# The Iron Age copper industrial complex: A preliminary study of the role of ground stone tools at Khirbat en-Nahas, Jordan

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**Abstract:**

The first industrial revolution in the southern Levant crystallized during the Iron Age when copper production reached scales never before seen in this part of the Middle East. Ever since copper ore was first smelted during the Chalcolithic period, the Arabah valley, and its widespread distribution of copper mineralization, was the main source for copper ore in the region. The main ore deposits are located in Timna (Israel) in the southern part of the valley, and some 105 km to the north, in the Faynan region (Jordan). Faynan is the largest copper ore resource zone in the southern Levant. Excavations at the Iron Age Faynan site of Khirbat en-Nahas and the recent final publication of that project have revealed peaks in industrial-scale production during the $10^{th}$ and $9^{th}$ centuries BCE. However, the role of ground stone tools in the Iron Age copper industry in Faynan has not been systematically presented. This paper presents a preliminary study of the ground stone assemblage from one excavation season at Khirbat en-Nahas, thereby highlighting the great potential for ground stone tools research at the site. Using the *chaîne opératoire* method of technological study, this paper takes a quantitative approach to the typological, material, and spatial distribution of ground stone artefacts at Khirbat en-Nahas to understand their role in copper production. Ethnoarchaeological study of hereditary bronze casting workshops in southern India provides a compelling model of how ground stone tools played a critical role in one of the most important dimensions of metal production in all periods - recycling - in an Iron Age copper factory.

**Keywords:** ground stone tools; copper metallurgy; Faynan; Iron Age; Jordan; Khirbat en-Nahas

## 1. Introduction

Ground stone tools have been important components of human technologies since earliest prehistory (Goren-Inbar *et al.* 2002; de Beaune 2004). Changes in ground stone tool forms and abundance have been linked in general ways to major economic disjunctions related to food processing, such as shifts in primary foodstuffs and the beginnings of farming (*e.g.*, Wright 1991; 1994). But ground stone tools also play a critical role in manufacturing activities, including pottery-making, hide-processing, woodworking, textile production, and many others. What are the differences between ground stone tool kits related to food

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processing versus manufacturing activities? Can archaeologists define distinctive characteristics of ground stone tool kits that relate to particular manufacturing activities? How do manufacturing ground stone tool kits change with shifts in the context and scale of craft production? These questions have rarely been asked, much less answered. In fact, addressing them will require a body of systematically derived, quantitative data for ground stone assemblages from well-documented and dated archaeological contexts along with compelling ethnographic analogy. One example is a recent study of ground stone tools at a Middle Bronze Age copper mining and production site in Cyprus that suggests that differences between domestic and industrial tool assemblages are detectable and may be helpful in identifying mining, smelting, and casting activity locales (Webb 2015). In this paper, we provide a quantitative analysis of the typological, material, and spatial distribution of ground stone artefacts from the 2006 excavations at Khirbat en-Nahas, an Iron Age copper industrial complex in Jordan's Faynan region. We also present selected examples of microscopic use-wear analysis to show its potential for refining assessments of tool functions. Finally, using ethnographic data from hereditary bronze casting workshops in southern India, we suggest a model for how ground stone tools played a critical role in one of the most important dimensions of metal production in all periods - recycling - in an Iron Age copper factory.

### 1.1. Khirbat en-Nahas and the metallurgical landscape

Khirbat en-Nahas, or "ruins of copper" in Arabic, has been the focus of investigations since the Iron Age fortress was first identified in the early 20$^{th}$ century by the Moravian explorer A. Musil. The site was later recorded and made famous by N. Glueck during his archaeological survey of Jordan in the 1930's-1940's. A. Hauptmann of the German Mining Museum, Bochum began systematic excavations at Khirbat en-Nahas in the 1980's. Excavations were continued in adjacent areas at the site by T. E. Levy and M. Najjar in the late 1990's and into the 2000's as a joint project of the University of California, San Diego (UC San Diego) and the Department of Antiquities of the Hashemite Kingdom of Jordan (Levy & Najjar 2006). These excavations are part of a regional project called the Edom Lowlands Regional Archaeological Project (ELRAP). (See Figure 1.)

Khirbat en-Nahas is located within an Iron Age metallurgical landscape – one of the best preserved ancient mining and metallurgy districts in the world. The geologic setting of Khirbat en-Nahas is unique in Southern Jordan in terms of the availability of igneous and metamorphic rock outcrops exposed from the Massive Brown Sandstone formations and alluvial deposits. (See Figures 1 and 2.) The area forms the "north-eastern extension of the Afro-Arabian Shield" (Rabb'a *et al*. 1996) and is characterized by numerous outcrops of basalt-producing volcanic dykes and exposed formations of dolomitic limestone (Rabb'a 1994; Rabb'a *et al.* 1996). The Burj dolomite-shale formation (often referred to as the DSL or Dolomite Limestone Shale unit, *cf*. Hauptmann 2007) is the principal copper ore–bearing unit. The ruins of Khirbat en-Nahas are located on a stratum of Salib Arkosic Sandstone. The surrounding hills are comprised of the "basement" rocks consisting predominantly of Finan Granitic rock and Hunayk Monzogranite that were formed during the Late Proterozoic Age (Rabb'a 1994; Rabb'a *et al.* 1996). The wadis that run through the area are part of the Dead Sea catchment and drain through the Wadi Arabah to the northwest. Wadi Ghuweir is a perennial stream that fed agricultural fields in the vicinity of Khirbat Faynan during different cultural periods. (See Figure 3.)

### 1.2. Excavation areas

Khirbat en-Nahas was excavated by the UC San Diego – Department of Antiquities of Jordan team during three field seasons, in 2002, 2006, and 2009. As indicated above, only the

2006 ground stone assemblage is published here. The excavations revealed evidence that the industrial-scale copper production peaked during the 10th-9th centuries BCE (Levy *et al.* 2004; Higham *et al.* 2005; Levy *et al.* 2014b). In this paper, we focus on the 2006 excavation areas A, F, M, R, and T (Figure 4.). The majority of areas excavated at Khirbat en-Nahas appear to be the foci of copper production, rather than domestic activity spaces. Each area is briefly described below.

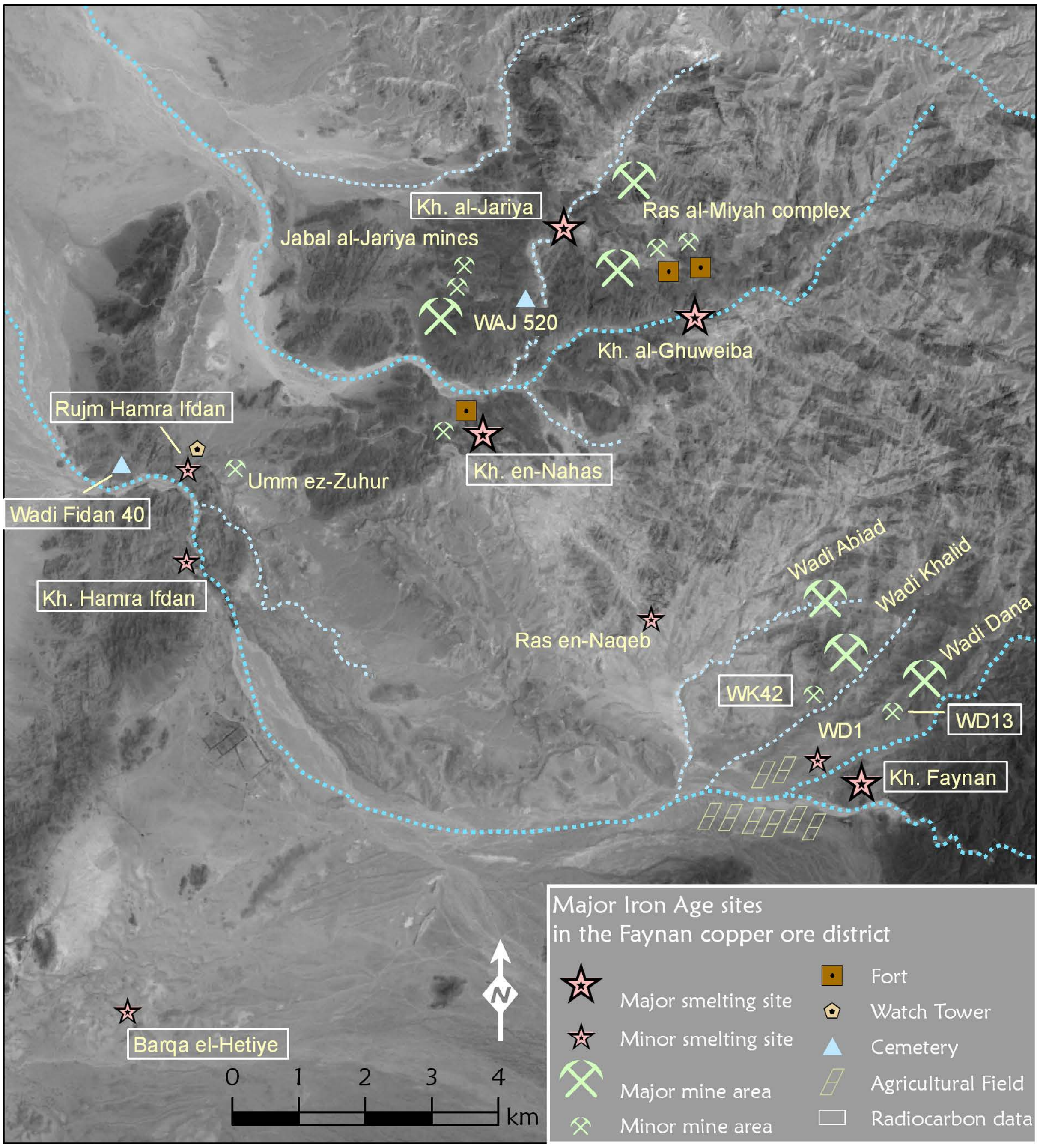


Figure 1. Map highlighting the major Iron Age sites and mining areas in the Faynan region of Jordan. The majority of these sites have been excavated and sampled by the UC San Diego Edom Lowlands Regional Archaeology Project (ELRAP) or the Deutsches Bergbau Museum. The area covers approximately 400 km$^2$. Khirbat en-Nahas has produced 118 high precision radiocarbon dates from stratified contexts. (Based on Levy *et al.* 2012: 200)

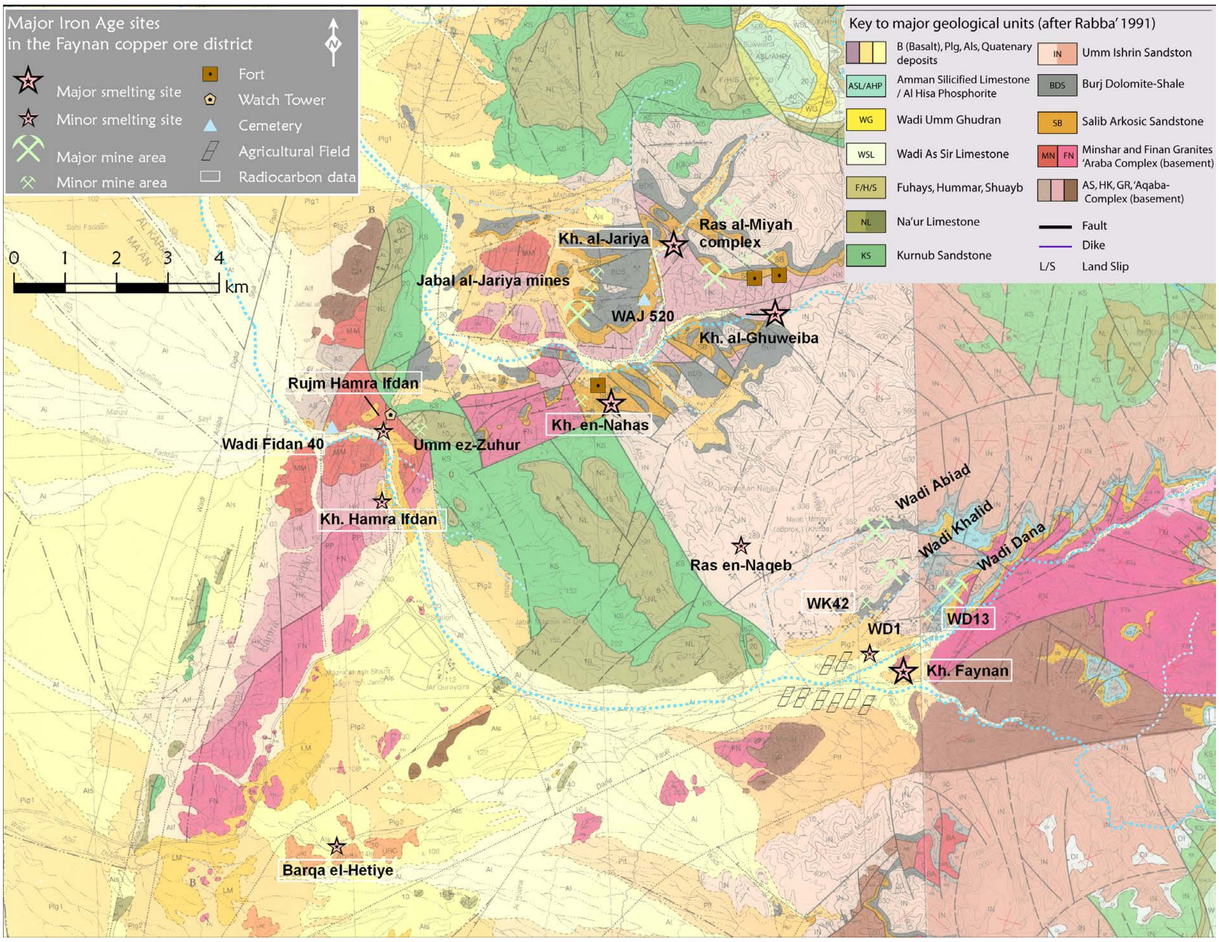

Figure 2. Simplified geological map of the Faynan region, Jordan with major Iron Age sites indicated. (Base map source: Rab'ba 1994.)

## Area A

A four-chambered gatehouse typical of Levantine Iron Age fortress architecture was revealed in Area A during 2002 (Levy *et al*. 2014b). Chambers 1 and 2 were excavated during that season, along with a probe at the base of the eastern side of the central passageway. There are two main building phases in the gatehouse. The monumental fortress gatehouse was first constructed during the 10$^{th}$ century BCE when large ashlar blocks were used to connect the gatehouse to the defence wall. In the following 9$^{th}$ century BCE, the gatehouse was decommissioned. At this time, the main passage was sealed, and the doorways to the various guard chambers were narrowed. During the 2006 excavation season, Chamber 3 and the central passageway were uncovered (Figure 5). In addition, two probes were opened on the north and south sides of the gate system. Extensive amounts of slag were removed from the central passageway, Chamber 3, and Probe 6. This suggests that, after the fortress gate's initial abandonment, the structure was reused for copper production. The majority of the ground stone artefacts from Area A were recovered from strata A1b and A2a. These strata correlate with the period of most intensive use of the gate system as a copper production facility and are $^{14}$C-dated to the mid- to late-9th c. BCE. The evidence of smelting in Area A closely corresponds with the chronology of copper production in other excavation areas at Khirbat en-Nahas.

## Area F

Excavation of Area F focused on sampling a section of the fortress wall to the northeast of Area A and an interior building inside the fortress walls. A building was uncovered on the south side of the wall (Figure 6) that was used to re-melt and refine copper after its initial smelting at Khirbat en-Nahas. The building consisted of two rooms and several smaller walled-off spaces. Two exceptionally large stone basins and one large standing stone were excavated in the western sector of Area F. Some slag was also found in this area. The building is interpreted as having been used for both cultic activities and copper re-smelting. The majority of ground stone artefacts were recovered from stratum F2a, a layer that yielded the most evidence for metal production in Area F. Tuyère pipes, glassy slag, and fragments of bellow pipes were mostly found only in this stratum (Levy *et al.* 2014b).

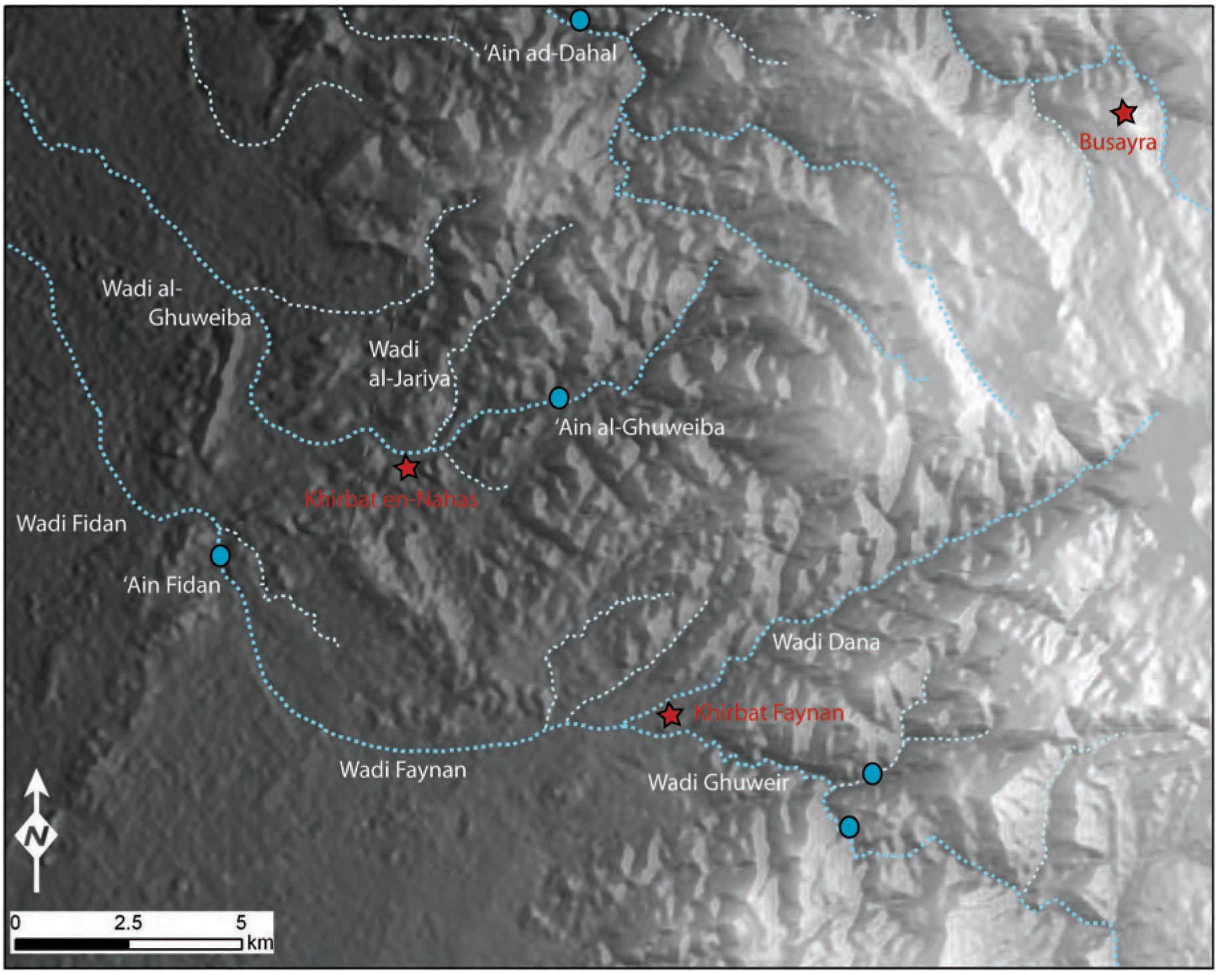

Figure 3. Map of the major drainage basins and springs (indicated by solid circles) in the area of Faynan, Jordan. The three most notable Iron Age archaeological sites are indicated by stars. (Based on Levy *et al.* 2014a.)

## Area M

Area M provides the deepest and best-preserved stratigraphic history of the site (Levy *et al*. 2008a). Excavation of Area M began in 2002 with a 1m probe into what appeared to be, from the surface remains, the site's largest slag mound. At that time, a building installation was uncovered in the south corner of the area. The building was further excavated in 2006 along with the adjacent slag mound (Figure 7). This revealed evidence of copper smelting activities and an additional building beneath the one that had been partially excavated in 2002. The stratigraphy of the slag mound section provides a comprehensive chronological index for the history of copper production at Khirbat en-Nahas. $^{14}$C dates from Area M demonstrate two phases of major industrial copper production in the 10$^{th}$ and 9$^{th}$ centuries BCE, with the building dating to the early 9$^{th}$ century BCE. A significant corpus of ground stone artefacts was excavated from Area M in 2006, and most of these artefacts are associated with periods of industrial-level copper production evident in strata M1b, M2a, and M2b (Levy *et al.* 2014b). Strata in Area M associated with the building are related to habitation rather than copper production and showed a lower density of ground stone artefacts.

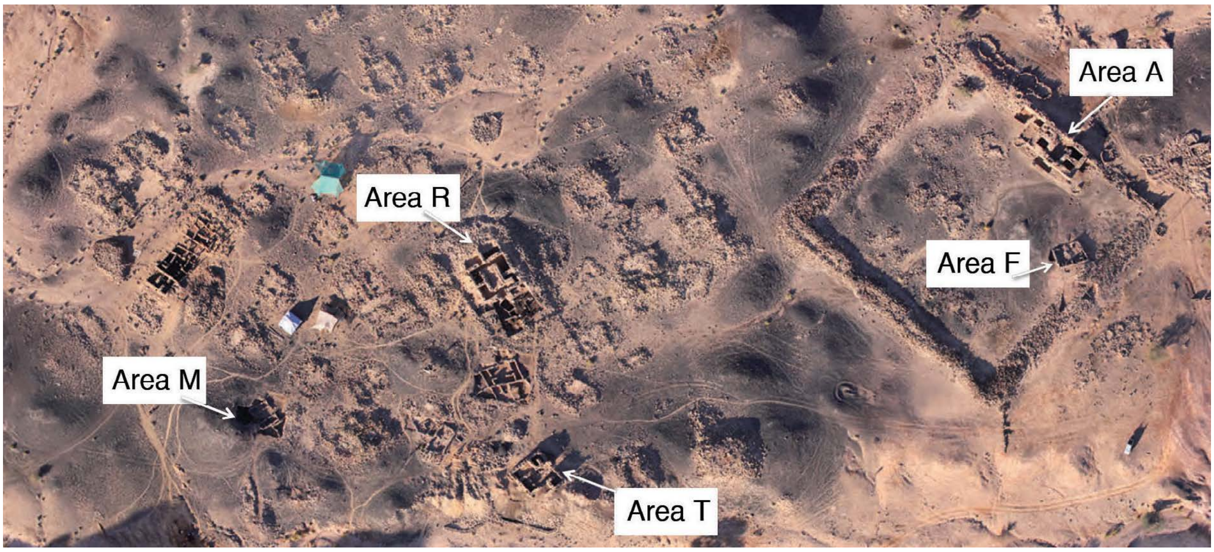


Figure 4. Image composite of Khirbat en-Nahas (ca. 10 ha; square fortress = ca. 73 x 73 m). Photographed from altitude of approximately 200 m. Areas A, F, M, R, and T were excavated in 2006. For scale, note the pick-up truck at lower right. Modified from Levy *et al.* 2014a.

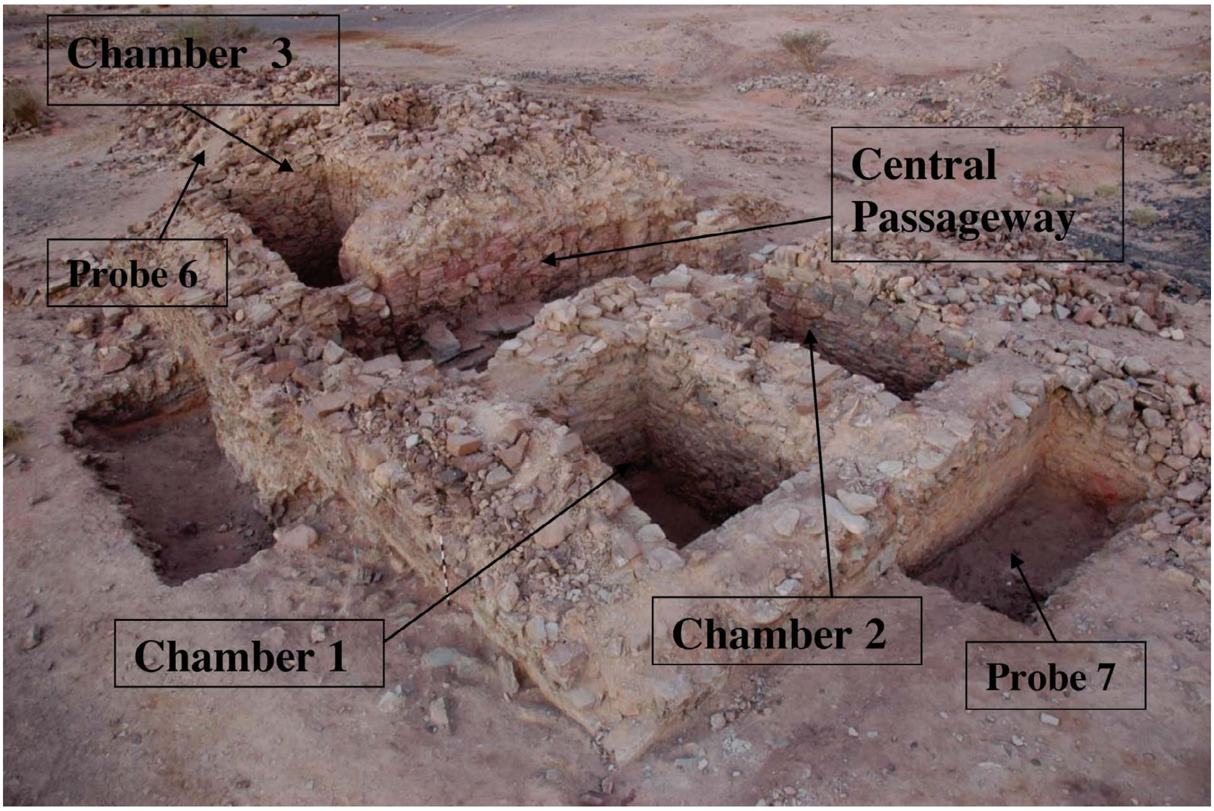


Figure 5. 2006 Khirbat en-Nahas excavation - Area A. Excavation area shown ca. 25 x 5 m. (Source: Levy *et al.* 2014b.)

Figure 6. 2006 Khirbat en-Nahas excavation - Area F. (Source: Levy *et al.* 2014b.)

## Area R

Area R includes one of the largest building structures yet uncovered at Khirbat en-Nahas. This building is distinctive because it is the only one known at the site enclosed by a low stone fence that included a throne (Levy *et al.* 2014b). These architectural elements, as well as the size of the building, suggest that it probably served as an elite residence beginning in the early 10$^{th}$ century BCE. Time constraints did not permit a full excavation of the building and several surrounding smaller structures. A few small probes and excavation of a large chamber to the south of the courtyard (Figure 8) suggest that the fence and building extensions correspond with structures uncovered in the nearby Area S excavated in 2002 and also the excavations completed by A. Hauptmann and the German Mining Museum (Fritz 1996). As with other areas investigated at Khirbat en-Nahas, activities that took place in Area R appear to have varied through time. The strata are complex and indicate distinct periods of building and copper production. Stratum R3a, $^{14}$C-dated to the late 10th century BCE (Levy *et al.*

2014b), yielded evidence of the most intensive copper production activities and the most ground stone artefacts in Area R.

Figure 7. 2006 Khirbat en-Nahas excavation - Area M. (Source: Levy *et al.* 2014b.)

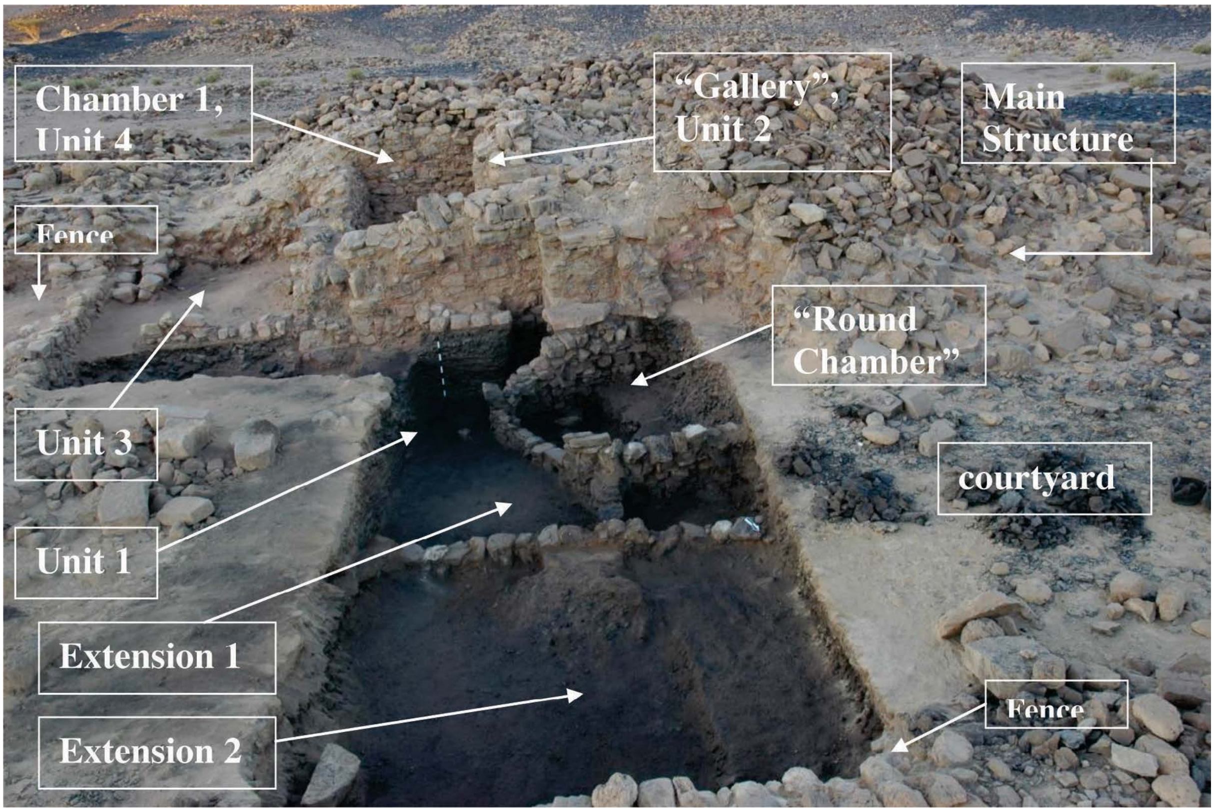


Figure 8. 2006 Khirbat en-Nahas excavation - Area R. (Source: Levy *et al.* 2014b.)

## Area T

Area T is located on the far eastern side of the site overlooking a secondary drainage that flows into the Wadi Guwayb. Excavation of Area T uncovered evidence of a 10$^{th}$ century BCE tower or elite residence with well-preserved stairs leading up to it, four smaller rooms, and an interior courtyard. (See Figure 9.) Some evidence of copper production is associated with the building in Area T. However, the architecture and artefacts are more suggestive of an administrative compound (Levy *et al.* 2014b). A layer of crushed slag underneath the walls of the main structure appeared to be most likely grading material, rather than evidence of metallurgical activities. Fifty-one percent of the total Area T ground stone assemblage is associated with stratum T1b, a level interpreted as predominantly wall-collapse and rubble. The ground stone artefacts found in Area T thus seem to represent the recycling of discarded tools as building materials.

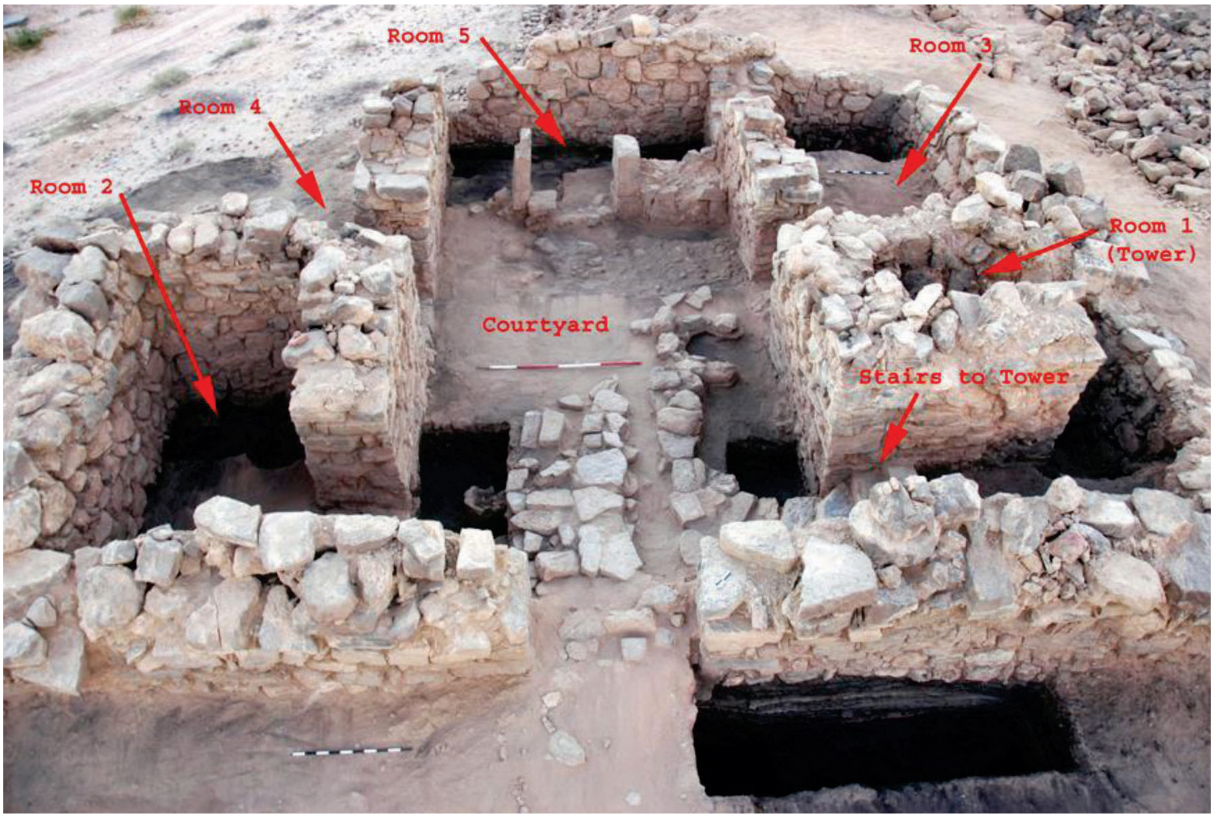

Figure 9. The 2006 Khirbat en-Nahas excavation - Area T. (Source: Levy *et al.* 2014b.)

## 2. Materials and methods

The ground stone assemblage from the 2006 excavations consisted of 454 artefacts (minimum number or MNI) distributed across areas A, F, M, R, and T (Table 1). The artefacts derive from Layers 1-5, which were dated to the 13$^{th}$-9$^{th}$ centuries BCE (Levy *et al.* 2014b). Artefacts were plotted in the field using digital surveying and Geographic Information System (GIS) software. As described above, many of the ground stone artefacts were found closely associated with evidence of smelting activities, such as slag mounds, tuyère pipes and furnaces. Artefacts were later cleaned, measured, and photographed in the lab.

Artefacts were categorized based on shape and size, macroscopic wear attributes, and configuration of wear surfaces following typologies established by previous researchers working in the Levant (*e.g.*, Wright 1991; 1992; Peterson 2000; Daviau 2002: 102-108, 122-161). Artefacts were also identified by lithic material type based on macroscopic examination.

In this paper, aspects of our typological summarization and use-wear interpretations follow principles of J. Adams' (2014) technological approach.

Table 1. Ground stone artifact count (MNI) by excavation area.

| Area | Count (MNI) | Percent |
|---|---|---|
| A | 43 | 9 |
| F | 22 | 5 |
| M | 170 | 38 |
| R | 82 | 18 |
| T | 137 | 30 |
| **Total** | **454** | **100** |

## 3. Results

### 3.1 Lithic material types

The 2006 ground stone assemblage from Khirbat en-Nahas is predominantly comprised of artefacts made of dolomitic rock and sandstone (Figure 10). These kinds of lithic materials are common in the vicinity of the site (Figure 2). Although volcanic outcrops are also readily visible and accessible from the site, only six artefacts in the ground stone assemblage (1.3%) were made of basalt. This stands in contrast with assemblages from domestic contexts at Trans-Jordan sites such as Tall Jawa (Daviau 2002: 102-108, 122-161) where basalt seems to be a more common material for ground stone tools and others that are dominated by basalt vessels and grinding slabs (see Wright 1991; Petit 1999; Ebeling 2002; Ebeling & Rowan 2004).

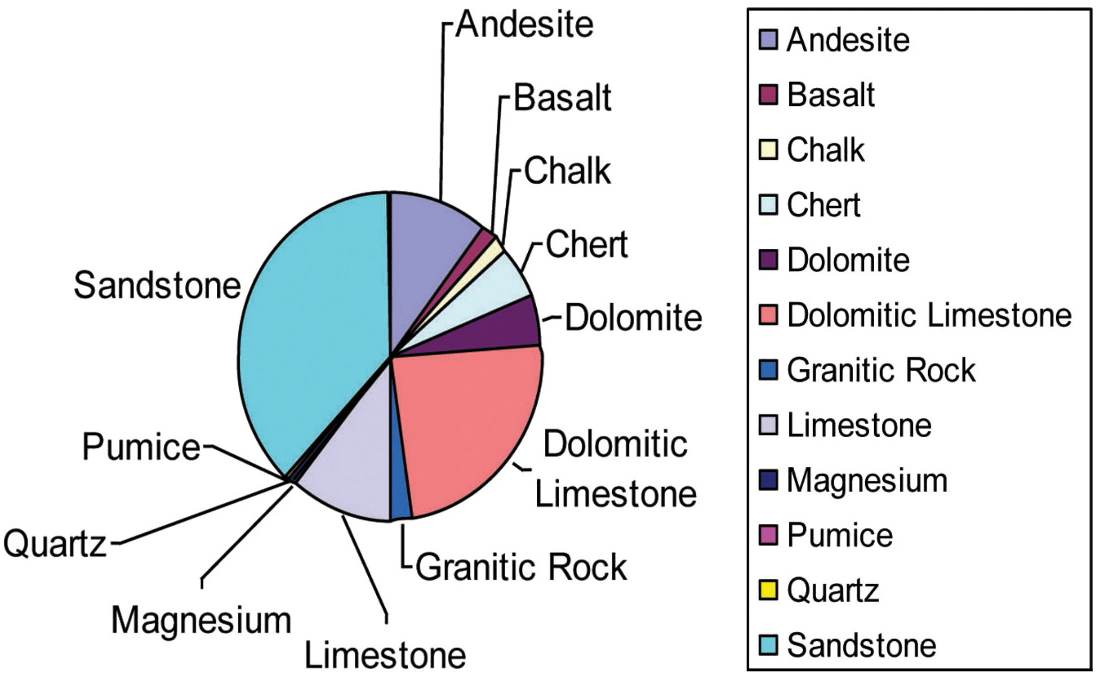


Figure 10. Relative lithic material distribution of assemblage (N=471).

### 3.2 Typological frequencies and spatial distribution

We identified 22 artefact types in the Khirbat en-Nahas 2006 ground stone assemblage. Types are described in section 3.3. Typological frequencies for each excavation area are provided in Tables 2 to 4. For analytical and presentation purposes, we have grouped the artefact types into handstones (handheld ‘active’ tools), netherstones (stationary ‘passive’ tools), multiple-use tools, and ‘other’ ground stone artefacts following Adams (2014: 94). In the summary table (Table 2), ‘Other’ consists of stone vessels and basins, door sockets, casting moulds, and worked stone objects that could not be assigned to any of the defined type categories. Although comparative quantitative data from other contemporary sites in the region is lacking, the ground stone artefact types identified at Khirbat en-Nahas are similar to those described for the Iron Age occupation levels at Tall Jawa in central Jordan (Daviau 2002: 102-108, 122-161) except for specific items mentioned below.

Table 2. Frequencies of summary ground stone tools categories by area. Chi Square = 19.406; Degrees of freedom = 12; p-value = 0.079. As the computed p-value is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H0: the rows and columns are independent.

| **Items** | **A (n=43)** | **F (n=22)** | **M (n=170)** | **R (n=82)** | **T (n=137)** | **Total (n=454)** |
|---|---|---|---|---|---|---|
| Handstone | 42 | 31 | 53 | 44 | 43 | 46 |
| Netherstone | 32 | 41 | 35 | 35 | 34 | 35 |
| Multiple-use tool | 26 | 14 | 2 | 16 | 16 | 14 |
| Other | - | 14 | 10 | 5 | 7 | 5 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** |

Table 3. Handstone type frequencies by excavation area. Chi Square = 30.240; Degrees of freedom = 36; p-value = 0.739. As the computed p-value is greater than the significance level alpha = 0.05, one cannot reject the null hypothesis H0: the rows and columns are independent.

| **Handstones** | **A (n=18)** | **F (n=7)** | **M (n=89)** | **R (n=36)** | **T (n=59)** | **Total (n=209)** |
|---|---|---|---|---|---|---|
| Dimpled hammerstone | 61 | 71 | 47 | 61 | 44 | 50 |
| Hammerstone | 22 | 29 | 27 | 8 | 22 | 22 |
| Grooved hammerstone | - | - | - | - | 3 | 1 |
| Grinding handstone | 11 | - | 4 | 11 | 5 | 6 |
| Pounder | 6 | - | 3 | 3 | 3 | 3 |
| Pestle | - | - | 4 | - | 2 | 3 |
| Polishing stone | - | - | 7 | 6 | 14 | 8 |
| Sharpening stone | - | - | 2 | 3 | - | 2 |
| Burnishing stone | - | - | - | - | 2 | - |
| Ballistic stone | - | - | 6 | 3 | 5 | 5 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** |

Table 4. Netherstone type frequencies by area. *‘Anvil’ and ‘small anvil’ types are combined in this table. Chi Square = 31.955; Degrees of freedom = 16; p-value = 0.010. As the computed p-value is lower than the significance level alpha = 0.05, one should reject the null hypothesis and accept the alternative hypothesis Ha: there is a link between the rows and columns

| **Netherstones** | **A (n=14)** | **F (n=9)** | **M (n=60)** | **R (n=29)** | **T (n=47)** | **Total (n=159)** |
|---|---|---|---|---|---|---|
| Anvil* | 21 | 56 | 8 | 7 | 11 | 13 |
| Dimpled anvil | 30 | 33 | 50 | 31 | 29 | 38 |
| Mortar | 21 | - | 10 | 10 | 11 | 11 |
| Saddle quern | 14 | 11 | 3 | 10 | 15 | 9 |
| Grinding slab | 14 | - | 29 | 42 | 34 | 29 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** |

Statistical analysis shows that the distribution of summary ground stone artefact categories is the same across all 2006 excavation areas at the site (Table 2). There are somewhat more handstones than netherstones (except in Area F, which has a very small sample size), and relatively few containers and other objects.

Comparison of handstone type frequencies shows that the area assemblages are also statistically the same in terms of the types represented and their relative abundance (Table 3). Hammerstones of all subtypes combined are by far the most abundant ground stone artefact at the site, comprising 73% of the handstone assemblage (34% of the entire assemblage). Among these, dimpled hammerstones (*e.g.*, Figure 11 A, B), a new type identified here for the first time at Trans-Jordan Iron Age sites, are the most common.

However, a breakdown of netherstone types across the areas indicates a statistically significant difference. In particular, Area F is distinctive with a very high frequency of anvils and a lack of mortars and grinding slabs. Notably, Area F has a very small sample size of netherstones. Taken together, anvils of all subtypes combined are the most common netherstone type, with dimpled anvils (*e.g.,* Figure 12 B), identified for the first time here, representing 38% of the 2006 netherstone assemblage.

### 3.3 Description of ground stone tool types from Khirbat en-Nahas, 2006 excavations

(Abbreviations: L - Length, W - Width, T - Thickness)

#### Handstones

*Dimpled Hammerstone* (N=109) Average dimensions (cm): 9.5 L x 7.75 W x 5.5 T

Dimpled hammerstones are characterized by the presence of a pit-like depression (or ‘dimple’) on at least one, commonly two, and sometimes up to six sides. The dimple is the result of impact damage. Fatigue wear is also evident on the edges of these tools, consistent with wear observed on non-dimpled hammerstones. Most artefacts of this type are complete. Dimpled hammerstones were made from a wide variety of lithic materials, the most common being durable rocks such as andesite, dolomite, and dolomitic limestone.

*Hammerstone* (N=48) Average dimensions (cm): 7.75 L x 7 W x 5.75 T

Hammerstones are characterized by battered surfaces and edges. Most are rounded or spherical in shape. Although hammerstones as a group include a wide variety of lithic materials, most were made from chert (a fine-grained silica-rich microcrystalline, cryptocrystalline, or microfibrous sedimentary rock).

*Grooved Hammerstone* (N=2) Average dimensions (cm): 10.5 L x 8.5 W x 5.5 T

Grooved hammerstones (or mauls, *cf*. Adams 2014:157) are characterized by a rounded proximal end that tapers slightly in the middle and terminates in a flattened distal end with an oval cross-section. These tools may have been hafted and would have been used in conjunction with a stationary stone surface (*e.g.,* an anvil). Both examples from Khirbat en-Nahas display heavily-worn working ends and edges.

*Grinding Handstone* (N=13) Average dimensions (cm): 15 L x 11.25 W x 6.5 T

Grinding handstones (‘manos’ in New World contexts) are handheld tools used in conjunction with grinding slabs and saddle querns. Grinding handstones are longer and more ovoid in shape than percussive tools found at Khirbat en-Nahas. To maintain an even pressure along the length of the handstone, they were mostly likely held with two hands and moved across the netherstone surface with a reciprocal stroke.


Figure 11. Selected handstones from Khirbat en-Nahas, 2006 excavations. A, dimpled hammerstone, Area A, Locus 183; B, dimpled hammerstone, Area M, Locus 672; C, hammerstone, Area M, Locus 721; D, grooved hammerstone, Area T, Locus 1541; E, grinding handstone, Area A, Locus 183; F, pounder, Area T, Locus 1517; G, pestle, Area M, Locus 701; H, polishing stone, Area M, Locus 707; I, sharpening stone, Area M, Locus 685; J, ballistic stone, Area R, Locus 1827. Individual squares in the scale bars are 1 cm wide.

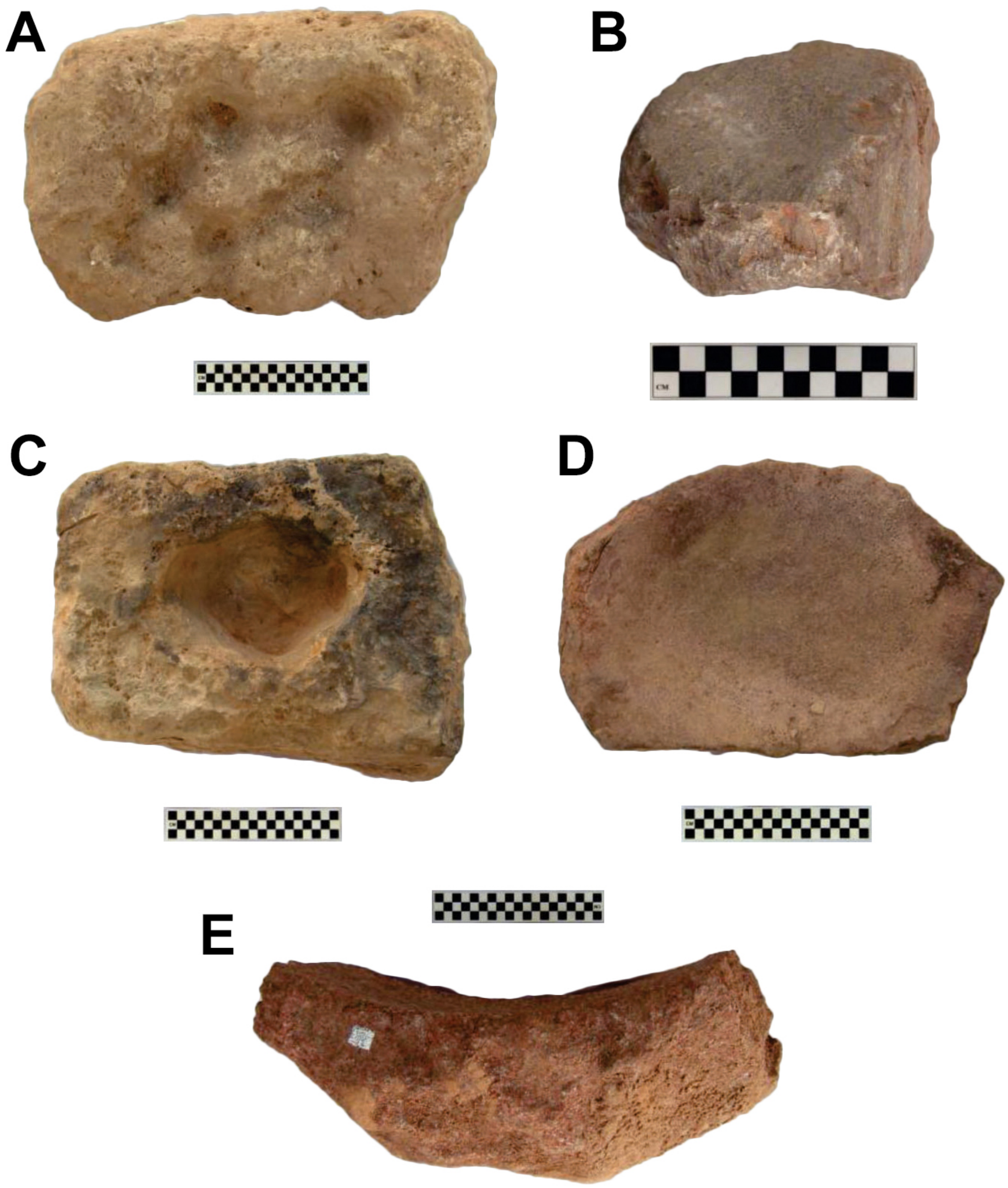


Figure 12. Selected netherstones from Khirbat en-Nahas, 2006 excavations. A, anvil, Area T, Locus 1519; B, small dimpled anvil, Area R, Locus 1804; C, mortar, Area T, Locus 1511; D, grinding slab, Area T, Locus 1523; E, saddle quern, Area T, Locus 1507. Individual squares in the scale bars are 1 cm wide.

*Pounder* (N=7) Average dimensions (cm): 9 L x 8 W x 6 T

Pounders are percussive tools that are similar to hammerstones, but differ from other handheld tools in that they are larger, heavier, and tend to be uniformly battered over all surfaces. They were probably used in conjunction with a stationary stone surface, most likely a large anvil.

*Pestle* (N=5) Average dimensions (cm): 10.75 L x 7 W x 5.25 T

Pestles are handheld tools that were used in conjunction with a mortar or anvil. Pestles differ from hammerstones and grinding handstones in that they are generally oblong in shape, making them a more useful tool for pounding, crushing or grinding with rotational or circular strokes within mortars. In the Khirbat en-Nahas 2006 assemblage, usually only the distal end showed traces of abrasive wear; the proximal end was shaped as a handle.

*Polishing Stone* (N=17) Average dimensions (cm): 9.25 L x 7.25 W x 4 T

Polishing stones vary in size and lithic material, but always have a uniformly-abraded surface consistent with fine multi-directional striations indicative of a combination of reciprocal and circular strokes. These handheld tools may have been used to smooth down rough edges on other tools or building materials.

*Sharpening Stone* (N=3) Average dimensions (cm): 14.75 L x 13.75 W x 7.25 T

Sharpening stones are characterized by long, linear grooves on their working surfaces. They are expediently made of medium-sized sandstone blocks. Adams (2014:82) refers to these kinds of tools as “grooved abraders”. All three of the sharpening stones at Khirbat en-Nahas displayed well-developed sheen within the grooves. The grooves become narrower and shallower at the ends.

*Burnishing Stone* (N=2)

Two objects were classified as burnishing stones. These tools have characteristics similar to Polishing Stones. They are used to alter an opposing surface through abrasive and tribochemical mechanisms.

*Ballistic Stone* (N=11) Average dimensions (cm): 4.25 L x 4 W x 3.75 T

Ballistic stones are the smallest ground stone artefacts in the Khirbat en-Nahas assemblage. These small, spherical objects were found in locations on the periphery of the fortress, possibly implying a role as weapons rather than in manufacturing. All but one was complete. They were made of either a relatively soft limestone (Burj Formation) or hard sandstone (Umm Ishrin Massive Brown Sandstone Formation).

**Netherstones**

*Anvil* (N=19) Average dimensions (cm): 37.75 L x 28.75 W x 12.75 T

Anvils are one of the larger types of ground stone tools. They are characterized by at least one pit-like depression (or ‘dimple’), and commonly multiple dimples, of various depths and circumferences. An anvil is a stationary platform used in conjunction with a hammerstone, pounder, or pestle. The presence of multiple dimples, together with the raw material choice of primarily durable rocks such as limestone, dolomite, and dolomitic limestone, suggests that these tools were probably used for an extended period.

*Small Anvil* (N=3) Average dimensions (cm): 19.5 L x 15.25 W x 9.75 T

Small anvils are rectilinear or square-shaped rocks with a series of shallow-to-deep depressions or pits created by the percussive force of a hammerstone, pounder, or pestle. The small anvils from the Khirbat en-Nahas 2006 assemblage are smaller than those classified in the ‘anvil’ category; the significance is that the small anvils might be considered portable. However, they were most likely not moved long distances.

*Small Dimpled Anvil* (N=62) Average dimensions (cm): 11.5 L x 8.75 W x 5.5 T

Small dimpled anvils are portable implements with impact fractures or pits that were most likely used in conjunction with hammerstones or pestles. These might be considered “lapstones” (Adams 2014: 94). Most small dimpled anvils from Khirbat en-Nahas were unifacial, although some displayed dimples on two surfaces. Most were made of durable lithic materials such as the locally available dolomite or dolomitic limestone.

*Mortar* (N=17) Average dimensions (cm): 25 L x 19.5 W x 12 T

Mortars are stationary bowl-like tools used in conjunction with pestles for crushing, stirring, or pounding an intermediate substance. They have deep circular concavities that confine the intermediate substance.

*Saddle Quern* (N=17) Average dimensions (cm): 36 L x 27.75 W x 16 T

Saddle querns are large, stationary tools used in conjunction with handstones. They usually exhibit a large, curving, rectilinear grinding surface that is more concave than that of a grinding slab. The majority of the saddle querns at Khirbat en-Nahas were quite large and most likely not as portable as the grinding slabs.

*Grinding Slab* (N=51) Average dimensions (cm): 22.25 L x 18.5 W x 8.75 T

Grinding slabs ('metates' in New World contexts) are stationary platforms used in conjunction with a grinding handstone. Variation in size is pronounced within this type: the smallest grinding slab measured (cm) 8 L x 3.75 W x 2 T, and the largest 52 L x 47.5 W x 12.5 T. Grinding slabs are characterized by rectilinear or ovoid working surfaces which are either flat or slightly concave and display striations indicative of reciprocal abrasive wear.

**Multiple-use tools**

*Multiple-Use Tool* (N=67) Average dimensions (cm): 15 L x 11.5 W x 6.75 T

A multiple-use tool is a tool that has been used in more than one activity. At Khirbat en-Nahas, these are primarily sequential secondary-use tools, rather than concomitant secondary-use tools (see Adams 2014: 24-27 for definitions). For example, tools which no longer served their original purpose effectively were re-used for another purpose: grinding slabs that broke and retained depressions were commonly re-purposed as mortars; small dimpled anvils and dimpled hammerstones that broke during use were commonly re-used as polishing stones.

**Other**

*Stone Vessel* (N=7) Average dimensions (cm): 12.75 L x 11 W x 5 T

Stone vessels function as portable containers. At Khirbat en-Nahas, these varied in size and nearly all of them were made of soft chalk or sandstone material. Only one of the vessels—a relatively deep bowl--was made of basalt. Most of the stone vessels found at Khirbat en-Nahas are evidenced by small fragments; one large fragment represented approximately 75% of a vessel.

*Stone Basin* (N=1) Average dimensions (cm): 36 L x 24 W x 13 T

The stone basin fragment in the Khirbat en-Nahas 2006 assemblage represents a large stationary container with an incision around the rim. Based on the recovered fragment, the basin would have had a large, bowl-shaped concavity. This vessel was made from a large block of the Umm Ishrin Massive Brown Sandstone formation.

*Door Socket* (N=2) Average dimensions (cm): 27.25 L x 20 W x 13 T

Both door sockets at Khirbat en-Nahas were found in Area T where a building interpreted as a tower or elite residence was excavated in 2006. The door sockets appear to have been modified processing or manufacturing tools--either a saddle quern with a deep depression, or a medium-sized mortar with a deep dimple pecked out of the centre. The deep depressions would have allowed a door resting on a pestle-like object to swing open and closed.

*Stone Casting Mould* (N=1) Average dimensions (cm): 20.5 L x 10.5 W x 5.75 T

The stone casting mould from Khirbat en-Nahas is similar to the sharpening stones in that it displays a series of long incised grooves. It differs from these in terms of the shape of the ends of the grooves. Grooves on the mold have ends that are rounded and well-defined; grooves on the sharpening stones taper and become shallower at the ends.

*Worked Stone* (N=10) Average dimensions (cm): 10.5 L x 7.25 W x 5.5 T

The worked stone category includes a variety of stone objects that were fragmentary and lacked distinguishing characteristics. Although clearly human-modified, these objects could not be assigned to any of the defined ground stone artefact type categories.

## 4. Discussion and conclusions

### 4.1 Tool function and activity types

Formal analysis of ground stone tools is, by itself, usually insufficient to identify specific tasks that took place in the past. Furthermore, numerous studies and ethnographic reports have highlighted the multi-functional nature of ground stone tools. Without assuming that there is a one-to-one correspondence between form and function, however, it is possible to classify the ground stone assemblage from Khirbat en-Nahas according to generic functional activities such as grinding, polishing, abrading, scraping, or percussing. These functional activities are assigned by considering tool design, wear surface configuration, and wear traces (levelling, striations, impact fractures, pits, sheen, crushed rock grains, removed rock grains) (following Adams 2014:53-54).

This kind of functional classification of the 2006 Khirbat en-Nahas ground stone assemblage indicates that percussive activities were the most common activities carried out at the site (Table 5). Preliminary microscopic use-wear analysis of a limited number of ground stone tools shows wear traces on tool surfaces consistent with percussive forces such as stone-on-stone pounding. (See Figure 13.) Grinding and crushing activities were also carried out; this is evidenced by the abrasion and fatigue wear on grinding slabs. (See Figure 14.) A systematic use-wear analysis of the Khirbat en-Nahas ground stone assemblage conducted in conjunction with replicative experiments could improve functional assessments. For example, in the Levant, saddle querns are usually associated with food processing, probably seed grinding (Wright 1994), but in some cases 'industrial use' has been inferred based on large size and context (Daviau 2002:103).

Table 5. Relative frequencies of functional activities represented in the Khirbat en-Nahas 2006 ground stone assemblage. * Ballistic stones, multiple-use tools and 'other' objects are not included.

| Item | Percent (N=357*) |
|---|---|
| Percussing | 67 |
| Grinding and Crushing | 27 |
| Polishing | 5 |
| Abrading | 1 |
| **Total** | **100** |

At Ambelikou *Aletri*, a Middle Bronze Age copper production site in Cyprus, saddle querns are noted to be very similar in size and form to those found in contemporary domestic contexts (Webb 2015:28). They are reported to differ, however, in terms of thickness and use-wear traces, notably lacking striations and sheen usually associated with seed grinding. Microscopic use-wear on a saddle quern from Khirbat en-Nahas (Figure 15) is consistent with fatigue wear (percussive forces) but there is no evidence of the abrasive wear that would be expected in cases of seed grinding. Detailed microscopic study of additional saddle querns from Khirbat en-Nahas could help assess whether the wear traces observed on the selected artefact shown in Figure 15 represent the primary use of the tool in a percussive activity, or, alternatively, the preparation of a rough working surface for purposes of seed grinding that was unused at the time of deposition. Residue analysis also has potential to provide direct evidence of ground stone tool use (*e.g.,* organic residues, Buonasera 2005; inorganic residues, Vardi *et al.* 2008).


Figure 13. Dimpled hammerstone from Khirbat en-Nahas; andesite rock. Photomicrograph (right) of centre of 'dimple' shows crushed rock grains, pits, loose rock particles, and 'frosted' appearance. Image width = 2 mm.

Figure 14. Grinding slab from Khirbat en-Nahas; sandstone rock. Photomicrograph (right) of centre of use surface shows pits, loose rock grains, surface levelling, and linear rock grain removal (striations). Image width = 7.5 mm.

## 4.2 Tasks and technological sequence

Additional kinds of evidence are necessary to relate the categorical functional activities represented by the ground stone assemblage at Khirbat en-Nahas to specific tasks within a technological sequence. Archaeological context and ethnographic analogy are two important inferential tools for this purpose.

First, it is clear that the extensive, systematic excavations, $^{14}C$-dating of depositional sequence, and precise recording of artefact find spots at Khirbat en-Nahas (Levy *et al.* 2014b) provide an accurate reconstruction of the industrial context from which the 2006 ground stone assemblage was recovered. As described above, these contexts, with the exception of Area T, are related to copper production. The association of the ground stone artefacts with the copper production activities is strongly supported. For example, in Area A many of the dimpled hammerstones were found embedded in slag layers, or encrusted with slag residue. In Area T, the ground stone artefacts are associated with wall collapse and were presumably recycled as building materials for the administrative complex uncovered there. Most likely, the ground stone tools used in building were acquired from on or near the site.

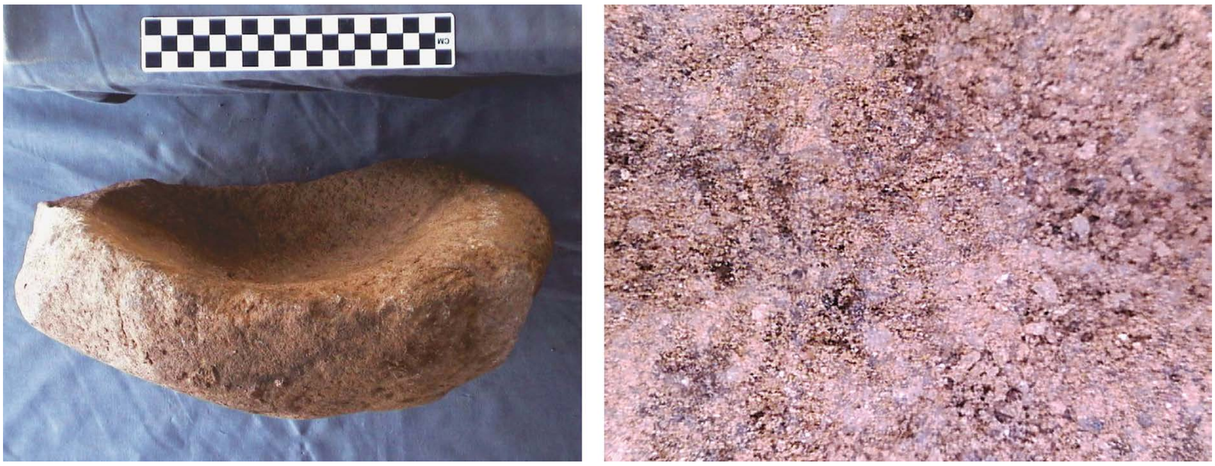

Figure 15. Saddle quern from Khirbat en-Nahas; sandstone rock. Photomicrograph (right) of centre of use surface shows pits and loose rock grains. Image width = 2 mm.

Second, ethnoarchaeology of Swamimalai bronze casting workshops (Levy *et al*. 2008b) reveals the role played by ground stone tools in traditional metal production. Khirbat en-Nahas was a copper mining and smelting location; however, bronze casting also involves the smelting of copper, including the processing of slag, and its combination with tin to produce bronze. Therefore, the Swamimalai workshops, while not providing a direct historical analogy for the Iron Age Levant, do help to illuminate how ground stone tools may have been used in a copper production context. As the majority of published ethnoarchaeological studies related to traditional metal production are from iron-making societies in West Africa (with the exception of Anfinset 2011), the Swamimalai study takes on special significance for understanding the Khirbat en-Nahas assemblage.

At Swamimalai, anvils, mortars and hammerstones are used by the craftsmen to pound, crush and grind slag and metal bits collected from crucibles and the floor of the workshop. (See Figure 16.) The recovered material is then re-smelted. Some of the Swamimalai ground stone tools bear a strong formal resemblance to the ground stone tools from the Iron Age copper production contexts at Khirbat en-Nahas, while others are clear functional parallels. (See Figure 17.) Comparison of use-wear on the ethnoarchaeological tools and the ground stone artefacts is an important next step toward supporting the inferences drawn from the ethnographic analogy.

### 4.4 Summary

Preliminary quantitative typological and functional analysis of the Khirbat en-Nahas 2006 ground stone assemblage indicates a predominance of tools related to percussive activities, including two artefact types from Levantine Iron Age contexts described here for the first time—dimpled hammerstones and dimpled anvils. The archaeological contexts from which the ground stone artefacts were excavated are consistent with industrial scale metallurgical production that was spatially and temporally segregated from domestic activities. It is important to note that, except for the dimpled anvils and dimpled hammerstones found at Khirbat en-Nahas, similar tool forms occur in published 'domestic' ground stone assemblages from the Iron Age site of Tall Jawa (Daviau 2002: 102-108, 122-161) in the ‘Amman region.

Figure 16. Metal recycling in a Swamimalai workshop: slag and metal bits collected from crucibles and sediment from the floor of the workshop (left) are pounded and crushed in stone mortars (right; Source: Levy *et al.* 2008b).

Figure 17. Swamimalai ground stone tools used to process slag recovered from crucibles and workshop floor: mortars and large anvil (left); dimpled hammerstone used as both a hammer and a small anvil (right; Source: Levy *et al.* 2008b).

Perhaps the ratio of tools involved in percussive vs. abrasive tasks is a hallmark of industrial ground stone assemblages associated with metallurgical production, rather than the tool forms themselves. Webb (2015: 33) and Vardi *et al*. (2008: 9) similarly noted high relative frequencies of percussive and crushing tools (pounders and hammerstones; large mortars and work surfaces) in Bronze Age metallurgical contexts. Additionally, the presence of appreciable numbers of multiple-use tools, especially sequential secondary use tools, may imply the intensive use or long term occupation of the site and expedience or lack of formality in tool design. Reuse of any available heavy stone for percussive or crushing activities has been suggested as a distinguishing characteristic of Bronze Age metallurgical versus domestic ground stone assemblages (Webb 2015: 33-34). Quantitative analysis and comparison of Levantine Iron Age ground stone assemblages from domestic contexts and additional metallurgical contexts, including those related to other excavation seasons at Khirbat en-Nahas, is needed to test these hypotheses.

The emphasis on percussive activities at Khirbat en-Nahas is consistent with tasks involved in the recycling of metal slag, ore or sediments observed in a traditional metal manufactory. The role of hammerstones and anvils at this Iron Age copper mining and smelting site would have been to break apart the slag in order to retrieve the copper prills trapped inside during the smelting process. Similarly, Vardi *et al.* (2008:15-17) concluded that stone hammers and anvils were used to crush metallurgical slag at the Early Bronze IV copper smelting site of ‘En Yahav (Arava valley) after XRF analysis showed high levels of elemental copper, manganese, and iron residues on stone tool surfaces. Likewise, although grinding slabs, saddle querns, and mortars are often considered food processing tools (Wright 1994), it is possible that at Khirbat en-Nahas they too had a role in industrial production and were employed to pound, grind and crush slag to extract copper prills, in conjunction with grinding handstones and pestles. As copper was a precious material, significant labour would have been invested in maximizing its retrieval. The ground stone tool assemblage at Khirbat en-Nahas may reflect the goal of maximal extraction and re-extraction of the copper content of smelting by-products. This interpretation is based primarily on the archaeological context of the artefacts and the ethnoarchaeology of the Swamimalai bronze casting workshops. Additional systematic microscopic use-wear study, replicative experiments, and residue analysis should be conducted in order to further investigate the role of ground stone tools at Khirbat en-Nahas.

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