or Arabian species to label 'cinnamon' and 'cassia,' and then to explain the shift in meaning to the Far Eastern species later on."

By the Hellenistic period and more so in the Roman era, the Asian spice trade with the West was well under way and is well attested historically and to a certain extent also archaeologically (Miller 1969; Salles 1993; Reade 1996; Thapar 1997; Burstein 2002; Pearson 2003; Ray 2003; Bellina and Glover 2004; McPherson 2004; Tomber 2008; Sidebotham 2011).[4]

Pearson (2003), however, suggested that Greeks and Romans tapped into age-old trade networks that endured for millennia, and some "prehistory" of exchange was also advocated by others (a partial list: Reade 1996; Salles 1996; Weinstein 2000; Burstein 2002:129; Ray 2003:277–8; Gupta 2004, 2005 and see more below). In support of such hypotheses, however, scholars either did not cite any evidence at all, or only parts of the relevant data. In this paper, we build upon those earlier discussions, and add hitherto unnoticed or new data in order to provide a critical, up-to-date summary of all the evidence that to our minds bears on the question of spice trade between South Asia and the Mediterranean prior to the 5th century BCE.

CINNAMON IN EARLY IRON AGE PHOENICIAN FLASKS, 11TH–10TH CENTURIES BCE

The details of our residue analysis of Phoenician flasks were presented in Namdar et al. (2013), where we focused on the analytical protocol and described in detail the chemical results. Here, we summarize the main points of that paper only briefly and concentrate on two other aspects of this research: its historical/archaeological background (the reason why we chose to analyze the contents of these specific vessels) and the contexts in which the flasks "operated" in the Levant. In the Future Prospects section, we claim that following a similar rationale might be instrumental in uncovering further evidence for trade in South Asian (and other) spices.

Background: Levantine Involvement in Inter-Regional Trade in the Early Iron Age and the Rationale of the Study

The last centuries of the Bronze Age (the 14th–13th centuries BCE) signal a peak in Mediterranean (including Levantine) commercial and political interconnections, well attested both by archaeological finds and by extensive ancient documentation (Liverani 2001). The downfall of all Late Bronze Age (LBA) political/economic regimes around the eastern and central Mediterranean, roughly in the course of the mid-13th to mid 12th centuries BCE, brought about the disappearance of these networks and concomitantly a drastic decline in inter-regional exchange. Traffic and the movement of goods, however, did not stop. Abundant archaeological data attest mainly to continuous maritime activities linking the Levant with termini and ports-of-call farther west—in Cyprus, the Aegean, and as far as the Iberian Peninsula, though certainly on a smaller scale than in the Late Bronze Age. Early Iron Age Mediterranean trade is attested mainly by "luxury" items such as metal objects, jewelry, and other trinkets of various materials; it most probably also involved the metals themselves (e.g. Gilboa et al. 2008 with references; Nijboer 2008; Thompson and Skaggs 2013). Since the administrations that controlled much of the Late Bronze Age interconnections have disappeared, many scholars perceive the LBA/Iron Age transition as accelerating a realignment of exchange modes from largely elite "state-administered" exchanges along substantivist lines, to less centralized, market/profit-oriented endeavors, propagated *inter alia* by lower echelons of society (Sherratt and Sherratt 1991, 1993; Liverani 2003; Bell 2006; Beaujard 2011).

4. The best archaeological examples are the large quantities of black peppercorns unearthed at the spice emporioum of Berenike in Egypt's Eastern Desert (Sidebotham 2011:224–6).

Within the Levant, Phoenicia in particular[5] provides a wealth of data regarding inter-regional exchanges in the early Iron Age. Beyond its participation in the aforementioned Mediterranean networks, it produced evidence for extensive maritime connections with Cyprus (e.g. Bikai 1987; Gilboa 1999b, 2012 with references; Gilboa and Goren, in press) and Egypt (Gilboa and Sharon 2008:156, figure on p. 169; Raban-Gerstel et al. 2008; Ben Dor Evian 2011; Waiman-Barak et al. 2014a). Possible Phoenician (and generally Levantine) contacts with regions farther to the south/southeast are still vague. The emergence of the renowned "Frankincense Route(s)" from Arabia may be assigned to the early Iron Age, or even to the Late Bronze Age (respectively, Finkelstein 1988:247; Kitchen 1997:136; vs. Liverani 1992; Artzy 1994; Jasmin 2005, 2006; cf. summary in Knauf et al. 2010). Admittedly, however, the evidence is still rather circumstantial.[6]

The Flasks

As opposed to the Late Bronze Age, in the early Iron Age ceramic containers hardly moved about the Mediterranean. The most notable exceptions are various small decorated containers shipped from Phoenicia to various adjacent regions, especially to Cyprus. Among them the "Phoenician Bichrome"containers have received much scholarly attention and are usually taken as the best proxy for early Iron Age Phoenician commercial enterprise (Bikai 1987). We, however, chose to focus on another group of containers—various small clay flasks— since they are by far the best attested Phoenician import found on the island (Karageorghis and Iacovou 1990:90; Gilboa et al. 2008).

The flasks (Figure 1) have relatively thick walls (usually ~1 cm, sometimes as thick as 2 cm; nr 5 in Figure 1). This indicates a special effort to prevent their breakage. They are of restricted capacity, ~50 mL, and equipped with very narrow necks/apertures (usually ~0.5 cm at the narrowest point), fit for slow pouring of liquid. The flasks are usually decorated with concentric circles in one or two colors. Although simple, the systematic embellishment of these flasks stands out against a background of mostly undecorated early Iron Age Phoenician ceramics, indicating that the decorations not merely exemplify some Phoenician ceramic *habitus*, but had a specific purpose/function. Rarely were these flasks left undecorated.[7]

All these characteristics, in conjunction with the vessels' circulation and find contexts (see below)—suggested to us that they must have been manufactured for the export of some precious liquid. Fabric analysis of such vessels demonstrates that the flasks we identified stylistically as Phoenician—both in Cyprus and in various regions in the southern Levant—were indeed manufactured there (in different locales; Gilboa and Goren, in press: Appendix 2, e.g. Amathus 11–15, Kouklia 1, 31, 34; and preliminarily Waiman-Barak et al. 2014b).Thus, we began this study as an attempt to understand this quite unusual Phoenician export by analyzing the contents of the flasks.

Regarding chronology: in Phoenicia, such flasks are known from the Late Bronze Age/Iron Age transition. They are especially common during Ir1a and Ir1b and then start to dwindle in numbers during the Ir1/2 transitional period and vanish in the course of Ir2a.[8] In Cyprus, the flasks are attested contemporaneously: from Late Cypriot IIIA, and then through LC IIIB and the entire Cy-

5. We use the term "Phoenicia" in the early Iron Age as denoting not only Lebanon, but also the coastal areas south of it, down to the Carmel coast in Israel; for the arguments, see e.g. Gilboa (2005, 2012) and Gilboa and Goren (in press).
6. And is inextricably connected to the question of the domestication of the dromedary and its dispersal in the Levant—an issue we do not pursue here.
7. We have some indications that on the undecorated examples the paint is simply not preserved.
8. We employ here the chronological terminology proposed in Gilboa and Sharon (2003) for Phoenicia, which corresponds to the one employed in Israel (Herzog and Singer-Avitz 2006, 2011; Mazar 2011:107; Arie 2013) as follows: Ir Ia = early Iron I; Ir1b = late Iron I; Ir1/2 = early Iron IIA; Ir2a = late Iron IIA.

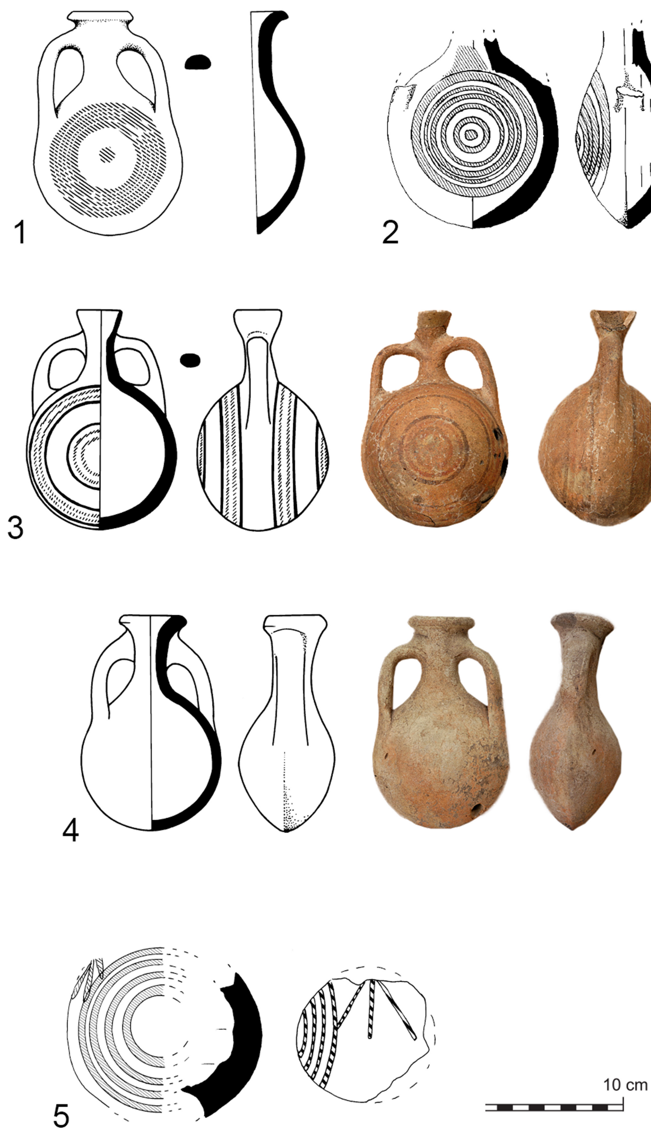

Figure 1 Examples of flasks containing cinnamon. 1. No. 2019, Tell Qasile; 2. No. 2279, Dor; 3. No. 2271, Tell Qasile; 4. No. 2269, Tell Qasile; 5. No. 2192, Dor.

pro-Geometric period (CG I–III; for the relative chronology and terminology in Phoenicia and the correlation to Cypriot horizons, see Gilboa and Sharon 2003). This means roughly the early 12th to mid-9th centuries BCE, a long-lasting phenomenon. However, the specific flasks that produced well-preserved organic residues (Table 1) date only to the Ir1a, Ir1b, and Ir1/2 horizons, the 11th to the mid- or late 10th century BCE.[9]

Results of the Residue Analysis

Selection of samples was dictated mainly by considerations of preservation and accessibility. We chose not to sample flasks in Cyprus since they have routinely been treated with acid and thus the organics absorbed in them may have been washed away. Flasks from Lebanon were inaccessible to

9. When exactly the Ir1/2 transition should be placed in absolute terms depends on one's stance in the debate regarding the ^{14}C chronology of the Iron Age in Israel—a dispute we cannot enter here.

Table 1 Details of flasks containing cinnamon. For a full molecular inventory of their extracts see Namdar et al. 2013, Table 2.

Lab nr.	Site, stratigraphy, registration details	Date and context	Illustration/reference
2019	Tell Qasile Str. XI #3066/ L227	Iron 1a, Temple 200 store-room	Figure 1:1; Mazar 1985:71, photo 73, Figure 20:12
2269	Tell Qasile Str. X #2120/L188	Iron 1b, Temple 131 store-room	Figure 1:4; Mazar 1985: Figure 37:10
2271	Tell Qasile Str. X #2126/L188	Iron 1b, Temple 131 store-room	Figure 1:3; Mazar 1985: Figure 37:7
2272	Tell Qasile Str. X #2133/L188	Iron 1b, Temple 131 store-room	Mazar 1985: Figure 37:15
2275	Dor Phase G/7b-a #99379/W9140	Iron 1|2, in domestic courtyard house	Unpublished
2278	Dor Phase D2/13 #09D2-7885/ L09D2-386	Iron 1a, store-room on lower floor of elite dwelling	Unpublished
2279	Dor Phase B/11 #71272-1/L7138	Iron 1a|b, domestic context	Figure 1:2
2281	Dor Phase D2/13 #10D2-5170/ L10D2-516	Iron 1a, room in elite dwelling, upper floor	Unpublished
2192	Dor Phase G/8 #98627/L9861	Iron 1a|b, cult room in domestic courtyard house	Figure 1:5; Gilboa 1999a: Figure 1:7
2194	Kinneret Str. V #10799/1/L4328	Iron 1b, Area U domestic context	Unpublished

us. Therefore, we only sampled vessels from sites in present-day Israel (Figure 2). We focused on vessels found in primary contexts. In 10 out of the 27 flasks analyzed, high amounts of cinnamaldehyde were detected, among many other molecules (for a detailed inventory of items analyzed and compounds detected, see Namdar et al. 2013:Tables 1, 2).[10]

Cinnamaldehyde is one of the three major components of cinnamon (Tomaino et al. 2005). It is a direct biomarker for cinnamon, since *Cinnamomum* is the only plant group that accumulates large quantities of cinnamaldehyde. This is due to a malfunction in its shikimic pathway, which in other plants produces lignin from cinnamic acid (Clark 1991; Whetten and Sederoff 1995). Cinnamaldehyde is a relatively unstable molecule, and its survival in the 10 flasks is attributed to an organic-inorganic binding, stabilizing the adsorbed molecules in the ceramic matrix. Other than the cinnamaldehyde itself, one of its degraded byproducts (benzoic acid) was also found in the extracts of these 10 items.

In addition, relatively small amounts of tartaric acid were detected in some of the flasks. Tartaric acid is often considered a marker for wine (Michel et al. 1993; Guasche-Jané et al. 2004, 2006; McGovern 2009), but this has recently been convincingly debated (DeBolt et al. 2006; Isaksson et al. 2010; Barnard et al. 2011). Therefore, based on the molecular assemblages detected in the flasks we cannot determine the type of liquid in which the cinnamon was immersed.

10. Among the other molecules, various myristate derivatives possibly point to another South Asian spice, nutmeg in this case, but this identification is not conclusive enough at this point; see the discussion in Namdar et al. (2010) and Gadot et al. (2014) for the problems in identifying the origin of a similar molecular assemblage in early Iron Age Philistine cultic chalices.

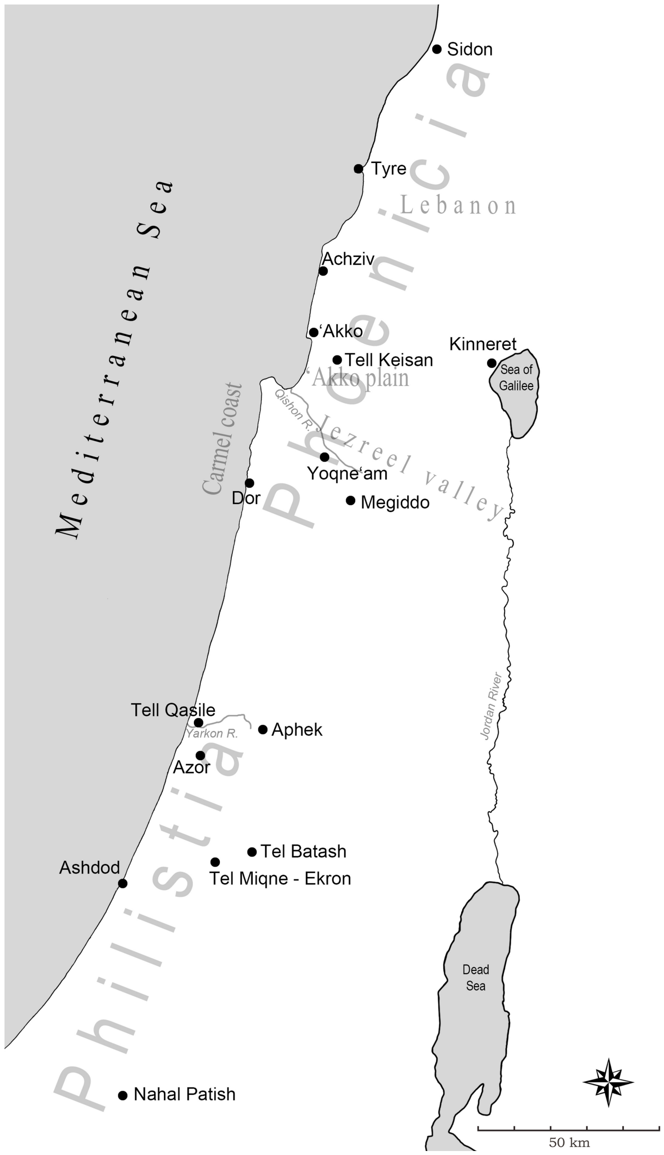

Figure 2 Map of the Levant with main sites mentioned in text.

The *Cinnamomum* family has more than 100 species, all native to South and Southeast Asia. *Cinnamomum verum* (*C. zeylanicum* Nees) occurs naturally mainly in Sri Lanka, southern India, and Myanmar (Ravindran and Babu 2004). *C. cassia* Blume (Chinese cassia/Vietnam cassia) is native mainly to southeast China and Vietnam, also to Laos and Myanmar (Kim Dao 2004; Ravindran et al. 2004; Senanayake and Wijeskera 2004). Currently, we cannot identify the exact cinnamon species present in the flasks. However, since none of the cinnamon species grew naturally (or were cultivated) anywhere else before early modern times (e.g. De Silva 1996:26), the cinnamon in the early Iron Age Levant could only have originated from the aforementioned regions. Since the flasks range in date from the 11th to at least the late 10th century BCE, they comprise the first attestation that the legendary trade of South Asian spices to the West was already underway at such an early period and that there was some durability to this export.

FIND CONTEXTS AND CIRCULATION

The 10 flasks that produced the traces of cinnamon originated from three sites in Israel—Tell Qasile, Tel Dor, and Kinneret—and are from both ritual and more mundane settings (Table 1, Figure 2). Four (nos. 2019, 2269, 2272, and 2275) are from the back storage room of the small Philistine temple at Tell Qasile. One (no. 2192 from Dor) is from a domestic building, found in a room that held various ceremonial paraphernalia (for the assemblage, see Stern 2000:Figure 47). The remaining five originated in various domestic contexts at Kinneret and Dor (nos. 2194, 2275, 2278, 2279, and 2281).

These contexts faithfully reflect the distribution of other Phoenician flasks in the southern Levant—mainly cultic/ceremonial contexts and various special caches, but also more "ordinary" contexts.[11] The largest assemblage known—more than 20 such flasks—is associated with the Tell Qasile Philistine temple, in Strata XII–X, spanning Ir1a–Ir1b (Mazar 1985:71–3; type FL 1). The four Tell Qasile flasks in our sample (Table 1) belong to this assemblage. Following the Tell Qasile case, our search for small flasks in temples and other cultic installations was rewarding. Still in Philistia, two such flasks were found in the newly discovered temple at Nahal Patish in southern Philistia (the northern Negev; Nahshoni 2009); another one, at Ashdod, lay just in front of the "apsis" of the apsidal structure in Stratum XII, commonly understood as having some cultic function (Dothan and Ben-Shlomo 2005:Figure 3.32:6). Another, at Tel Mikne-Ekron, was situated on a plastered stepped platform—unanimously associated with ceremonial activity—in one of the small side rooms of the early Iron Age monumental Building 350/351 (Dothan 2003; Mazow 2005:145, 248, 358). Hardly any temples are known from early Iron Age Phoenicia, but at Megiddo in the western Jezreel Valley, four small flasks were found in Temple 2048 (Stratum VIA, Ir1b; see Arie 2006:239 with reference to previous publications).

Beyond formal temples, such flasks are known from specific contexts associated with ceremony in domestic settings. At Dor, for example, one flask originated in a room where some conspicuous consumption of liquids took place, and which was understood (on other grounds), as a place for the gathering of men—a *marzeah* (Gilboa et al. 2014). At Kinneret, a flask in a room of a courtyard house accompanied a shrine model and an elaborate kernos bowl (Ir1b; Nissinen and Münger 2009:Figure 4). The Phoenician flasks were clearly cached with other precious objects/commodities. The best examples are from Ashdod. In Area H, Stratum XII (Ir1a), two flasks originated in small rooms in the undoubtedly "elite" structure there. These small rooms could only have been storage spaces and indeed were defined as "treasuries" (Dothan and Ben-Shlomo 2005:25, 29, Figure 32.2, 5; Plan 2.5). They held objects of gold, ivory, and more (Dothan and Ben-Shlomo 2005:Plan 2.7 upper) but the possible meaning of the small, crude flasks in them has not been addressed. In Area G at Ashdod, a cache of four such flasks was found in another small storage space, accompanied by a female figurine and an ivory cosmetics box (Dothan and Porath 1993:Figure 32: 10, 12, 13, 15; Plan 10: Room 4117). At the major tell of Jatt on the eastern fringes of Israel's Sharon coastal plain, two such flasks were part of an extraordinary cache composed mainly of elaborate metal objects (Ir1b; Artzy 2006:Pl. 25:2, 3).

Beyond "special" contexts, such flasks are common in domestic and domestic-cum-industrial areas, especially in Phoenicia and its immediate environs (at Dor: Gilboa et al. 2014; at Tell Keisan: Briend and Humbert 1980:Pl. 76; at Yoqne'am: Ben Tor et al. 2005:22–9; at Kinneret: S. Münger, personal communication; and at Megiddo: Arie 2006:208–10, esp. F1a, F1b, F5). In Philistia, flasks in such contexts are less frequent (e.g. at Tel Batash: Panitz Cohen and Mazar 2006:116).

11. The discussion refers only to vessels found in primary deposits in the Levant. In Cyprus, most of the known flasks are from tombs.

To sum up, the Phoenician flasks are especially common in ritual and elite contexts, but not confined to them. Because we did not identify the flavored substance in the flasks, we cannot deduce their exact function. Such small flasks could have held a variety of precious substances, not necessarily mulled with Far Eastern spices. We submit, however, that the occurrence of cinnamon in nearly 40% of our samples indicates that many of them did. Cinnamon, therefore, was not a rarity in the early Iron Age Levant.

Regarding circulation: Asian spices traded to the West traveled in dry form, as they have throughout history (e.g. Casson 1984:232; Keay 2006:116, 187, 227–9). Cinnamon was usually transported as quills made from the dried inner stem-bark of this species. The cinnamon in the flasks, therefore, represents a *secondary industry* related to the spice trade. Namely, in some centers in Phoenicia, cinnamon (and most probably other fragrant substances) was immersed in as yet unidentified liquids and then distributed in locally made flasks within Phoenicia and its environs, and also to other neighboring regions, such as Philistia and Cyprus.

BROADENING THE PERSPECTIVE

Since it has generally been accepted that cinnamon and cassia reached Europe already in the 5th century BCE,[12] here we are interested in further attestations of Asian spices in the West in earlier periods—in the Bronze and Iron Ages.

Botanical Evidence

Direct Evidence

The earliest clear evidence of spices from South Asia comes from the mummy of Ramesses II (reign ~1279–1213 BCE). Grains of *Piper nigrum* (black pepper) were found in his abdomen and nasal cavities, apparently part of the spices used in the mummification process. They were identified by both radiography and botanical analysis (Lichtenberg and Thuilliez 1981; Plu 1985:174, Figures 100:1d; 101:1, 3, 5). Black pepper in this period could only have originated in southern India (Fuller et al. 2011:547). The only other unequivocal botanical attestation of a South Asian spice in the West dates to the 7th century BCE—a flower of *C. cassia* in the sacred precinct of Hera at Samos (Kučan 1995:52–3, Figure 36b).

Other attestations are for the time being ambiguous. In the early 20th century, Edouard Naville reported on actual nutmeg remains at Deir el-Bahari in Egypt, in an 18th Dynasty context (16th–14th centuries BCE). He associated it with Hatshepsut's expedition to Punt depicted at that site (Naville et al. 1913:18). This find, however, has never been fully published. Similarly, Buccelati and Kelly-Buccelati (1983:54) claimed to have found cloves—another Southeast Asian spice—at Terqa on the middle Euphrates, in a context dated ~1600 BCE, but this identification too has never been substantiated.

Indirect Evidence

Beyond the direct identification of South Asian spices in the West, evidence for other botanical (and faunal) translocations between South Asia, China, and Africa provide the wider context against which the early spice trade may be understood. These have recently been summarized in the framework of the Oxford-based Sealinks Project, investigating contacts across the Indian Ocean from an interdisciplinary and *longue durée* perspective (e.g. Boivin and Fuller 2009; Fuller et al. 2011, with references to earlier studies). These scholars convincingly argue that the movements of various

12. For the possibility that *komakon* mentioned by Theophrastus of Lesbos (late 4th century BCE) should be read as nutmeg, see Van Alfen (2002:59 with references).

Asian and African cultivars should be attributed to maritime agency, and point to systematic trade across the Indian Ocean starting no later than the 2nd millennium BCE. Other than the two extremes—India and northeast Africa—it also involved sites in southwestern Arabia (within present-day Yemen). For example, starting in the 2nd millennium BCE at the latest, African crops are attested at various sites in western and northern India. In an east-to-west direction, Chinese *Panicum* (millet) is present in Nubia and southwest Arabia (Fuller et al. 2011:Figure 1). Indeed, it has been argued that this "corridor"—connecting East Africa, Arabia, South Asia, and Southeast Asia—is the context against which the emergence of the spice trade should be understood. Its beginning has been attributed to the early Iron Age (Boivin et al. 2009:265). A similar conclusion was reached by Gupta (2004) in a study investigating the development of maritime activity across the Indian Ocean vis-à-vis the harnessing of the monsoonal winds. Further to the west, in Hala Sultan Tekke in southeast Cyprus, citrus seeds (identified as citron, *C. medica*) have been found in a late 13th century BCE context (Hjelmqvist 1979:113, 125, n. 1). The date has been questioned by Zohary et al. (2012:146) because the seeds have not been ^{14}C dated. But since there are several of them, in secure archaeological contexts (Hunt 1978:18–9; F1159 and F1160), we see no reason for these doubts.

It is widely accepted that citrus originated in South/Southeast Asia (Webber et al. 1967; Dugo and Di Giacomo 2002; Pagnoux et al. 2013 with references). Recently, however, Langgut et al. (2013) demonstrated that citron was transferred to the Levant and cultivated there in the 5th/4th centuries BCE. Since it is unclear how early this practice may have started, citrus seeds in Cyprus may have arrived from nearby regions (or even been cultivated locally).[13] Whatever the case, they attest to some sort of botanical transfer between South/Southeast Asia and the Mediterranean during or prior to the 13th century BCE.

Lastly, another possible example of an "early" Asiatic cultivar in the west is rice (*Oryza sativa* L.), identified in Tiryns in the Greek Argolid in a Late Bronze Age context (Kroll 1982:469, Figure 1:2; cf. Sallares 1991:23). Rice originated in Southeast Asia, from where it spread to India and other regions, but it is not attested as a crop in the Near East nor farther to the west before Hellenistic times, at the earliest (Zohary et al. 2012:73–5 with references). Since, however, only one grain was identified, this unusual discovery will have to be corroborated by future finds (cf. Muthukumaran 2014).

Textual Possibilities

Egyptian Texts

Various Egyptian documents of the 2nd millennium BCE mention the botanical term *ti-spš*, translated by several Egyptologists as cinnamon (e.g. Beaux 1990:130; cf. Nunn 1996:152, Table 7.4; Breasted 2001 IV:§§234, 240, 286, 344). This translation has been extensively cited (e.g. Darby et al. 1976:797; Manniche 1999:17; Kiple and Ornelas 2000 II:160; Toussaint-Samat 2009:437; Broodbank 2013:360). *Ti-spš* was a prestigious substance, offered by kings to temples and deities (e.g. Grandet 1994 II:70). It was frequently used in medicinal concoctions, other unguents, and perfumed oils, and mentioned in love songs (Bardinet 1995; Manniche 1999:39, 44, 54). Other scholars, however, have rejected or doubted the translation of *ti-spš* as cinnamon [e.g. Caminos 1954:209, 468; Erman and Grapow 1971 V:243; Altenmüller and Moussa 1991:15, 42; Faulkner 1991:294 ("tree and its spice"); Grandet 1994 II:83 ("aromatic tree"); Bardinet 1995; implicitly also Kitchen 1999].[14]

13. For the possibility that citrus may already have been acclimatized in Egypt in the 15th century BCE, see Amigues (2005:367–8 with references).

14. For some other views, see Janssen (1966:86–7). Several Egyptian documents allude to *ti-spš* wood, *ti-spš* sticks (reeds? quills?), *ti-spš* root, and possibly *ti-spš* "sawdust" (see listing in Bardinet 1995:583; Breasted 2001 IV: §286).

The *ti-spš* case, for the time being, remains unresolved. It is clear, however, that this was no Egyptian spice. New Kingdom documents record *ti-spš* as reaching Egypt from the south—from Punt [Breasted 2001 II:109, §265; III:57, §116; for the location of Punt along the east African coast, or in western Arabia (or even in Syria) see summary in Meeks 2002]. On the other hand, the Mit Rahina inscription, dating to Amenemhet II's reign in the 19th century BCE, mentions 217 sacks of *ti-šps* brought by an Egyptian maritime expedition returning from Asia, most probably from the north Levantine coast (Marcus 2007:144 and references; the term was indeed understood by him as denoting cinnamon, or alternatively camphor).

Hebrew Bible

Potentially Far Eastern spices are alluded to in the Hebrew Bible. Hebrew *qinman*/*qinnamon* is mentioned three times (Exodus 30:23; Proverbs 7:17; Song of Songs 4:14), alongside other precious fragrant spices. In Exodus, it is one of the ingredients prescribed by God to Moses for the holy anointing oil in the tabernacle. The identification of this substance as one of the *Cinnamomum* species of South Asia is widely accepted (Olck 1899; Moldenke and Moldenke 1952:76; Zohary 1982:202; Casson 1984; Keel 1994:180; Brown 1995:42; Amigues 1996; Goyon 1996:653; Amar 2002:123, 125: nn. 538, 539; Jacob 2011:11–2; Hurowitz 2012:241). Conversely, as mentioned, De Romanis (1996) and Crone (2004) suggest that this is a yet unidentified African or Arabian plant.

Hebrew *qeẓiot* (in plural) and *qeẓia*h (singular, as a personal name) is usually taken to refer to *C. cassia* (Zohary 1982:203). They appear respectively in Psalms 45:9 and Job 42:14 and are translated as "cassia" in the Vulgate (Kraus 1993; Brown 1995:71–2; Amar 2002:104, n. 369; Wilson 2007:476). Hebrew *qiddah* (Exodus 30:24; Ezekiel 27:19) is usually also identified with cassia (cf. Zohary 1982:203; Ammar 2002:104–5).[15] In Ezekiel, it is listed among the merchandise passing through Phoenician Tyre.

In the framework of this paper, it is impossible to consider the extremely complex issue of the dates of composition, transmission, and redaction of all these biblical texts. Generally speaking, though several of them may include "early" (10th–8th century) references, they cannot be evoked to demonstrate the presence of Asian spices in the Levant before the late Iron Age (8th/7th centuries BCE) and most of these texts were extensively edited in exilic and post-exilic times (6th/5th centuries BCE).[16]

Other Texts

In other textual corpora of the Near East and the Mediterranean, South Asian spices have rarely been identified. Bottéro (1957:341), Potts (1997:65–66), and Jursa (2009) describe the difficulties in identifying specific spices in general and the scarcity of such identifications, contra to the variety of spices that had been in use. In cuneiform texts, we are aware of two such instances. Ginger (*Zingiber officinale*), which is native to South Asia (Bentley and Trimen 1880; Purseglove et al. 1981), is listed in one of Esarhaddon's succession treaties (7th century BCE), in a medical context

15. And see nn. 538, 539 for references to scholars who claim that before the 13th century CE only *C. cassia* was known in the Near East (similarly Sima 2000:277, n. 83; vs. Zohari 1982:202–3). In this case too, De Romanis and Crone propose unspecified plants were of African origin.

16. For Exodus 30 in particular and the Priestly corpus (P) in the Pentateuch in general, e.g. Kaufmann 1972; Hurvitz 1982 ("early views"); vs. Schmid 1999; Houtman 1993 I:2; Blenkinsopp 1996; Albertz 2011; Baden 2012:173–4; 247–8 ("late views"); for Proverbs, e.g. Clifford 1999:3–6; Hurowitz 2012 I:10–17; for Song of Songs, see summaries in Keel 1994:4–5; Stoop-van Paridon 2005:11–3; for Psalms in general and Psalm 45 in particular, e.g. Kraus 1993:452; Goldingay 2006–2008 I:30; for Job, e.g. Hurvitz 1974; Wilson 2007:1–2, 6; for Ezekiel, see summary in Liverani 1991:66, 71, 79; all with references to earlier literature.

(Parpola and Watanabe 1988:56, line 644). In a Neo-Babylonian letter (6th century BCE), cinnamon was identified (Jursa 1997:30, 2009:165; Sima 2000:277).[17] The same letter also lists *ka-ṣi-'a-tu*, possibly to be read as cassia (Zadok 1997).

The earliest allusion to an Asian spice in European literature belongs to the 7th or early 6th century BCE. The renowned Lesbian poet Sappho mentions cassia (mingled with myrrh and frankincense), among other eastern luxurious objects and substances, when describing the nuptials of Hector of Troy and Andromache (Fragment 44; e.g. Carson 2002). This precedes Herodotus' and Melanippides' accounts by at least a century and has been frequently overlooked (but see Crone 2004:254; Amigues 2005:373).

SUMMARY AND DISCUSSION

The cinnamon in the 11th–10th century flasks is of special significance since it demonstrates that in the early Iron Age this particular spice was rather widespread in the southern Levant, and to a certain extent was consumed down the social ladder. This is not an anecdotic find. Since the flasks that produced the cinnamaldehyde extend *grosso modo* over 150 yr, it also suggests an export of some regularity, at least in that period. This discovery, alongside Ramesses II's earlier black pepper (13th century BCE), and the later cinnamon flower at Samos (7th century BCE), demonstrates unequivocally that South Asian spices reached the Mediterranean long before the 5th century BCE, at least from the Late Bronze Age. From the 7th century BCE, South Asian spices start to be identified in the written record as well (Esarhaddon, Sappho, and possibly some of the biblical texts). Textual evidence regarding earlier periods is not conclusive, but we submit that current readings of the Egyptian and biblical references should be reconsidered in light of the botanical and residue analysis information summarized herein. As mentioned, spices are only part of a larger array of vegetal commodities that were transferred from South Asia westward over vast distances, at least from the 2nd millennium BCE.

Concomitant questions, of course, must concern the trade routes and modes of trade.[18] *A priori*, however, we admit that there in not much we can say in this regard. Extrapolating from the better-known later periods, when trade was conducted *inter alia* (though not only) through established *emporia* and trading diasporas, facilitated by diplomacy and to a significant extent manipulated by rulers/administrations (e.g. Sidebotham 2011:34, 37, 253–4 for the Hellenistic and Roman periods), would be totally speculative and ahistoric. Specifically for "our" cinnamon, the problem of routes is exacerbated by our inability to determine its geographical origin(s)—anywhere in the vast expanse from south China to south India/Sri Lanka and further east.

The Sealinks researchers, for example, argue that the specific plants they discuss (above) were distributed via a circuitous sea route around the Arabian Peninsula (Figure 3), in part exploiting the monsoon system (similarly Gupta 2004 and implicitly Beaujard 2011:Figures 3.3–3.8). According to them, these exchanges involved societies in southern Arabia and/or the agency of Gujarati (northwest Indian) seafarers (Boivin et al. 2009; Fuller et al. 2011:546–7). Gupta (2004:148–9, with references) suggests that at least from the second half of the 2nd millennium BCE Austronesian seafarers/traders sailed from Southeast Asia as far west as the Gulf of Aden.

The maritime circum-Arabia route (with possible Arabian intermediacy) is only one of several options (and from Arabia/East Africa northward to Egypt and the Levant there are several alternatives).

17. Sima (2000:277 and nn. 82, 83) discusses the specific species of cinnamon which may have been referred to.
18. We reiterate that the routes through which the dry spices reached the Mediterranean sphere, and the subsequent circulation of some spiced commodities in Phoenician flasks as discussed above, are two separate issues.

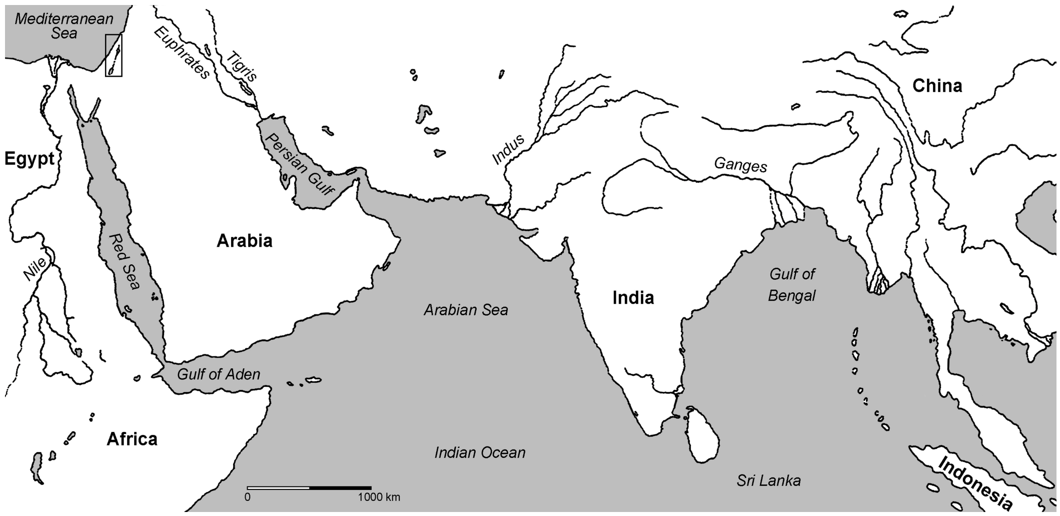

Figure 3 Map of South Asia, Arabia, East Africa, and the Near East

Even the ever-accumulating evidence for thriving Bronze and Iron Age communities in various parts of Arabia (Magee and Carter 1999; Edens at al. 2000; Magee 2004; Hausleiter 2011) does not necessarily promote the Arabian option. Another main route linking South Asia to the West ran through the Mesopotamian river system (Potts 1995:1459) and cinnamon from China would probably have had a different itinerary altogether (Christian 2000; Kuzmina 2008).[19] Moreover, multiple routes and competing networks and agents are also likely. Regarding spices specifically, in the present state of research we cannot even assess if later spice trade—of the Persian period and onward—was indeed "tapping" into age-old networks, or if trade routes fluctuated with time and political setting.[20]

All this notwithstanding, it is highly probable that spices that traveled all the way to the Levant did not halt there and were marketed farther west to Cyprus and to more remote Mediterranean destinations, comprising one of the invisible commodities in Mediterranean commerce.

The early Iron Age cinnamon also demonstrates that spices from the east continued to be traded westward and were in demand even after the Bronze Age collapse and the downfall of most of its elites. Access to such commodities must have played some part in shaping early Iron Age social identities. However, during the 11th to early 9th centuries BCE, between the fall of Hatti and imperial Egypt and the ascendancy of the Neo-Assyrian apparatus, in all regions in Asia, Arabia, and Africa who possibly partook in these endeavors, there were no "great powers." It was an age of small-scale fragmented polities, none of which could have orchestrated or controlled any considerable part of this sequence. This was no *hochkommerz.* Therefore, in line with the Sealinks researchers (and with Horton 1997), we argue that at least in the early Iron Age this trade and the cultural contacts it generated involved entrepreneurs in small-scale societies, and undoubtedly some down-the-line mechanism.[21]

19. For potential routes, see also Astour 1995:1403, 1411–2, figure on p. 1404; Reade 1996:15–6; Chakrabarti 1998:305, 307–9; Hoyland 2001:14; Burstein 2002. The question of whether the reported cinnamon originated in even more distant regions in Southeast Asia is moot at present. For trade networks operating between India and maritime Southeast Asia at least from the 2nd/1st millennia BCE—*inter alia* involving various botanical substances—see e.g. Gupta 2005; Zumbroich 2007–2008; Fuller et al. 2011:548–9, Figure 2.

20. For example, Darius I's conquest of the Indus Valley, and his propagation of maritime exploration—as known from Herodotus's (3.44) account of the expedition led by Scylax of Caria (Panchenko 1998, 2003)—may have impacted trade routes significantly.

21. Boivin et al. (2009:262) argue the same regarding a significant part of Egypt's Punt trade.

FUTURE PROSPECTS

Identifying further evidence for "early" Asian spice trade to the West may revolutionize our perceptions of the development of long-range trade in the Old World and possibly also of Eurasian–African world systems (Gills and Gundar Frank 1993; Gupta 2004; Sherratt 2006; Beaujard 2011; Fuller et al. 2011). This merits concerted effort. One line of investigation is the re-examination of texts from the relevant regions, with the specific Asian spices question in mind. The apparent near absence of such substances in the large body of 2nd and 1st millennia texts in various parts of the Mediterranean/Near East looms large, especially in those extensively preoccupied with commodities, such as the el-Amarna corpus or Neo-Assyrian tribute and booty texts.

Botanical analyses of well-sifted assemblages in the target regions comprise another obvious avenue (and perhaps more mummies need to be looked at), in order to move beyond serendipitous discoveries such as those listed above. It remains to be seen to what extent such spices have survived and may be detected in the archaeological record beyond arid regions, and at complex sites such as the stratified Near Eastern tells.

Here, therefore, we would like to underscore the option of residue analysis as a promising avenue. Mulled beverages (especially wine, e.g. McGovern 2009) and a large variety of drugs, unguents, and aromatics—which comprised extracts of spices and other plants—were an integral part of daily life in the Old World, of commerce, ritual, and of the afterlife (Merrillees 1962; Knapp 1991; Jacob 2011; for Egypt, Lucas and Harris 1989; Bardinet 1995; Manniche 1999). Occasionally, indeed, this has been demonstrated by residue analysis (Serpico et al. 2003; McGovern 2007; Stern et al. 2008). Therefore, a very good chance to detect archaeologically (any) spice is by investigating chemically the contents of vessels in which such commodities may have been stored, transported, or used.[22]

Finally, deciphering exchanges over such immense distances will require the input of scholars dealing with an extensive geographical spectrum—far beyond our areas of expertise. We can only hope that this paper will indeed encourage such cooperation and new ways of linking the histories of the Indian Ocean and the Mediterranean.

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22. Recent residue analysis of cultic receptacles of the Middle Bronze II in Israel also identified botanical substances that originated in South Asia, suggesting that such trade may be of even greater antiquity; see preliminarily Zuckerman et al. (2014).

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THE TRANSITION FROM BRONZE TO IRON IN CANAAN: CHRONOLOGY, TECHNOLOGY, AND CONTEXT

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ABSTRACT. In the framework of the European Research Council–funded project, "Reconstructing Ancient (Biblical) Israel: The Exact and Life Sciences Perspective," we carried out multiple analyses on iron and bronze objects from provenanced contexts in Israel, as well as on previously unidentified metallurgical remains from the production of both metals. In addition, we counted anew iron and bronze objects from well-stratified contexts and studied metalworking sequences at major sites, which included those that had undergone the bronze/iron transition. This enabled us to clarify some of the issues related to the bronze/iron transition in the southern Levant. Using this evidence, we showed that iron was not used for utilitarian purposes before the Iron I (late 12th century BCE) and that iron only became dominant concurrently with the beginning of its systematic production during the Iron IIA (10th–9th centuries BCE). A strong correlation between iron and bronze production suggests that during the Iron I local independent bronzesmiths adopted the new iron technology. Under local administrations that developed during the Iron IIA, workshops that previously produced bronze turned to iron production, although they continued to manufacture bronze items as a secondary venture. Significantly, at some of the major urban centers iron production was an independent industry that included the entire operational sequence, including the on-site smelting of the ore. This development appears to have been a major contributor to the transition to systematic production of iron.

INTRODUCTION

The transition from a bronze- to iron-based metal technology has been the subject of much discussion. Initially, the understanding of the development of iron technology was mainly based on the synchronic and diachronic distribution of objects as a means to determine when and where iron took precedence over bronze (Waldbaum 1978, 1980, 1982; Snodgrass 1980; McNutt 1990). The artifactual evidence, combined with textual sources, indicated that iron was produced in eastern Anatolia since as early as the late 3rd millennium BCE. The only earlier evidence is of isolated iron objects that were probably made of meteoric rather than smelted iron (for bibliography see Waldbaum 1999). During the Late Bronze Age, roughly the second half of the 2nd millennium BCE, there was a substantial increase in the number of iron objects and in their distribution, which ranged from Mesopotamia to Greece, as well as the Levant, Anatolia, and Egypt. There is also a recurring mention of iron in Hittite texts and, to a lesser extent, in contemporary Assyrian records (Pleiner and Bjorkman 1974; Curtis et al. 1979; Muhly et al. 1985).

Towards the end of the 2nd millennium BCE, iron began to be used for utilitarian purposes in Cyprus and the Levant (see below). In other regions, such as the Aegean, Anatolia, Caucasia, and Egypt, utilitarian iron use began during the 1st millennium BCE (see bibliography in Veldhuijzen 2005; for Caucasia see Khakhutaishvili 2009; Erb-Satullo et al. 2014). Noteworthy is the occurrence of utilitarian iron in western Iran during the very beginning of the 1st millennium (Pigott 1980, 1989), and the significant textual evidence for iron use in Assyria during the 9th century BCE (Pleiner and Bjorkman 1974).

With the lack of evidence for actual iron production, technological investigations have concentrated on the analysis of iron objects (see bibliography in McConchie 2004:21–33). Analysis of several iron objects from Cyprus and the Levant appeared to indicate the use of advanced heat treatments, such as quenching, lending support to the idea that Cyprus played a role in the dissemination of iron in the late 2nd millennium BCE (Stech-Wheeler et al. 1981; Maddin 1982; Smith et al. 1984; Davis et al. 1985; Astrom et al. 1986; Muhly et al. 1990; Muhly 2006; but see McConchie for criticism).

The Iron Age in Israel: The Exact and Life Sciences Perspective
Edited by Israel Finkelstein, Steve Weiner, and Elisabetta Boaretto

In general, the discussion of the introduction of iron focused on questions of ethnicity (who introduced the technology? the Philistines?) and necessity (why was it necessary to replace bronze with iron? e.g. ecologic or economic circumstances, such as shortage of raw materials and wood for the production of bronze) (Snodgrass 1971; Muhly 1982; Wertime 1982; Muhly et al. 1985; Waldbaum 1989, 1999; see also McConchie 2004). The discussion gradually shifted to considering the social, economic, and political circumstances that were behind this crucial transition (Pigott 1989; Sherratt 1994; Mirau 1997; Pickles and Peltenburg 1998).

In the course of the discourse, evidence for iron production dating to the Iron IIA surfaced in two excavations: Tell Hammeh in Jordan, where smelting activities were performed, and at Tel Beth-Shemesh in Israel, where the finds were interpreted as representing smithing activity (Veldhuijzen and Van Der Steen 1999; Bunimovitz and Lederman 2003; Veldhuijzen and Rehren 2007; Veldhuijzen 2009). Analysis of these finds yielded new interpretations of the chain of events that led to the precedence of iron over bronze, and demonstrated the importance of discovering production venues in any attempt to reconstruct this process (Veldhuijzen 2005, 2012; Bunimovitz and Lederman 2012).

In the framework of the ERC-funded project, "Reconstructing Ancient (Biblical) Israel: The Exact and Life Sciences Perspective," we were granted the opportunity to generate new data that could be used for a broader reconstruction of the bronze to iron transition. The research program entailed the systematic collection of varied data, both artifactual and in excavations, in order to study the production and utilization of both bronze and iron in the relevant periods (Late Bronze and Iron Ages). Our goals included the following:

1. Studying of the composition of bronze throughout these periods.
2. Detecting the origin of the copper through lead isotope analysis of objects and ingots.
3. Analyzing the distribution, technology, and style of bronzeworking remains.
4. Identifying iron-production venues by sampling and analyzing potential contexts, using metallurgically oriented excavation methods developed specifically for this purpose.
5. Studying the microstructure of a large number of well-dated iron objects in order to address questions regarding carburization, quenching and tempering.
6. Studying iron production remains from ongoing and past excavations in order to determine the type of process represented (smelting, refining, or smithing).
7. Compiling an updated catalog of bronze and iron objects from well-stratified contexts in order to refine and update the study of the development of iron use (utilitarian vs. precious or ceremonial, tools vs. weapons, etc.).

In this review, we wish to summarize the new evidence for iron use and production obtained from our studies, as well as from several other recent investigations (such as excavations at Faynan and Timna), which yielded significant relevant information that allows us to provide a more informed reconstruction of the bronze-to-iron processes.

THE DEVELOPMENT OF IRON USE

In her seminal study of the development of iron use, Waldbaum (1978) compiled a list of iron objects from Canaan, showing how their numbers gradually increased from the 12th to 10th centuries BCE. Based on this data and other available data from regions surrounding the Mediterranean, Snodgrass (1980) suggested three broad stages for the development of iron technology. According to his scheme, during most of the Bronze Age iron was used rarely and only for prestige and ceremonial purposes (Phase 1), while in the early Iron Age, it was used for the first time for utilitarian purposes but was still outnumbered by bronze (Phase 2). Only during the 10th century BCE or later did iron became dominant (Phase 3). McNutt (1990), in order to re-evaluate the hypothesized Philistine monopoly of iron technology, compiled an updated list of iron objects and was able to show that excavations in Philistia did not yield more iron items than any other contemporary region. A more updated version of this inventory, including bronze objects in addition to iron ones, was published by Gottlieb (2010). Her study targeted the uniformity of the transition, showing that sites with a strong Canaanite bronzeworking tradition adopted iron later than others.

In order to refine our understanding of the development of iron use, and in light of recent excavations at various sites that yielded additional bronze and iron objects (i.e. Tel Rehov, Khirbet Qeiyafa, Megiddo, and Hazor), we compiled an updated, comprehensive database of bronze and iron objects (Yahalom-Mack et al., forthcoming). The database includes bronze and iron objects from settlement sites throughout Israel, dating from the Late Bronze III (henceforth "LBIII")[1] until the end of the Iron Age. Only well-dated objects from secure stratigraphic contexts were included, so that some of the objects included in Waldbaum's study were excluded, resulting in a relatively smaller, but much more reliable data set.

We are well aware of the inherent methodological problems in comparing the number of iron objects with the number of bronze, as there is a major difference in the preservation of these materials (bronze objects, unlike iron ones, were naturally remelted; iron, on the other hand, corrodes, sometimes to full disintegration or loss of shape), and due to contingency of excavation (Yahalom-Mack et al., forthcoming). Despite this, the artifactual evidence remains a significant, and sometimes the only, indicator for the advent of iron.

Following is a summary of the development of iron use from its earliest appearance in the Late Bronze Age until its dominance in the Iron IIA, according to the three stages determined by Snodgrass (1980), enhanced by the results of the present study (Figure 1).

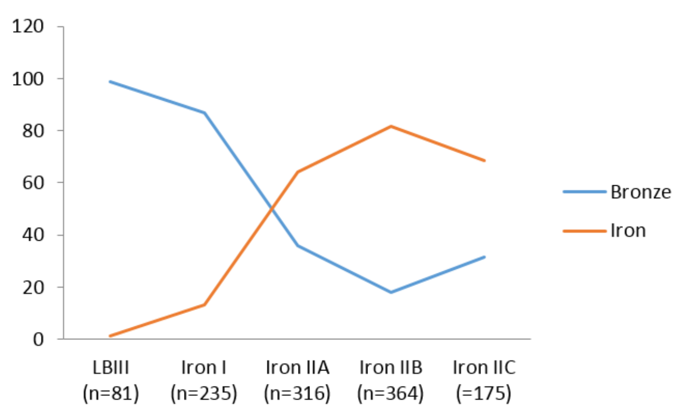

Figure 1 Percentage of iron tools and weapons from LBIII to Iron IIC

1. This term, used to describe the period of the 20th Dynasty occupation of Canaan during most of the 12th century BCE, is referred to by others as Iron IA (Stern 1993:1529; Mazar 2011:105). For the subsequent period, which begins with the withdrawal of the Egyptians from Canaan in the late 12th century BCE, we use the term Iron I. This period is also termed Iron IB (Stern 1993:1529; Mazar 2011:105).

Phase 1 (LBII)

The earliest iron objects in the Levant have been dated to the Late Bronze Age (Waldbaum 1980:76). However, while several Syrian sites, such as Ugarit, Minet el-Beida, and Alalakh, yielded iron objects (more than one each), in Canaan the number of iron items dating to this period is limited: an LBII burial at Megiddo yielded an iron ring (Guy and Engberg 1938:162, pl. 128:19, Figure 176.7), and a contemporary burial in Pella in the eastern Jordan Valley yielded a corroded iron bracelet (Notis et al. 1986). Other scarce iron finds originated in other burial contexts that are said to be related to the Late Bronze Age, but are not securely dated (Smith et al. 1984; but see Muhly 2006 for a revised dating; for the disturbed context of the iron knife from T 113 at Tell es-Sa'idiyeh see Green 2006:308, footnote 13). The small jewelry items and trinkets from the Hathor shrine at Timna are often quoted as LBII examples of iron products. However, these could be dated anywhere between the time of Seti I and Ramesses V (late 14th to mid-12th century BCE), as shown by a recent re-evaluation of the stratigraphy and chronology at that site (Avner 2014:110, footnote 79).

Thus, careful scrutiny of the iron objects found in Late Bronze Age contexts in Canaan shows that the miniscule number of objects that have been discovered might very well have been imports, and in fact, there is no convincing evidence for iron production in Canaan during the Late Bronze Age.[2]

Phase 2

The second phase in Snodgrass' original scheme, which pertained to the introduction of iron for utilitarian purposes, although still subordinate to bronze, covered a long period of time, the 12th to 10th (and even 9th) centuries BCE, that is, the LBIII, Iron I, and Iron IIA in relative chronology terms. Our study has shown that this development has significant substages, which are divided here into an early and a late phase.

Phase 2 Early (LBIII)

The new database in the present study shows that there were no utilitarian iron objects during the entire LBIII. The only iron objects that could be securely considered for this period are in fact a relatively large number of iron bracelets found in burials dated from the 12th century BCE and possibly two bi-metallic knives (see details below), which were not included in our database as they came from burials. Notably, these are prestige items and indicate an independent stage in the development of iron technology, in which routine production of iron, but *not* for utilitarian items, is inferred. This phenomenon cannot be related to the first stage of iron use in the Levant (see above, Phase 1), when iron objects were unique and rare; also not to the second stage of development, which includes the limited production of objects for utilitarian purposes (see below, Phase 2 Late). As we were reluctant to introduce a new terminology for the process, and since this phase continues during the Iron I and therefore overlaps with the appearance of utilitarian iron objects, we have decided to divide Snodgrass' second stage of development into two parts: the routine production of iron jewelry during the LBIII is termed Phase 2 Early.

More than 30 iron anklets/bracelets were found in a LBIII tomb in the Baq'ah Valley, Jordan (Notis et al. 1986; Waldbaum 1999:32–4). Significantly, these were found together with high-tin bronze jewelry of similar types (McGovern 1986). Similar iron jewelry items were found in a contemporary burial cave at Pella in the Jordan Valley (Waldbaum 1999:33, following McGovern 1988:52). It

2. At two sites dating to the Late Bronze Age, iron smelting has been hypothesized: Lachish, where an amorphous lump from Level S-2 was identified through analysis as speiss, and Tel Yin'am, where ironworking remains were allegedly found (Liebowitz 1983; Rothenberg 1983; Liebowitz and Folk 1984; Pigott 2003; Shalev 2004a; Veldhuijzen and Rehren 2007). The validity of this evidence cannot be authenticated without further study.

may be that the iron objects from the Hathor shrine at Timna should be dated to the same time (as noted above) and are related to the same phenomenon. This relatively large number of iron anklets/bracelets suggests that even though they might have been considered precious as a result of their use and context, they were certainly neither rare nor unique; on the contrary, they appear to have been quite routinely produced.

Based on the near absence of imported material in the Jordanian Baq'ah burials, the similarity of the iron bracelets in these burials to those made of bronze, and the proximity to iron ore deposits in the area of Ajlun and Wadi Zarqa, Notis et al. (1986:277) suggested that the iron bracelets were locally produced, although the initial impetus may have come from outside.

The phenomenon of iron jewelry in Canaan in the LBIII recalls the contemporary production of bi-metallic knives (iron blades with ivory handles and bronze rivets) in neighboring Cyprus and suggests that in both regions, a routine production of prestige iron objects of specific and singular types preceded the production of iron for utilitarian purposes. Not all scholars agree that the iron knives in Cyprus were prestige items (Pickles and Peltenburg 1998; Muhly 2006). However, their wide occurrence in burials certainly suggests that even if used daily, these were not strictly utilitarian objects (Sherratt 1994, 2003). Bi-metallic knives similar to those abundant in Cyprus were found in 12th–10th century BCE contexts in the southern Levant (Dothan 1989, 2002). However, none of those dated to the 12th century BCE originate in well-dated contexts. The earliest stratified example is probably the one found in a Philistine temple (Building 319) of Stratum XII at Tell Qasile (Mazar 1985:6–8, Figure 2; Dothan 2002). The cultic nature of the context further emphasizes the nonutilitarian nature of these knives, which may well have been brought from Cyprus rather than locally produced.

The question of whether iron technology had disseminated from Cyprus has been widely discussed and will not be repeated here (Stech-Wheeler et al. 1981; Maddin 1982; Snodgrass 1982; Waldbaum 1982, 1989, 1999; Wertime 1982; Sherratt 1994, 2003; Muhly 2006). However, had this been the case, then we would expect the production of iron knives rather than bracelets in this early phase, as at that time this was the main type of object produced from iron in Cyprus. As this is not the case, a Cypriot impetus for the production of iron bracelets seems unlikely for this early stage.

In summary, utilitarian iron objects did not appear in the first half-to-middle of the 12th century BCE as previously suggested; only prestige items were produced during this time.

Phase 2 Late (Iron Age I)

The major development in the Iron I was that iron objects were no long restricted to burials or cultic contexts. Archaeologists were finding for the first time, albeit in small numbers, utilitarian objects made of iron in settlement sites throughout the country. These included both tools and weapons, such as a chisel from Stratum IB at Taanach, a large implement from Stratum VII at Tel Rehov, a sickle from stratum XVII at Tel Yokneam, a dagger and a needle from Stratum VIA at Megiddo, and several other objects. Iron bracelets/anklets and bi-metallic knives continued to be unearthed. According to the updated database, during the Iron I, iron tools and weapons comprised ~13% of the total objects of these categories. As these included the aforementioned bi-metallic knives, some of which were not strictly utilitarian during this time, the relative number of iron objects termed utilitarian may be even lower. This figure shows that iron was secondary to bronze at this time, while the occurrence of bi-metallic knives and the continued production of iron bracelets suggest that iron maintained its value as a precious metal, alongside its limited use for more functional items.

Phase 3 (Iron IIA)[3]

During the Iron IIA, a significant change occurred as iron became dominant, comprising an average of over 60% of the metal tools and weapons. At several sites where an early Iron IIA phase could be discerned, the average number of iron tools and weapons in this early phase alone reached only ~40%, suggesting that the process was gradual and that iron became dominant only in the later part of the Iron IIA. Notably, at those sites that were newly established in the early part of the Iron IIA, such as Arad Stratum XII and Beer-Sheba Stratum VII in the Beer-Sheba Valley and Khirbet Qeiyafa in the Elah Valley, iron was the dominant metal, while at contemporary sites with a Bronze Age bronzeworking tradition, the average amount of iron was smaller (such as Tel Masos and Megiddo; see also Gottlieb 2010). The situation at Qeiyafa is even more interesting, as it is earlier than Arad XII and Beer-Sheba VII, and is dated either to the very early Iron IIA or transitional Iron I/IIA.[4]

The increase in the number of iron tools and weapons (the latter in particular) continued and reached its peak during the Iron IIB, comprising over 80% of the metal assemblage (not counting over 300 iron arrowheads from the Assyrian siege of Lachish in 701 BCE). The absolute number of iron tools and weapons dropped considerably during the Iron IIC and their relative proportion fell to below 70%. It should also be noted that our results show that throughout the Iron Age, over 80% of the jewelry was made of bronze. As will be indicated below, there is a clear association between the sharp increase in the average number of iron utilitarian objects during the Iron IIA and evidence of iron production within the urban centers during this time (see below).

DEVELOPMENT OF IRON PRODUCTION: CHRONOLOGY AND CONTEXT

We currently have evidence for iron production (smelting and/or smithing) from nine Iron Age sites (Figure 2); in six of these (Hazor, Megiddo, Tel Rehov, Tell Hammeh, Beth-Shemesh, and Tell es-Safi/Gath), this industry dates as early as the Iron IIA (described below). At Beer-Sheba, evidence for iron production is dated to the Iron IIB (Eliyahu-Behar et al. 2013), and at Dor and Tel Sera' to the Iron IIC (Rothenberg and Tylecote 1991; Eliyahu-Behar et al. 2008). In some cases, iron production remains were identified after the excavation had already been completed (Hazor, Beer-Sheba, Tel Rehov), while in others, iron production was identified during the course of excavation and was exposed using metallurgically oriented field methods (Tell Hammeh, Beth-Shemesh, Tell es-Safi/Gath, Megiddo). The latter enabled a much more complete evaluation of the iron-producing process. The accumulated new evidence allows a glimpse into the relative and absolute chronology of the adoption of iron in the southern Levant and its context.

Tel Hazor

Excavations in Area A at Hazor (1989–2006) produced 45 complete and many more fragmented slag cakes and other iron-production remains in Iron II contexts (Strata XA–V). These originated mainly from a series of buildings along the Strata X–IX city wall, not far from the six-chambered gate (Ben-Ami 2012). The earliest production remains consist of two slag cakes found on a Stratum Xa (Iron IIA) floor (Yahalom-Mack et al. 2014). In Stratum IX, several concentrations of slag cakes were found. Below the floor of one structure of Stratum IX (Building 9127), which contained iron slag cakes, were bronzeworking remains. This is significant, as it indicates an official(?) decision to replace bronzeworking with iron production. In Stratum VIII (transitional Iron IIA–B), with the expansion of the city and change in its layout, iron production expanded into the center of the acropolis. In Strata IX–V, square tuyère fragments were found associated with slags and

3. For absolute chronology of the Iron IIA according to the Modified Conventional Chronology, see Mazar (2011). For the absolute dates according to the Low Chronology, see Finkelstein and Piasetzky (2011).
4. The substantial use of iron in this unique administrative settlement will be discussed elsewhere.

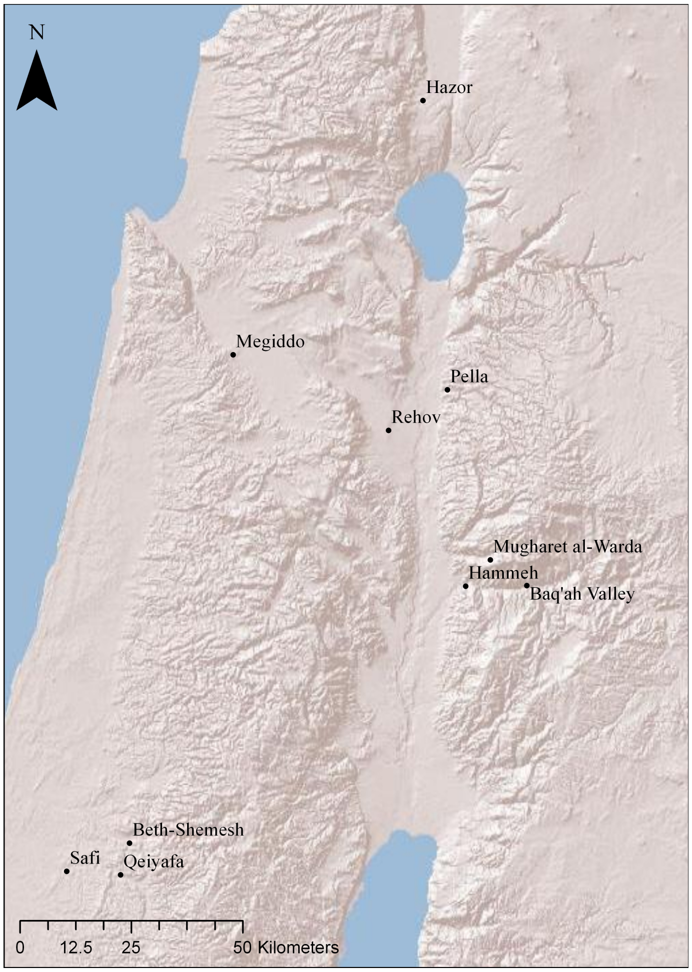

Figure 2 Map showing selected sites with evidence of iron production.

with various installations and accumulations of ash. Notably, bronzeworking debris was associated with iron-production remains in various strata, indicating interaction between the two technologies during the Iron II (Yahalom-Mack et al. 2014).

Tel Megiddo

Iron production remains were found during the 2012 excavation season in the southeastern part of the mound. The earliest remains comprise a single iron slag cake found in Area Q, Level Q-5 (University of Chicago's Stratum VB) on a floor together with bronzeworking debris. In Level Q-4 (Stratum VA–IVB), near the northeastern corner of pillared Building 12/Q/95, a dark layer of sediments, ~10 cm thick, with hammerscales and a considerable amount of charcoal, was found. Chemical analysis showed that the sediments were contaminated by copper. A couple of tuyère fragments, square in cross-section, were found in the same building at approximately the same level. In the 2014 season, excavations east of the building unearthed considerable evidence for iron production, with over 30 iron slag cakes, numerous iron hammerscales and prills, as well as tuyère fragments. The remains appear to originate in a sequence of hearths related to Levels Q-5-2, located next to large tabuns. These finds, which still await detailed investigation, support Schumacher's reports of an iron smithy in a room adjacent to the outer side of the eastern wall of the courtyard of Palace

1723, located just a few meters away from the iron production remains in Area Q (Schumacher 1908:130–2, Figures 191–194, plates XXIX and XLII). It is thus indicated that iron production was performed east of the palace. Notably, in this part of the mound, bronzeworking was practiced nearly continuously throughout the Late Bronze and Iron Ages. Since bronzeworking was practiced in domestic contexts, the shift to iron production associated with public architecture indicates the involvement of a central administration in the transition from bronze to iron production at Megiddo.

Tel Rehov

In Area E at Tel Rehov, both iron and bronze production debris were uncovered, including two iron slag cakes and other iron production debris alongside bronze spatter and prills, as well as a large amount of iron and bronze scrap. The evidence comes from Stratum E-1b (Stratum V, Iron IIA) in a context that served as an open-air sanctuary in the subsequent Stratum E-1a (Stratum IV, also Iron IIA), including a *bamah* with *masseboth*, as well as an offering table and a pottery altar. Even though it was not securely determined whether the area had already served as a sanctuary in Stratum E-1b, the continuity of activity within the courtyard and surrounding building suggested that this is highly likely (Mazar, forthcoming; Yahalom-Mack, forthcoming).

Tell es-Safi/Gath

A smithy in Area A at Tell es-Safi/Gath was exposed in a controlled, metallurgically oriented excavation (Eliyahu-Behar et al. 2012). The evidence included two different features, a black depression and an orange pit, each representing a different *in situ* activity related to iron production, inferred by the presence of hammerscales, slag prills, and smelting slag. This indicated that the entire process of iron production, from the smelting of the ore to the forging of the final product, was conducted at the site. In addition, analyses showed that a crucible found on top of the orange pit was used for bronze production and that sediments from the smithy were contaminated by copper. These suggested that both iron and bronze were produced/worked at the smithy. Notably, tuyères, both round and square in cross-section, were found in and around the two features. The smithy was related to Stratum A-4 (early Iron IIA) and was probably associated with cultic activity identified nearby. Radiocarbon dates obtained from grape seeds found in the black hearth gave calibrated 2σ dates of 935–800 BCE (93.4% probability).

In the 2014 season, excavations in the lower city, Area D, unearthed a relatively large collection of slag (more than 15 complete, and many more fragments), very similar in appearance to the molten slag found *in situ* in Area A. In association with the slags, a pile of more than 10 tuyère fragments, both round and square in cross-section, was unearthed. These remains, yet to be analyzed, were found in a postdestruction layer of the 9th century and thus appear to be later than the workshop identified in Area A.

Tell Hammeh

Tell Hammeh is a relatively small mound located in the central Jordan Valley close to the Zarqa River and to the iron ore deposit at Mugharet al-Warda. Excavations at the site uncovered extensive remains of iron smelting and primary smithing operations, with no indication of contemporaneous habitation or other nonmetallurgical use of the site (Veldhuijzen and Rehren 2007). Large quantities (more than 700 kg) of various types of slags and some 350 tuyère fragments, charcoal, and some possible furnace(?) structures were identified in a clear stratigraphic context evidently used strictly for metallurgy. About 60% of the slags were identified as tapping items, while the remainder were various forms of slag cakes (rusty lumps of heterogeneous slag material and partly or hardly reduced hematite ore formed at the bottom of the hearth), and other byproducts, all attesting to smelting activities. No secondary smithing slags (resulting from the forging of end products) were identified (see discussion of the technological sequence and the schematic figure below). ^{14}C analysis of two short-lived olive wood charcoal samples from the production phase provided 1σ dates ranging between 1000–900 and 940–850 calibrated BCE (Veldhuijzen 2005:92; Veldhuijzen and Rehren 2007:191).

Tel Beth-Shemesh

Excavations in Area E revealed several phases of industrial and commercial activity next to large public buildings (Bunimovitz and Lederman 2003). Evidence for metallurgical activity was identified; therefore, during the 2003 season a metallurgically oriented excavation was initiated. The assemblage of metallurgical debris consisted of at least 65 individual round concavo-convex slag cakes (together with many more fragments), hammerscales, numerous fragments of square tuyères together with other technological ceramic and metal artifacts (both iron and copper). Based on the analysis of slags, and especially on the fact that tapping slags were absent, Veldhuijzen concluded that the activity at Tel Beth-Shemesh represented a secondary smithing operation, as opposed to iron smelting and/or primary bloom-smithing (Veldhuijzen 2005; Veldhuijzen and Rehren 2007).

From the pottery assemblage, it appears that none of the iron production remains at Beth-Shemesh predate the Iron IIA, and that the majority in fact date to the later part of this period. ^{14}C dating of three burned olive pits from the smithy yielded a ~900 BCE date.

In summary, at both Hazor and Megiddo, long sequences of metalworking were exposed. At both sites, there appears to be an association between iron production and public buildings. This was also the case at Tel Beth-Shemesh (Bunimovitz and Lederman 2012). At Hazor, some of the iron production remains from Stratum IX were found immediately above bronzeworking debris. This indicated that an official decision was possibly involved to replace bronzeworking with iron production. At Megiddo, in Late MB–Iron I domestic contexts, bronzeworking was identified. When a change in the town layout occurred during the Iron IIA, a time during which public buildings were erected, iron production took precedence over that of bronze. At Beth-Shemesh, too, bronzeworking during the Iron I had taken place mostly in and between domestic houses (Yahalom-Mack 2009).

While it has been suggested, based on ethnographic studies, that metalsmiths working in domestic contexts are more likely to be independent specialists, while those working in association with public building may be “attached specialists” (e.g. Costin 1991), it is nevertheless necessary to support such a scenario for the Iron Age with further evidence. In the case of Megiddo, the occurrence of iron production remains in the vicinity of Palace 1723 renders it likely that the formerly independent metalsmiths were now attached to the ruling elite at the same time that they shifted from mainly bronze to mainly iron production.

At Tell es-Safi/Gath, the joint iron and bronze smithy was located just outside a possible shrine. At Tel Rehov, joint iron and bronze metallurgy was most likely practiced in an open cult place. This suggests a strong association between cult and metalworking at these sites. The presence of metalworking debris within cultic contexts was attested at a number of sites, e.g. the Middle Bronze Age standing-stone complex at Hazor (Yahalom-Mack et al. 2014) and the Late Bronze or early Iron Age Hathor shrine at Timna in the Arabah Valley (Rothenberg 1988).

DEVELOPMENT OF IRON TECHNOLOGY

The production of iron is a long process that can be roughly divided into three main stages: the smelting (reduction) of the ores to produce a bloom, the refining of the bloom (primary smithing) to produce a more compacted metal (a bar ingot), and the forging of the end product (secondary smithing) (e.g. Tylecote 1980; Maddin 1982). All of these stages together can be performed at the smelting site near the ores, or elsewhere, in and around settlement sites. Alternatively, iron could be smelted near the ore deposit and traded in the form of a bar to urban or rural smithies, where secondary smithing would be carried out until the final product is formed. Figure 3 shows a schematic representation of the described sequence.

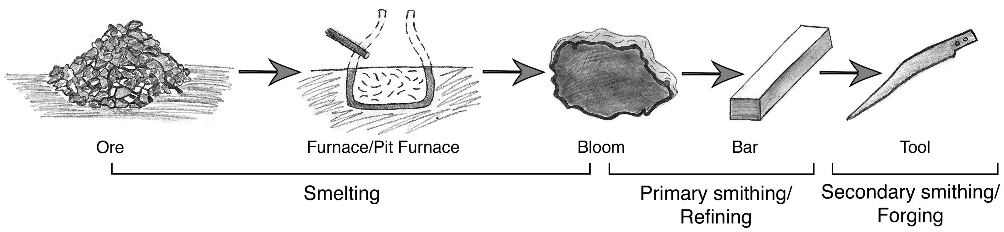

Figure 3 A schematic representation of the iron production processes: smelting, refining, and forging

This sequence, termed "the bloomery process," produces a variety of byproducts: tapping slag, slag cakes, bloom fragments ("gromps"), hammerscales, and other associated paraphernalia, such as tuyères.

Smelting

Iron smelting (similar to copper smelting) requires a controlled reducing environment obtained with the help of an air-supply system. In Europe, it appears that, initially, pit furnaces were used; these were domed and later developed into shaft furnaces (Tylecote 1980; Joosten 2004; Paynter 2006). Tapping furnaces, in which slag was liquefied and tapped outside the furnace through a hole, were a later development (Tylecote 1987). In the southern Levant, no complete smelting furnace that would enable a full reconstruction of the furnace shape[5] has been preserved; nevertheless, this type of smelting technology can be deduced from the remaining slag. The choice of smelting technique (pit/shaft/tapping furnace) might be related to the available knowledge, and/or to the initial amount of raw material (ore) processed, and will determine the type of slag formed (Tylecote 1987).

Tapping furnaces produce characteristic slags with a typical smooth surface that shows clear flow patterns, which result from fast cooling rates outside of the furnace. In the Iron Age southern Levant, Tell Hammeh is the only site that produced tapping slag (Veldhuijzen and Van Der Steen 1999; Veldhuijzen and Rehren 2007).

Smelting in pit furnaces results in rounded slag cakes with a concavo-convex cross-section. These are also formed at the bottom of smithing hearths (Bachmann 1982; Paynter 2006). In contrast to tapping slags, which are clearly associated with smelting based on their morphology, the macroscopic appearance of slag cakes cannot be used to determine whether they are the byproducts of smelting, primary smithing, or secondary smithing activities. However, microscopic analysis of such slags may be used in order to differentiate the stage at which they were formed.

In a recent study (Eliyahu-Behar et al. 2013) aimed at defining the iron production activity at settlement sites, whether smelting or smithing, we analyzed iron slag cakes from Iron IIA contexts at

5. An attempt at such a reconstruction was proposed for the remains of a 7th century BCE furnace at Tel Sera' (Rothenberg and Tylecote 1991).

Hazor, Beer-Sheba and Tel Rehov, as well as amorphic artifacts that we subsequently identified as bloom fragments. Analysis of the slag cakes showed that these were likely the byproducts of smelting. This was based on the analysis of small vesicular inclusions/formations of a white material, a key element identified in almost all the analyzed slag cakes. Detailed analysis of these inclusions and the iron oxide matrix surrounding them (which is characterized by a fine line texture showing preferred orientations, typically characteristic of an ex-solution phase) showed that the iron oxide matrix and the white inclusions were formed at a high temperature, possibly by the reaction of some Ca-rich material and the iron ore during smelting.

When viewed in light of the occurrence of bloom fragments at Beer-Sheba and Hazor, we suggest that all stages of iron production, including the smelting of iron ores, were performed within these urban centers. Ore then would have been brought to the settlement sites and knowledge of smelting would have been in the possession of the urban metalsmiths during the Iron IIA-B.

Smithing

Following smelting, primary and secondary smithing are conducted. In primary smithing, the bloom is hammered when red-hot to form the consolidated metal. In secondary smithing, the metal is forged into a final product. The process comprises the repeated heating of the iron metal in a charcoal bed (a hearth) and hammering it on an anvil in order to create the desired shape. These steps involve various techniques and heat treatments, including carburization, quenching, and tempering that will influence the mechanical properties of the product, rendering it into steel.

It has been suggested that iron became widely used for utilitarian purposes only when it gained technological superiority over bronze (e.g. Maddin 1982; Muhly et al. 1985; Waldbaum 1999; Muhly 2006). As carbon content alone does not ensure hardness greater than that of bronze, additional heat treatments are required in order to achieve the desired result (see McConchie 2004:58, Figure 2).[6] Assuming that a technological breakthrough was achieved in the course of the Iron Age that resulted in the dominance of iron over bronze in the Iron IIA, we would expect that iron objects dating to the LBIII and Iron I would show technological inferiority. However, this is not indicated by our analyses of iron objects (unpublished data).

Carburization

Carburization is a term used in order to indicate a deliberate action by which an iron object, already in its final form, is heated in a carbon-rich atmosphere for a prolonged period of time, increasing its carbon content in order to produce steel (Maddin 1982; Notis et al. 1986:277). Scott and Eggert (2009) refer to the act of deliberate carburization as "secondary carburization" and to the spontaneous absorption of carbon into the bloom during smelting as "primary carburization." The notion that steel could only be made by "secondary carburization," although it prevailed in the early years of research, has gradually been replaced by the realization that "primary carburization" could occur by direct reduction in the bloomery smelting furnace.

The carbon content of steel may vary between 0.02 to 1.2 weight percent (wt%) and will determine the mechanical properties of the metal (Scott and Eggert 2009). Low-carbon ($C < 0.5$ wt%) steel will leave the metal quite soft, ductile, and weak, while excess carbon will result in a harder but brittle metal ($C > 1.2$ wt%) (Sauveur 1912:Lesson IV; Reed-Hill 1973). Significantly, the carbon content

6. The hardness of Late Bronze Age daggers with ~10% Sn can reach up to 290 Hv (Shalev 2004b:Appendix 2), while for example the hardness of low-carbon steel ≤0.5% C without heat treatments ranges between 80–120 Hv, and after quenching can increase up to 800 Hv (Scott and Eggert 2009:16).

in some areas of the aforementioned bloom fragments that were analyzed was estimated to be as high as 0.6–0.7 wt% carbon, indicating that carburization occurred spontaneously (see discussion in Eliyahu-Behar et al. 2013).

The most obvious way to distinguish between primary and secondary carburization is when a gradient of the carbon content can be observed from the surface of an object to its interior (Maddin 1982). Unfortunately, this is hardly relevant for ancient iron objects that have undergone severe corrosion that consumed their entire outer surface. Hence, in most cases, a gradient is not apparent and we therefore are not able to differentiate between deliberate and spontaneous carburization based on this criterion alone (Maddin 1982 and see below).

A major aim in our research was to address the question of carburization and related heat treatments through systematic analysis of objects from the late 2nd and early 1st millennia BCE. For this purpose, 60 iron objects from several major Iron Age urban centers in Israel, including Tel Hazor, Tel Rehov, Khirbet Qeiyafa, Tel Megiddo, and Tell es-Safi/Gath, were sampled and metallographically analyzed. The assemblage included various tools and weapons, as well as a few bracelets. The objects were chosen carefully from well-stratified and securely dated contexts spanning the Iron I and Iron IIA (with the majority of the items naturally dating to the latter period). Among the objects were three bi-metallic knives (two from late Iron I Megiddo and one from Khirbet Qeiyafa dated either to the late Iron I or transitional Iron I/IIA).

Significantly, none of the objects subjected to this analysis were fully preserved in metallic form and, in fact, the opposite was observed. All the objects had undergone considerable swelling due to corrosion. Following sectioning and polishing, secondary corrosion layers were identified at their outer perimeters and within cracks throughout the samples. The outer layers of the objects were usually consumed by corrosion and therefore deliberate carburization treatment could not be inferred.

In many of the objects, only very small islands of metallic iron were preserved, from tiny specks on the order of a few microns to some larger ones, up to several hundred microns. The largest island of about 3 mm metallic iron was preserved in a single tool from Megiddo. Despite this poor metallic preservation, we were able to observe "ghost structures" (i.e. pseudomorphs preserving the original metallic structure, see Knox 1963; Notis 2002) in almost all the objects. Our conclusions are therefore based mainly on the study of these structures and are occasionally reinforced by etching experiments performed on the micrometallic remnants preserved in isolated objects.

The results showed that "ghost structures" of pearlite, clearly indicating the presence of carbon, were present in almost all the objects (excluding three), demonstrating that almost all were made of steel. The carbon concentrations reflected a range of compositions from low-carbon hypoeutectic steel to high-carbon and hypereutectic microstructures. Many of the samples showed a homogeneous distribution of the pearlite content, though in some cases variable carbon concentrations were estimated in different parts of the sample. In addition, high-carbon content (estimated as over 1%) was observed in three of the samples, in which the pearlite grains were surrounded by cementite, indicating a highly brittle metal.

Previous analyses of iron objects revealed that many were in fact steel (Stech-Wheeler et al. 1981; Smith et al. 1984; Notis et al. 1986; Maddin et al. 1987; Muhly et al. 1990). Gradients of carbon content were almost never observed, except in three extraordinary well-preserved objects from Kinneret and Taanach.[7] No convincing correlation was reported between carburization, or the lack of it, and certain object types. Nevertheless, the authors concluded that the objects were carburized, in the sense that a deliberate action was performed (secondary carburization). Notis, in his analysis of the LBIII steel bracelets found in the Baq'ah, could not identify definitive evidence for surface carburization treatments, and thus raised the possibility that the steel had been produced spontaneously during smelting (Notis et al. 1986:277). Thus, carbon content alone cannot be taken as indication that the Iron Age metalsmith was aware of the benefits of placing an object in charcoal fire for a prolonged period of time. This and the fact that carburized objects already occur during the LBIII suggest that deliberate carburization was unlikely a crucial development in iron technology that was responsible for rendering iron dominant.

Quenching and Tempering

In order to produce high-quality steel, which would be considerably harder than bronze, carburized iron from a temperature exceeding 723°C was immersed into water or oil for extremely rapid cooling (quenching). This action generated a rearrangement of atoms to form martensite, which resulted in a much harder though brittle metal. In order to relieve the brittleness caused by quenching, reheating (tempering) was required (Maddin 1982; Notis et al. 1986:278).[8]

Such martensitic structures were possibly identified in two or three of our samples (unpublished data). Notably, these are not easily identified in ghost structures. However, from the evidence at hand, it appears that quenching was not routinely performed. The earliest examples of quenching originated in exceptionally well-preserved objects from 12th century BCE Idalion, Cyprus (Tholander 1971; Maddin 1982). After re-examining the photo micrographs of these objects, McConchie (2004:31–5) claimed that the evidence for quenching was not convincing. Moreover, based on the poor state of preservation of the 60 objects analyzed for this study, we have expressed our doubts (see footnotes 8 and 9) concerning the date of exceptionally well-preserved objects, such as those from Idalion.

In summary, our data suggest that a range of steels existed during the Iron Age, indicating the lack of systematic, deliberate carburization. In general, as no difference was found between earlier and later objects or between different regions, it appears that there is no indication that a technological breakthrough was achieved during this period and it seems that the process was more *ad hoc* than deliberately planned. These conclusions coincide with the results of earlier analyses of iron objects from different regions throughout the Ancient Near East, which suggested, according to McConchie (2004:33), that "the iron was generally low in carbon, occasionally varying in composition to quite high-carbon contents, and usually not thermally treated." With the lack of heat treatments, iron was not necessarily superior to bronze and thus the "superiority of iron over bronze" claim certainly cannot be used to explain the bronze/iron transition (see also Pigott 1989; McConchie 2004).

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7. In light of the overall poor state of preservation of the sampled objects, exceptionally well-preserved iron objects remain an enigma and should be dated independently. Naturally, this can be done using the ^{14}C dating method (see footnote 8).
8. The question of quenching and tempering was raised mainly in relation to an iron pick from Mt. Adir, as it had been fully preserved in metallic form, and based on metallographic analysis, had undoubtedly been both quenched and tempered (Davis et al. 1985). Although dated by the excavator to the Iron Age, the typology of the object did not have a single Iron Age parallel and its exceptionally good state of preservation cast doubt on this date. It was therefore recently subjected to ^{14}C dating, which yielded a date with 95.4% probability in the 2nd century BCE (Sariel Shalev and Elisabetta Boaretto, personal communication). These results were never published because of the remaining possibility that tannin used in the conservation of the object had affected its dating, even though the sample had been drilled from the core. It thus appears that the object, which had been considered one of the earliest examples of steel, can no longer be regarded as relevant to this topic. Recent salvage excavations conducted by the Israel Antiquities Authority near Ein Shadud yielded an identical iron pick of the Roman period (Ron Beeri, personal communication). The pick is extremely heavy, suggesting a good preservation of its metal. Future analyses will enable a comparison between this pick and the one from Mt. Adir.

COPPER PRODUCTION AND BRONZEWORKING

As noted earlier, bronze production continued during the entire period of introduction of iron technology into the southern Levant and is therefore relevant for understanding the process. The number of sites with evidence of bronzeworking at the time of the 19th and 20th Egyptian Dynasties' presence in Canaan (such as Tel Rehov and Tel Mor)[9] is considerably smaller than the number of sites that existed following their departure. Widespread bronzeworking during the Iron I is indicated by the distribution of metallurgical production remains, which were found at 12 sites in different regions. Notably, bronzesmiths during this time appear to have been located in or between domestic units (e.g. Tel Megiddo, Beth-Shemesh, Tel Dan, Tel Dor, Tell Qasile) and/or concentrated in industrial quarters (Tel Dan, Tel Yokneam), rather than in the vicinity of public buildings (Yahalom-Mack 2009).

The results of excavations at sites in Wadi Faynan and the renewed excavations at Site 30 in Timna suggest that copper production flourished in the Arabah between the 11th and 9th centuries BCE, *after* the Egyptian withdrawal from Canaan; this is based on a large number of ^{14}C dates (Levy et al. 2004, 2008; Ben-Yosef et al. 2012). Particularly for Timna, this conclusion is a major conceptual change, as the mining and smelting operations there were previously attributed mainly to the Egyptians of the 19th and 20th Dynasties, with a hiatus during the 11th century BCE (Rothenberg 1988, 1990). The supposed abandonment of the site during the Iron I, a short while after the Egyptian withdrawal from Canaan, fit well with the "shortage of supplies" theory for the adoption of iron (see Introduction). The renewed dating suggests exactly the opposite; copper was in fact widely available when the first utilitarian iron objects appeared. Significantly, lead isotope analysis of bronze objects and crucibles from Iron I contexts showed that copper from the Arabah was indeed used at settlement sites during this time (Yahalom-Mack and Segal, forthcoming).

Thus, the departure of the Egyptians, who had previously controlled at least some of the bronzeworking during the Late Bronze Age, coupled with decentralized political structure and the availability of copper from the Arabah Valley, may have created advantageous circumstances for the adoption of iron technology.

With respect to the question of tin availability for the production of bronze, analysis of 95 copper-based artifacts from LB II–Iron II contexts showed that tin-bronze was continuously used and that the average tin (Sn) content (5–6 wt%) was maintained throughout the periods (unpublished data).[10] This supports earlier studies that showed there was no shortage of tin during the transition period—a shortage that would have driven Iron Age smiths to shift to iron (Waldbaum 1989, 1999; Pickles and Peltenburg 1998).

One of the most significant results of the present study is the material evidence provided for the association between bronze and iron production during the Iron II. We can point to some indirect evidence suggesting that bronzesmiths adopted iron technology during the Iron I and were producing iron in addition to bronze in their workshops. One example stems from Megiddo Hoard 12/Q/76,

9. The bronzeworking practice uncovered at Tel Rehov (13th century) and Tel Mor (early 12th century) incorporates the use of canals, which were probably used to contain the crucible, which is very similar to bronzeworking activities found at Qantir/Pi-Ramesses in the Egyptian Delta (Yahalom-Mack 2009). Significantly, at Tel Mor, several such installations were found adjacent to a monumental 20th Dynasty stronghold (Barako 2007). This seems to indicate that at some point or in some locales, the Egyptians were reluctant to use local Canaanite bronzesmiths and decided to bring their own metalworkers from Egypt (Yahalom-Mack 2009).

10. The chemical and lead isotope analysis was performed in collaboration with Irina Segal, Israel Geological Survey, and will be published elsewhere.

found in Stratum VIA in Area Q in the southern part of the mound (Hall et al., forthcoming). This example traces evidence of continuous metalworking during the Late Bronze and Iron Ages (bronzeworking and later ironworking along with bronzeworking). The hoard contained bronze artifacts, several iron blades, and significantly, bi-metallic knives, together with many beads made of semi-precious stones, some of which remained unworked. The bronze rivets and several other bronze objects were analyzed for their chemical and lead isotope composition. The results showed that all the objects, the rivets among them, were made of copper that likely originated in the Arabah but certainly not in Cyprus. The context and contents of the hoard suggest that it belonged to a local metalsmith engaged in the production of jewelry, as well as iron, bronze, and bi-metallic objects, both prestige and utilitarian in nature.

DISCUSSION

As we have shown, considerable new information can now be added to the existing data related to the bronze/iron transition in Canaan. The economic and sociopolitical background for the crucial years (~1200–800 BCE) is now much more coherent, especially with regard to copper/bronze production and trade. The study of well-dated bronze and iron objects from sites throughout the region provides a higher resolution of our understanding of the development of iron use. In addition, significant evidence for iron production, which was almost completely missing from past discussions of the subject, is now available. The scope of this evidence and its analysis thus allows a better understanding of the process, the level of craftsmanship and its context, but raises new questions and reopens old ones.

Origin of Iron Technology

Based on the evidence from Transjordan, we know that, although not common, routine production of iron jewelry for funerary deposits began during the LBIII. While iron jewelry was likely produced locally, the technical knowledge seems to have come from elsewhere. Since jewelry dominated the iron assemblage in Transjordan, while mainly knives were being produced during this time in Cyprus, there is no reason to suspect that the knowledge had disseminated from Cyprus.

It has been suggested that iron technology traveled with (Assyrian? Hittite?) metalsmiths from collapsed Late Bronze Age palatial centers. Based on texts and finds, we know they were producing or experimenting with iron (e.g. Muhly et al. 1985). Zaccagnini (1990) strongly objected to the notion of "itinerant smiths" disseminating iron technology, but at the same time described, also based on texts, craftsmen fleeing palaces and being re-absorbed in nonpalatial settlements. There is no evidence for this in the archaeological record; however, it is perhaps worth mentioning the double-jar adult burials dated to the second part of the 13th century BCE that were found at the Tell es-Sa'idiyeh cemetery, located in the Jordan Valley. As these are rare in the southern Levant and common in central Anatolia during the 13th century BCE, it has been suggested that they belonged to refugees from the disintegrating Hittite empire (Gonen 1979; Negbi 1991). Although in the rich Late Bronze Age tombs of Tell es-Sa'idiyeh no iron bracelets were found, this can illustrate the movement of people into the southern Levant in general and into this region in particular.

Where and by Whom was Iron Produced during the Iron I?

There is no direct evidence, in the form of iron slag cakes or other metallurgical remains, for iron production during the Iron I. As we know that iron was in fact used during this time, albeit in relatively small amounts, and assuming that the objects were not imported (see below), production must have taken place either in or around settlement sites or near iron ore deposits. Regarding the latter, the only iron ore deposit for which we have evidence for exploitation is Mugharet al-Warda in Transjordan, and it is dated no earlier than the Iron IIA. In the search for iron production remains, we recommend exploring Iron I bronze workshops within settlement sites, as we know that iron production (smelting and/or smithing) during the Iron IIA took place in the traditional bronzeworking areas (as exemplified at Hazor and Megiddo). Notably, iron production remains from Tell Tainat in the Amuq Valley, dated to the 12th century BCE, were found in a workshop together with bronzeworking remains (Roames 2010). We are discouraged by the fact that tuyères, square rather than round in cross-section, which are always associated with ironworking, are entirely absent from Iron I contexts. We are nevertheless encouraged by finds such as Hoard 12/Q/76 from Megiddo (see above) that provide indirect evidence for the engagement of bronzesmiths in iron production during the Iron I.

The possibility, although unlikely, that iron was imported into Canaan during the Iron I, needs to be addressed. There are in fact indications that some bi-metallic knives were imported from Cyprus. One example is the bi-metallic knife from Philistine temple Building 350 at Tell Miqne/Ekron, which was found together with a bronze wheel of a miniature Cypriot stand (Dothan 2002). However, using lead isotope analysis of bronze rivets of three bi-metallic knives from Megiddo and Qeiyafa, we were able to show that copper from the Arabah rather than Cyprus was used in their production (unpublished data). These knives were likely local imitations and attest to local iron production during the late Iron I.

Iron Production during the Iron IIA

Iron became dominant during the Iron IIA. Evidence shows that iron smelting and/or forging activities were now conducted in urban centers by metalworkers likely attached to local administrations. As far as we can conclude from the analyses of the objects, no major breakthrough in forging techniques was achieved in the course of the Iron Age, which could have accounted for the full adoption of iron technology. It is unlikely that the dominance of iron during the Iron IIA is the result of newly developed heat treatments.

One important element that appears to have enabled the systematic production of iron is the ability of urban metalsmiths to smelt (and not merely forge) iron. The identification of the production activity as involving the smelting of iron raises some questions on related aspects, including the feasibility of transporting iron ore into the urban centers, the variability of smelting techniques, and the possibility of identifying iron producers as former bronzesmiths.

The idea that iron ore was transported into settlement sites during the Iron Age at first appears unlikely. However, this is mainly because of the prevailing analogy to copper, which ever since the Chalcolithic period was smelted near the mines (e.g. Levy and Shalev 1989). To date, we do not know which iron ore deposits, excluding Mugharet al-Warda in the Ajlun highlands, were used during the Iron Age and what the distances were between the various deposits and the workshops. The iron ores of Mugharet al-Warda were smelted at nearby Tell Hammeh during the Iron IIA and this was certainly not the only iron ore source at the time, as has been demonstrated by Blakelock et al. (2009), who showed, based on the analysis of slag inclusions, that the artifacts from Beth-Shemesh could not have been made from the Ajlun iron ores. Needless to say, identifying relevant iron ore sources and the ability to provenance iron objects remains a major challenge in the study of the development of iron technology in the southern Levant during the Iron Age.

Based on the analysis of iron slag, three different smelting technologies existed simultaneously during the Iron IIA: pit smelting resulting in molten slag, pit smelting resulting in slag cakes, and the use of tapping furnaces. This diversity in smelting techniques is intriguing but appears to be characteristic of the bloomery process in general (Killick 1991; Craddock 1995:234–85). Notably, square in-section tuyères of the same type were found in association with all of these iron smelting techniques. Based on the existing evidence, it may be suggested, however, that pit smelting is associated with urban metalworking while tapping furnaces are linked with smelting in the vicinity of an iron ore deposit. This diversity may be thus related to production scale. This is reinforced by the use of tapping furnaces for copper smelting at Timna and Faynan.

We have suggested that bronzesmiths were smelting iron within their bronze workshops. In the following lines, we wish to explain how they adapted to a technology very different from their own. Bronzeworking and copper smelting appear to be separate activities during the Iron Age. It has been demonstrated that smelting in the Arabah was likely conducted by local tribal groups (Levy et al. 2008; Ben-Yosef 2010), while bronzeworking at settlement sites was handled by local Canaanite bronzesmiths. Based on the evidence from bronze workshops, we know that the bronzesmiths were not involved in copper smelting. Instead, they were regularly melting, refining, alloying, and casting copper/bronze in crucibles to produce the artifacts in demand (Yahalom-Mack 2009). These processes entailed crucibles, usually placed in simple pits; charcoal; and the inflation of air using bellows and tuyères. Iron smelting merely required, according to our reconstruction, a simple pit (possibly domed), charcoal, and an air supply. These were already available for the bronzesmith. The required temperature for Iron Age iron smelting, around 1100–1300°C, is only slightly higher than that needed by the bronzesmith, and could have been obtained with the available air system. What bronze workers lacked in order to smelt iron was the understanding of the smelting/reduction concept in general (as they were not copper smelters) and knowledge of the bloomery process in particular. The latter was essentially a compromise, in which iron is smelted without fully liquefying the metal.

It may be concluded that while the smelting of iron required only minor changes in the realm of physical conditions, major conceptual changes and a whole new body of knowledge were needed. Albeit beyond the scope of this paper, we must note that this new understanding explains, more strongly than ever, why the bronze/iron transition changed so profoundly the symbolic and ideological comprehension of the smiths and their role in society (Forbes 1950:79ff; McNutt 1990; Bunimovitz and Lederman 2012, and bibliography therein).

We have shown that once bronzesmiths adopted the new technology, an official initiative that came with statehood brought on the full transition from bronze to iron, probably benefiting from the availability and low cost of the iron ore and most significantly, from full control over the process (see also Bunimovitz and Lederman 2012). At least in some of the urban centers, this process included the entire *châine operatoire*, from smelting to forging. These administrations had the authority and the organizational skills to carry out this type of production and the ability to allocate the manpower imperative in iron production (Pigott 1989).

The accumulating production and artifactual evidence show that the major development in the bronze/iron transition occurred during the Iron IIA. The situation in the southern Levant appears to coincide with that in other Near Eastern regions, where this transition is not as well evidenced in the material culture. The connection between the full adoption of iron, the rise of states and great empires such as Assyria, and the consolidation of their armies during the early 1st millennium (e.g. Waldbaum 1978; Pigott 1989; Bunimovitz and Lederman 2012) is now based on hard evidence from the southern Levant. This notion is reinforced by the current artifactual evidence that shows that the number of iron objects, weapons in particular, increased during the 8th century BCE, in the face of the Assyrian threat, and decreased (also in proportion to bronze) after the Assyrian conquest.

Many questions still remain, including the following:

1. The relationship with Cyprus. Even though we stated that the initial phase of iron production in the southern Levant need not be associated with iron production there, the subsequent imitation of bi-metallic knives and their manufacturing procedure, which may have included quenching, suggests that the southern Levant was influenced to some extent by Cyprus. The lack of production remains on Cyprus does not at this time provide an opportunity for comparison.

2. Since the material in Cyprus is derived mainly from cemeteries, a comparison with the material from the settlement sites in the southern Levant is difficult. The dominance of iron in the Cypro-Geometric I cemeteries suggests that this metal remained a prestigious item during this period.

3. How do the copper industry activities in the Arabah, which peaked during the 10th–9th centuries BCE according to ^{14}C dating, relate to iron production in the urban centers during this time? How did the systematic production of iron influence, if at all, the fate of the mining and smelting activities in the Arabah?

CONCLUSIONS

The initial phase of iron production in the LBIII included the routine production of precious objects, namely jewelry for funerary deposits. We have shown that only after the withdrawal of the Egyptians from Canaan and with the beginning of intense copper production in the Arabah during the Iron I, iron began to be produced for utilitarian purposes. This production was likely carried out by independent bronzesmiths. Iron became the dominant metal by the Iron IIA. It took an administrative decision, possibly related to increasing threats from Aram and later Assyria, to produce iron systematically. The impetus for the breakthrough in the transition from copper to iron was the technical ability to smelt iron locally under the auspices of the urban administration. The economic feasibility, and particularly the ability to control all steps in the *châine operatoire* on a local level, soon made iron, despite its inferiority to bronze, the much preferred metal throughout the Levant.

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IRON AGE PIGS: NEW EVIDENCE ON THEIR ORIGIN AND ROLE IN FORMING IDENTITY BOUNDARIES

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ABSTRACT. This article reviews recent studies of pigs in the Iron Age in the southern Levant. The studies were carried out as part of the European Research Council–funded Ancient Israel project, with the aim of examining questions of identity and ethnic boundaries, with special emphasis on Philistia and ancient Israel. On the Philistine side, the results show a dichotomy in pork consumption between urban centers and the rural sector, and suggest that European domestic pigs were brought to the Levant by the Sea Peoples, most probably to secure the supply of meat. Reviewed with previous evidence, we suggest that economic motivation was the driving force for pork consumption and abandonment. Regarding ancient Israel, new studies show that avoiding pork was a widespread phenomenon of much of the Iron Age in both the highland and the lowlands outside of Philistia. They also point to a rise in pork consumption in lowlands sites of the Northern Kingdom in the Iron IIB and suggest a link between this phenomenon and the early consolidation of the taboo on pigs in Judah in late-monarchic times.

INTRODUCTION

Iron Age pig husbandry in the southern Levant has been studied extensively, primarily in order to understand the biblical prohibition on consumption of pork (Leviticus 11:7; Deuteronomy 14:8). Hesse's (1990) survey of numerous archaeozoological publications led scholars to propose that the absence or presence of pigs is the only way to distinguish between early Israelites and Philistines in the Iron I (Finkelstein 1997), and in fact throughout the Iron Age (Faust 2006:37–8). This notion led researchers to focus on pig frequencies at specific sites (e.g. Lev-Tov 2000, 2010, 2012; Raban-Gerstel et al. 2008; Kheati 2009), and to discuss issues of cultural and identity boundaries in the early phase of the Iron Age (e.g. Bunimovitz and Faust 2003; Killebrew and Lev-Tov 2008; Bunimovitz and Lederman 2011; Tamar et al. 2013), as well as cultural acculturation during later phases of the period (Faust and Lev-Tov 2011). Studies on pig husbandry and consumption also raise the question of the roots of the biblical taboo. For many years, a dominant theory pointed to the Sea Peoples as the "prime movers" behind a strong pig culture that was brought from the Aegean Basin. This became a symbol of their identity in the eyes of their neighbors—the early Israelites—who avoided pigs in general and pork consumption in particular in order to draw the identity line between the two groups, a typical "us" and "them" situation (Stager 1995; Finkelstein 1997). There were those who argued for a more cautious attitude, considering numerous reasons that could influence the decision to raise pigs (Hesse and Wapnish 1997, 1998). These include site function (e.g. Lev-Tov 2000), economic-political factors (Zeder 1996, 1998), and ecological issues (Harris 1987). Hesse and Wapnish (1998) also correlated the high frequency of pigs to the subsistence strategy of the newcomers' society, which opted for exploiting pigs as a fast source of meat until the migrating groups were efficiently settled in the new land.

The prevalent theory, according to which the Iron I Sea Peoples brought a strong pig culture from their homeland (e.g. Killebrew and Lev-Tov 2008) that caused the contemporary local highlanders—the early Israelites—to avoid pigs, has recently been challenged by new data regarding both sides of the Philistine/Israelite equation.

On the Sea Peoples side, since it is acknowledged that pork consumption played an important role in the diet of at least some of the Iron I migrants from the west and northwest (Yasur-Landau 2010), one may ask: how did these groups plan their voyage to the east? The strong trade connections

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between the Aegean and the Levant during the Late Bronze Age (manifested mainly by transfer of ceramic vessels) must have provided the migrants with information about the target lands for their migration. Still, what did groups of Sea Peoples know about the availability of pigs in the Levant? Did they plan to bring pigs with them from their homeland? Was there an advantage to bringing pigs from the Aegean? And what was the process of growth of pig consumption in Philistia? What were the dietary lines between the new migrants and the local groups within Philistia?

On the Israelite side, the taboo on pigs comes from biblical literature that dates not earlier than the late 7th century BCE, that is, several centuries after the migration of the Sea Peoples and the rise of ancient Israel in the highlands. How, then, do we bridge between the realities in the Iron I and the emergence of the biblical law in the late Iron II?

These questions led us to focus our interest on pig husbandry and consumption, and the current paper offers a review of our results. A detailed description of the research can be found at Sapir-Hen et al. (2013) and Meiri et al. (2013). The following two tracks were pursued:

1. Advances in archaeological and archaeozoological research were deployed to better understand patterns of pig husbandry and pork consumption in the region. For this purpose, Sapir-Hen et al. (2013) created a comprehensive database of published and unpublished reports on faunal remains. In order to achieve a fine resolution analysis, they considered only assemblages that could be assigned to one of eight ceramic subphases of the Late Bronze and Iron Ages: Late Bronze II and III, early and late Iron I, early and late Iron IIA, Iron IIB, and Iron IIC (for the ceramic phases see e.g. Zimhoni 1997; Herzog and Singer-Avitz 2004, 2006). Pig frequency levels were based on Grigson (2007) and defined as follows: insignificant <2%, significant 2–7%, and highly significant >7%.

2. Ancient DNA was extracted from pig bones, covering periods from the Middle Bronze Age to the present. The results were then compared to published data from across Eurasia. The aim was to verify the genetic origin of the Philistine pigs. In other words, the team attempted to check whether the Philistines brought pigs from their homeland or merely enhanced the raising of local pigs (Meiri et al. 2013).

These studies were made possible by methodological advances such as progress in fine-tuning the chronological phases of the Iron Age, accumulation of new data on pig frequencies and their exploitation (full list in Sapir-Hen et al. 2013), and progress in molecular methods that enable the extraction of DNA from ancient specimens (e.g. Shapiro and Hofreiter 2012 and references therein).

THE PHILISTINES

The Philistines constituted one group among the Sea Peoples who probably migrated to the Levant from various locations in the eastern Mediterranean—the Aegean Basin, Cyprus, and/or southern Anatolia (e.g. Lev-Tov 2006; Yasur-Landau 2010). Identifying immigrants' culinary behavior can shed light on patterns of their movement and early history in the new land. As pig husbandry and pork consumption are major characteristics of the main urban Philistine sites (see below), the question of whether they brought their pigs (and their kitchen traditions) with them, or relied on the local fauna, is crucial for understanding the nature of their migration in particular and the migration of ancient groups in general. A genetic study (Meiri et al. 2013) demonstrated that pigs from Late Bronze Age sites in Israel (until ~1150 BCE) depict haplotypes of modern and ancient Near Eastern pigs, meaning that they were of local origin. European haplotypes (foreign pigs) became dominant in the Iron IIA (~900 BCE; Figure 1). During the ~250 yr between the two periods, pigs could have been brought to the region in multiple events. As the archaeological evidence points to growing amounts of pig consumption in the Philistine urban centers, specifically during the early Iron Age (see below), it is reasonable to attribute a significant part of this translocation of domestic European pigs to the Sea Peoples in general and the Philistines in particular. Currently, ancient DNA information from Iron Age Philistine sites is still missing, and the first European pigs identified thus far come from Megiddo, located about 150 km north of the main Philistine centers. The 250-yr gap can be explained as representing the time needed for the European pigs to expand northward, or it may imply that the data from the early phases of the Iron Age are insufficient. Future study of pig bones from Philistia may therefore "close" this gap. A similar pattern in genetic signature is observed in Anatolia, where the major transition to a European haplotype also took place during the Late Bronze–early Iron Age (Ottoni et al. 2013). The notion that the pigs were carried along with various immigrant groups to different locations suggests that the exploitation of this animal, also by the Sea Peoples, was not a unique cultural trait but rather motivated by economic factors (see more below).

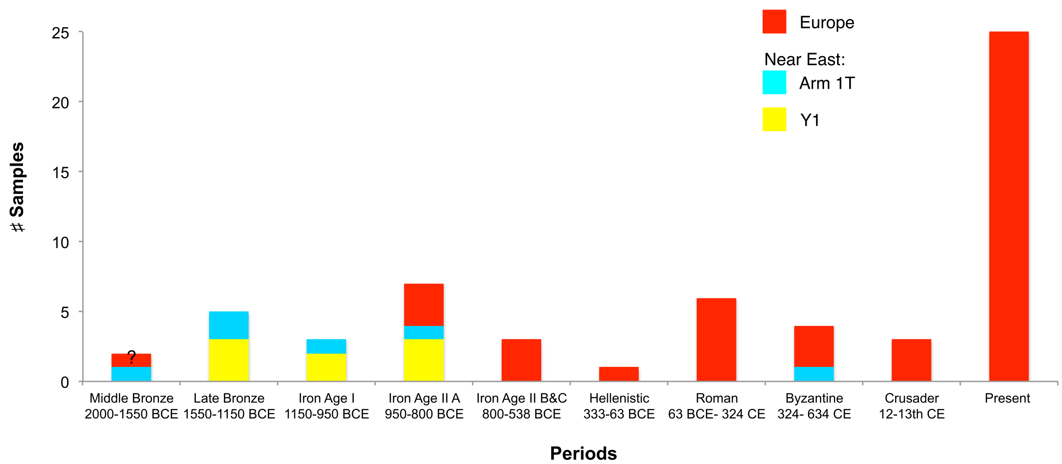

Figure 1 Pig samples with particular mtDNA genetic signature in Israel across the different time periods. This figure is from Meiri et al. (2013) © 2014 Nature Publishing Group.

If the Philistines did indeed bring their pigs with them, we are faced with questions regarding their motivation: Should pork consumption be attributed to cultural preferences (e.g. Faust and Lev-Tov 2011)? Looking at the data for Iron I sites in Philistia, Sapir-Hen et al. (2013) identified a pattern according to which the exceptionally strong appearance of pigs is characteristic of the main urban sites but not of the smaller settlements and the rural sector [Figure 2; note that data on the Iron Age fauna from Ashkelon has not yet been fully published and that the preliminary numbers (in Hesse 1990) are not correlated to strata]. This phenomenon was also observed by Maeir et al. (2013), who suggested that various unspecified factors (ecological, economic, or functional), rather than ethnicity, were responsible for this dichotomy. Faust and Lev-Tov (2014) argued otherwise; they maintained that the urban/countryside contrast may stem from the fact that the rural sector was inhabited by a number of groups rather than solely by Philistine immigrants (see also Uziel 2007; Gadot 2008). They suggested that the rural sites were under Philistine political control without having been inhabited by them, and thus ethnicity is the only factor contributing to the urban/rural dichotomy. However, Sapir-Hen et al. (2013) demonstrated that pig presence or absence cannot be used as an ethnic marker (see below).

Of all the aforementioned factors, ecological settings seem to be the least likely responsible for differences in pig frequencies. While raising pigs necessitates proximity to a water source, this is also

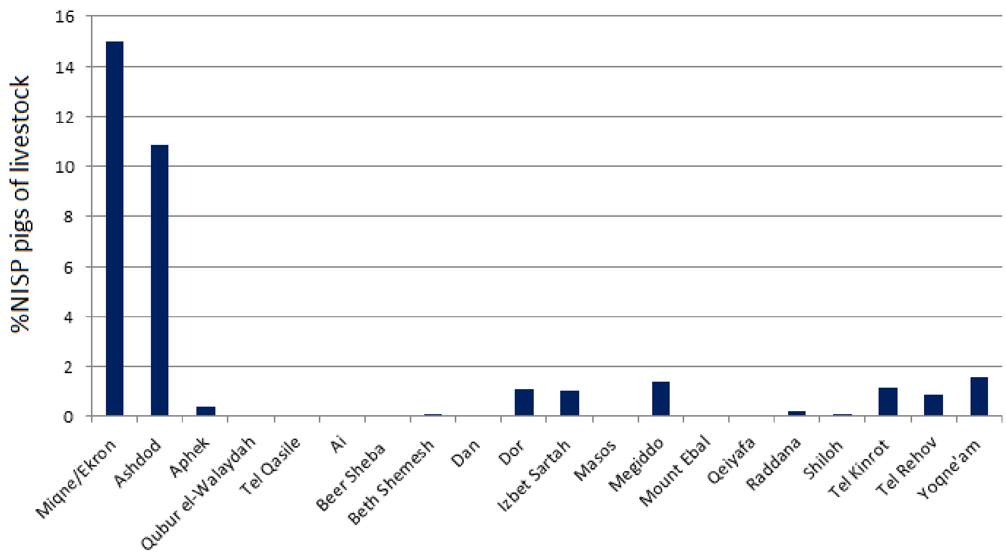

Figure 2 Pig frequencies (out of livestock) during the Iron I. Full data and refrences in Sapir-Hen et al. (2013:Table 1).

the case for cattle, whose frequencies differ between sites with no correlation to pig frequencies or climate [in terms of annual precipitation, which affects both water supply and available vegetation (Sapir-Hen et al. 2014)]. Moreover, as the Iron Age populations mastered herd management, it is less likely that (at least in the "green" parts of the region) local environmental factors had such an impact on domesticated animal frequencies (see also Sasson 2010; Sapir-Hen et al. 2014 for the discussion on climatic vs. social impact on animal husbandry decisions).

Thus, economic or functional factors seem more probable to explain the urban-rural dichotomy. Still, this dichotomy cannot stem from better economic conditions in the cities, as larger numbers of pigs are usually correlated with lower economic status (Hesse and Wapnish 1997) and with household economy rather than a centralized one (Zeder 1996). The difference must therefore stem from dissimilar economic motivations at different sites, as was suggested by Lev-Tov (2000:208, 2010) regarding Tel Miqne/Ekron. Note that the livestock economy of neighboring Beth Shemesh and Tel Miqne/Ekron differs both in terms of pig frequencies (Bunimovitz and Lederman 2011; Tamar et al. 2013) and relative frequencies of cattle and of sheep vs. goats (Sapir-Hen et al. 2014). Thus, the economies of these sites may be viewed as complementary to each other (Sapir-Hen et al. 2014). Trading between Beth Shemesh and Philistine sites is also evident in the pottery assemblages (Bunimovitz and Lederman 2011).

At the end of the Iron Age, Philistine sites—though not *all* the urban centers—show a decline in pork consumption (Lev-Tov 2010; Hesse et al. 2012; see discussion regarding Tell es-Safi/Gath in Lev-Tov 2012; Maeir et al. 2013). This change is considered as demonstrating an acculturation process, when the Philistines lost their "unique traits" (Faust and Lev-Tov 2011). However, an economic rather than cultural motive for the decrease in pork consumption was suggested by Owen (2005) and Lev-Tov (2010) regarding the Tel Miqne/Ekron assemblages. Owen (2005) proposed correlating the decrease in pork consumption with changing practices of pigs' raising: preliminary isotopic evidence suggests that in the early Iron Age pigs were kept in the countryside, while later at least a portion of them were kept inside the city. City breeding may have posed a "threat" to the elite because it extends autonomy to the household economy (Zeder 1996, 1998), which, in turn, motivated the "elite" to encourage the abandoning of pork consumption. More data are needed to establish the validity of this proposal. An additional explanation, that pork consumption is discouraged in times of centralized power (Zeder 1996, 1998), was suggested by Lev-Tov (2010). He related the decrease in pork consumption, along with other observed changes in animal economy, to the city's incorporation into the economic system of the Neo-Assyrian Empire.

ANCIENT ISRAEL

Sapir-Hen et al. (2013) showed that lack of pigs, or very low frequency of pigs, is a common feature of all Iron I sites outside of Philistia, sites that were inhabited by different cultural or ethnic groups. This continues traditional economic strategies that had been common in the Late Bronze Age (see also Tamar et al. 2013). This pattern puts into question the ability to differentiate between Canaanites/early Israelites and Philistines based on pig evidence alone, and suggests that significant consumption of pork can only serve to identify the population of the Philistine urban centers in the Iron I. In Jordan, Tell el-Umeiri (Field B, refuse pit; Peters et al. 2002) and Hesban (Strata 19; von den Driesch and Boessneck 1995) display significant (as defined in Grigson 2007) frequencies of pigs, though appreciably lower than the ones in the Philistine city centers—2.5% and 4.75%, respectively [2%, on the border of insignificance, in Kh. el Mudayna in Moab (Lev-Tov et al. 2011)]. More information is needed from Jordan in order to decide whether pig culture there is different from areas west of the Jordan River.

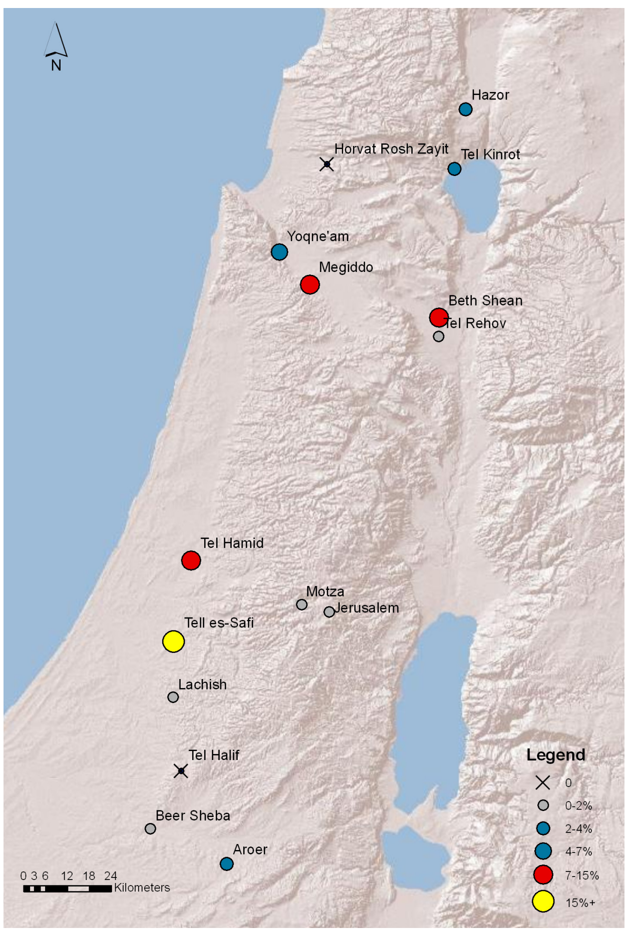

Figure 3 Pig frequencies (out of livestock) in the Iron IIB. Figure (and full data and references) first appeared in Sapir-Hen et al. (2013).

The fine chronology resolution study enables detecting changes within the Iron Age. During the Iron IIA, when the political landscape was characterized by emerging territorial kingdoms, a few sites in Israel show higher frequencies of pigs, though no explicit pattern can be detected (Sapir-Hen et al. 2013:Table 1). In Judah, the situation is similar to previous periods, with insignificant amounts of pig remains. In Tel Rehov, a site that exhibits Aramean characteristics, pork consumption is slightly over 2% in the late Iron IIA and is insignificant in the Iron IIB (Tamar et al., forthcoming).

An intriguing pattern appears in the Iron IIB (Figure 3). In this phase, a dichotomy is evident between sites located in the lowland territories of Israel and Judah. Pigs appear in significant frequencies in the former. Moreover, the pigs found in north Israelite assemblages reflect an important component of the local economy; they were raised and consumed on-site (Sapir-Hen et al. 2013). These changes in pig frequencies cannot be attributed to different environmental conditions, site function, or political and economic status; rather, they should be associated with economic motivation based on the need to provide a sufficient meat source to the growing population (because of diminishing open areas available for pasture) in the Northern Kingdom (discussion in Sapir-Hen et al. 2013). Interestingly, in the Iron II, European pigs appear at north Israelite sites such as Megiddo (Meiri et al. 2013). They either expanded naturally or were intentionally distributed from Philistia along trade routes, thus associating the increase in pork consumption in the Northern Kingdom with commercial contacts with Philistia. As suggested earlier, the population of Judah could have avoided pigs for cultural reasons throughout the Iron Age. For the Iron IIC, there is lack of data from northern lowlands sites; Judahite sites continued avoiding pork, while most Philistine sites show a decline in pork consumption (see above).

DISCUSSION

The results of the studies reviewed here raise new questions for understanding both the Philistine and ancient Israel cultures. In support of the previously suggested theory, based on the archaeological and genetic results, we propose that the Philistines brought pigs with them from their homelands. International connections in the eastern Mediterranean were common before and during the Philistines' arrival, and it is reasonable to assume that these connections were also exploited in the transit of animals and their products. The studied sample is insufficient to establish whether the phenomenon of pig movement should be attributed solely to the Philistines; in fact, we do not believe it should. However, combined with the archaeological evidence for the growing numbers of pigs in the Philistine urban centers, we believe it should be at least partly attributed to them. Still, pork consumption is not a characteristic of all contemporary assemblages in the Aegean Basin (Yasur-Landau 2010:295–9). The question remains, therefore, as to the driving force for this phenomenon. As the major transition to European haplotypes is also evident in other parts of the Ancient Near East (Ottoni et al. 2013), the movement of pigs may have been economically motivated. Rather than being a Philistine "traditional" food from home, pigs could have been put on the ships in order to provide meat during the dangerous voyage and a quickly reproduced meat supply in the target lands (see also Hesse and Wapnish 1997:247–8). The migrants may also have opted for taking their own pigs for a practical reason—to clean the ships. Economic motivation also seems to be the probable explanation for the difference in pork consumption between the Philistines' urban and rural sectors, and the driving force for the abandonment of this practice at the end of the Iron Age.

Additional studies are needed in order to decipher the precise patterns of pig frequencies in urban centers and rural sectors in Philistia. Furthermore, acknowledging that the autochthonous population in Philistia was not annihilated, and that the Sea Peoples had come from a variety of lands, intrasite analysis of Iron I assemblages at the Philistine city centers may help monitor cultural if not "ethnic" lines between different segments of their population (for the significance of intrasite investigation see Sapir-Hen et al., in press).

The emergence of a pig taboo in the southern highlands in the early Iron I as an "us" versus "them" boundary makes sense. But why do pigs not appear in assemblages from the northern part of the highlands, e.g. from sites that are bordering on the Jezreel Valley, far from Philistia? Was there a general Israelite (or highlands) identity as early as the early phase of the Iron I? To answer this question, additional data are needed from highlands sites that border on the Jezreel Valley and the coastal plain of the Sharon and, even more important, from the highlands east of the Jordan River, which gave birth to other territorial kingdoms and hence identities a short while after the Iron I.

The newly detected pattern of dichotomy between Israel and Judah in the Iron II may hint at the reason (or one of the reasons) behind the emergence of the pork taboo. The biblical decree (Lev 11:7; Deut 14:8) comes from the world of Judah in late monarchic and early post-exilic times. Our work demonstrates that pork avoidance fits the reality in Judah in the Iron IIB–C, but does not reflect daily life in the Northern Kingdom, at least not in its lowland sites, in the Iron IIB. Also, pig frequencies in Philistia had already diminished considerably at that time. Thus, promotion of pig avoidance could have been directed not toward the Philistines, who already began losing this cultural trait, but towards the northern Israelites who moved to Judah in the decades after the collapse of the Northern Kingdom in 720 BCE (see further discussion in Sapir-Hen et al. 2013).

CONCLUSIONS

The new data and synthesis (Meiri et al. 2013; Sapir-Hen et al. 2013) shed light on the origin, husbandry, and consumption of pigs in the southern Levant in the Iron Age. They indicate that European pigs were introduced to the region not later than the beginning of the Iron IIA, probably by the Sea Peoples. They also put some common conventions in question. The first is that distinguishing between Philistines and other groups can almost automatically be achieved based on pig frequencies. The emerging picture is much more multifaceted than was previously perceived: it is evident that pork consumption is not indicative to all sectors of the population in Philistia, and that pork avoidance is not restricted to one group (or region). Our study seems to demonstrate that all pig-related decisions were economically driven. The second common notion challenged by our work is that the pig taboo in ancient Israel emerged from the "us" and "them" conflict with the Philistines. Rather, we suggest that this taboo stemmed from a conflict within Judah in the late Iron II—between local Judahites who avoided pigs as early as the Iron I (possibly because of conflicts with the nearby Philistines) and Israelites who moved to Judah in the late 8th and early 7th centuries BCE, bringing with them pig-culture traits.

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COMPUTERIZED PALEOGRAPHIC INVESTIGATION OF HEBREW IRON AGE OSTRACA

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ABSTRACT. This article surveys ongoing research of the Legibility Enhancement of Ostraca (LEO) team of Tel Aviv University in the field of computerized paleography of Hebrew Iron Age ink-written ostraca. We perform paleographic tasks using tools from the fields of image processing and machine learning. Several new techniques serving this aim, as well as an adaptation of existing ones, are described herein. This includes testing a range of signal-acquisition methodologies, out of which multispectral imaging and Raman spectroscopy have matured into imaging systems. In addition, we deal with semi- or fully automated facsimile construction and refinement, facsimile, and character evaluation, as well as the reconstruction of broken character strokes. We conclude with future research directions, addressing some of the long-standing epigraphic questions, such as the number of scribes in specific corpora or detection of chronological concurrences and inconsistencies.

INTRODUCTION

The field of Hebrew Iron Age epigraphy (the study of inscriptions and writing) is important for the domains of biblical archaeology, the history of ancient Israel, and biblical studies. The most abundant texts that have come down to us from the First Temple period are on ostraca (clay potsherds inscribed in ink or incised), belonging primarily to the major corpora of Samaria (Reisner et al. 1924; first half of the 8th century BCE), Arad (Aharoni 1981), Lachish (Torczyner et al. 1938), Horvat Uza (Beit-Arieh 2007), and Tel Malhata (Beit-Arieh, in press), the latter four dating mainly to ~600 BCE. The ostraca are traditionally handled by experts who create manual facsimiles (binary depictions of the text), text transliterations, and translations. This analysis culminates with a construction of paleographic tables, comparing characters across different inscriptions, corpora, and periods, and thus helping to date inscriptions originating from contexts that are not well dated.

Naturally, such an effort is prone to subjective reasoning. This might explain the lack of experts' consensus on various epigraphic matters, for instance, the shape and characteristics of specific letters along the time axis, the interpretation of certain words in a text, and the degree of proximity or dissimilarity between characters. In particular, scholars dealing with Hebrew Iron Age epigraphy are divided over issues such as the relationship between Israelite and Judahite writing, the number of scribes in a given corpus, dating of certain inscriptions based on paleographic criteria, and the overall model of Iron Age writing development. As expected, the disparity of epigraphers' views regarding these issues leads to different archaeological and historical interpretation and understanding of the Iron Age in the Levant.

The present research of the Legibility Enhancement of Ostraca (LEO) team of Tel Aviv University deals with Iron Age ink-written ostraca. It addresses several important challenges in Iron Age epigraphy via adaptation and development of automatic image acquisition and analysis techniques, reducing human intervention. Among the issues at stake are obtaining the best imagery of the ostraca, improving the existing images and facsimiles of ostraca, automatically generating facsimiles, as well as analyzing and reconstructing individual handwritten characters.

The methods dealing with these problems can roughly be divided among the domains of image acquisition and automated facsimile evaluation and creation. Following this division, the next sections

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specify the techniques we developed, along with the main results. We conclude the paper with future research directions.

IMAGE ACQUISITION

Following millennia of being buried in the ground, ostraca display problematic features common to ancient texts, e.g. they are found broken, in many cases illegible, with stains and erased sections, or blurred ink. In addition, the ostraca were probably considered as an inexpensive, sometimes expendable medium. This is as opposed to papyri (which have mostly perished due to the local climate) or the rare monumental stone inscriptions, which had higher standards of writing (lapidary script). Furthermore, a potential hazard, specifically facing ostraca, is the fast ink fading after being unearthed. As a consequence, an adequate documentation of the ostraca immediately upon excavation is necessary. The negatives from the 20th century excavations are also gradually deteriorating, strengthening the need for digital documentation.

For documentation purposes, we attempted both an adaptation of already existing techniques, as well as development of new, potentially promising methods of image acquisition. The conventional imaging techniques include scanning of old negatives (depicting ostraca prior to their fading), standard digital imagery, and multispectral image acquisition. The pursuit for new imaging methods covered Raman spectroscopy, X-ray fluorescence, regular and IR point spectroscopy, and fluorescent imaging.

Scanning of Existing Negatives

The scanning of old negatives is an ongoing effort, aiming at assembling digital copies of all existing negatives of First Temple period ostraca. The task is performed utilizing a scanner (Microtek ArtixScan M2) capable of handling several types of negatives, including glass. So far, we have scanned hundreds of Hebrew Iron Age ostraca negatives depositories at the Israel Antiquities Authority, Tel Aviv University, and the Harvard Semitic Museum.

Multispectral Image Acquisition

The modern digital imagery provides us with detailed high-resolution data. However, the spectral information of the regular RGB (red, green, blue) imagery is usually insufficient, as only three color channels are recorded (see Figure 1). Therefore, our initial attempts at standard digital photography were soon substituted by multispectral (MS) techniques (Faigenbaum et al. 2012). Such methods were previously found to be beneficial in later historical documents written on parchment (e.g. Knox et al. 1997; Easton et al. 2003).

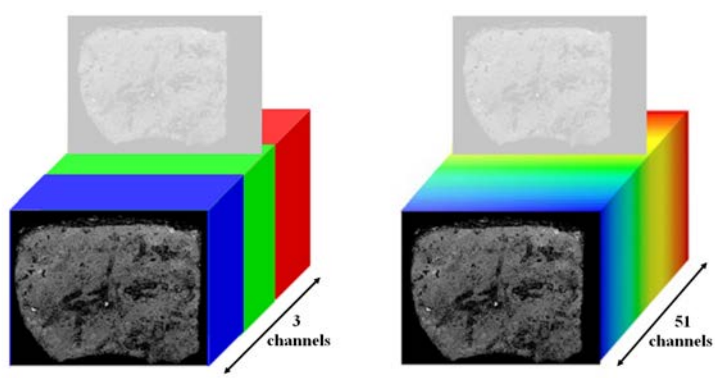


Figure 1 An illustration of RGB vs. multispectral data

We examined 33 Hebrew Iron Age ostraca from Horvat Uza, Horvat Radum, and Tel Malhata, sites located in the Beer Sheba Valley (Beit-Arieh 2007, in press), using a high-end commercial spectral imager, in order to establish an optimized imaging procedure. To assess the quality of the resulting images, we developed a new quality evaluation measure, which takes into account various contrast and brightness transformations. We showed that each ostracon possesses a unique wavelength range, where its readability is enhanced. Subsequently, we found that it is sufficient to use a small set of bandpass filters in order to acquire the most favorable images. This study paved the way towards constructing a low-cost multispectral device for the purpose of ostraca imaging.

Applying the MS imaging system was beneficial in several cases (Sober et al. 2014; Faigenbaum et al. 2015 and in press). For example, Figure 2 compares the standard and optimized MS images of Inscription No. 3 from Horvat Uza. In the enlarged parts of the images, one can see several characters that were absent or vague in the former, while present and legible in the latter.

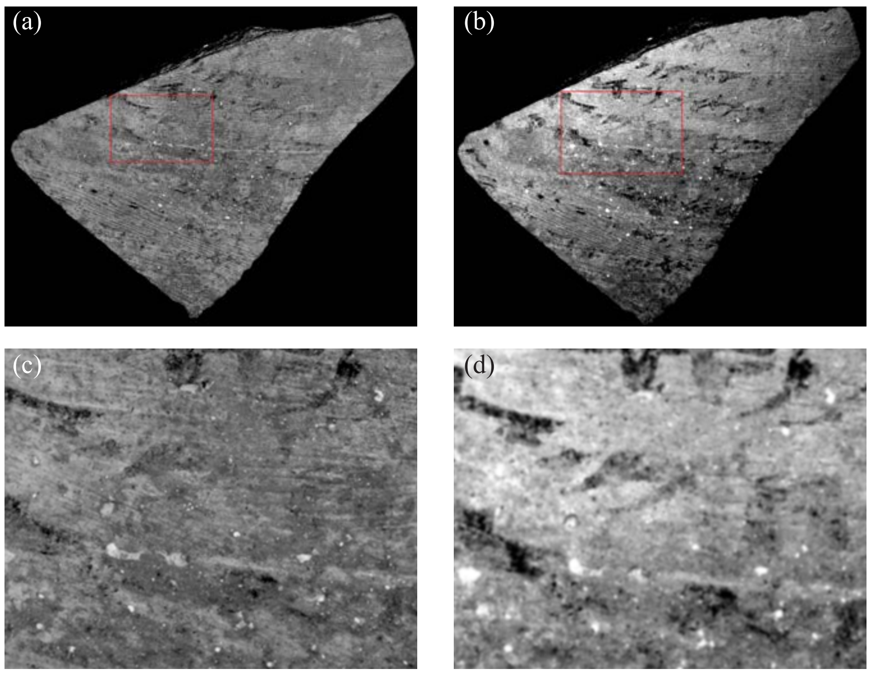


Figure 2 Ostracon No. 3 from Horvat Uza: (a) a full color image (~400–700 nm) converted to grayscale; (b) an image with enhanced readability (700–720 nm); (c, d) zoom-in on the area marked in red in images (a, b), respectively.

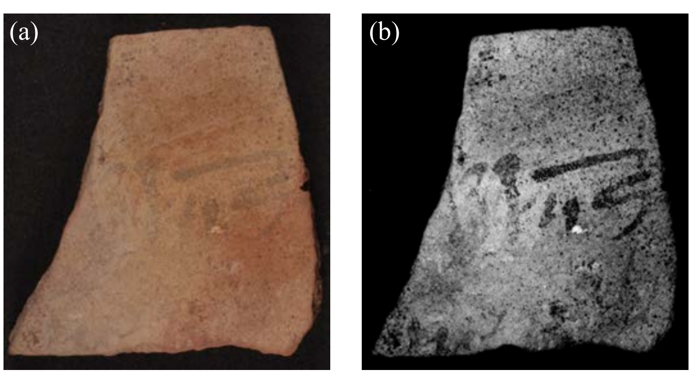


Figure 3 Two images of Inscription No. 13.056-01-S01 from Qubur el-Walaiydah, taken a year after excavation: (a) a color image; (b) image taken with the MS system at the wavelength range of 670–715 nm.

Another interesting example is a Hieratic 12th century BCE inscription from Qubur el-Walaiydah in the southern coastal plain of Israel, with an overall improvement by MS imaging, as displayed in Figure 3.

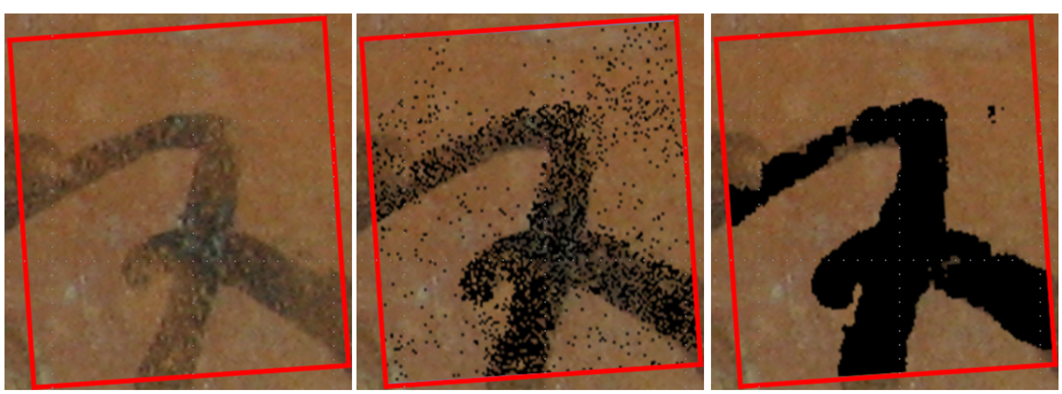
Raman, XRF, and Other Image Acquisition Methods

We tested several approaches to image acquisition. These were based on attempts to differentiate between "signals" of ink and clay on a microscale. Among the techniques considered were X-ray fluorescence (XRF), regular and IR point spectroscopy, fluorescent imaging, and Raman spectroscopy. With the exception of XRF and Raman spectroscopy, these methods did not yield significantly different signals.

Using the XRF (Nir-El et al., in press), we determined that the red ink in a rare red ink ostracon from the Tel Malhata corpus (Beit-Arieh, in press) contains iron as the principal component. We can therefore assume that the ink's pigment contained iron oxides, most probably hematite, Fe_2O_3. We also carried out an XRF analysis on the black ink of another Tel Malhata ostracon. We found that the net concentration of iron in the black ink of this ostracon is consistent with zero. Although the analysis could not explicitly identify carbon (since its characteristic X-ray energy is far below the detection threshold), we suspect that it is carbon-based (e.g. soot), mainly based on our Raman results (see below). Since we did not find a differentiating material in common black ink ostraca, XRF was not used as a basis for a new image acquisition mechanism.

On the other hand, our Raman spectroscopy experiments showed a clear distinction between clay and black ink spectra, which was utilized to construct a macroscale scanning device (Shaus et al. 2013a, unpublished data). This method exploits the observed difference to produce a new automated facsimile (black and white image) of the inscription. Our method circumvents the preparatory ink composition analysis (common in Raman spectroscopy), allowing for a straightforward detection of indicative Raman lines (wavelengths). Utilizing these lines, the most legible facsimiles are obtained.

The method was tested on an Edomite ostracon from Horvat Uza. The scans were performed on a character level. In Figure 4, a scan result of one character, as well as a facsimile created after simple postprocessing steps, can be seen. *A posteriori* analysis also revealed several indicative Raman lines, including ~1600 cm^{-1} (corresponding to aromatic rings, possibly humic acid or soot).



(a) (b) (c)

Figure 4 Raman scanning: (a) photograph of the scanned area; (b) scanning result overlaid; (c) scanning result after post-processing.

Currently, the scans and their processing take several days to accomplish, even for a single character. Scanning a whole inscription would likely take several weeks, and therefore was not pursued. Still, the process can be accelerated in the future using novel Raman technologies (Schlücker et al. 2003). This opens the possibility to produce facsimiles of entire ostraca in a completely automated and bias-free fashion.

FACSIMILE EVALUATION AND CREATION

Evaluation of Manual Facsimile

In accordance with the key role of facsimiles in epigraphic research, attention should be devoted to quality evaluation that is independent of the human eye. By *quality evaluation* we mean an assessment of how well a given facsimile represents the original writing on the ostracon.

We established a straightforward mathematical procedure (algorithm) that quantifies the quality of the fit between the facsimile and the image of a given ostracon (Shaus et al. 2010, 2012a). The quality of the fit is evaluated on a relative basis, ranking different facsimiles of the same ostracon. Figure 5 illustrates the correspondence between a facsimile and an ostracon image. Figure 6 shows three different depictions of the same character, overlaid on top of the ostracon image.

Figure 5 Arad ostracon No. 1 (Aharoni 1981): (a) facsimile overlaid over the ostracon's image; (b) aligned facsimile.

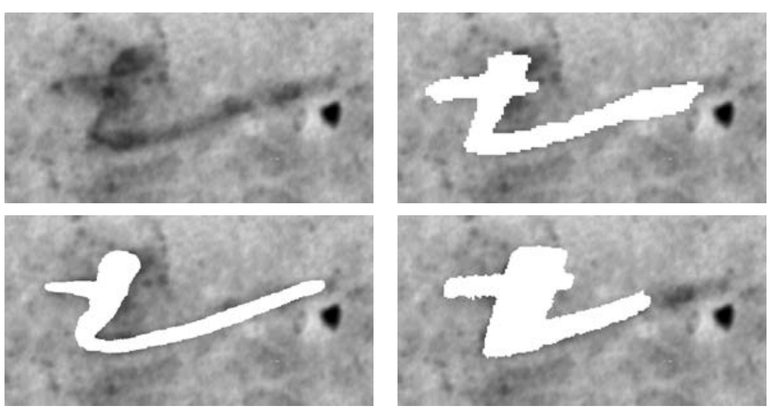
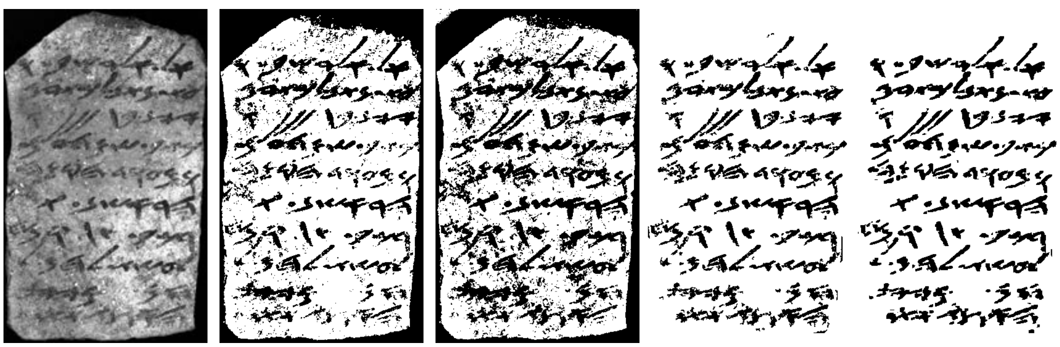


Figure 6 Arad ostracon No. 34: facsimiles of the same character created by three different individuals (details in Shaus et al. 2012a). The lower left facsimile was ranked first by the algorithm.

The proposed procedure was tested on a few cases in order to assess its reliability. A certain amount of variability was found between the facsimiles produced by different scholars, leading to different evaluation scores. It is interesting to note that the facsimiles with the best score were produced by a draftsperson rather than an epigrapher. This supports the assumption that the prior knowledge possessed by the epigraphers influences their documentation.

Creation of a New Facsimile

Our experience with facsimile evaluation convinced us that automated facsimile creation techniques ought to be pursued. As a first step, several existing binarization techniques were implemented, tested, and found to be inadequate for our purpose (Figures 7a–c). Therefore, a new method for automatically creating a facsimile was developed (Shaus et al. 2012b; see Figure 7d). This technique uses a digital image of an ostracon, as well as some information from an existing manual facsimile, in order to obtain an automatic and improved binarization (facsimile). A further noise reduction step, based upon automatically learned characteristics of the writing, has been developed and tested (Shaus et al. 2013b; see Figure 7e).



(a) (b) (c) (d) (e)

Figure 7 Arad ostracon No. 1 and its binarizations: (a) ostracon image; (b) Otsu (1979); (c) Niblack (1986); (d) Shaus et al. (2012b); (e) Shaus et al. (2013b).

Our experience with binarizations paved the way to a method that dealt with the evaluation of individual characters, as opposed to the binarization of entire ostraca (Faigenbaum et al. 2013). We chose to pick the most plausible characters on an individual basis, combining the best of all the binarization options. The characters were judged relying on their intrinsic properties (measuring the smoothness, completeness, and the amount of noise within the character). The algorithm managed to produce a credible ranking of characters' binarizations, comparable to human experts' opinions (Figure 8 illustrates the ranking results).

Even though the aforementioned algorithms produce results superior to a manual facsimile, they may still be insufficient for automated epigraphic analysis purposes. This is especially relevant in cases where parts of the character are missing. Therefore, a semiautomatic procedure for restoration of incomplete handwritten character strokes was developed (Sober 2013; Sober and Levin, unpublished data; see Figure 9). The method attempts at imitating the reed movement by using manually sampled key points of a character. The resulting character's reconstruction provided us with a smooth and complete facsimile, complemented by a full mathematical description of the constituent strokes. This opens the possibility of extracting sophisticated mathematical features, which may be used for letter analysis and comparison purposes in the future.

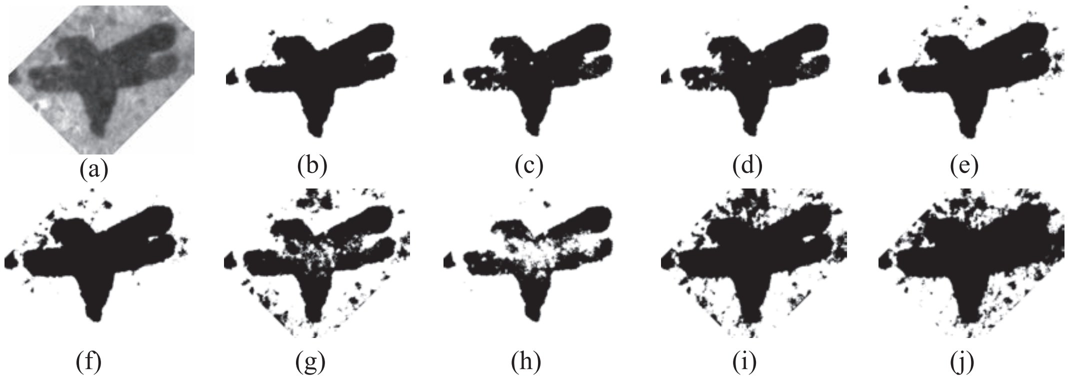


Figure 8 Expert's ranking of one character's facsimiles produced by several algorithms, in decreasing quality order; *w* is the window size, a parameter in the following algorithms (see details in Faigenbaum et al. 2013): (a) original image; (b) Sauvola and Pietikäinen (2000) [*w*=200]; (c) Shaus et al. (2012b), including unspeckle stage; (d) Shaus et al. (2012b); (e) Otsu (1979); (f) Niblack (1986) [*w*=200]; (g) Niblack (1986) [*w*=50]; (h) Sauvola (2000) [*w*=50]; (i) Bernsen (1986) [*w*=50]; (j) Bernsen (1986) [*w*=200].

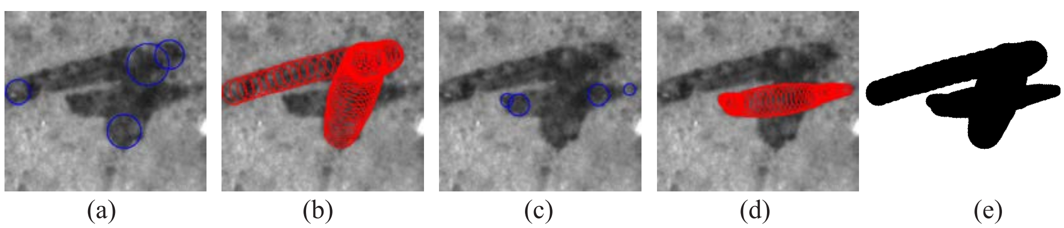


Figure 9 Reconstructing a *yod* from Arad ostracon No.1: (a, c) the initially sampled points; (b, d) the reconstructed strokes; (e) the resulting facsimile.

FUTURE RESEARCH DIRECTIONS

Our main objective is to perform paleographic tasks using tools from the fields of image processing and machine learning. This does not aim at replacing human experts, but rather supplying them with additional modern tools to perform their tasks. Our research paves the way to applying such techniques to the disciplines of Iron Age epigraphy and paleography.

The legible images obtained by the various methods, along with automated facsimiles, are already usable in their own right. Moreover, one of our main research goals is the establishment of a database containing the most legible images of Hebrew Iron Age ostraca.

Ostraca images can also be perceived as the foundation blocks in a large computerized epigraphy building currently under construction. Borrowing ideas from the field of optical character recognition, we are currently designing a metric that measures the similarity between two characters. The metric relies on extraction of features describing the shape of the characters. We use both well-established and new descriptors, and aim at combining them into a single efficient measure.

Based on this metric, paleographic comparison (cluster analysis) can be performed at the character, inscription, or the corpus level. Using this analysis, we are beginning to address some of the long-standing epigraphic questions, such as the number of scribes in a specific corpus or detection of chronological concurrences and inconsistencies.

Another research direction is an automated creation of paleographic tables. This may be achieved by means of detection (or calculation) of the most representative prototype for each of the characters present in the inscription. This may also be performed on a corpus basis. Initial experiments demonstrate the soundness of several of these research directions.

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