Industrial apiculture in the Jordan valley during Biblical times with Anatolian honeybees

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Although texts and wall paintings suggest that bees were kept in the Ancient Near East for the production of precious wax and honey, archaeological evidence for beekeeping has never been found. The Biblical term "honey" commonly was interpreted as the sweet product of fruits, such as dates and figs. The recent discovery of unfired clay cylinders similar to traditional hives still used in the Near East at the site of Tel Reḥov in the Jordan valley in northern Israel suggests that a large-scale apiary was located inside the town, dating to the 10th–early 9th centuries B.C.E. This paper reports the discovery of remains of honeybee workers, drones, pupae, and larvae inside these hives. The exceptional preservation of these remains provides unequivocal identification of the clay cylinders as the most ancient beehives yet found. Morphometric analyses indicate that these bees differ from the local subspecies *Apis mellifera syriaca* and from all subspecies other than *A. m. anatoliaca*, which presently resides in parts of Turkey. This finding suggests either that the Western honeybee subspecies distribution has undergone rapid change during the last 3,000 years or that the ancient inhabitants of Tel Reḥov imported bees superior to the local bees in terms of their milder temper and improved honey yield.

Apis mellifera | domestication | biogeography | climate change | Iron Age IIA

Egyptian wall paintings and Ancient Near Eastern texts suggest that bees were kept for the large-scale production of precious wax and honey (1–3). However, actual evidence for beekeeping in antiquity had not been found before the recent discovery of what appears to be a well-organized apiary at Tel Reḥov in the middle Jordan valley in northern Israel (Fig. S1*A*) (4, 5). Tel Reḥov is one of the largest Iron Age sites in Israel. A city 10 ha in area flourished there between the 12th and 9th centuries Before Common Era (B.C.E.). The apiary includes ≈30 hives (of 100–200 estimated) that were made as unfired clay cylinders. The hives have a small hole on one side for the bees to enter and exit and a lid on the opposite side for the beekeepers to access the honeycomb (Fig. S1 *B–D*). Three rows of such hives were located in a courtyard that was part of a large architectural complex that was severely destroyed, most probably at the end of the 10th or beginning of the 9th centuries B.C.E. (Fig. S1*D*) (4–6). In terms of Biblical historiography, this period corresponds with the United Monarchy of David and Solomon and the beginning of the kingdom of northern Israel. The location of such a large apiary in the middle of a dense urban area is puzzling because bees can be very aggressive, especially during routine beekeeping practices or honey harvesting. It is conjectured that this location was dictated by the need to protect the valuable hives (1–3).

The objectives of the current study were to confirm that the clay cylinders were indeed ancient hives, and, contingent on affirming this objective, to gain insights into beekeeping practices during ancient times. The contents of several clay cylinders were examined and were found to contain remains of honeybees from a subspecies different from the race currently local to Israel and the surrounding region. These findings identified Tel Reḥov as the location of the most ancient apiary yet found in situ and suggest that beekeeping already was an elaborate agricultural practice in Israel 3,000 years ago.

Results

Three radiometric dates of grain found spilled from a broken storage jar just east of the hives produced a calculated average ^{14}C calibrated date of 2735 ± 25 y B.P. and calibrated dates in 68% probability (1σ) are 897–891 (8.4%), 881–836 (59.8%) B.C.E. and in 2σ are in the range of 923–826 (95.4%) B.C.E. These radiometric dates are slightly later than eight measurements of two samples previously taken from concentrations of grain in the destruction debris to the west of the hives (6). The calculated average date of all three measurements is 2767 ± 6 y B.P. The calibrated dates in 68% probability are 968–964 (3.1%), 924–896 (55.6%), 873–862 (9.5%) B.C.E., and in the 2σ, the range is 970–840 B.C.E. (Table S1 and Fig. S2). This calibration suggests a date between the end of the United Monarchy and the foundation of the Omride Dynasty in northern Israel.

Two of the hives contained charred honeycomb remains with many honeybee body remains embedded in a dark, shiny, solid material (probably made of sugars mixed with other material from bees and honeycombs (Fig. S3). Most of the bee remains were identified as workers based on the typical anatomy of the head, compound eyes, legs, or sting apparatus (Fig. 1 *A* and *B* and Fig. S3, *Top*). In addition to hard cuticular structures, remains of soft tissues such as thoracic flight muscles, brains, eyes, and internal organs in the abdomen were clearly identifiable (Figs. 1 *C* and *D*). Remains of drones were found which could be distinguished from workers by their much larger compound eyes and the morphology of the mouth parts (Fig. 2*A* and Fig. S3, *Bottom*), and remains of larvae and pupae, which are preadult life stages with a relatively soft external skeleton, were found (Fig. 2*B*).

The question arose whether the bees kept in these hives were indeed the local subspecies *Apis mellifera syriaca* that is characterized by highly developed defensive behavior and therefore is unsuited to keeping adjacent to human settlements (7–9). The Western honeybee *Apis mellifera* is classified into approximately two dozen subspecies that, based on single nucleotide polymorphism (10), morphometric analyses (11), and mitochondrial DNA polymorphism (12), commonly are organized into four major geographically and evolutionary distinct groups: western and northern Europe (M), eastern Europe (C), the Near East and central Asia (O), and Africa (A) (Fig. S4). To classify the ancient honeybees, the

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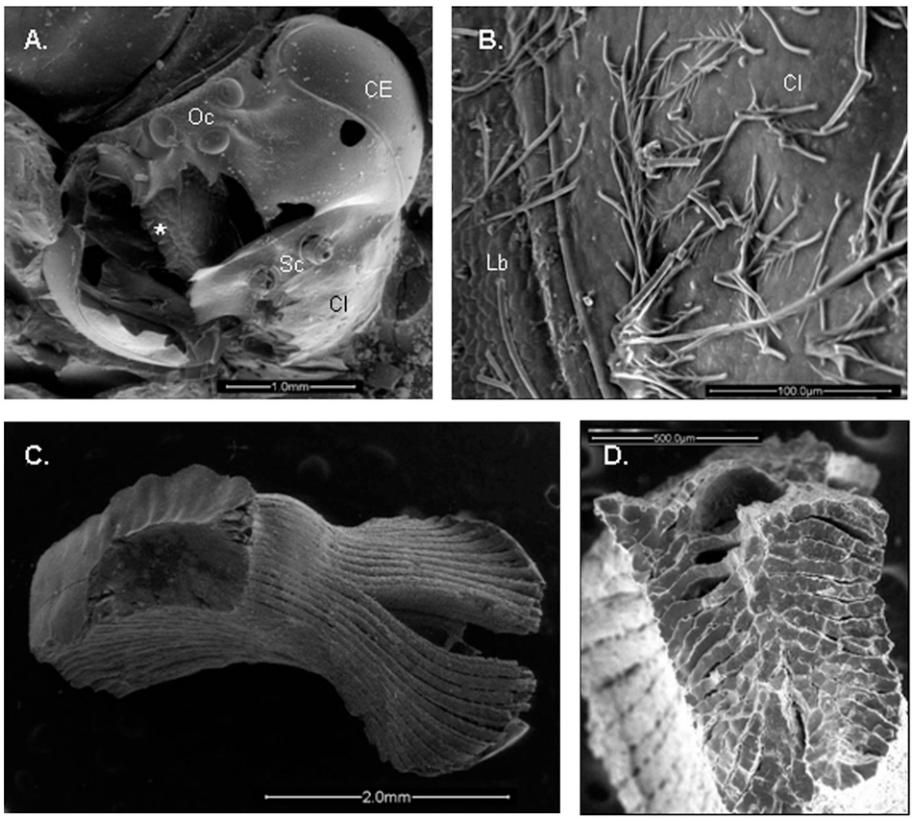

Fig. 1. Micrographs of remains of worker bees from the Tel Reḥov apiary. (*A*) A dorsal view of a worker head. The asterisk indicates remains of internal eye and brain tissue. (*B*) Frontal part of a worker head showing branching hairs. (*C*) Thoracic flight muscles, dorsal part facing upward. (*D*) A horizontal cut through the thoracic flight muscles. CE, compound eyes; Cl, clypeus; Lb, labrum; Oc, ocelli; Sc, scape segment of the antenna.

material from the hives was screened rigorously for well-preserved remains. Although most remains were fractioned or damaged, relatively well-preserved remains of 17 wings and several dozen legs were identified, which were subjected to detailed examination under an environmental scanning electron microscope (ESEM). One hind leg and two wings with clear cells were of sufficient quality to allow us to perform morphometric measurements comparable to those available for present-day subspecies over the entire distribution range of *A. mellifera* (13).

The hind leg showed a complete and well-conserved femur attached to the trochanter and coxa (Fig. S5*A*). The length of the femur (2.68 mm) was at the extreme end of the range of the local

Table 1. Summary of morphometric analyses comparing bee remains from the Tel Reḥov with representative samples of bees from present-day subspecies

Subspecies	Hind leg Femur	Second cubital cell*		Third submarginal cell*	Evolutionary branch
		All-branch analysis	O-branch analysis	O-branch analysis	
A . m. mellifera	0.264	<0.0001			M
A. m. sicula	0.969		<0.0001	<0.0001	C
A. m. carnica	0.886			0.008	C
A. m. macedonica	0.621	0.006			C
A. m. cecropia	0.503	—	<0.0001	<0.0001	C
A. m. ligustica	0.653	<0.0001			C
A. m. caucasica	0.156	<0.0001	<0.0001	0.147	O
A. m. anatoliaca	0.630	0.994	0.999	0.821	O
A. m. meda	0.188	0.000002	<0.0001	<0.0001	O
A. m. cypria	0.302		<0.0001	<0.0001	O
A. m. adami	0.220		<0.0001	0.024	O
A. m. syriaca	0.103	<0.0001	<0.0001	<0.0001	O
A. m. lamarckii	<0.0001	<0.0001			A
A. m scutellata	0.001	<0.0001			A
A. m. jemenitica	<0.0001	<0.0001			A
A. m. ruttneri	0.539		<0.0001	<0.0001	A
A. m. intermissa	0.934	<0.0001			A

The Syrian subspecies , its neighbors, and the Anatolian subspecies are shown in bold. Additional subspecies for which the femur length differed significantly from the Tel Reḥov bee (outside the 5–95% confidence limits) are presented in Table S1.
**P* value was obtained from a discriminant analysis with all PC scores. Values show probability of erroneously rejecting the null hypothesis.

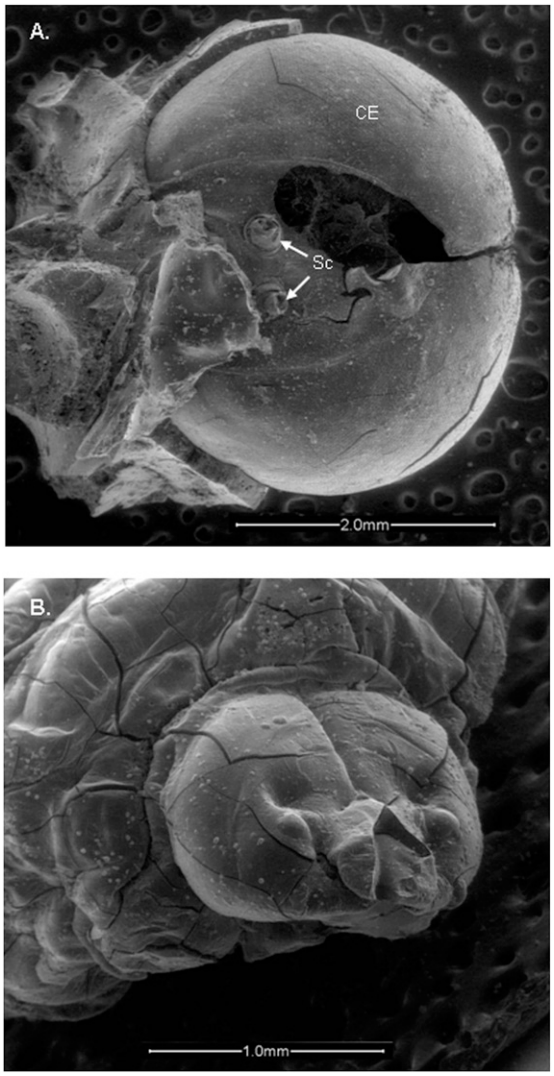

Fig. 2. Micrographs of a drone head (*A*) and larva (*B*). Abbreviations are as in Fig. 1.

A. m. syriaca and the Persian subspecies *A. m. meda*, the nearest neighboring subspecies of *A. m. syriaca* to the north. It was significantly different from the Egyptian bee *A. m. lamarckii*, the neighboring subspecies to the south, all of the sub-Saharan subspecies ($P = 0.051$ for *A. m. capensis* from South Africa), and *A. m. iberiensis* from Spain. The measurement of this femur fell in the 25% and 75% percentile range of only eight subspecies, all belonging to the Near Eastern and eastern European lineages (Table 1 and Table S2). Of these subspecies, the one with the closest geographical distribution was the Anatolian bee, *A. m. anatolica*, from Turkey.

One of the wings has an intact second cubital cell (Fig. S5B) that initially was compared with subspecies from all four evolutionary branches. The principal components analysis (PCA) generated 10 significant principal components (PCs) (eigenvalues >1), which explained 91.8% of the measures' variation. The plot of the two PC scores indicated that the Tel Rehov sample belongs to the Middle and Near East (O) evolutionary branch. Notably, the wing values for the Tel Reḥov bee fall within the *A. m. anatoliaca* samples (Fig. S6 and Table 1). To refine the subspecies further, an additional analysis was performed with only subspecies typical to the Mediterranean and the Near East (including *A. m. adami*, *A. m. cypria*, *A. m. cecropia*, *A. m. ruttneri*, and *A. m. sicula*, which were not included in the first analysis). The PCA for this analysis again placed the Tel Reḥov sample in the middle of the *A. m. anatoliaca* samples (Fig. 3A) and outside the *A. m. syriaca* range. Discriminant analysis with all PC scores indicated the Tel Reḥov bee was significantly different from *A. m. syriaca* and all subspecies ($P < 0.0001$) other than *A. m. anatoliaca* ($P = 0.999$). The second wing remains had all three submarginal cells and a first medial cell, but only the third submarginal cell was informative for discriminating the subspecies. A PCA with the two first PC scores for subspecies of the Mediterranean and the Near East (including *A. m. carnica*, which was not included in the analyses of second cubital cell) positioned the Tel Reḥov sample outside the *A. m. syriaca* and *A. m. meda* sample range (Fig. 3*B*). In the complementary discriminant analysis with all PC scores, the Tel Reḥov bee differed from all the subspecies in the analysis ($P = 0.024$ for *A. m. adami*; $P = 0.008$ for *A. m. carnica*; $P < 0.0001$ for all other subspecies) except for *A. m. anatoliaca* ($P = 0.821$) and *A. m. caucasica* ($P = 0.147$) (Table 1).

Discussion

The Bible commonly refers to Israel as "a land flowing with milk and honey," but in only two cases does this description clearly refer to bee honey, both in relation to wild bees (Judges 14:8–9 and 1 Samuel 14:27). In no case does the Bible mention beekeeping as an agricultural practice, and the term "honey" commonly has been understood as sweet fruit secretion. The exceptional preservation of the bee and honeycomb remains that were discovered within the clay cylinders at Tel Reḥov provides solid and unequivocal identification of these containers as ancient beehives. To the best of our knowledge, this site is the most ancient apiary yet discovered in situ in the Old World. The estimated large scale of the apiary, its location in the middle of an urban area, the evidence suggesting a large number of bees in the hives, and the remains of drones and larvae all suggest that that beekeeping already was an important and well-developed practice in Israel during the 10th–9th centuries B.C.E. The location of such a large apiary within an urban area further suggests that the bees and hive products were valuable and needed to be protected. The honey and beeswax were highly prized as food ingredients and for a large number of other functions (1–3). For example, beeswax was used in the lost-wax technique of bronze melting. In this same period, copper was mined in the large mines of Feinan in the east of the Arabah valley (14), and perhaps copper from Feinan and the beeswax from Tel Reḥov were used in metal casting in the Jordan valley, recalling the Biblical reference to bronze work that took place in the Jordan valley in relation to the construction of Solomon's temple in Jerusalem (1 Kings 7:46).

The remains of drones and brood (larvae and pupae) may suggest further that these forms were abundant in the hive at the time of its destruction. Brood and drones typically are most common during the spring and summer and are least common during the winter.

The morphometric analyses for three distinct morphological structures similarly rejected the hypothesis that the Tel Reḥov bees were the local *A. m. syriaca*, its neighboring subspecies *A. m. lamarckii* or *A. m. meda*, or any other subspecies except the Anatolian honeybee *A. m. anatoliaca* (*A. m. Caucasica* was rejected only in the analyses of the second cubital cell). The analyses of the wing cells are valuable specifically because of their size-independence, avoiding possible confounding effects of changes in organ size because of the effects of heat or time. Individual variation is unlikely to account for our results, because our statistical analyses rely on a large and representative database of present-day subspecies.

A possible explanation for our findings is that the geographical distribution of the honeybee subspecies 3,000 years ago was different from today and that bees other than *A. m. syriaca* were prevalent in the north of Israel. Changes in geographical distribution over time commonly are explained by changes in climate or by genetic traits that allow animals to adapt to new habitats. The Western honeybee originated in Africa and subsequently

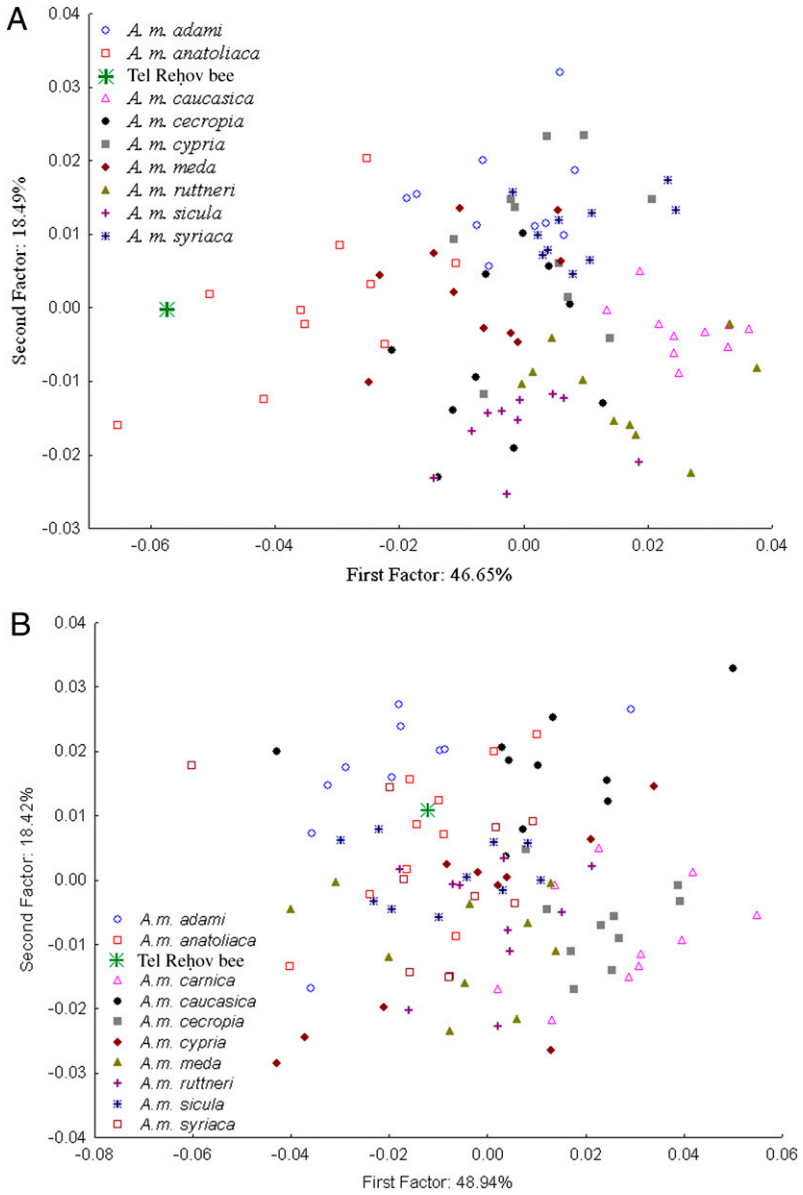

Fig. 3. Scatterplots of the PCA for wing-cell samples from remains of bees from Tel Reḥov and present Near Eastern and Eastern European Apis mellifera subspecies. (*A*) Analysis for the second cubital cell. (*B*) Analysis for the third submarginal cell. Complementary discriminant analyses with data from all PC scores are summarized in Table 1. Micrographs for the samples used for these analyses are presented in Fig. S5. Wing cell nomenclature is based on ref. 28.

expanded into Eurasia in two or more independent ancient expansions (10, 15). The divergence among the subspecies is estimated at 0.7–1.3 million years (11, 16). Relative to this period of adaptation of each subspecies to its local climate and habitat, the ~3,000 years elapsed from the estimated destruction of the Tel Reḥov apiary is very short. The Anatolian bee *A. m. anatoliaca* resides mainly in areas characterized by high precipitation and cool climate, whereas Tel Reḥov is located in the Jordan valley, one of the warmest and driest regions in Israel. Was the climate during the 10th–9th centuries B.C.E. significantly different from now? Although there is no consensus concerning the climate in Israel during this period, it commonly is accepted that it was not significantly colder or wetter than today (e.g., refs. 17–19 and references therein).

Another possibility is that the inhabitants of Tel Reḥov deliberately imported bees most suitable for their industry. Indeed, the Syrian bee might be a poor choice for large-scale beekeeping within an urban setting such as Tel Reḥov because of its aggressiveness, high tendency to swarm, and low honey yield (7–9, 11, 20). Because of these traits, attempts to develop a modern beekeeping industry with *A. m. syriaca* bees in Israel and elsewhere in the Near East failed (7–9). The solution in the 20th century was to import honeybee races (such as the Italian bee *A. m. ligustica,* the Caucasian bee *A. m. caucasiaca*, and, in Jordan, the Anatolian bee as well) that are better suited for large-scale beekeeping (9, 21, 22). Comparative studies indicate that Anatolian bees are amenable to large-scale beekeeping and are superior to the Syrian bees in terms of their calm temper, propolis production, low robbing tendency, and three- to eight-times higher honey yields (e.g., refs. 20, 23, 24).

There is evidence that beekeeping was practiced in Anatolia during the Late Bronze Age (1); Hittite laws dated to the 14th–13th centuries B.C.E. contain severe punishments for thieves of bee swarms and hives (25). The Zenon papyri from Egypt suggest that transferring bees in portable hives or pottery jars was practiced in the third century B.C.E. (1). An Assyrian memorial stele

dated to the mid-eighth century B.C.E. (about 100–150 y later than the beehives at Tel Reḥov) describes the importation of honeybees from a country called "Habha," probably in the Zagros or Taurus mountains (modern day southeastern Turkey or northwestern Iran), about 300–400 km to the north or northeast of the land of Suhu on the Middle Euphrates (the modern border zone between Syria and Iraq) (26). This information suggests that long-distance transport of bees was technically feasible and could cover the ∼500 km separating the Taurus' southernmost ridges in Turkey and Tel Reḥov. However, to keep a pure Anatolian line, the Tel Reḥov beekeepers would have needed to requeen their colonies repeatedly or to import new swarms of bees. The honeybee queen mates while flying into congregation sites with drones from the surrounding area, and therefore virgin Anatolian queens would have been most likely to mate with local Syrian drones. Thus, keeping the Anatolian line requires not only sophisticated beekeeping skills but also reliable and easy supply lines. Finds at Tel Reḥov, such as imported pottery, amulets, and fish bones, indicate that during the 10th–9th centuries B.C.E. the city maintained trade connections with Phoenicia (the modern Lebanese coast), Cyprus, Egypt, and Greece. Although direct evidence for trade relations between Israel and Anatolia in this period was not found, such relations could have existed, either directly or indirectly.

Our discoveries indicate that bees were kept in Israel during Biblical times and that beekeeping was much more sophisticated 3,000 years ago than previously appreciated. The evidence that the honeybees at Tel Reḥov are not the local subspecies raises the possibility that the influence of human activities on honeybee distribution already was significant in ancient times.

Materials and Methods

Dark material differing from the surrounding clay in two adjacent cylindrical clay hives was collected and brought for a detailed analysis in the laboratory. Remains that were relatively intact were glued on carbon bands and introduced to the electron microscopy analysis using the Quanta 200 ESEM (FEI). The working conditions were accelerating voltage 15 kV and pressure 0.38 Torr. The imaging was done with secondary electrons imaging mode. The Sigmascan imaging system was used for measuring leg samples. The obtained values were compared with similarly measured values available for present-day subspecies at the Morphometric Bee Databank in Oberursel, Germany (http//www.institut-fuer-bienenkunde.de). This database includes 1,585 colony means, each taken from at least 10 worker bees (Table S2). Because it already had been demonstrated that a single wing cell can discriminate *A. mellifera* subspecies (27), the wing cells (following the nomenclature in ref. 28) were analyzed in relation to its shape in a size-independent comparison using elliptic Fourier descriptors (EFD) (29) in the SHAPE software package (30). The morphometric measurements for wings from the Tel Reḥov bee remains were compared with measurements for present-day subspecies from wing photographs of specimen from the Morphometric Bee Databank in Oberursel. For each subspecies, we measured 10 workers per colony from ∼10 different colonies. The variance–covariance matrix of 100 estimated EFD coefficients was used as input in a PCA. This procedure enables us to summarize the shape information and to reduce the dimensionality of the variables (31). The PCs with eigenvalues >1 were used for a complementary discriminant analysis that included all PC scores and in which we compared the Tel Reḥov bee with each of the subspecies. The PCA and the discriminant analysis were performed using Statistica 6.0 software.

Radiometric dates of the beehives come from three samples of charred grain found in the destruction debris covering the hives. In all three cases, a large amount of charred grain was found in the same place. Two of the samples (Loci 2422 and 2441) came from the destruction debris west of the hives; in Locus 8465 the grain was found spilled from a broken storage jar just east of the hives. In two of the samples, three repetitions were measured; in the third sample, five repetitions were measured; altogether there are 11 available dates from this context (Table S1 and Fig. S2). For measuring ^{14}C, proportional gas counting and accelerator mass spectroscopy methods were used. OxCal v.4.1.5 software [© Bronk Ramsey, 2010 (32)] was used to prepare the calibrated dates and graphs.

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