Israel Finkelstein, Shirly Ben Dor Evian, Elisabetta Boaretto, Dan Cabanes, Maria-Teresa Cabanes, Adi Eliyahu-Behar, Shira Faigenbaum, Yuval Gadot, Dafna Langgut, Mario Martin, Meirav Meiri, Dvora Namdar, Lidar Sapir-Hen, Ruth Shahack-Gross, Arie Shaus, Barak Sober, Michael Toffolo, Naama Yahalom-Mack, Lina Zapassky and Steve Weiner

Reconstructing Ancient Israel: Integrating Macro- and Micro-archaeology[1]

I. Introduction

The study of ancient Israel's texts and history has been a keystone of European scholarship since the Enlightenment. From the beginning of the 19th century, biblical exegesis contributed impressively to our understanding of these topics. Biblical archaeology joined in about a century later and provided critical evidence for the material culture of ancient Israel, shedding new light on its history. Yet, until recent years (and in certain circles up until today) biblical archaeology was dominated by a conservative interpretation of the texts and was not given a true independent role in recon-

1 This study is supported by the European Research Council Advanced Grant n° 229418. The project is directed by I. Finkelstein of Tel Aviv University and S. Weiner of the Weizmann Institute of Science. Y. Gadot serves as archaeology director and S. Ben Dor Evian as the administrative director of the project. The different tracks of the project are being carried out by E. Boaretto, A. Fantalkin and M. Toffolo (radiocarbon); R. Shahack-Gross, D. Cabanes, M. Cabanes and D. Friesam (geoarchaeology); M. Meiri, E. Halpern and M. Safra (DNA); E. Kagan, D. Langgut, T. Litt, F. Neumann and M. Stein (palynology); M. Martin (ceramic petrography); A. Eliyahu-Behar, N. Yahalom-Mack and S. Shilstein (metallurgy); Y. Benenson and E. Zapassky (daily mathematics); S. Faigenbaum, D. Levin, M. Moinester, E. Piasetzky, B. Sass, A. Shaus, B. Sober and E. Turkel (epigraphy); D. Namdar and L. Goldenberg (residue analysis); G. Bar-Oz, L. Sapir-Hen, L. Weissbrod and R. Zukerman (archaeozoology). The work started in February 2009 and should last for five years.

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structing ancient Israel's history. In addition, the contribution of conventional archaeological research has somewhat diminished, since much of its input is now the accumulation of additional data in well-known fields of this discipline. Textual exegesis, too, can hardly revolutionize the field, as the number of new pieces of evidence (texts found at excavations) is limited. Thus, in view of the above-mentioned limitations of biblical archaeology, the sparsity of available real-time historical records (consisting mainly of Assyrian sources and inscriptions unearthed in excavations), the biblical testimony's substantial chronological distance from the events that it describes along with the theological agenda not only of its original authors but also of many modern scholars, the task of reconstructing the world of ancient Israel accordingly stands in need of new directions and fresh evidence. Both can be found in dramatic developments in archaeology in recent years.

Biblical archaeology, to date, has dealt mainly with the macroscopic evidence, that is, what can be seen by the naked eye – architecture, pottery assemblages and other artifacts, animal bones, settlement patterns etc. A lot of additional information can however be extracted from the micro-archaeological record – the record that is revealed with the help of instrumentation.[2] This includes, for example, the mineralized bodies that plants produce (phytoliths) that provide information on the use of plant materials at a site; pollen, which may shed light on the paleo-environment and subsistence practices in the past; the mineral components of the sediments that may include remnants of ash from wood fires and signs of exposure to elevated temperatures indicating past pyrotechnological practices; the mineral components of ceramics which may determine their place of production and patterns of trade; the organic molecules captured inside ceramics which may determine vessel use; and the study of metal objects for reconstructing ancient production processes. Perhaps one of the most important aspects of the micro-archaeological record is the carbon-14 concentration in organic remains that can provide a reliable absolute chronology for archaeological finds and thus help reconstruct the past.

II. The Project

In our European Research Council (ERC) funded project entitled *Ancient (Biblical) Israel: The Exact and Life Sciences Perspective,* we use a novel ap-

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proach to integrate the macro and microscopic archaeological records from the Iron Age. The project is organized into ten tracks that were formulated in order to shed light on five main themes related to ancient (biblical) Israel:

1. The time of Ancient Israel:
   a. *Radiocarbon:* correlating the chronology of Ancient Israel with neighboring lands, especially the Mediterranean basin, as well as enhancing the dating of the different phases in the Iron Age and deepening understanding of relative chronology based on ceramic typology.
2. The genesis of Ancient Israel:
   a. *Ancient DNA:* collected from humans and animals to track origin and movement of ancient populations.
   b. *Geo-archaeology:* understanding formation processes, use of space, and tracking subsistence economy practices in Ancient Israel by examining sediments in sites that represent Iron Age towns and villages.
   c. *Palynology:* studying cores of sediments from the Dead Sea and Sea of Galilee in order to obtain information on paleoclimate, subsistence practices and settlement oscillations.
3. The life of Ancient Israel:
   a. *Ceramic petrography:* reconstructing production and trade patterns in ceramic vessels – the most common type of macro-artifact in the field.
   b. *Metallurgy:* tracking technological advances, specifically the shift from bronze to iron, during the Iron I–IIA period.
4. The mind of Ancient Israel:
   a. *Daily mathematics of dimensions:* examining pottery vessels to discern, for example, the relationship between units of length and volume for the sake of determining the "mathematical" knowledge of the people of the Iron Age.
   b. *Epigraphy:* using advanced computational methodologies in order to study the development of writing in Israel and Judah.
5. The identity of Ancient Israel:
   a. *Residue analysis:* of pottery vessels in order to determine the usage of vessels, culinary practices and long-distance trade.
   b. *Archaeo-zoology:* studying a large number of assemblages from different sub-phases of the Iron Age in different regions and varied contexts in order to better understand subsistence strategies in the past.

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Fig. 1: A laboratory in the field – Megiddo 2010.

In most of the ten tracks the investigations are being conducted with special reference to both the diachronic and synchronic dimensions. This is done by comparing finds in one site/region along the chronology scale and comparing a given assemblage to finds from the same period in other regions.

III. The Strategy

An important component of our methodology is the very close integration of the macro- and microscopic archaeological records starting in the field. In other words, we replace the traditional system of an "expert" coming occasionally to the site in order to collect samples with a team of archaeologists and researchers from the exact and life sciences alike, some of whom operate an on-site laboratory. The outcome is a continual sharing of knowledge – from stratigraphy and architecture to the smallest microscopic items.

We integrate the traditional excavation methods with the use of an on-site laboratory (Fig. 1) that enables parts of the microscopic record to be revealed in the real time of the excavation, minimizing the loss of information by the use of inappropriate excavation methods and sampling procedures. The work then continues in the laboratory after the excavation,

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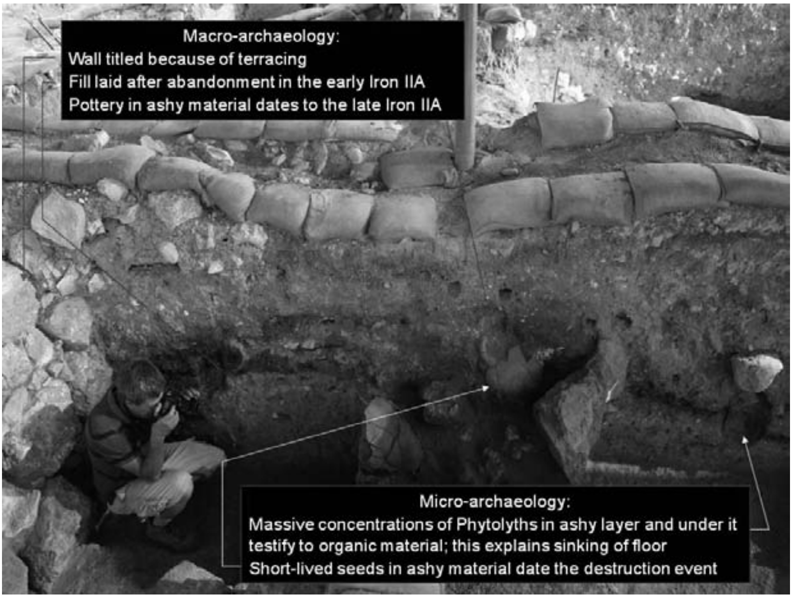
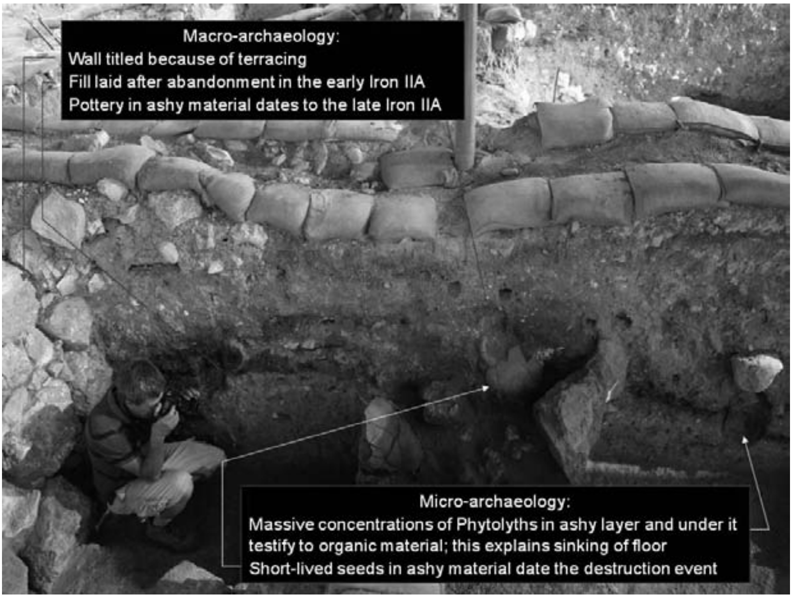


Fig. 2: A baulk in Area Q at Megiddo, showing Iron IIA sediments, demonstrating the integration of macro- and micro-archaeology data in an attempt to resolve stratigraphic problems.

subsequently oscillating between field and laboratory. The end product is a more detailed and better integrated understanding of the archaeological record.

The picture in Figure 2, taken in Area Q at Megiddo in the fall of 2010, demonstrates this integrative approach. It shows a baulk with evidence for fire and broken Iron Age vessels, and a much-tilted floor (on the right). This baulk, along with similar ones in the area, posed difficult questions regarding accumulation of sediments, reason for the tilting, the nature of the fire, and the nature and exact date of the ceramic assemblage. A week in the field of the entire team – field archaeologists, geo-archaeologists, radiocarbon specialists and others – helped to decipher many of these questions. Much of the sediment was laid down after a short abandonment of the site. Massive concentrations of phytoliths (mineralized bodies produced in plants) both in the ashy layer and below it indicate that large amounts of organic material accumulated in this area. The subsequent loss of the organic material by degradation may account for the sinking of the floor (Fig. 2 right-hand side). Grain seeds in the storage jar in the ashy material were radiocarbon dated to the 9th century B.C.E. This integrated



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IV. Course of Work and Some Results

1. The Time of Ancient Israel

The application of the integrative approach described above has revolutionized the manner in which radiocarbon dating is used to build an absolute chronological framework. Radiocarbon dating is all about context. Indeed, some recent studies demonstrate how dating samples originating from insecure contexts can lead research astray.[3] Therefore, in order to ensure that only samples derived from the most reliable contexts are analysed, a dating project must start with extensive work in the field by the dating experts along with the excavation team. Strict criteria are used to define such solid contexts whose reliability is documented in the field. Accordingly, our project under the directorship of E. Boaretto has abandoned the widespread practice of area supervisors collecting samples for dating and then submitting them for analysis to a radiocarbon laboratory. Dating starts in the field, and the same team then characterizes the quality of the materials to be dated. For the most commonly used materials for dating – charred botanical remains and bones – strict pre-screening criteria has been developed in order to select the best preserved samples. For bones, the major component of interest is the protein collagen, as it is a short-lived dateable material. Bones are pre-screened for the best preserved collagen in the field by using the Fourier Transform Infrared Analysis (FTIR) and the splitting factor of the mineral fraction. The analysis continues in the laboratory, where FTIR is used to characterize the purity of the collagen before the sample is prepared for carbon-14 analysis. The states of preservation of charred short-lived organic materials are assessed by monitoring the weight losses that are incurred during sample purification procedure (poorly preserved samples lose more weight). FTIR is used to assess the purity of the charred samples after cleaning, and samples with large

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proportions of clay (and its associated carbon) are rejected. The carbon-14 concentrations are determined by accelerator mass spectrometry (AMS).

Ancient Israel was closely connected to other regions in the ancient Near East and the eastern Mediterranean basin. Thus, one of the major objectives of this track is to correlate the absolute chronology of the different phases of the Iron Age Levant, which is fairly well documented, with the chronologies of neighboring lands, especially the Aegean basin. The relative chronology of Greece from approximately the 11th–9th centuries B.C.E is well known, but the absolute chronology of the Greek Proto-Geometric and Geometric layers depends in many ways on the Levant (Greek sherds found in well-dated Levantine layers).[4] The problem is that sherds of these periods found in the east are either poorly stratified or potentially residual. In order to address this problem we are using the integrative approach (including the field component) to obtain radiocarbon dates from two Iron Age sites in central Greece, namely Lefkandi and Kalapodi.

One objective of the radiocarbon track is to better understand the strengths and weaknesses of relative dating which is based on pottery seriation. For instance, we wish to see whether layers carrying similar pottery assemblages in different parts of the Levant indeed date to the same decades. Our project is essentially a follow-up on the study of high resolution absolute chronology of the Iron I/II transition carried out by I. Sharon, A. Gilboa, T.A.J. Jull and Boaretto.[5] The resolution of dates in Iron I–IIA demonstrated that two different events that occur within a century could be differentiated. This however requires an extraordinarily large number of samples, mainly due to the noise introduced into the study by samples from poorly defined contexts.

We also aim to improve our understanding of the absolute chronology in comparison to the relative ceramic typology by working on sites with dense stratigraphy. Megiddo features about twelve well-distinguished layers with good ceramic assemblages over the approximately six centuries of the Late Bronze IB–Iron IIA time span. We are now radiocarbon dating this sequence and, by doing so, establishing the most detailed radiocarbon framework for a single site in the ancient Near East. These dates are expected to shed light on events related to the history of Ancient Israel. For instance, previous work has already hinted that the destruction of the late-Canaanite (late Iron I, late 11th and early 10th centuries B.C.E) cities in the

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Jezreel Valley was a gradual process rather than a result of a single event. It has also indicated that the 9th century B.C.E conflicts between the northern kingdom and Aram Damascus left a series of destruction layers in the northern valleys. These destructions can probably be affiliated with several different events.[6]

2. The Origin and Identity of Ancient Israel: Pigs, Humans and Genetics

The blueprint of life is embedded in the DNA, which is a large and unstable molecule that easily breaks down. Despite the very small amounts of preserved ancient DNA, DNA fragments can often be found in fossil bones, probably because they are protected by the mineral.[7] With the development of very powerful molecular biological techniques, even these small semi-degraded fragments can be analysed and the sequences of their components (nucleotides) deciphered. These sequences of nucleotides are in fact the genetic information. The capability of analysing ancient DNA was developed in the late 1980s[8] and over the years the methods have become increasingly more powerful. This genetic information can provide fascinating insights into different aspects of past life.

In our project directed by M. Meiri, we are addressing two topics using ancient DNA (aDNA): the origin of the pig populations in the Iron Age Levant and the genetic affinities of humans from different areas within the region.

Pig bones from the Iron Age exhibit uneven distribution. Their frequency depends on the region where the site is located and on the chronological phase within the period. While they are fairly commonly found in sites affiliated with the Philistines, they are rare or absent in sites in the central hills.[9] The absence or presence of pigs has been correlated with en-

6 I. Finkelstein and E. Piasetzky, "Radiocarbon-Dated Destruction Layers: A Skeleton for Iron Age Chronology in the Levant," *Oxford Journal of Archaeology* 28 (2009): 255 – 274.

7 M. Salamon et al., "Relatively Well Preserved DNA is Present in the Crystal Aggregates of Fossil Bones," *Proceedings of the National Academy of Science* 102 (2005): 13,783 – 13,788.

8 R. Higuchi et al., "DNA sequences from the quagga, an extinct member of the horse family," *Nature* 312 (1984): 282 – 284.

9 B. Hesse, "Pig Lovers and Pig Haters: Patterns of Palestinian Pork Production," *Journal of Ethnobiology* 10 (1990): 195 – 225; idem, " Husbandry, Dietary Taboos and the Bones of the Ancient Near East: Zooarchaeology in the Post-Processual World," in *Methods in the Mediterranean: Historical and Archaeological Views on Texts and Archaeology* (ed. D.B. Small; Mnemosyne Sup 135; Leiden: Brill, 1995), 197 – 232.

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6 I. Finkelstein and E. Piasetzky, "Radiocarbon-Dated Destruction Layers: A Skeleton for Iron Age Chronology in the Levant," *Oxford Journal of Archaeology* 28 (2009): 255 – 274.

7 M. Salamon et al., "Relatively Well Preserved DNA is Present in the Crystal Aggregates of Fossil Bones," *Proceedings of the National Academy of Science* 102 (2005): 13,783 – 13,788.

8 R. Higuchi et al., "DNA sequences from the quagga, an extinct member of the horse family," *Nature* 312 (1984): 282 – 284.

9 B. Hesse, "Pig Lovers and Pig Haters: Patterns of Palestinian Pork Production," *Journal of Ethnobiology* 10 (1990): 195 – 225; idem, " Husbandry, Dietary Taboos and the Bones of the Ancient Near East: Zooarchaeology in the Post-Processual World," in *Methods in the Mediterranean: Historical and Archaeological Views on Texts and Archaeology* (ed. D.B. Small; Mnemosyne Sup 135; Leiden: Brill, 1995), 197 – 232.

vironmental, social, political and cultural factors.[10] In the current study, archaeozoologist L. Sapir-Hen has noticed an interesting dichotomy in the frequency of pig bones in the Iron II between the lowlands of Israel and the lowlands of Judah, and demonstrated the complexity of factors influencing pork consumption. DNA analysis of pig bones will hopefully shed light on the origins of the pig populations: Did the so-called "Sea Peoples" bring pigs with them from the Aegean, for example? Were some or all of the Iron Age pigs domesticated from the wild indigenous populations just as they were elsewhere in Europe and Asia? And what were the cultural boundaries between populations raising pigs and those with no evidence for pig husbandry?

The study of preserved DNA in fossil human bones is fraught with the difficulty of contamination by modern human DNA. Thus, extreme precautions need to be taken to minimize this risk. These precautions include carrying out the DNA extraction and analysis in ultra-clean laboratories. Our project has involved the construction of such a laboratory. It is also imperative to work on the best preserved bones, which have the highest likelihood of containing well preserved ancient human DNA that can be reliably differentiated from modern contamination. In order to identify such bones, S. Ben Dor Evian and M. Cabanes have pre-screened many fossil animal bones for the presence of the preserved protein in bone called collagen, which is much easier to identify than DNA. The rationale is that, because proteins are also unstable, well preserved collagen suggests a greater likelihood for well preserved DNA. This correlation between collagen and DNA preservation has been noted in human bones from the Chalcolithic period in the Levant.[11]

Work on this track has only recently started and therefore it will take some time until we can hope to get first results.

3. Iron Age Settlement Patterns and the Environment: Palynology

The highlands of Canaan, the hub of Ancient Israel, feature sharp settlement oscillations in the Bronze and Iron Ages. For instance, in the area between the Jezreel and Beer-sheba Valleys the number of sites grew to ca. 250 in the Middle Bronze, dropped to ca. 30 in the Late Bronze, and then grew again to ca. 250 in the Iron I. Taking into consideration the steppe nature of the eastern and southern parts of this region, these oscil-

10 E. g., Hesse, "Pig Lovers" (see n. 9); M.A. Zedar, "The Role of Pigs in Near Eastern Subsistence: A View from the Southern Levant," in *Retrieving the Past* (ed. J.D. Seger; Winona Lake: Eisenbrauns, 1996), 297 – 312.

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Fig. 3: The Nahal Zeelim gully. The pollen record in the sediments reveals the vegetation history of the Judean highlands in the last five millennia.

lations could have resulted from small climatic changes. The oscillations may also reflect changes in human behavior, such as subsistence practices influenced by economic and social factors rather than climate factors.

A powerful tool that can shed light on these settlement oscillations is the pollen record in the sediments of the Dead Sea and the Sea of Galilee. These basins are repositories of pollen transported from the highlands by both wind and *wadi* streams. The pollen records can provide information on the relative quantities of the major vegetation types in the highlands in antiquity and this in turn can reflect both climatic- and human-induced changes.

The palynologist D. Langgut is working on sediment cores from the Sea of Galilee and (together with Frank Neumann) the sediments from the narrow gully of Nahal Zeelim, formed near the shore of the Dead Sea as a result of the recent drop in sea level (Fig. 3). The sedimentary sequence exposed in the gulley is now thick-enough to reveal the pollen record of the last five millennia. In the Sea of Galilee, members of our team T. Litt from the University of Bonn and M. Stein from the Hebrew University drilled a core from the center of the lake. In order to shed light on minute and rapid changes in the vegetation of the highlands, the pollen samples are analysed at a resolution of ca. 20 years – a resolution not yet attempted in our region.

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Preliminary results from the sediments of the Zeelim gully indeed show clear oscillations in the pollen record during the Late Bronze and Iron Ages. In general, fluctuations in the Mediterranean vegetation curve point to climate changes while fluctuations in the olive pollen curve represent changes in the highlands olive horticulture activity. Tree clearing and pasture activities are also evident from the Dead Sea pollen spectrum. In order to achieve a proper interpretation we need reliable dates along each core. Accordingly, we are now engaged in a rigorous radiocarbon dating project, including directly dating the pollen itself – a challenging task because of the relatively low pollen concentrations characterizing our research area.

4. Domestic Lifestyles in Ancient Israel

The integrated macroscopic and microscopic archaeological records can reveal different aspects of past lifestyles. Under the directorship of R. Shahack-Gross, we deploy several analytical tools for this purpose. For understanding different uses of space we use phosphate and phytolith concentrations as tracers for locations where organic materials had been deposited in the past (livestock enclosures, dumps, toilets, storage). We use minerals to reconstruct domestic pyrotechnological practices (i. e., cooking, destruction by fire) and to study fuel sources within macroscopic remains of ovens and kilns.[12] For information on diet and economic practices we use detailed morphotype phytolith analysis, and bones from animals that were eaten (work of L. Sapir-Hen). The key to integrating the macro- and micro-archaeological records in this sub-track is the study of thin sections of embedded sediments using mainly the petrographic microscope. This so-called micro-morphological approach provides information on the *in situ* spatial relations of sediment components as deposited, shedding light on, for example, primary deposition processes by humans versus transport and reworking of sediment components by natural agents such as wind and water.[13]

The difficulty in reconstructing lifestyles relates to abandonment processes. In the normal course of village or town life, houses are not abandoned and then left untouched. Secondary use of abandoned structures is widespread, and thus the artifact distribution pattern most likely to be found when excavated will reflect this secondary use. One way of over-

12 R. Shahack-Gross, "Approaches to Understanding Formation of Archaeological Sites in Israel: Materials and Processes," *Israel Journal of Earth Sciences* 56 (2007): 73 – 86.

13 M.A. Courty et al., *Soils and Micromorphology in Archaeology* (Cambridge Manuals in Archaeology; Cambridge: Cambridge University Press, 1989).

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coming this complication is by working on destruction levels. However, it must also be taken into consideration that during catastrophic events such as destructions, the macro- and to a lesser extent the micro-artifacts may more likely reflect the special needs of the moment (preparation for a siege or for a battle), rather than ”normal” daily lifestyles. Another way to overcome this complication is by studying in detail the processes taking place in abandoned structures.[14]

Siliceous plant phytoliths are invaluable for reconstructing past lifestyles, as they can be used to determine the ways in which plants were used for food, construction, fodder, bedding, matting and more.[15] D. Cabanes has critically examined evidence showing that, under certain circumstances, phytoliths can dissolve and/or be abraded. Such taphonomic processes can lead to incorrect interpretations of the phytolith record, especially when determining the ratios between straw and spiklets that originated from cereals.[16] This is critical for evaluation of agricultural and herding practices. We are now testing these hypotheses by field studies at the rural Iron Age site of Izbet Sartah. As phytolith distributions can be very helpful in planning the optimal excavation strategy, we developed a rapid method for determining phytolith concentrations whereby some 10 to 20 samples can be processed within 4 – 6 hours (i. e., from one day to the next).[17] Our work at Izbet Sartah also demonstrates the potential of using phytolith concentration in order to delineate the boundaries of a site, including the surrounding work areas where architectural remains are absent.

We have applied many of these methods to analyse in detail an area at Tel es-Safi/Gath that was buried by the events that destroyed the site in the late 9th century B.C.E.[18] We could show that following the actual destruction, erosional processes continued for decades and eventually left an accumulation of destruction debris nearly one meter thick.[19]

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14 D. Friesem et al., “Degradation of Mud Brick Houses in an Arid Environment: A Geoarchaeological Model,” *Journal of Archaeological Science* 38 (2011): 1,135 – 1,147.

15 D.R. Piperno, *Phytoliths. A Comprehensive Guide for Archaeologists and Paleoecologists* (Lanham: AltaMira Press, 2006).

16 D. Cabanes, S.Weiner and R. Shahack-Gross, “Stability of Phytoliths in the Archaeological Record: A Dissolution Study of Modern and Fossil Phytoliths,” *Journal of Archaeological Science* (forthcoming).

17 O. Katz et al., “Rapid Phytolith Extraction for Analysis of Phytolith Concentrations and Assemblages During an Excavation: An Application at Tell es-Safi/Gath, Israel,” *Journal of Archaeological Science* 37 (2010): 1,557 – 1,563.

18 A.M. Maeir, “The Historical Background and Dating of Amos VI 2: An Archaeological Perspective from Tell es-Safi/Gath,” *VT* 54 (2004): 319 – 334.

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Fig. 4: The Negev Highlands site of Atar Haroa. Extraction of a block with sediments from the floor.

An interesting example of how micro-archaeology may reflect on broad historical questions is provided by studies carried out in Iron IIA Negev Highlands sites by R. Shahack-Gross (geo-archaeology), Boaretto (radiocarbon) and M. Martin (petrography of pottery vessels). These sites (Fig. 4) were described in the past as "Israelite fortresses" from the time of King Solomon that were destroyed in the course of the Sheshonq I campaign to Canaan in the second half of the 10^{th} century.[20] Other studies proposed sedentarization processes of local pastoral nomads who practiced mixed pastoral activity and seasonal dry-farming.[21] Our sediment investigation in one of these sites indicates that the inhabitants' subsistence economy was based on animal husbandry, with no evidence for seasonal dry-farming.[22] Radiocarbon dating of short-lived samples from two sites

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22 R. Shahack-Gross and I. Finkelstein, "Subsistence Practices in an Arid Environment: A Geoarchaeological Investigation in an Iron Age Site, the Negev Highlands, Israel," *Journal of Archaeological Science* 35 (2008): 965 – 982.

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show that they were inhabited between the second half of the 10th century and relatively late into the 9th century,[23] rejecting both the notion that they can be associated with a mid-10th century northern polity and the idea that they were destroyed in the late 10th century. Mineralogical observations by Martin show that a certain number of both wheel and hand-made vessels from these sites were produced in the Araba Valley at sites connected with copper production. This seems to indicate that the inhabitants of the Negev Highlands sites were in contact with the large-scale copper production centers at Feinan.[24] Hence, in this case, micro-archaeology revolutionized what we know about the Negev Highlands sites – their nature and time as well as their inhabitants' subsistence strategies.

The transformation of raw materials into useful synthetic materials (pyrotechnology) produces some of the most durable components of the archaeological record, such as ceramics and plaster. A most interesting product of pyrotechnology found at Tell es-Safi/Gath from the late Iron I is hydraulic plaster.[25] In addition to the normal calcite component of lime plaster, hydraulic plaster contains a silicate-based additive that polymerizes and contributes to the hardening process. Thus, this type of plaster can harden under water and is therefore called hydraulic plaster. Although it is best known from the Roman period, there have been reports of hydraulic plaster from as early as the Neolithic Age. The problem is proving that the silicate component of the plaster was added deliberately and not by accidental mixing. In the study of two overlying floors at Tell es-Safi/Gath, we showed that both were composed of hydraulic plaster and that the silicate phase was deliberately added, judging from the fact that both floors are of identical composition and contain silicate minerals obtained from outside the local area. It is of particular interest to note that there are reports that hydraulic plaster was used prior to this time in the Aegean,[26] raising the

23 For one of the sites see E. Boaretto, I. Finkelstein and R. Shahack-Gross, "Radiocarbon Results from the Iron IIA Site of Atar Haroa in the Negev Highlands and their Archaeological and Historical Implications," *Radiocarbon* 52 (2010): 1 – 12.

24 And possibly also Timna; for more on these sites see T. Levy et al., "Reassessing the Chronology of Biblical Edom: New Excavations and ^{14}C Dates from Khirbet en-Nahas (Jordan)," *Antiquity* 78 (2004): 865 – 879; idem et al., "High-Precision Radiocarbon Dating and Historical Biblical Archaeology in Southern Jordan," *Proceedings of the National Academy of Sciences* 105 (2008): 16,460 – 16,465; E. Ben-Yosef et al., "The Beginning of Iron Age Copper Production in the Southern Levant: New Evidence from Khirbat al-Jariya, Faynan, Jordan," *Antiquity* 84 (2010): 724 – 746.

25 L. Regev et al., "Iron Age hydraulic plaster from Tell es-Safi/Gath, Israel," *Journal of Archaeological Science* 37 (2010): 3,000 – 3,009.

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interesting possibility that this skill was brought from that region to the Levant by the Sea Peoples.

Based on the findings of metal artifacts, during the early period of the Iron Age, bronze was still the most commonly produced metal in the Levant.[27] Very little, however, is known about the modes of production of bronze and iron and about the pace of transition from one metal to the other. N. Yahalom-Mack and A. Eliyahu-Behar's detailed excavation of a small Iron IIA (9th century B.C.E) area from a stratum at Tell es-Safi/Gath revealed the remains of a metal "workshop" that essentially comprised a few macroscopic metal associated artifacts (mainly a crucible, a few tuyère fragments and a piece of slag) and a fairly rich microscopic record. The microscopic data showed that bronze and iron alike were produced at the site, based on the analysis of a lined pit and another depression containing iron hammerscales.[28] The fact that so few macroscopic artifacts were found probably explains why such workshops could easily have been overlooked in other, more traditional excavations.

5. Ritual Practices in Ancient Israel

Information on ritual practices is most often derived from the macroscopic record, mainly in the form of architecture (temples, shrines, alters, etc.) and ceramic objects whose style might suggest some form of ritual practice. One such ceramic object is the so-called "chalice" – a bowl on a high leg-shaped base. Chalices are often found in ritual architectural contexts as well as in domestic contexts, which casts some doubt on their use as ritual objects. D. Namdar's analysis of the small lipid (fat) molecules preserved in voids inside the ceramic of chalices from an Iron IIA repository pit at the site of Yavneh in Philistia showed that many of the samples contained molecules that could produce fragrances and, in some cases, hallucinogenic effects – properties consistent with the use of chalices in a ritual context.[29] Similar molecules were found by our team in chalices from two other contemporary sites in Philistia.[30]

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27 Recently Y. Gottlieb, "The Advent of the Age of Iron in the Land of Israel: A Review and Reassessment," *Tel Aviv* 37 (2010): 89 – 110.

28 A. Eliyahu-Behar et al., "Iron and Bronze Production in Iron Age IIA Philistia: New Evidence from Tell es-Safi/Gath, Israel," *Journal of Archaeological Science* (forthcoming).

29 D. Namdar, R. Neumann and S. Weiner, "Residue analysis of chalices from the repository pit," in *Yavneh I. The Excavation of the "Temple Hill"* (ed. R. Kletter, I. Ziffer, and W. Zwickel; OBO Series Archaeologica 30; Fribourg: Academic Press, 2010), 167 – 173; D. Namdar et al., "Hallucination-Causing Compounds in Votive Objects from an Iron Age Philistine Repository Pit, Israel," *Antiquity* (forthcoming).

30 Y. Gadot et al., "Chalices in Iron Age Philistia: Production, Function and Content" (forthcoming).

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Based on the findings of metal artifacts, during the early period of the Iron Age, bronze was still the most commonly produced metal in the Levant.[27] Very little, however, is known about the modes of production of bronze and iron and about the pace of transition from one metal to the other. N. Yahalom-Mack and A. Eliyahu-Behar's detailed excavation of a small Iron IIA (9th century B.C.E) area from a stratum at Tell es-Safi/Gath revealed the remains of a metal "workshop" that essentially comprised a few macroscopic metal associated artifacts (mainly a crucible, a few tuyère fragments and a piece of slag) and a fairly rich microscopic record. The microscopic data showed that bronze and iron alike were produced at the site, based on the analysis of a lined pit and another depression containing iron hammerscales.[28] The fact that so few macroscopic artifacts were found probably explains why such workshops could easily have been overlooked in other, more traditional excavations.

5. Ritual Practices in Ancient Israel

Information on ritual practices is most often derived from the macroscopic record, mainly in the form of architecture (temples, shrines, alters, etc.) and ceramic objects whose style might suggest some form of ritual practice. One such ceramic object is the so-called "chalice" – a bowl on a high leg-shaped base. Chalices are often found in ritual architectural contexts as well as in domestic contexts, which casts some doubt on their use as ritual objects. D. Namdar's analysis of the small lipid (fat) molecules preserved in voids inside the ceramic of chalices from an Iron IIA repository pit at the site of Yavneh in Philistia showed that many of the samples contained molecules that could produce fragrances and, in some cases, hallucinogenic effects – properties consistent with the use of chalices in a ritual context.[29] Similar molecules were found by our team in chalices from two other contemporary sites in Philistia.[30]

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27 Recently Y. Gottlieb, "The Advent of the Age of Iron in the Land of Israel: A Review and Reassessment," *Tel Aviv* 37 (2010): 89 – 110.

28 A. Eliyahu-Behar et al., "Iron and Bronze Production in Iron Age IIA Philistia: New Evidence from Tell es-Safi/Gath, Israel," *Journal of Archaeological Science* (forthcoming).

29 D. Namdar, R. Neumann and S. Weiner, "Residue analysis of chalices from the repository pit," in *Yavneh I. The Excavation of the "Temple Hill"* (ed. R. Kletter, I. Ziffer, and W. Zwickel; OBO Series Archaeologica 30; Fribourg: Academic Press, 2010), 167 – 173; D. Namdar et al., "Hallucination-Causing Compounds in Votive Objects from an Iron Age Philistine Repository Pit, Israel," *Antiquity* (forthcoming).

30 Y. Gadot et al., "Chalices in Iron Age Philistia: Production, Function and Content" (forthcoming).

The analysis of these ceramic derived lipid molecules (known as "residue analysis") is proving to be an important source of information in the Levant not only for identifying ritual practices, but also for deducing vessels' contents and from this information shedding light on topics such as foodways and trade. We are pursuing both of these questions.

In a detailed study of one area at Tell es-Safi/Gath we observed that there was a clear-cut correlation between the absence of lipids in ceramic fragments and associated sediments exposed to elevated temperatures. The latter determination was based on the alteration of the clays in the sediments in which the fragments were buried. We thus demonstrated that residue analysis studies should also begin in the field with a detailed study of the contexts in which the ceramics are found.[31]

6. The Mind of Ancient Israel and its Neighbors

Can modern research shed light on intellectual abilities of Iron Age Levantine people, such as mathematical capability? One way to address this is to use pottery vessels in order to evaluate the ability of people to carry out elaborate measurement in estimating the volumes of valuable commodities. Most pottery vessels, including those that served for trade, do not have a simple shape, e. g., cube, sphere or cylinder, and therefore estimating their volume requires a sophisticated knowledge, at least on the practical level (i. e., without awareness of complicated mathematical formulae).

An interesting example is the "torpedo"-shaped storage jar of the Iron IIB in the 8th century B.C.E. Torpedo jars have a cylindrical body, a pointed base and a right-angle rim. Petrographic analysis shows that they were produced in sites along the Phoenician coast.[32] Two shipwrecks with hundreds of "torpedo" storage jars were found in deep waters in the southeastern Mediterranean Sea off the coast of Ashkelon. A robot removed 22 of the vessels for further investigation.[33] The cargo found in the two shipwrecks seems to consist of a single loading "event," a single port of origin, a single commodity and possibly a single production center. I. Benenson, L. Zapassky and Y. Gadot measured these jars as well as other "torpedo" jars from land sites in Israel. The results show that the jars from the shipwreck constitute a special sub-type and evince a high level of standardiza-

31 Namdar et al., "The 9th Century" (see n. 19).

32 C.A. Aznar, *Exchange Networks in the Southern Levant during the Iron Age II: A Study of Pottery Origin and Distribution* (Ph.D. thesis; Cambridge: Harvard University, 2005), 66 – 68, 157 – 160.

33 R.D. Ballard et al., "Iron Age Shipwrecks in Deep Water off Ashkelon, Israel," *AJA* 106 (2002): 151 – 168.

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tion. Since the jars were produced in Phoenicia, where Egyptian culture had been greatly influential since proto-historical times, and since they were made for Egyptian customers,[34] we analysed their dimensions in Egyptian units. We noted a link between the units of length and volume: the height of the cylindrical part of the jar is close to one Egyptian royal cubit (52.3 centimeters). In the case that the circumference of the jar is one cubit and two palms, the volume is four Egyptian hekats (19.2 liters). This interesting relation between units of length and volume in storage jars built for maritime trade does not hold for the inland Judahite royal storage jars of the *lmlk* type, which were produced with a different system of measurements in mind.

Another strong connection to the intellect of Ancient Israel is the development of the Hebrew script. Scholars proposed a clear line of development for the ancient Hebrew letters according to the study of inscriptions (mainly ostraca).[35] These studies depend on the production of facsimiles and are therefore influenced by the subjective eye (and mind) of the scholar. A. Shaus, B. Sober and S. Faigenbaum – with the help of a team of physicists, chemists and mathematicians – aim to overcome this difficulty. Our first objective was to produce an automated facsimile of an ostracon. Attempts to do this using a laser that causes emission of a light signal from the surface of the ostracon (Raman spectroscopy) showed that the ink signal differs from that of the ceramic. Thus, the ink distribution can be mapped. However, the method is not practical due to the considerable amount of time required to produce a single facsimile. Spectral imaging of ostraca was also attempted using visual color and infrared wavelengths, in order to determine which wavelengths are optimum for improving the legibility of ostraca. Images taken around the optimum wavelength (in the region 500 – 800 nm) provide significantly improved readability compared to the usual color images of ostraca. The team also developed a facsimile quality evaluation method which enables different facsimiles to be compared for the same ostracon, allowing objective identification of the best facsimile.[36] The next and most important phase in this track will be the deployment of computerized methods in order to compare letters in dif-

34 L.E. Stager, "Phoenician Shipwrecks in the Deep Sea," in *Sea Routes: Interconnections in the Mediterranean 16th–6th c. BC* (ed. N. Stampolidis and V. Karageorghis; Athens: University of Crete and the A. G. Leventis Foundation, 2003), 233 – 247.

35 E. g., J. Naveh, *Early History of the Alphabet: An Introduction to West Semitic Epigraphy and Palaeography* (Jerusalem: Magness Press, 1987).

36 A. Shaus, I. Finkelstein, and E. Piasetzky, "Avoiding the Eye of the Beholder: Automated Ostraca Facsimile Evaluation" (forthcoming).

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V. Concluding Comment

This large and diverse project is already producing interesting results that shed light on ancient (biblical) Israel. The hallmarks of this project involve our development of new analytical techniques and approaches to many different problems, our integration of field work with laboratory work including laboratory work in the field, and our focus on an approximately 600 year period that was undoubtedly a fascinating time in the Levant. Although the project is just half way along, we expect to produce new insights into the archaeology of this period and illuminate problems related to the history of ancient Israel. We also anticipate developing new methods and approaches that can be applied to many other periods and regions throughout the world.

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