Subsistence practices in an arid environment: a geoarchaeological investigation in an Iron Age site, the Negev Highlands, Israel

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Abstract

The Negev Highlands (southern Israel) is an arid zone characterized by settlement oscillations. One settlement peak occurred in the early Iron Age IIA (late 10th and early 9th centuries BC). The most conspicuous structure in many sites of this period is an oval compound comprised of an internal courtyard surrounded by rooms. Two hypotheses for the function of these oval compounds are that they served as Israelite fortresses which guarded the southern border and routes of the Solomonic kingdom, or that they represent local agro-pastoral groups. In order to gather more information regarding the subsistence practices conducted in these oval compounds, we carried out a small-scale excavation at the site of Atar Haroa. We focused on sediment sampling and used several geoarchaeological, as well as isotopic, techniques in order to identify macroscopic and microscopic remains related to animal husbandry and crop agriculture. The remains identified from the archaeological sediments were compared with modern reference materials collected from abandoned Bedouin camps. The excavation included two half rooms and several test pits in the courtyard of the oval compound, featuring one Iron Age occupation level composed of gray sediments and relatively small amounts of pottery, bones and macro-botanical charred remains. Micromorphological, mineralogical, dung spherulite and isotopic analyses carried out on the gray occupational sediments from the rooms show that they originate from wood ash and dung, both used as fuel. Similar analyses of the gray sediments in the courtyard show that they originate only from degraded livestock dung. Phytolith analyses show that the gray anthropogenic sediments have similar concentrations of phytoliths as in control (yellowish) sediments and in the dung of winter free-grazing desert livestock and lichen-grazing black dwarf Bedouin goats. Phytoliths indicative of cereal crops are completely absent in the archaeological dung remains, indicating that cereal crops were not processed by the site inhabitants. Based on ethnographic and archaeological parallels, and on the presence of grinding stones and absence of sickle blades in the excavated rooms, we infer that the inhabitants at the oval compound at Atar Haroa subsisted on livestock herding and bought or exchanged cereal grains. Our results support the hypothesis that the inhabitants at the oval compound at Atar Haroa were desert-adapted pastoralists, rather than garrisoned soldiers.

Keywords: Negev Highlands; Iron Age; Atar Haroa; Fortress; Subsistence; Dung; Phytoliths; Nitrogen isotopes

1. Introduction

The Negev Highlands (Fig. 1a) is an arid region in southern Israel, characterized by a set of parallel, northeast-southwest oriented anticlines and synclines of Mesozoic and Cenozoic sedimentary rocks. Its elevation ranges from ca. 400 m above sea level in the north to ca. 1000 m in the south. Precipitation ranges around 100 mm per year. The vegetation is mostly Saharo-Arabian with an Irano-Turanian niche in the east. The combination of higher elevation, relatively better precipitation and alluvial wadi beds available for seasonal agriculture makes the Negev Highlands an improved
ecological niche for human activity relative to the areas surrounding it.

1.1. Archaeological background to the problem

The history of the Negev Highlands is characterized by sharp settlement oscillations (Rosen, 1987; Finkelstein, 1995). Several periods—the Early Bronze II, Intermediate Bronze, early Iron IIA, Nabatean, Byzantine and Early Islamic periods—feature relatively strong human activity, with remains of hundreds of sites spread across the region. Finds retrieved from excavated sites and from stone terraces and dams in valleys attest to seasonal agricultural activity at least in some of these periods. Other periods, such as the Middle and Late Bronze, most of the Iron Age and the Medieval periods, did not leave any material remains behind (but see Rosen et al., 2005 for dung in rock shelters dating to the so-called empty periods). Scholars have debated the reasons for these oscillations. Some related them to climatic changes (e.g., Rosen, 1987), and argued that periods with no remains reflect very low-profile human activity if not population void. Others (e.g., Finkelstein, 1995) explained the Negev Highlands oscillations on the background of socio-political and economic change within the local southern population, that is, as shifts along the nomadic-sedentary continuum.

This study focuses on the wave of settlement in the early Iron IIA (late 10th to early 9th centuries BCE, hereafter described simply as “Iron Age”; for the identification of this ceramic phase see Herzog and Singer-Avitz, 2004). About 400 Iron Age sites have been recorded in the Negev Highlands (e.g., Haiman, 1994; Cohen and Cohen-Amin, 2004), and a relatively large number of them (ca. 50) were excavated (Cohen and Cohen-Amin, 2004). The more elaborate sites include enclosed compounds (usually referred to as “fortresses”), houses and installations such as livestock enclosures, water cisterns, threshing floors and silos. Despite the thorough field investigation, the nature of these sites remains a matter of dispute. Some scholars see them as representing the activity of the Israelite United Monarchy (of the 10th century BCE) along the main trade routes in the desert (e.g., Cohen, 1979). Accordingly, they interpret the main component in many of the sites—the enclosed compound—as a fortress built by the northern authority in order to exert its control over the area. Other scholars see the sites as representing a sedentarization process of local, pastoral-nomadic groups (Rothenberg, 1967; Finkelstein, 1984). A middle of the road view reconstructs a settlement system that included fortresses, year-round settlements and seasonal camps (Haiman, 1994, 2003). Yet, all three theories face difficulties. For example, no evidence for military activity has so far been identified; the presence of livestock enclosures has never been proven; and the contemporaneity of the different features in a given site has not been verified.

Over half a century of archaeological research has not resolved this matter, which is crucial for deciphering the history of the arid zones of the Levant. One of the reasons for this gridlock is that past research did not deploy all possible tools of modern archaeology—even in the 1970s and 1980s, when they have already been available. Previous excavations focused on ceramics and stratigraphy, ignoring finds related to the subsistence economy and to the use of space within settlements. Fine-grid excavation and careful sieving, which could have retrieved important data on the daily life in the settlements under discussion, were not deployed. No full-blown study of the faunal assemblages, which could have shed light on the animal component in the subsistence economy, was conducted. Archaeobotanical studies (mainly after flotation of sediments from selected areas), which could have provided important data on the agricultural activity and other forms of exploitation of the environment, were not carried out. Also missing are data concerning activity areas within the settlements and statistical information which could have thrown light on the temporal evolution of a given site. As a result, the above-mentioned interpretations for the Iron Age wave of settlement remained speculative.

A full retrieval of information related to subsistence economy and activity areas is therefore essential for interpreting the nature of the Iron Age settlements in the Negev...
Highlands. In this article we present preliminary results of a study in the course of which we carried out a small scale modern-method excavation in one of the more elaborate early Iron IIA sites in the region, named Atar Haroa (Fig. 1b). This single-period site includes an oval compound (the "fortress") with a belt of broad-rooms surrounding a large courtyard, a group of pillared houses and what seemed to be a threshing floor. The site had been excavated in the 1960s by Cohen (1970) (Fig. 2), who unearthed three rooms in the oval compound and one four-room house north of it. Cohen identified the oval compound as an Israelite fortress that was built in the days of King Solomon in order to control the desert routes and the southern border of the kingdom. In each of the excavated rooms Cohen reported a gray-colored floor with signs of ashes, which he interpreted as evidence for the destruction of the site in the course of the military campaign of Pharaoh Sheshonq I (biblical Shishak—1 Kings 14: 25) in the late 10th century BCE. Sheshonq I mentioned sites in the Negev in his victory relief engraved on a wall of the Temple of Amun at Karnak in Upper Egypt. Cohen’s finds included northern and locally-made pottery, grinding stones and a few animal bones. In one of the loci he uncovered a hearth and cooking vessels. It is noteworthy that no arrow heads and/or sickle blades were found at the site. These finds characterize many other Iron Age sites in the Negev Highlands (Cohen and Cohen-Amin, 2004).

All past hypotheses implied that the inhabitants of the Iron Age sites in the Negev Highlands engaged in agro-pastoralism. Even those opting for a military interpretation argued that the soldiers who were garrisoned in the fortresses also engaged in seasonal agricultural activities (Haiman, 1994, pp. 50–51; Cohen and Cohen-Amin, 2004, p. 156). In the current study we specifically aimed at determining whether the inhabitants of Atar Haroa conducted an agro-pastoral way of life by comparing geoarchaeological indicators for agro-pastoralism from sediments, between Bedouin (traditional inhabitants of the Negev Highlands adapted to living in this arid environment) abandoned camps and the enclosed compound at Atar Haroa.

1.2. Ethnographic background to Bedouin society in southern Israel

The Bedouins are semi-nomadic tribal pastorlists who also conduct opportunistic small scale agriculture. Socio-economic changes and government restrictions in the 20th century forced them to change their traditional economic practices. The importance of pastoralism decreased due to the rise in the cost of living and government induced sedentarization programs. In parallel, an emphasis on market economy gained importance. Contemporary Bedouins in Israel live in either government-established Bedouin towns or in spontaneous tent and house settlements. The degree of sedentism decreases from the northern to the southern parts of the Negev (Ginguld et al., 1997; for detailed reviews on the Negev Bedouins see e.g., Marx, 1967; Abu-Rabia, 1994). In most cases current Bedouin camps are composed of one to five households.
Each household includes a tent and separate livestock enclosures for sheep, goats and camels. Donkeys may be corralled as well but mostly roam freely. Herds of sheep and goats range between 25 and 500 head per household (Perevolotsky and Perevolotsky, 1979; Perevolotsky et al., 1989; Ginguld et al., 1997). In the recent past camps were relocated seasonally for better exploitation of the limited natural resources and in order to improve the micro-climate conditions or the sanitary state of the camp surroundings. But with the establishment of permanent housing (made from cement or tin plates) the seasonal movement is disappearing (Ginguld et al., 1997).

Current economic activities of the Negev Bedouin differ from what is considered “traditional” Bedouin life-style, and thus from the subsistence economy of ancient agro-pastoralists who may have lived in this region. Still, the current study is based on the premise that societies adapted to survival in arid environments make similar use of the landscape and materials available in this landscape. Specifically, analogies can be derived for certain aspects of present-day Bedouin and Iron Age societies in the Negev Highlands (Wylie, 1988). The similar aspects are sheep and/or goat herding, climate, topography, soils, vegetation and exploitation of rangeland resources and herd management that are determined by the needs of people and their livestock. Therefore, the current study focuses on herd management practices and primarily on the identification of degraded dung remains as evidence for pastoralism. An in-depth study of dung remains can also reveal whether a pastoral society complements its subsistence by crop agriculture (see below).

1.3. Human subsistence practices through livestock dung analysis

Ethnoarchaeological accounts on Middle Eastern and Indian agro-pastoral societies have made it clear that the close relationship with livestock is often reflected in the use of livestock dung as building material and as a source of fuel (Watson, 1979; Kramer, 1982; Miller, 1984, 1996; Reddy, 1999; Anderson and Ertug-Yaras, 1998; see also Sillar, 1999 for similar observations in Peru and Bolivia). Ethnoarchaeological studies have also shown that animal dung kept by agro-pastoral societies represent a diet based on a mixture of wild and domestic plants. The animals are usually herded away from the site, feeding on wild vegetation, but their diet is supplemented by fodder of both wild and domestic plants. Indeed, contemporary Bedouin of the Negev supplement their herds’ diet by either storing bought hay stacks, a by-product of modern cereal harvesting, or by acquiring permits to have their herds graze on the stubble left in contemporary wheat fields (to the north of the Negev Highlands) after harvesting the crops (personal observations). Moreover, Bedouins sometimes grow their own crops which in bad harvest years are used to fodder their livestock. This custom is also known in other agro-pastoral societies (e.g., barley in Iran, sorghum in India and various legumes and grasses in the Levant—Watson, 1979; Reddy, 1997; Turkowski, 1969, respectively).

The dietary components of livestock thus reflect the socio-economic activities of their keepers. These dietary compositions may be reconstructed archaeologically in two ways, one through charred seeds in hearths that were fueled by dung (Miller, 1984, 1996; Reddy, 1999) and the other through the opaline phytolith composition in dung (Powers et al., 1989; Shahack-Gross et al., 2003, 2005; Albert et al., 2008). We therefore put much weight in this study on the identification of livestock dung in the sediments of Atar Haroa, its spatial distribution in the site, its state of preservation, and its preserved contents as either charred seeds and/or opaline phytoliths. Because this study aims at determining, among other questions, whether the courtyards in the oval compounds (the “fortresses”) were in fact used as livestock enclosures, our excavations were carried out in both the rooms and the courtyard of Atar Haroa.

Degraded livestock dung in archaeological sites can readily be identified using several geoarchaeological methods. Studies of dung remains in relatively humid climates around the world have been carried out since the 1980s (e.g., Macphail and Goldberg, 1985; Powers et al., 1989; Wattez et al., 1990; Courty et al., 1991; Brochier et al., 1992; Goldberg and Whitbread, 1993; Canti, 1997, 1998, 1999; Shahack-Gross et al., 2003, 2005; Albert et al., 2008). The indicators that can be used to identify degraded and burnt livestock dung listed in these studies include the presence of opaline phytoliths, dung spherulites, authigenic (i.e., in situ forming) minerals such as phosphate-minerals and gypsum, and calcium-oxalate druses. In addition, a micro-laminated undulating structure and sediment compaction due to trampling serve as micromorphological indicators. These studies were carried out using various techniques, most notably micromorphology, mineralogy and phytolith analyses. In this article we present a study on the remains of livestock dung in a desert environment (ca. 100 mm annual rainfall), in which we used the above techniques and a new application of stable nitrogen and carbon isotopic compositions. The study includes an ethnoarchaeological component in which dung from contemporary and abandoned Bedouin camps was subjected to similar geoarchaeological analyses as those conducted on the sediments from the oval compound at Atar Haroa.

2. Materials and methods

2.1. Modern reference samples

In order to be able to identify agro-pastoral activities through dung remains in the Negev Highlands’ dry climate we conducted a pilot study that focused on sampling livestock dung in abandoned Bedouin encampments, as well as sampling of fodder plants. This was done in two different sites, in the Yatir and the Nahal Avdat areas (Fig. 1). The Yatir encampment is located in a forested area on the border between the south Hebron hills and the Beer-Sheba valley (elevation ca. 800 m a.s.l.; precipitation ca. 300 mm annually). The Nahal Avdat encampment is located in the center of the Negev Highlands (elevation ca. 600 m a.s.l.; annual precipitation less than
100 mm). The encampment sampled in the Yatir area was abandoned a few weeks before our visit. The shepherd was still in the area and supplied information as to the encampment’s organization and herding practices. This site included two enclosures for sheep. One was used during the spring only, with the dung representing free grazing with no commercial supplements. The other enclosure was used during the summer and included dung of sheep that were both free grazing and foddered by a commercial mixture of grains. The encampment in the Nahal Avdat area had been in use between 1982 and 1984, and has not been frequented since. It was located with the help of a local Bedouin man who lived in this camp at his father’s quarters and herded his goats. The encampment, referred to locally as Wadi er-Ramliyeh, was inhabited by four families, each having their own tent. Each family owned camels, donkeys and black dwarf goats—all of them were free grazing and kept in different enclosures. It is noteworthy that “traditional” Bedouin pastoralism was based on herds of the black dwarf goat, a goat breed that is especially adapted to extremely dry conditions. This has been the main reason for sampling at the Nahal Avdat site.

Sampling in both the Yatir and Nahal Avdat sites was conducted by opening ca. 0.5 by 0.5 m test pits in the enclosures, to a depth where the contact between the organic matter and the soil below was identified. Bulk samples, ca. 10 g each, were placed in plastic vials. Block samples which included the organic matter and the soil below were carved out of the test pit profiles. All profiles were photographed and then covered. Control test pits of similar dimensions were opened tens of meters away from the abandoned encampments. Bulk sediment samples were collected into plastic vials and are referred to in this article as control sediment samples (or simply “controls”). With the help of the Bedouin guide we also sampled local fodder, for which he supplied information as to its palatability to the different animal species. Notably, he mentioned that the black dwarf goats favor grazing on local lichen (Ramalina maciformis). He added that free grazing animals in the region subsist on whatever is available with a typical cycle, in which annual grasses are grazed in the spring and their contribution to the diet becomes lowest towards the end of the winter. Therefore, in addition to the samples obtained through the ethnoarchaeological study, we collected fresh dung in various places in the Negev Highlands, noting the season of year and the defecating animal species.

2.2. Excavation at Atar Haroa

A small scale excavation at the Iron Age site of Atar Haroa (G.R. 1359 0352, elevation 555 m, annual precipitation ca. 100 mm) was conducted in May 2005. We opened two half rooms in the oval compound (ca. 6 m² in the east and 4 m² in the west), a ca. 5 m² extension from the eastern room into the courtyard, two test pits (ca. 1 m² each) in the courtyard, one test pit (ca. 1 m²) in the “threshing floor” to the south of the oval compound, and control pits away from the site (Fig. 2). The excavation was carried out in a fine-grid of 1 by 1 m squares, and all the excavated material had been sieved through 0.5 cm pore size. The sieved material was placed into plastic bags and was later hand-picked in the laboratory. A hearth that had been identified in Locus 1 (in the eastern room) was sampled into plastic bags and later subjected to flotation using a simple water tank and 0.5 mm sieve. Wood charcoal collected through flotation was sent for botanical identification. Macroscopic remains, including ceramics, possible flint artifacts, grinding stones and bones, were mostly hand-picked during the excavation. They are currently being studied. Several charred seeds and date pits were either hand-picked or picked after flotation, and are currently being studied; four of them have been submitted for radiocarbon dating after preliminary identification of the seeds. Bulk and block sediment samples were systematically collected during the excavation. Bulk samples were placed into plastic vials and blocks were sampled according to ordinary procedures with the aid of plaster of Paris due to the high friability of the sediments (Courty et al., 1989).

2.3. Analytical procedures

Bulk sediment samples were used for mineralogical, phytolith, spherulite and stable nitrogen and carbon isotopic analyses. Mineralogical identifications were conducted using Fourier Transform Infrared (FTIR) spectroscopy (Nicolet 380, Thermo Electron Corporation) following the well established procedure described by Weiner and Bar-Yosef (1990). Determination of the concentration of phytoliths in sediments as well as in dung and plants was done following the quantitative method of Albert et al. (1999). Analyses of phytolith morphologies are currently being done. Determination of the concentration of dung spherulites in sediments and modern dung follow the quantitative method of Albert et al. (1999), adjusted to total sediments rather than acid treated sediments. The modern dung samples were ashed in an oven at 550 °C for 4 h. About 1 mg of either total bulk sediment or ashed dung was weighed directly on a microscope slide, mixed with Entellan New (Merck) glue, covered by a cover glass and the dung spherulites were counted.

Block samples for micromorphological examination were impregnated by polyester resin according to conventional procedures, sawed into 5 × 7.5 cm sub-blocks from which 30 µm thick thin sections were prepared. All microscopic examinations, i.e., phytolith, dung spherulites and micromorphology, were conducted using a polarizing light microscope (Nikon, Labophot2-pol). Micromorphological samples were described following Bullock et al. (1985) and Courty et al. (1989).

A simple experiment was conducted in the laboratory in order to monitor for mineralogical transformations in the ash of the wood Tamarix aphylla. The experiment was initiated because gypsum crystals of various forms have been identified in ashy anthropogenic sediments at Atar Haroa (see below). The ash of tamarisk is composed of dehydrated biogenic gypsum (i.e., anhydrite; Weiner, pers. commun.; Tsartsidou et al., 2007), we therefore tested whether simple wetting and drying may transform the anhydrite ash (CaSO₄) back into gypsum (CaSO₄ · 2H₂O). Modern wood, bark and leaves of Tamarix

aphylla were ashed in an oven at 550 °C for 4 h. The mineralogical composition of the ash was determined using the FTIR technique. About 0.02 g of ash were placed in a glass dish and distilled water was added in small aliquots and let dry in room temperature. Grain mounted slides were prepared for the following conditions: 2 days in 5 ml, 6 days in 15 ml, 13 days in 40 ml, and 15 days in 50 ml. The last portion was subjected to FTIR analysis.

Sediment and modern dung samples for the determination of stable nitrogen and carbon isotopic compositions were prepared by dissolving carbonates in 6 N hydrochloric acid solution and washing with distilled water 3 times. The acid-insoluble fraction was dried at 60 °C for 24 h and the dry pellet was homogenized using mortar and pestle. Sub-samples of 2–3 mg were weighed into tin capsules (Elemental Microanalysis Ltd., Okehampton, UK, 3 × 5 mm² #D1002) and their δ¹³C and δ¹⁵N values were determined by combustion (1050 °C) in an elemental analyzer (Carlo Erba EA1108) linked to an isotope ratio mass spectrometer (Optima IRMS, Micromass, Manchester, UK). Three replicates of each sample were analyzed. Two samples of a laboratory working standard cellulose (calibrated for δ¹³C according to the PDB international standard), and two samples of Acetanilide standard (Elemental Microanalysis Ltd., #B20CC, calibrated for δ¹⁵N against air) were introduced every 12 samples and were used to calibrate each run. Correction was applied to account for the influence of a blank cup. The precision was ±0.1‰ for δ¹³C and ±0.15‰ for δ¹⁵N.

3. Results

In this preliminary report we describe the results of the excavation starting with the macro-stratigraphy followed by a short description of the macroscopic remains. These are followed by detailed descriptions of the micromorphological, phytolith, spherulite and isotopic analyses. A full description of the macroscopic finds, radiocarbon measurements and phytolith morphological analyses will be published in the final report of the project.

In general, the walls of the oval compound are built of local chert boulders (an outcrop of the Mishash chert formation is found a few tens of meters from the site). The floors (“beaten earth”) were reached in both excavated half-rooms below ca. 1 m of collapsed stones from the walls and roof. A single occupation layer was observed in Locus 1 while Locus 6 may have included 2 or 3 superimposed occupation layers. The depth of the floor in the courtyard (below the current surface) changes according to the topography of the hill, i.e., dipping toward the northwest; thus its depth in Locus 3 is ca. 10–20 cm below surface and ca. 60–70 cm below surface in Loci 4 and 7 (Fig. 2).

3.1. Macro-stratigraphy

The lowermost unit reached was sterile. It was composed of reddish-brown clay mixed with fragments of chert and limestone. The topmost part of this sediment was the surface on which human activities took place, i.e., the floors. In Loci 1 and 6, the uppermost 1–2 cm of the floors included many white nodules. Such nodules are absent in the floors encountered in Loci 4 and 7. The floors in both the rooms and the courtyard were covered by 2–10 cm thick gray-colored, fine sediment, identified as anthropogenic deposit (i.e., occupation debris; Fig. 3). The partial remains of a hearth were uncovered in the southeast corner of Locus 1. In the courtyard excavation the gray occupation debris appeared patchy (i.e., not forming a continuous layer).

The pottery from Atar Haroa dates to the early Iron Age IIA phase of the ceramic sequence in southern Israel (cf., Cohen, 1970 and see Herzog and Singer-Avitz, 2004). Two date palm pits collected from the gray deposit, one from each room, were AMS dated. The two results are different and show only slight overlap. The date obtained from the pit collected from Locus 1 range between 910 and 790 BC calibrated, 2σ, while the date obtained from the pit collected from Locus 6 range between 1120 and 890 BC calibrated, 2σ (E. Boaretto, pers. commun.). At this point we can only state that the radiometric dates indeed fall within the time frame of the Iron Age IIA period. More samples have been submitted for radiocarbon dating in order to try to narrow down the timing of habitation at the oval compound at Atar Haroa.

The gray deposits on the floors of the rooms and courtyard are covered by fine yellow loess sediment. In the room loci, the yellow loess sediment is mixed with large chert stones that represent the collapse of the walls and roof after the site had been abandoned. Similar stones “litter” the courtyard. They were found only close to the walls in Loci 3 and 8, and were absent further towards the central part of the courtyard in Loci 4 and 7. The thickness of the yellow loess sediment is ca. 70 cm in Loci 1, 4, 6 and 7, and varied between 10 and 20 cm in Locus 3. These variations show that the rooms as well as the inner northern walls of the oval compound served as “dust traps” for the yellow loess and that the yellow loess had accumulated after abandonment, i.e., is post Iron Age.

3.2. Macroscopic finds

The macroscopic finds include ceramics, grinding stones, bones, snail shells, wood charcoal, charred seeds, charred dung pellets, and possible fragments of mud bricks. The snail shells are intrusive, representing burrowing activity. Fresh, probable rodent coprolites were detected through dry sieving in the northwest corner of Locus 1, indicating that burrowing has been intensive. Pottery, grinding stones and a few charcoal fragments were found in the yellow loess fill in the room loci, but most of the finds relate to the floor and the gray deposit above it. The density of the finds is low compared to Iron Age strata at tell sites.

Preliminary identification of wood charcoal shows the presence of three species, all local desert trees and shrubs, namely Tamarix aphylla, Retama raetam and Populus euphratica (N. Lipshitz, pers. commun.).
3.3. Micromorphology and mineralogy of the stratigraphic units (micro-stratigraphy)

Complete micromorphological descriptions are given in Table 1. Reddish-brown sterile sediment is found above the limestone and chert bedrock in the courtyard. It is composed of calcite, clay and quartz where the sediment groundmass is calcitic clay in which quartz silt grains are randomly distributed. Chert rock fragments, calcitic nodules and fragments of snail shells also occur randomly in this sediment with no preferred orientation. The microstructure is highly granular to crumbly, possibly due to intensive bioturbation (Fig. 4a). The voids are compound packing, vughs and vesicles. Micro-morphologically, the fabric of this sediment seems to represent an extremely disturbed, poorly developed soil.

The floors encountered in the rooms are the topmost part of the sterile reddish-brown sediment. The groundmass is compact, composed of highly calcitic clay and includes anthropogenic debris (mostly charcoal and bone fragments). Gypsum and calcite nodules are abundant at the contact between the floor and the gray fill above it. Gypsum occurs as small (up to 6 mm) nodules showing a variety of crystal habits, including lenticular, prismatic and hypidiomorphic crystals. The gypsum seems to have been mostly developing into the groundmass rather than in voids. The microstructure is granular to crumb, including vughs and vesicles. Snail shell fragments are sometimes aligned horizontally (Fig. 4b). The courtyard floor lacks the gypsum nodules and compaction noted in the room floors.

The gray-colored sediment in the rooms (i.e., occupation debris) is very rich in micritic calcite and gypsum and also includes dahlite that originates from microscopic bone fragments. The calcite mostly derives from wood ash, showing characteristic pseudomorphs after calcium oxalate crystals (Franceschi and Horner, 1980). The “dirty” and micritic appearance of the gypsum possibly indicate that it originates from re-crystallization of the anhydrite ash produced by Tamarix aphylla, identified among the charred wood remains (S. Weiner, pers. commun.; Tsartsidou et al., 2007; and see Section 3.4. below). The calcitic ash is partially re-crystallized, while the gypsic component is either re-crystallized in the form of nodules or present as gypsic micritic groundmass. Dung spherulites are abundant (Fig. 4c). Locus 6 includes three phases of floors and fills, each ca. 2 cm thick (Fig. 5a). The fill deposits include charcoal and bone fragments. Planar voids are present in addition to vughs and vesicles, and the microstructure is slightly laminated. The topmost deposit in Locus 6 is almost pure calcite, composed almost completely of dung spherulites (Fig. 4d). It also includes phosphate and gypsum nodules. This deposit has a massive structure, not including charcoal or bone fragments, and seems to have derived from degraded dung rather than from burned dung. Seven almost intact globular features, measuring ca. 1 cm in diameter, have been collected through flotation of the hearth material.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Location and description</th>
<th>Micromorphological description</th>
<th>Interpretation</th>
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<tbody>
<tr>
<td>RARB-1</td>
<td><strong>Locus 4, 553.62-553.90</strong></td>
<td>Lower: Basal reddish “soil”</td>
<td>Quartz silt and fine sand with occasional chert rock fragments and micritic calcite nodules in a calcitic clay groundmass. Many snail shell fragments. Granular to crumb microstructure. Vughs, vesicles, channels, chambers and compound packing voids.</td>
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<td>Middle: Gray sediment</td>
<td>Very few silt quartz grains in a calcitic clay groundmass including black speckles, organically stained areas and possible phosphate nodules. A few bone fragments are present and abundant dung spherulites. Granular to massive microstructure with vughs and vesicles.</td>
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<td></td>
<td>Upper: Yellow-gray mixed sediment</td>
<td>Quartz silt and fine sand grains in a calcitic clay groundmass. Many snail shell fragments, occasional microscopic fragments of charcoal and bones. Granular to crumb structure with vughs and vesicles.</td>
</tr>
<tr>
<td>RARB-2</td>
<td><strong>Locus 6, 553.50-553.45</strong></td>
<td>Possible mud brick</td>
<td>Yellow sediment with occasional chert rock fragments and micritic calcite nodules composed mainly of quartz silt and fine sand in a calcitic clay groundmass. Includes snail shell fragments. Massive microstructure with many large elliptical and elongated voids.</td>
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<tr>
<td>RARB-3</td>
<td><strong>Locus 1, 554.06-553.99</strong></td>
<td>Lower: Yellow sediment</td>
<td>Quartz silt and fine sand grains, sparitic limestone, and chert rock fragments in a calcitic clay groundmass. Snail shell fragments. Voids infilled with micritic calcite or hypidiomorphic gypsum crystals. Granular to crumb microstructure with vughs and vesicles.</td>
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<td></td>
<td>Middle: “floor”</td>
<td>Similar to above but more compact, including charcoal and bone fragments. Abundant and relatively large (a few mm in diameter) nodules of micritic calcite and gypsum aligned horizontally. Snail shell fragments aligned sub-horizontally.</td>
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<tr>
<td></td>
<td></td>
<td>Upper: Gray and black sediments</td>
<td>Dense clay, calcite and gypsum groundmass. Calcite and micritic gypsum derive mostly from wood ash. Wood ash shows signs of re-crystallization. Charcoal and bone fragments, abundant dung spherulites. Snail shell fragments are aligned. Vughs, vesicles and planar voids.</td>
</tr>
<tr>
<td>RARB-4</td>
<td><strong>Locus 1, 554.08-554.01</strong></td>
<td>Lower: yellow-brown sediment</td>
<td>Similar to the lower part in RARB-3 Basal turbated soil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle: dark brown sediment</td>
<td>Slightly burned part of the yellow sediment below, with abundant micritic calcite nodules.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper: Black and gray sediment</td>
<td>Calcitic and gypsic ashes with typical pseudomorphs after calcium oxalate crystals. Abundant dung spherulites, charcoal and other carbonized fibers, bone fragments. Porous structure with vertical drainage channels. The drainage channels reach the burned floor sediment where calcite nodules accumulate. Unburned snail shell fragments.</td>
</tr>
</tbody>
</table>
from Locus 1. In thin section, the material identified in these globular features is composed mostly of brown to black “amorphous” organic matter and occasional charred fibers and includes abundant dung spherulites (Fig. 4e). Based on these and the isotopic analyses (see Section 3.6. below), we identify the globular features as caprine dung pellets.

The gray-colored sediment that forms the occupation debris in the courtyard bears clear evidence that it has originated from ruminant dung. This observation is based primarily on the abundance of dung spherulites. The sediment is highly turbated and the dung remains are mixed with soil material. In places where somewhat intact dung deposits were identified, they appear as granular to massive rounded features composed of calcitic clay, including black speckles and areas that appear to be stained by organic matter (Fig. 4f). A few microscopic bone fragments are present as well.

The yellow-colored loess sediment that overlies the anthropogenic deposits is primarily composed of calcite, quartz and clay. Yellow-colored, porous, fist-size fragments of sediment were collected in Locus 5. Micromorphologically the sediment includes the same components as the local soils but is highly compacted and has a massive microstructure. It includes large

Table 1 (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location and description</th>
<th>Micromorphological description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RARB-5</td>
<td>Locus 6, 553.39-553.29</td>
<td>Yellowish -gray sediment</td>
<td>Highly turbated wood and dung ash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quartz silt and fine sand grains in a calcitic clay groundmass. Charcoal fragments, typical calcite pseudomorphs after calcium oxalate biominerals, dung spherulites, gypsum nodules, snail shell fragments. Granular to crumb microstructure with vughs and vesicles</td>
<td></td>
</tr>
<tr>
<td>RARB-6</td>
<td>Locus 6, 553.26-553.20</td>
<td>See description for same locus and elevations in sample RARB-7, below</td>
<td>Anthropogenic fill composed of wood and dung ash</td>
</tr>
<tr>
<td>RARB-7</td>
<td>Locus 6, 553.30-553.10</td>
<td>Lower: basal reddish-yellow soil Quartz silt and fine sand grains, and fragments of weathered limestone and chert in a calcitic clay groundmass. Gypsum nodules show either a radial arrangement of fibrous crystals or composed of micritic crystals. Micritic calcite nodules, snail shell fragments. Massive, prismatic and crack microstructures</td>
<td>Compacted local soil</td>
</tr>
</tbody>
</table>

Middle I: lower floors

Similar to above but more compact, with micritic gypsum as an integral part of the groundmass

Floor

Middle II: lower fills

Composed of five distinct layers, from bottom to top: 3-mm thick layer composed of quartz sand grains cemented by micritic gypsum; ca. 1-cm thick gray layer composed of calcite, gypsum and dung spherulites showing planar voids; massive yellow clayey sediment ca. 1 cm thick; ca. 5-mm thick black layer composed almost purely of calcitic ash and dung spherulites; ca. 1-cm thick layer composed of yellow clayey sediment

Five distinct episodes of anthropogenic activities alternating between using wood and dung as fuel, and preparing new floors from local sediments

Upper I: upper floor

The topmost part of the yellow clayey sediment mentioned above

Floor

Upper II: upper fill

Yellow-gray sediment (ca. 2 cm thick) in which dung spherulites form the groundmass. Nodules of micritic gypsum and amorphous phosphate are present

Dung remains

RAR-100b | Locus 1, 554.09 | Black globular feature, ca. 1 cm in diameter, collected after flotation | Highly porous material composed primarily of organic matter. The organic matter appears as brown-black fibers and black speckles. Dung spherulites are abundant. Other materials identified include gypsum and calcite nodules, quartz grains and snail shell fragments | Preserved, possibly charred, intact dung pellet of ovicaprine origin

For location of loci refer to Fig. 2. Levels are given in meters above sea level.
planar and lenticular voids, ranging from 5 to 20 mm in length (Fig. 5b). These properties are not known to occur in natural soils. We interpret this material as fragmented mud bricks that were tempered by vegetal material (cf. Fig. 5b and c).

In summary, the sterile reddish basal sediment shows evidence for extreme disturbance. Its uppermost part was compacted in the room loci and is marked by a laminar appearance of gypsum and calcite nodules, horizontally aligned snail shell fragments, and bone and charcoal fragments. The gray deposit in the room loci includes evidence for originating from both calcitic and gypsic wood ashes, as well as ashed and carbonized dung pellets. Evidence for vegetal tempered mud bricks was identified in Locus 5. The gray deposit in the courtyard loci differs from that of the room loci by lacking evidence.
for burning, which indicates that the dung remains in the courtyard had degraded in situ. The thickness of these deposits in the courtyard (2–10 cm after degradation) testifies to the large amounts of dung that had accumulated in this locality.

3.4. Mineralogical transformation of Tamarix aphylla wood ash

Mineralogical and morphological transformations in the ash of this wood species occur in the presence of distilled water (pH ≈ 6). FTIR analysis and microscopic observation show that the dry ash is composed of the mineral anhydrite in the form of rhombic shaped crystals in the wood and bark, and as micritic masses in the leaves (Fig. 6a and b). Calcite is also present in low amounts in the leaf ash. After submerging the ash in 15 ml of distilled water for 6 days most of the rhombic anhydrite pseudomorphs are still present and small spherulitic forms appear (Fig. 6c). These spherulites are ca. 6–12 μm in diameter and thus resemble dung spherulites in dimensions. They can be distinguished from dung spherulites by having low order black and white interference colors and by sometimes having a rosette-like structure in plane polarized light. After submerging the ash in 40 ml of distilled water for 13 days all of the rhombic ash crystals disappear. At this stage the dominant forms are micritic masses that include many spherulites and large hypidiomorphic crystals sometimes appearing as long fibers (Fig. 6d). Calcitic nodules also seem to have been formed, and large spherulites with high order interference colors are also present (Fig. 6d). FTIR analysis of ash that was submerged in 50 ml of distilled water for 15 days shows that it is composed of gypsum and monohydratecalcite (CaCO₃ · H₂O). These results show that where Tamarix aphylla was used as fuel in antiquity, gypsum nodules are expected to form after recrystallization in the presence of water. This recrystallization process seem to occur fairly fast (on the scale of days to weeks in laboratory conditions, thus possibly during one winter season in nature).

3.5. Phytolith and dung spherulite analyses

Phytolith and dung spherulites concentrations are presented in Table 2. Phytolith concentrations are lowest at the control sediment samples and the shrub samples, ranging from zero...
to hundreds of thousands of phytoliths per 1 g sediment or plant ash. Phytolith concentrations in modern livestock dung that we collected in the Negev Highlands and Yatir areas ranges from hundreds of thousands up to almost 10 millions in 1 g of ashed dung—amounts comparable in its upper limits to that of a local annual grass (Fig. 7). A relationship exists between phytolith concentrations and seasons of the year. Concentrations are highest in dung collected fresh during the spring and lowest in dung collected fresh during the winter, the latter is at the same range as those of both control sediments and local shrubs (Fig. 7). Concentrations in modern dung and modern fodder materials were calculated per 1 g of ashed sample. Numbers separated by commas (,) indicate several different samples. Note that the average error on these measurements is ca. ±30%.

3.6. Stable nitrogen and carbon isotopic compositions

The results of isotopic measurements performed on the organic material present in modern livestock dung, archaeological and control sediment samples are presented in Table 3. The carbon isotopic compositions range between −15‰ and −25‰, (Fig. 9), where the lightest compositions indicate organic matter that derives from C3 vegetal input and the heaviest composition indicates a mixture between C3 and C4 vegetal input. Modern dung and archaeological gray sediments from Atar Haroa have similar ranges of δ15N values, all of them heavier than 9‰ (Fig. 9). These values are distinctively higher than values

Table 2
Concentrations of phytoliths and dung spherulites (expressed as millions in 1 g sediment) in modern and archaeological samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Phytolith concentration</th>
<th>Dung spherulites concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern dung</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black dwarf goats (free ranging, 1984)</td>
<td>Nahal Avdat (Wadi er-Ramliyeh)</td>
<td>0.2</td>
<td>37</td>
</tr>
<tr>
<td>Camels (free ranging, 1984)</td>
<td>Nahal Avdat (Wadi er-Ramliyeh)</td>
<td>4.9</td>
<td>100</td>
</tr>
<tr>
<td>Donkeys (free ranging, 1984)</td>
<td>Nahal Avdat (Wadi er-Ramliyeh)</td>
<td>1.8</td>
<td>90</td>
</tr>
<tr>
<td>Goats (spring 2005)</td>
<td>Nahal Aqrab</td>
<td>9.6</td>
<td>200</td>
</tr>
<tr>
<td>Camels (spring 2005)</td>
<td>Nahal Aqrab</td>
<td>5.2</td>
<td>4</td>
</tr>
<tr>
<td>Camels (winter 2005)</td>
<td>Nahal Haroa</td>
<td>0.9</td>
<td>13</td>
</tr>
<tr>
<td>Sheep (free ranging, spring 2005)</td>
<td>Yatir</td>
<td>6.3</td>
<td>5</td>
</tr>
<tr>
<td>Sheep (free ranging + supplements, summer 2005)</td>
<td>Yatir</td>
<td>4.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Black dwarf goats (in captivity, 2006)</td>
<td>Zoological Garden, Tel-Aviv U.</td>
<td>4.8</td>
<td>0</td>
</tr>
<tr>
<td>Ibex (free ranging, autumn 2006)</td>
<td>Avdat</td>
<td>3.6</td>
<td>62.5</td>
</tr>
<tr>
<td>Archaeological gray-colored sediments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Courtyard gray sediment</td>
<td>0.06, 0.02, 0.02</td>
<td>0.01, 0.0005, 0</td>
<td>0.3, 76.3</td>
</tr>
<tr>
<td>Atar Haroa Floated dung pellet</td>
<td>0.3</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Locus 1</td>
<td>0.1</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Locus 6</td>
<td>0.001</td>
<td>3.5, 76.3</td>
<td></td>
</tr>
<tr>
<td>Control sediments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Southwest of site</td>
<td>0.01, 0.0005, 0</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Southeast of site</td>
<td>0</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Nahal Avdat (Wadi er-Ramliyeh)</td>
<td>North of site</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Yatir Northeast of site</td>
<td>0.7</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Basal reddish soil</td>
<td>0.003, 0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Atar Haroa Upper yellow loess</td>
<td>0.3</td>
<td>4.0, 0.8</td>
<td></td>
</tr>
<tr>
<td>Fodder from the Negev</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramalina maciformis</td>
<td>Lichen, preferred by black goats</td>
<td>0.2</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Peganum harmala</td>
<td>Perennial, preferred by donkeys</td>
<td>0.05</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Anabasis articulate</td>
<td>Shrub, eaten by camels and goats</td>
<td>0.01</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Stipa capensis</td>
<td>Annual grass, prevalent in the Atar Haroa vicinity</td>
<td>15.2</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Artemisia sieberi</td>
<td>Shrub, Atar Haroa vicinity</td>
<td>0.1</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Concentrations in modern dung and modern fodder materials were calculated per 1 g of ashed sample. Numbers separated by commas (,) indicate several different samples. Note that the average error on these measurements is ca. ±30%.
obtained from control sediments (Fig. 9). One of the globular shaped features, identified using micromorphology and spherulite analysis as caprine dung pellet, is composed of ca. 10% carbon and obtains the highest $\delta^{15}N$ value ($18^{\circ}$). Clearly, nitrogen isotopic compositions may serve as another indicator for the identification of archaeological dung remains. The results reported here show that the gray sediments found on the floors at Atar Haroa have originated from livestock dung. Based on this conclusion, we note a difference in the C3 content between modern dung and archaeological dung that may reflect higher input of C4 vegetation in the latter.

### 4. Discussion

This study provides, for the first time, quantitative and unequivocal evidence relating to the formation processes in an Iron Age site in the Negev Highlands and to the subsistence practices of its inhabitants. The site is characterized by relative scarcity of macroscopic finds. The macro- and microscopic artifacts and materials identified in this study include grinding

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**Table 3** Results of stable carbon and nitrogen isotopic measurements for samples from modern dung from Nahal Avdat (Wadi er-Ramliyeh) and Atar Haroa

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\delta^{13}C$</th>
<th>Standard error</th>
<th>$\delta^{15}N$</th>
<th>Standard error</th>
<th>% C</th>
<th>% N</th>
<th>C/N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wadi a-Ramliyeh</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black dwarf</td>
<td>$-24.62$</td>
<td>$0.50$</td>
<td>$13.49$</td>
<td>$0.03$</td>
<td>$36.43$</td>
<td>$2.72$</td>
<td>$13.39$</td>
</tr>
<tr>
<td>Camels</td>
<td>$-23.38$</td>
<td>$0.08$</td>
<td>$14.02$</td>
<td>$0.34$</td>
<td>$17.90$</td>
<td>$1.65$</td>
<td>$10.88$</td>
</tr>
<tr>
<td>Donkeys</td>
<td>$-23.65$</td>
<td>$0.29$</td>
<td>$11.03$</td>
<td>$1.22$</td>
<td>$19.24$</td>
<td>$1.63$</td>
<td>$11.78$</td>
</tr>
<tr>
<td>Control</td>
<td>$-21.32$</td>
<td>$0.47$</td>
<td>$6.38$</td>
<td>$2.25$</td>
<td>$0.40$</td>
<td>$0.05$</td>
<td>$7.98$</td>
</tr>
<tr>
<td>Atar Haroa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dung pellet</td>
<td>$-21.32$</td>
<td>$0.82$</td>
<td>$17.51$</td>
<td>$0.79$</td>
<td>$10.50$</td>
<td>$0.83$</td>
<td>$12.70$</td>
</tr>
<tr>
<td>Courtyard I</td>
<td>$-19.11$</td>
<td>$0.54$</td>
<td>$12.31$</td>
<td>$1.22$</td>
<td>$2.27$</td>
<td>$0.18$</td>
<td>$12.53$</td>
</tr>
<tr>
<td>Courtyard II</td>
<td>$-19.47$</td>
<td>$0.10$</td>
<td>$14.38$</td>
<td>$0.03$</td>
<td>$1.35$</td>
<td>$0.13$</td>
<td>$10.36$</td>
</tr>
<tr>
<td>Control I</td>
<td>$-23.61$</td>
<td>$0.10$</td>
<td>$7.15$</td>
<td>$0.37$</td>
<td>$0.82$</td>
<td>$0.09$</td>
<td>$9.49$</td>
</tr>
<tr>
<td>Control II</td>
<td>$-15.80$</td>
<td>$0.55$</td>
<td>$5.21$</td>
<td>n.m.</td>
<td>$0.32$</td>
<td>$0.04$</td>
<td>$8.11$</td>
</tr>
</tbody>
</table>

The large standard errors reflect sample heterogeneity. n.m, not measured.

---

**Fig. 7.** Plot showing the distribution of phytolith concentrations (as number of phytoliths per 1 g of sediment or per 1 g of ashed dung or plant material) in modern dung samples, gray sediments from the oval compound of Atar Haroa, control sediments and fodder plants collected at the Negev Highlands. Note that the range of concentrations is significant in the modern dung samples, possibly reflecting seasonality ($Sp$ = spring, $Su$ = summer, $Au$ = autumn, $W$ = winter), while the range of phytolith concentrations in the archaeological sediments and in the controls is very small. Note also that the phytolith concentrations in the archaeological sediments are most similar to concentrations encountered in winter free grazing in the Negev Highlands, in free ranging black goats and in local shrubs, while higher concentrations reflect input of grass to the livestock diet. The apparent similarity in phytolith concentrations between the controls and archaeological sediments does not indicate a similar origin, as reflected in both higher concentrations of dung spherulites and elevated $\delta^{15}N$ values in the archaeological sediments (see text).

**Fig. 8.** Plot showing the distribution of dung spherulite concentrations (as numbers of spherulites in 1 g of sediment or ashed dung) in modern dung, gray sediments from Atar Haroa “fortress” and control sediments. Note that spherulite concentrations in the archaeological gray sediments are in the same range as that of modern dung samples and distinctively higher than their concentrations in control sediments. These results serve as an indication that the archaeological gray sediments originate from degraded livestock dung.

**Fig. 9.** Plot showing the relationship between carbon and nitrogen isotopic compositions of the organic matter from modern dung samples (full line oval), archaeological gray sediments (dashed line oval), and control sediments. Note the $\delta^{15}N$ values typical of modern dung and their similarity to the values obtained from the archaeological gray sediments, as compared to the controls. These results serve as an indication that the archaeological gray sediments originated from degraded livestock dung. Note also the apparent difference in $\delta^{13}C$ values between the modern dung and archaeological dung. This may reflect climatic differences and should be further investigated.
stones and ceramic vessel remains and very few bones and charred seed remains, clear evidence for livestock dung in the site’s courtyard, and the use of dung as fuel in the hearth identified in Locus 1. These finds indicate that activities at the site where primarily domestic. It is noteworthy that sickle blades and arrow heads are totally absent from ours as well as Cohen (1970) findings. Only a few sickle blades were found in the many excavations of early Iron Age II A sites in the region (Cohen and Cohen-Amin, 2004, p. 142; see discussion below). There is no evidence for a catastrophic destruction of the oval compound at Atar Haroa. The ashy deposits found in both room loci originated from domestic hearths and the scarcity of macroscopic finds indicates that planned abandonment took place in antiquity.

The presence of a few pottery sherds, one half grinding stone, and fragments of mud bricks in the rubble above the gray living horizons probably indicates that the inhabitants of the site used the roofs for certain activities. The use of roofs for storage and summer activities in desert environments is well documented (Kramer, 1982; F. H. Cushing, 1882-3). After abandonment and wall/roof collapse, the site has been partially covered by yellow loess. Based on these sedimentological considerations, it is obvious that the “threshing floor” located south of the oval compound, whose floor is the upper part of the yellow loess unit, must date to recent times. Note that terraced stream beds in the Negev Highlands, also found in the vicinity of Atar Haroa, mostly date to the Roman/Byzantine periods (Goldberg, 1984).

4.1. Material identification and formation processes

The local sediment that was present during the Iron Age is composed of poorly developed reddish-brown clay mixed with limestone and chert fragments. It is highly turbated, probably by snails whose shells are abundant in the sediments in and around the site, but presumably also due to anthropogenic activities in the area during the Iron Age. Gypsum is present in the archaeological levels as well as the reddish basal sediment but seems to be absent from the yellow loess unit. Notably, gypsum nodules are abundant in the floors and gray deposits of the rooms but are absent in the courtyard sediments. The gypsum occurs as long fibers, lenticular and hypidomorphic deposits of the rooms but are absent in the courtyard sediments. The presence of a few pottery sherds, one half grinding stone, and fragments of mud bricks in the rubble above the gray living horizons probably indicates that the inhabitants of the site used the roofs for certain activities. The use of roofs for storage and summer activities in desert environments is well documented (Kramer, 1982; F. H. Cushing, 1882-3). After abandonment and wall/roof collapse, the site has been partially covered by yellow loess. Based on these sedimentological considerations, it is obvious that the “threshing floor” located south of the oval compound, whose floor is the upper part of the yellow loess unit, must date to recent times. Note that terraced stream beds in the Negev Highlands, also found in the vicinity of Atar Haroa, mostly date to the Roman/Byzantine periods (Goldberg, 1984).

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The local sediment that was present during the Iron Age is composed of poorly developed reddish-brown clay mixed with limestone and chert fragments. It is highly turbated, probably by snails whose shells are abundant in the sediments in and around the site, but presumably also due to anthropogenic activities in the area during the Iron Age. Gypsum is present in the archaeological levels as well as the reddish basal sediment but seems to be absent from the yellow loess unit. Notably, gypsum nodules are abundant in the floors and gray deposits of the rooms but are absent in the courtyard sediments. The gypsum occurs as long fibers, lenticular and hypidomorphic crystals, but also as micritic masses. All of these crystallitic admixtures are present in the experiment (Fig. 6). Tamarisk species are known to include biogenic minerals composed of gypsum in their tissues (Storey and Thomson, 1994). Upon burning, the gypsum looses its water molecule and transforms into anhydrite while keeping the shape of the crystals, i.e., crystals that are pseudomorphs of anhydrite after gypsum (Fig. 6a). The anhydritic ash undergoes processes of re-crystallization to various degrees when subject to episodes of wetting and drying in water which results in neo-formation of gypsum (Fig. 6c and d). The presence of gypsum nodules in the reddish basal sediment in the room loci is caused by infiltration of sulfate-rich solutions from the gray deposits above them. This conclusion is reinforced by the presence of vertical drainage channels that occur in the gray deposits and end at the contact of the gray deposits with the reddish floor sediment. Indeed, gypsum and calcite nodules most abundantly occur at this contact between the floor and the gray deposit. The presence of monohydrocalcite indicates that carbonate is also present in the ash of tamarisk, and possibly also formed due to diffusion of atmospheric CO₂ into the water in the experimental setup. We note that the monohydrocalcite in the experiment appears as relatively large (up to 45 μm) spherulites that exhibit high order interference colors (Fig. 6d). Monohydrocalcite is highly unstable in ambient conditions and is thus rare in nature. It readily transforms into the more stable mineral calcite. Indeed, we have not identified monohydrocalcite in the archaeological sediments but did observe calcitic nodules, as mentioned above.

The absence of gypsum in the gray courtyard sediments indicates that tamarix ash was not present there in sufficient amounts to form secondary nodules, which also explains the absence of gypsum nodules in the basal reddish sediment in the courtyard of the oval compound. The fact that gypsum first crystallizes as small spherulites that appear somewhat similar to dung spherulites may result in either overestimation of dung spherulite presence in sediments that formed from tamarisk ash re-crystallization, and/or a complete misidentification of degraded dung remains. It is therefore essential to support the identification of degraded dung remains by as many lines of evidence as possible, and in this context a mineralogical identification of sediments containing small-sized spherulites is important.

Clearly, dung remains are present both in the courtyard and the rooms. They are identified based on the high abundance of dung spherulites and the high nitrogen isotopic value of the organic matter left in the gray sediments found on the floors. In the courtyard the dung signal is somewhat mixed due to turbation processes, while dung spherulites are quite abundant in the rooms’ gray deposits and seem to have mainly originated from the use of dung as fuel. Although contemporary Bedouins in the Negev do not use dung as fuel (preferring to use Retama sp. for this purpose), this practice is well documented in other areas in Asia (e.g., Miller, 1984 in Iran; Anderson and Ertug-Yaras, 1998 in Turkey; Reddy, 1999 in India). The use of dung as fuel is characteristic of areas where wood fuel is scarce and also characterizes societies whose socio-economy is at least partially dependant on livestock (e.g., Watson, 1979 for Iran; Sillar, 1999 for highland Peru). The use of dung and tamarisk wood as fuel, the latter considered as the least preferred source of fuel by contemporary Bedouins of the Negev, may indicate that the environmental conditions around Atar Haroa during the Iron Age occupation were harsher than in modern times. The difference in the carbon isotopic composition of dung between the modern and archaeological samples that we have analyzed so far (Fig. 9) shows more reliance on C₄ vegetation grazing in the Iron Age
dung samples. Most C4 plants in the Negev environment belong to the Chenopodiaceae, a plant group that is adapted to arid and saline conditions and mostly includes small shrubs (Shomron et al., 1981). Most of the grasses in Israel follow the C3 photosynthetic pathway. It seems that Iron Age livestock in the Negev Highlands region browsed more on C4 plants than modern livestock. The possibility that this disparity indicates a climatic difference, i.e., more arid conditions during the Iron Age relative to the modern era, should be further investigated.

4.2. Characteristics of dung from arid environments

The dung remains identified at Atar Haroa are substantially different from published accounts on the identification of livestock dung (e.g., Shahack-Gross et al., 2003, 2005; but see also Macphail et al., 1997). The major differences are in the concentration of phytoliths and in the micromorphological features. Previous studies have noted that dung in livestock enclosures includes large amounts of phytoliths and that a sub-horizontal microlaminated structure develops due to trampling (Shahack-Gross et al., 2003, 2005). In this study we show that phytolith concentrations in dung collected in various locations and seasons in the Negev have a large range (Fig. 7). High phytolith concentrations have been obtained from fresh dung collected during the spring when annual grasses are available for grazing. As conditions turn drier, phytolith concentrations become lower (Fig. 7), indicating that the main species available for grazing are shrubs and leaves of woody species generally known to produce less phytoliths per mass of dry matter than grasses (e.g., Albert et al., 1999; Tsartsidou et al., 2007 and references therein). Evidence of stabilizing and foddering employing tree-shredding or leaf hay that also resulted in low amounts of phytoliths, have also been documented in European sites (Boschian and Montagnani-Kokelji, 2000; Macphail et al., 1997). We therefore conclude that the low concentrations of phytoliths in the archaeological dung remains from Atar Haroa are the result of a diet based on low-phytolith-producing fodder. The possibility that phytoliths were present in the sediments and dissolved after abandonment is unlikely as the soils in the Negev are calcitic with a pH range of about 7–8, and water availability to promote intensive dissolution of opal is low.

Two modern samples of dung have concentrations of phytoliths similar to those obtained from the archaeological sediments, i.e., winter free grazing by a camel and year-round free grazing by black goats. This similarity indicates that herds were either kept at the site during the winter only, and/or that the herds were composed solely of black goats. Black goats are highly adapted to desert conditions. They graze on almost all plant species and prefer the lichen Ramalina maciformis as fodder (Bedouin guide I. Kashchar, pers. commun.; Noy-Meir, 1974; Garty et al., 1995). The concentration of phytoliths in Ramalina maciformis is ca. 0.1 million phytoliths in 1 g of lichen ash. Preliminary results of phytolith morphological analysis indicate that the majority of opaline phytoliths from Ramalina maciformis (ca. 90%) do not have consistent morphologies. These results indicate that a diet based on this lichen species will result in dung with low concentration of phytoliths, most of them without consistent morphologies. Similar attributes characterize the dung remains identified at Atar Haroa oval compound. More research into the phytolith morphologies of Ramalina Maciformis is needed in order to unequivocally identify its remains in archaeological dung.

A major difference exists between dung remains in moist vs. dry climates. The dung of livestock fed on grasses that are abundant in moist climates is rich in grass phytoliths. Trampling of such dung will result in a microlaminated structure and its degradation results in the formation of authigenic phosphate minerals (Shahack-Gross et al., 2003, 2005). The dung of free grazing livestock in dry environments such as the Negev Highlands is characterized by low concentrations of phytoliths, absence of a microlaminated structure after trampling and only occasional authigenic phosphate minerals. Dung spherulites are usually absent after degradation in moist climates, possibly due to dissolution (Canti, 1997, 1998, 1999; Brochier et al., 1992). On the other hand, the conditions in dry climates promote their preservation. Thus, indicators for the identification of degraded dung of free grazing animals in dry climates are merely two—presence of dung spherulites and elevated δ15N values. The nitrogen isotopic composition of dung has so far been indirectly analyzed in studies related to manuring practices (Bol et al., 2005; Choi et al., 2002; Simpson et al., 1999). These studies highlighted the empirical observation that degraded organic matter is enriched in the heavy nitrogen isotope. Similar results have been obtained from modern and archaeological livestock enclosures in Kenya (Shahack-Gross et al., 2008). Here we report the application of this isotopic technique for the identification of dung remains in an arid environment.

The quantitative determination clearly shows that the gray sediments in Atar Haroa are enriched in dung spherulites relative to control sediments (Fig. 8). There is no correlation between the spherulites concentrations in modern dung to either species, season of the year or grazing area. Similar observations were reported by Canti (1997, 1998, 1999).

4.3. Archaeological and historical implications

Overall, the Iron Age inhabitants of the oval compound at Atar Haroa were clearly engaged in livestock herding. The low concentrations of phytoliths in the dung remains indicate that the animals were free grazing, mostly on low phytolith producing plants (e.g., tree leaves and shrubs) and possibly on lichens. The absence of dendritic long cell phytoliths that are indicative of domestic cereals shows that the diet of herded animals was not supplemented with agricultural by-products. Recent studies in Iron Age sediments from Tel Dor, an urban site located in the Mediterranean zone of Israel, identified many white and gray layers composed almost purely of phytoliths and interpreted as dung remains (Shahack-Gross et al., 2005; Albert et al., 2008). These layers have concentrations of phytoliths in the range of several to tens of millions in...
1 g sediment, and include 3–8% of dendritic long cell phytoliths out of the total phytolith assemblage, testifying that a part of the fodder was based on domestic cereals. The complete absence of phytoliths indicative of domestic cereals such as wheat and barley indicates that the herds kept at Atar Haroa were not fed chaff left after cereal agricultural processing and did not graze on the stubble left in fields after the harvest.

The data in this study imply therefore that the Iron Age inhabitants of the oval compound at Atar Haroa did not practice cereal agriculture, as it is highly improbable that they would not have fed their herds on their agricultural by-products and graze them in their fields after the harvest. One may suggest that this is an indication that the site was occupied seasonally—only in the winter (and that in the summer the inhabitants moved further north, e.g., to the Beer-Sheba valley where dry-farming is better attested). Yet, the quality of construction at the site, as well as finds such as imported northern vessels and grinding stones, seem to oppose this option. This means that the Iron Age pastoralists that inhabited the oval compound at Atar Haroa were sedentary.

Near Eastern pastoralists may become sedentary if they engage in a secondary source of livelihood such as agriculture, exploitation of desert resources needed in the sedentary lands, or trade (e.g. Cribb, 1991, p. 39; for various models see Awad, 1959; Finkelstein and Perevolotsky, 1990). An example from the modern era is the manganese mines of Umm Bugma in western Sinai, which encouraged Bedouin settlement in their vicinity. Recent excavations at the site of Khirbet en-Nahas in Wadi Feinan (in the northern Arabah south east of the Dead Sea) have shown that between the late 12th century and the mid 9th century BC it was the largest copper production center in the entire Levant (Levy et al., 2004, 2005). Activity at Atar Haroa covers the later part of this time-span. The exceptional prosperity at Khirbet en-Nahas and along the routes leading from it to the Mediterranean ports (e.g., through the Beer-Sheba Valley) could have provided the inhabitants of Atar Haroa and other sites in the Negev Highlands with a secondary source of livelihood and thus enable sedentarization without practice of agriculture. The gradual replacement of the Arabah copper by copper from Cyprus in the course of the 9th century BC could have brought about the decline of the Negev Highlands settlement phenomenon (Finkelstein, 2005; Fantalkin and Finkelstein, 2006).

It therefore seems that the inhabitants of the oval compound at Atar Haroa were engaged in full time pastoralism and that they did not practice seasonal dry-farming in the alluvial floodplains near the site. The absence of sickle blades from this site, as well as from other contemporary sites in the Negev Highlands (Cohen and Cohen-Amin, 2004, p. 142), supports this conclusion. The presence of grinding stones indicates that the inhabitants did process grain, which they must have acquired from sedentary communities further to the north through trade or exchange. This conclusion is further supported by the fact that cereal grains cleaned from chaff after threshing are devoid of phytoliths (Tsartsidou et al., 2007). Indeed, pottery vessels which were made in urban centers in the sedentary lands found at the site (Cohen and Cohen-Amin, 2004; and our excavation) attest for connections with such northern sedentary communities. Such a system of exchange could have been carried out on a routine basis if the Negev Highlands sites were part of a desert polity which included urban and village communities in the Beer-Sheba Valley and the Nahal Besor Region; we refer to the large urban site of Tel Masos and villages such as Arad, Tel Esdar, Beer-Sheba and Nahal Yatir, which also date to the early Iron Age IIA (Finkelstein, 1995, pp. 103–126). In any event, our finds render the military fortress interpretation for the oval compound at Atar Haroa highly unlikely.

5. Conclusion

The results presented in this study are the first step in reconstructing the subsistence economy of Iron Age sites in the Negev Highlands and investigating their formation processes and activity areas. The emerging picture, through the application of a multitude of modern archaeological and scientific approach, is that the oval compound at Atar Haroa represents habitation by caprine herding pastoralists that supplemented their diet with bought or exchanged grains; they did not practice seasonal dry-farming. Our results add to the current knowledge regarding the socio-economic adaptation of human populations to survival in harsh environments. Finally, our study shows that the site had not been destroyed in a military assault.

The implications from this study are important for understanding broader issues related to the subsistence economy in arid areas of the Levant and beyond, and for investigating the relationship between the inhabitants of these areas with nearby sedentary communities and central authorities. Overall, this is the first step to understanding the mechanisms behind the settlement oscillations in the Negev Highlands.

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