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Up the Wadi: Development of an Iron Age Industrial Landscape in Faynan, Jordan

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ABSTRACT

In 2014, the Edom Lowlands Regional Archaeology Project renewed excavations at Khirbat al-Jariya (KAJ), an Iron Age copper smelting site in Faynan, Jordan. Located roughly 3 km from the prominent smelting center Khirbat en-Nahas (KEN), KAJ was an integral component of Early Iron Age (ca. 1200–800 B.C.) copper production in Faynan, one of the largest copper ore deposits in the southern Levant. To date, the site had only been investigated by surveys and limited excavation; the 2014 excavations opened two areas (the largest extant building and a slag mound sounding) to explore the social dynamics and temporal intricacies of copper production. The excavation results, detailed site remapping, paleobotanical analysis, and new radiocarbon dates suggest KAJ more rapidly developed into a large-scale copper production center than previously believed, likely as a strategic expansion to the industry at KEN. This reinterpretation sheds new light on the development of the Iron Age industrial landscape in Faynan.

KEYWORDS
Khirbat al-Jariya; Edom; Levant; metallurgy; copper production

Introduction

Following the Late Bronze Age collapse (ca. 1200 B.C.) of eastern Mediterranean civilizations (Cline 2014; Wiener 2018; Knapp and Manning 2016), populations in the Wadi Arabah, a rift valley running from the southern tip of the Dead Sea to the Gulf of Aqaba, experienced rapid economic and political development. In particular, large-scale copper smelting industries were developed in Faynan (Jordan) and 105 km to the south at Timna (Israel). During the Early Iron Age (ca. 1200–800 B.C.), these industrial-scale copper production centers likely capitalized on the sustained demand for the metal, despite the breakdown of the Late Bronze Age economic networks (Figure 1). These two regions, united by a similar geology and metallurgical technology despite their geographical separation (ca. 105 km), were likely two components of a broad, integrated industrial landscape, possibly associated with the biblical Edomites (Avishur 2007; Ben-Yosef 2018; Ben-Yosef et al. 2012; Levy, Ben-Yosef, and Najjar 2014, 2018). Faynan, on the northeastern side of the Arabah and ca. 30 km south of the Dead Sea (Figure 1), is one of the largest copper ore resource zones in the southern Levant and was the main hub of Iron Age copper exploitation, attested by the ca. 100,000–130,000 tons of slag, a waste byproduct from the smelting process (in comparison to an estimated few thousand tons in Timna for all periods) (Hauptmann 2007, 147; Ben-Yosef 2010, 617). Thus, Faynan provides a critical case study for evaluating and understanding the development of Early Iron Age copper production in the southern Levant.

Since the early 2000s, the archaeology of Iron Age Faynan has been the focus of ongoing excavations conducted by the joint University of California, San Diego—Department of Antiquities of Jordan Edom Lowlands Regional Archaeology Project (ELRAP) (Levy, Ben-Yosef, and Najjar 2014). To investigate the relationship between social evolution and the development of large-scale copper production, ELRAP has surveyed and excavated many of the Iron Age smelting and mining sites in the region. The scale and intensity of copper smelting during the Iron Age is best represented by Khirbat en-Nahas (KEN), the largest Iron Age copper production center in the southern Levant and the cornerstone for understanding the development of both metallurgy and social complexity in Faynan during this period (Levy et al. 2014). An estimated 50,000–60,000 tons of copper slag are present at the site among the remains of over 100 buildings, including a large fortress (ca. 75 × 75 m) (Hauptmann 2007, 127; Levy, Ben-Yosef, and Najjar 2014). Rigorous collection of radiocarbon dates by ELRAP, more than 100 samples from stratified contexts, place smelting activity at KEN in the 12th–9th centuries B.C. (Levy et al. 2008, 2014). The 12th–10th centuries B.C. represent the beginning and gradual intensification of production at KEN, which culminated in the construction of the large fortress, monumental building, and other structures in the early 10th century B.C. The 10th–9th centuries B.C. are associated with a more intensive phase of production, evidenced by a new archaeometallurgical assemblage including larger tuyères and tap slags (Ben-Yosef et al. 2019; Ben-Yosef 2010; Levy et al. 2014). However, KEN is only one component of the Iron Age industry in Faynan. As such, ELRAP intensified efforts to clarify the development of an industrial landscape in Faynan through excavation and survey at the nearby smelting center up the wadi, Khirbat al-Jariya (KAJ). The new data presented here indicates that KAJ experienced a much more rapid development more closely linked to KEN than previously understood. This understanding suggests the presence of a more widespread and integrated industrial complex in the northern Arabah Valley in the 11th–10th centuries B.C.

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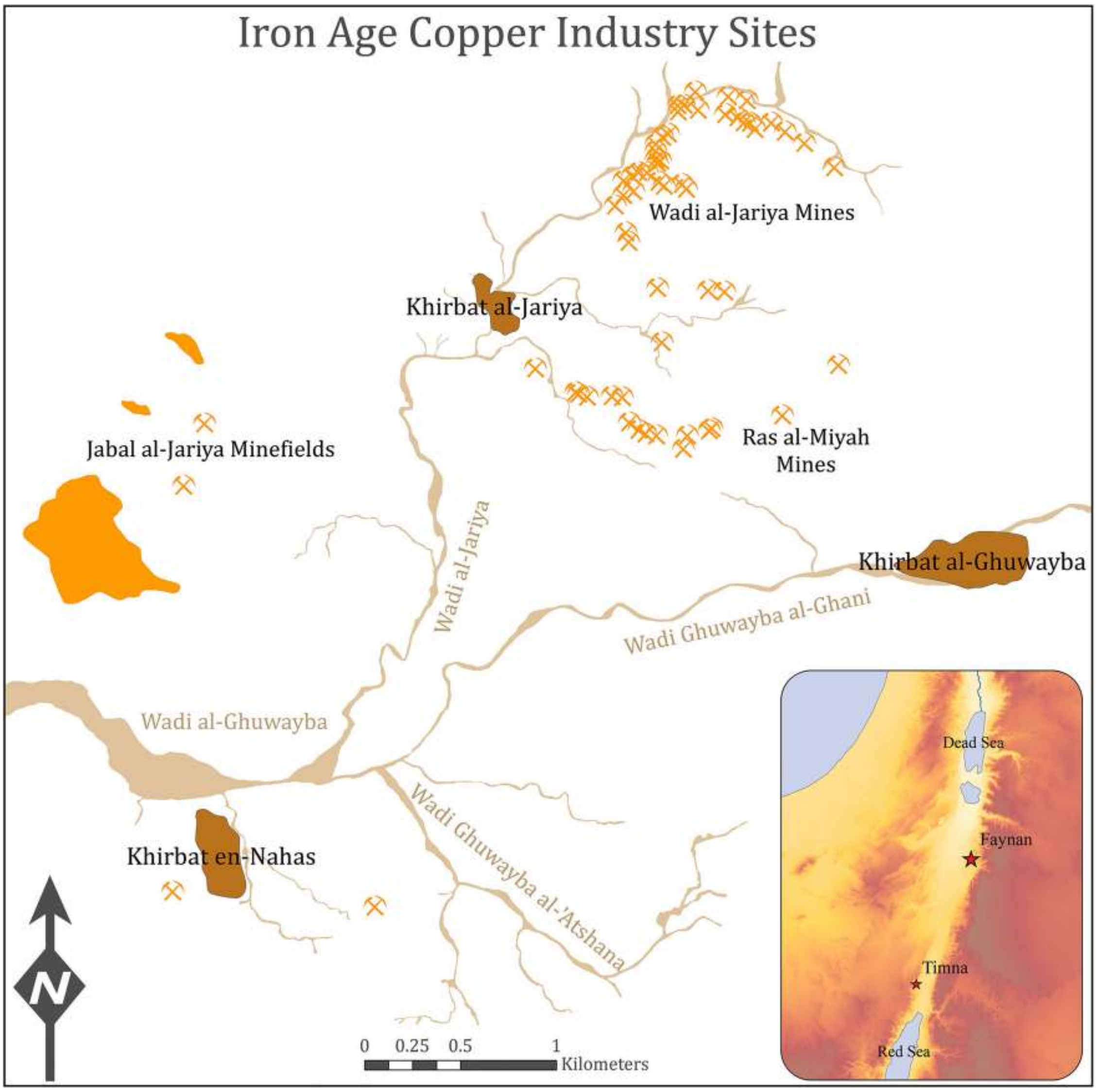

Figure 1. Map of Khirbat al-Jariya and its immediate surroundings, including the main production site Khirbat en-Nahas, the more sparsely built Khirbat al-Ghuwayba, the Wadi al-Jariya mines, and the Jabal al-Jariya minefields. Khirbat al-Ghuwayba, as depicted on the map, spreads across two sides of a wadi containing the perennial spring, Ain al-Ghuwayba.

Archaeological Research at Khirbat al-Jariya

Khirbat al-Jariya (KAJ) is the second largest Iron Age copper smelting site in Faynan, with an estimated 15,000–20,000 tons of copper slag (Hauptmann 2007, 131) (Figure 2). Today, KAJ covers an area of roughly 4.8 ha, straddling the Wadi al-Jariya. Despite erosion in the central portion of the site due to the deepening and changing course of the wadi, archaeological features, including slag mounds and architectural collapse, remain visible on the surface (Figure 2). The site was first reported by Kitchener (1884) during his explorations of Faynan (Ben-Yosef and Levy 2014a), and Glueck (1935, 23–26) subsequently described the site as part of his larger regional survey, attributing it to the Early Iron Age based on ceramic typology. Hauptmann (2007) and a team from the German Mining Museum investigated KAJ as part of geological and archaeometallurgical surveys of Faynan, and they also dated the site to the Early Iron Age based on technical ceramics (such as tuyères) and a few radiocarbon dates. Finally, in 2002, Levy, Najjar, and Adams surveyed KAJ as part of the Jabal Hamrat Fidan Project, producing the first topographic and architectural map of the site (Levy et al. 2003, fig. 16).

KAJ was first excavated in 2006, when an ELRAP team supervised by E. Ben-Yosef opened a stratigraphic probe into a slag mound and associated structure in the southern part of the site (Area A, Figure 3) (Ben-Yosef et al. 2010). The small structure (Structure 276) was excavated to a habitation surface; however, its function and relationship to the adjacent slag mound remained somewhat enigmatic (Ben-Yosef et al. 2010, 738–740). In contrast, the slag mound sounding reached bedrock, providing a complete history of metallurgical activity in this part of the site (Ben-Yosef et al. 2010, 732–738). Crushed slag, copper ore, and ash found directly above/on the bedrock suggested KAJ was originally established specifically for copper production (Ben-Yosef et al. 2010, 736). Material culture collected from the slag mound included both domestic remains (mostly ceramics) and metallurgical by-products (decomposed furnace fragments, tuyères, charcoal, etc.) (Ben-Yosef et al. 2010, 732). Despite the mixed assemblage, this excavation provided a detailed record of copper production and metallurgical technologies at KAJ.

The 2006 excavation, though small and localized, was critical in establishing an occupational history of KAJ for the first time. Furthermore, the collection of nine stratified radiocarbon dates and a geomagnetic archaeointensity dating investigation established an absolute chronological framework for

Figure 2. Photograph of Khirbat al-Jariya looking roughly northeast. The surface of the site is populated with architectural collapse and large slag mounds. The Wadi al-Jariya runs along the left edge of the photo, with the site extending outside the frame.

the site's habitation and use (Ben-Yosef et al. 2010). The dating indicated that KAJ was occupied from the mid-11th century B.C. until the mid–late 10th century B.C., securely placing the copper production early in the Iron Age. Ben-Yosef and colleagues (2010, 743) concluded that the earliest phases of settlement at KAJ would have consisted of opportunistic exploitation of the copper resources near the site (Figure 1), with production gradually developing into an industrial-scale endeavor (similar to what was seen at KEN, but on a smaller scale) before it was abandoned. The site was abandoned in the late 10th century B.C., potentially as a result of the campaigns of the Egyptian Pharaoh Sheshonq I (biblical Shishak), as supported by a contemporaneous disruption and reorganization of production at KEN and a Sheshonq epigraphic amulet discovered in the Faynan region (Ben-Yosef et al. 2010, 744; Levy et al. 2014; Levy, Münger, and Najjar 2014). In sum, the 2006 excavations at KAJ situated the site in the early phases of copper smelting in Faynan, with a steady growth in the scale of production.

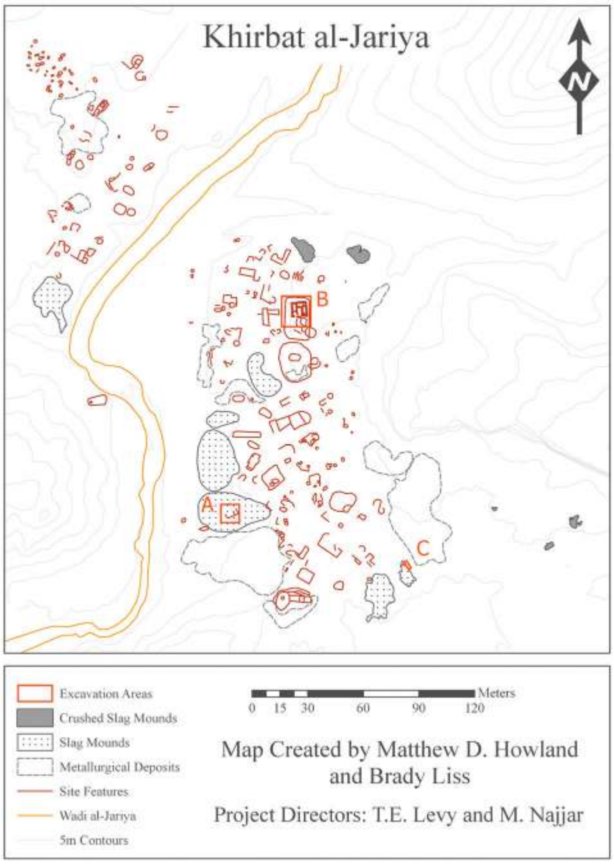

Figure 3. New map of Khirbat al-Jariya produced based on an orthophotograph from the ELRAP balloon photography system that allowed more precise mapping of archaeological features. "Metallurgical Deposits" refers primarily to what appears to be scatters of slag on the surface of the site; however, they were not investigated further and could be larger deposits/mounds upon excavation.

These excavations also contextualized KAJ in the development of metallurgy in the Wadi Arabah more generally. Recent research suggests Faynan was potentially one component of a larger metallurgical and sociopolitical system that encompassed the entire Arabah valley, particularly, both Faynan and Timna (Ben-Yosef et al. 2019). The trajectory of this system during the Late Bronze and Iron Ages was detailed and divided into four developmental phases (Phases 0–3) by Ben-Yosef and colleagues (2019, fig. 5). Phase 0 represents the beginning of copper production in the Arabah, which first began in Late Bronze Age Timna under the hegemonic control of the Egyptian New Kingdom, with no contemporaneous production in Faynan (Ben-Yosef et al. 2019, 8). Despite Egyptian control, the workforce appears to have been composed primarily of the local population (Ben-Yosef et al. 2019, 8). Following the collapse of the Egyptian New Kingdom, copper production continued in Timna, but also began in Faynan in the Iron Age (ca. 1140 B.C.), representing the transition to Phase 1 (Ben-Yosef et al. 2019, 8). Correlations between the archaeometallurgical assemblages and trends in technological changes between Timna and Faynan suggest they were now part of a unified political entity, potentially the Edomites (for detailed discussions, see Ben-Yosef 2010; Ben-Yosef et al. 2019, 8–12). Phase 2 is identified by the introduction of defensive elements and abandonment of unprotected smelting sites in both regions at roughly the beginning of the 1st millennium B.C., and Phase 3 (beginning approximately around 925 B.C., following the campaign of Sheshonq I) is associated with major reorganizations of metal production, a new archaeometallurgical assemblage, and an improved efficiency in smelting (Ben-Yosef et al. 2019). Following this schema and the excavation results, KAJ is associated with production Phases 1 and 2 in the Wadi Arabah: the beginnings of copper production in Faynan and its development in the Early Iron Age.

Following the 2006 excavation season, however, several questions concerning KAJ remained unanswered, necessitating renewed excavations in the 2014 season. The control and organization of the copper industry at KAJ was unclear from the preliminary excavations, so the 2014 season attempted to identify the sociopolitical structure of metal production by focusing on a potentially administrative or residential context (Area B). Furthermore, the Area A slag mound provided significant archaeometallurgical insight, but this feature is only one of the many slag mounds at the site. To further investigate the archaeometallurgical record, an additional slag mound (Area C) was selected for a test probe excavation. In order to identify and understand the relationships between metallurgical and administrative/residential areas of KAJ, the site was also comprehensively remapped using the ELRAP balloon aerial photography platform and 3D photogrammetry techniques. Finally, sieving and flotation of excavated sediment produced a substantial botanical dataset, providing new data about fuel selection for smelting and preliminary evidence concerning subsistence practices. The integration and analysis of these diverse datasets contributes to a more holistic understanding of the site and facilitates a reinterpretation of KAJ as an organized expansion of metal production in Early Iron Age Faynan.

Survey and Site Mapping

The first goal when returning to KAJ was to methodically remap the site, since existing maps (e.g., Levy et al. 2003, fig. 16) lacked a complete representation of the distribution and layout of archaeological and archaeometallurgical remains, based on a comparison of the map to what could be seen on the ground. The ELRAP team used a balloon platform with an attached camera to capture thousands of low-altitude aerial photographs and produce 3D models for a comprehensive and spatially accurate representation of KAJ (Figure 4) (Howland, Kuester, and Levy 2014). This photogrammetric approach also allowed for generation of spatially referenced, high-resolution GIS (Geographic Information System) datasets, such as orthophotographs and digital elevation models, at resolutions unparalleled by otherwise available data, such as satellite imagery (Howland et al. 2015). In turn, these datasets were used to create site maps through vectorization in GIS (Figure 3). Maps produced using these combined methods are often more accurate, and in many cases far more comprehensive, than mapping efforts from the ground, as was previously done at KAJ.

The results of the aerial photography and mapping project shed new light on the distribution of archaeological remains at KAJ (Howland et al. 2015). The produced orthophotograph, providing an aerial perspective with ca. 2 cm resolution, facilitated detailed vectorization of all site features in GIS. The new map (Figure 3) affords a more accurate depiction of the density of copper slag mounds and concentrations at the site, revealing 19 new slag deposits and scatters that were not present on the previous map generated by Total Station survey (cf. Levy et al. 2003, fig. 16). This map also differentiates slag deposits by type, including slag mounds, mounds of crushed slag, and slag scatters (all of which were ground-truthed), providing a more nuanced understanding of the spatial distribution of the remains from copper smelting. Moreover, it was possible to identify dozens of architectural features that were not previously mapped, which also facilitates greater understanding of the scale of the industry and site use. Finally, the new map also helped guide excavation decisions over the course of the field season, such as identifying the most centrally located structure for excavation.

In general, the newly discovered features fall within the original spatial boundaries defined for the site and conform to what is seen at other smelting sites in Faynan, with slag being primarily deposited along the outskirts with some smaller deposits among the architecture. While the identification of new slag mounds inherently suggests a larger scale of production at KAJ than previously believed, it is difficult to estimate the amount of slag without excavations, as slag mounds can contain 40% or less slag (Ben-Yosef 2010, 338). The mounds of crushed slag at KAJ were previously mentioned by Hauptmann (2007) but were mapped for the first time here. In antiquity, slags were frequently crushed to extract extraneous bits and prills of metallic copper trapped in the slag matrix during smelting, and it is considered a standard step in the ancient metal production chaîne opératoire in Faynan and beyond (Hauptmann 2007, 245–246; Hauptmann and Löffler 2013, 80; Ben-Yosef 2010, 929; outside of Faynan: e.g., Rothenberg 1990, 5, 39; Bassiakos and Catapotis 2006, fig. F.9). Crushed slag served additional functions, such as pottery temper (including in ceramics from KAJ), a metallurgical flux, and as foundations for structures (Martin et al. 2013; Smith, Goren, and Levy 2014; Smith and Levy 2008; Ben-Yosef, Najjar, and Levy 2014, 810–812; Ben-Yosef and Levy 2014b, 942). Crushed slag mounds at KAJ are towards the furthest extent of the site (on its northeastern and southeastern boundaries), similar to what is seen at Khirbat en-Nahas (Ben-Yosef 2010, 329–331). Some of these mounds

Figure 4. Three-dimensional model of Khirbat al-Jariya produced using low-altitude aerial photography and digital photogrammetry. This model provided the basis for the georeferenced orthophotograph used to create the new map of the site (Figure 3). A 3D version of this image is available at https://doi.org/10.1080/00934690.2020.1747792.

Figure 5. Orthophotograph of Building 2 before excavation. Note the stone circles on the right side (marked with dashed, white lines) representing modern repurposing of the collapse.

are in close proximity to the excavations at Area B and possibly provide some indication of the function of the building (discussed further below).

Excavations

Area B—Building 2

In order to investigate the social organization of copper production at KAJ, the ELRAP project directors decided to excavate half of the largest architectural complex visible

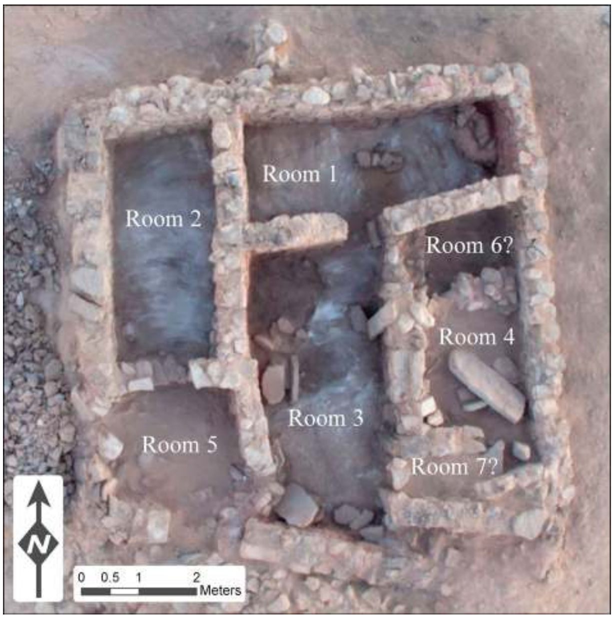

Figure 6. Aerial photograph of Building 2 following excavation.

on the surface, located in the northern part of the site with a central position on a high, natural bedrock outcrop (Area B, Figures 5, 6). The building was selected based on the potential for uncovering a possible elite residence/administrative context similar to those seen at Khirbat en-Nahas (such as Areas R and T—see Levy et al. 2014). Excavation revealed a structure (Building 2) measuring approximately 7.5 × 7.5 m with between four and seven possible rooms—it was difficult to determine the room organization on the eastern side of the building, as it was not fully excavated (Figure 6). Unlike the central building at KEN (Area R), there was no evidence of a second story at KAJ. The building was likely accessible through two entrances in its southern wall connecting the building to a central alley which separated it from another large, potentially related but unexcavated, structure immediately to its south. Excavations discerned seven unique strata associated with the building's occupation and abandonment.

Building 2 was constructed directly on the local bedrock, which likely functioned as the surface for the initial occupation (Stratum B2c). All of the major walls on the perimeter and interior of the building, which are adjoining, were constructed at the beginning of this stratum. The end of the first occupation is identified by the entrances to Rooms 4, 6, and 7 being intentionally blocked, after which they went out of use for the remainder of the site's habitation, creating an undisturbed context (Figure 7). As the building likely experienced a second occupation on the bedrock surface (discussed further below), during which the floors were presumably cleaned as part of normal habitation/use, artifacts associated with the first occupation would only be excavated in these blocked eastern rooms of the structure (4, 6, and 7); however, as previously mentioned, these rooms were not completely excavated. Thus, material culture from the initial occupation of Building 2 is extremely limited, and the stratum is primarily identifiable by the construction of the building.

Following the blocking of the interior doorways, there was a second occupation in Building 2 (Stratum B2b), which similarly used bedrock as a surface in the structure, indicated by the blockages also being built directly on bedrock. Finds relating to this occupation were excavated immediately above the bedrock, with small patches of beaten earth possibly representing a floor in Rooms 1, 2, and 3. In addition, a semicircular stone installation faced with mudbrick was excavated in the eastern end of Room 1; the interior of the installation was left unexcavated. Artifacts collected from the floors in Rooms 1 and 2 were primarily ground stone artifacts, including hammerstones and grinding slabs, as well as some pottery (pottery analysis is ongoing and will be the subject of a future publication). Room 3, the central space of Building 2, was unique in the discovery of a grinding feature with a finely crafted grinding slab and associated grinding stone in situ. The ground stones were immediately adjacent to a possible bedrock mortar but separated by a standing stone slab (Figure 8). In addition, crushed slag was found within and around the bedrock mortar (similar to mortars and mounds of crushed slag found northeast of Building 2, discussed further below). A possible crushed slag floor surface was excavated in the northwestern corner of the room and likely connects to the grinding feature. Following the end of this second occupation period, a layer of fill (Stratum B2a/b) accumulated on the bedrock. The excavated

Figure 7. Blocked doorways in the north-south central wall in Building 2 preventing access into the eastern rooms.

material from the fill was difficult to definitively attribute to a particular occupation (B2a or B2b) and was classified as belonging to its own stratum (B2a/b).

The subsequent and final occupational phase (Stratum B2a) in Building 2 was identifiable by a significant accumulation of ceramics, including a possibly reconstructable vessel in Room 2 on top of the preceding fill. A small north-south partition wall excavated on top of the fill in Room 1 was also associated with this stratum. The excavation of some hammerstones and grinding slabs similarly indicated the presence of an occupation horizon. Following this final phase, the structure went out of use, as represented by the wall collapse embedded in aeolian sediment (Stratum B1b and B1c) both within and surrounding the standing architecture. Some of the collapsed stone was repurposed in modern times (Stratum B1a) to construct circular structures (approximately 2–5 m in diameter, Figure 5). These installations were potentially animal pens built by the local Bedouin community.

Area C—slag mound

To build on the metallurgical narrative constructed from the 2006 excavations, a large slag mound on the southeastern extent of the site was selected for a small excavation probe (Area C, Figure 3) (see also Liss and Levy 2015). The slag mound was identified based on a visible scatter of broken slags, and a cut by a mining road from the 1960s on its northeastern edge revealed additional metallurgical remains below the surface. A 1 × 1 m sounding was excavated to a depth of ca. 1.75 m, where local bedrock was discovered (Figure 9). Above the bedrock was a significant accumulation of crushed

Figure 8. Unique grinding installation in Room 3 of Building 2, including finely crafted grinding slab (with associated grinding stone) and possible bedrock mortar (at tip of arrow with hammerstone and slag chunks) separated by standing stone slab.

Figure 9. Completed excavation probe in the slag mound of Area C.

slag, roughly 80 cm thick (Stratum C2d). The excavated material from this stratum was almost entirely finely-crushed slag with only some bits of charcoal and a few pottery sherds. Above the slag, there was a drastic transition in material culture; this new layer of ashy sediment yielded significant domestic refuse, including pottery, charcoal, charred date seeds, burnt bones, and a ground stone artifact (Stratum C2c). A stone feature consisting of four stones in a line was excavated as well; however, its function was indeterminable, as it continued into the section. Atop this stratum was a thin, compact layer of tan sediment, possibly from weathered technical ceramics related to metal production, such as furnace fragments and/or tuyères (Stratum C2b). The associated artifacts included pottery sherds, possible pieces of technical ceramic, and a broken copper ring. The final layer of the slag mound was another metallurgical phase dominated by large fragments of both tap slag (ranging from 5–25 cm in diameter) and furnace slag embedded in a dark-brown, ashy sediment totaling about 50 cm thick (Stratum C2a). Charcoal, broken technical ceramics, and some pottery sherds were also collected. This second layer of metallurgical waste was probably the final period of copper production prior to the abandonment of KAJ.

Slag Processing Installations

The new map and excavations at KAJ confirmed the significant role of secondary slag processing at the site originally identified by Hauptmann (2007, 131–132). Hauptmann's (2007, 131) survey of KAJ located a notable presence of crushed slag (estimated 100 tons) on the southern edge of the site. In addition to mapping these mounds (three in total), the 2014 ELRAP expedition identified and mapped two additional crushed slag mounds northeast of Building 2 on the northern limits of KAJ (Figure 3). Further exploration of these features revealed bedrock mortars associated with the mounds (similar to those described by Hauptmann [2007, 125] at Ras en-Naqb) (Figure 10), but not previously reported on at KAJ. Ten bedrock mortars were identified and mapped near the two heaps of crushed slag in the northeast, and one additional mortar was discovered by the crushed slag in the south. One of the northern mortars was still filled with crushed slag, clearly connecting them to the grinding process. The excavations from Building 2 also corroborate the importance of crushing activities at the site. Artifacts collected from the bedrock surface in the building were dominated by hammerstones and grinding slabs (potentially used for slag), and a possible bedrock mortar was centrally located in Room 3. The

Figure 10. Close up of bedrock mortars with some crushed slag still inside and scattered at bottom of photograph.

northwestern corner of this room was also possibly surfaced with a layer of crushed slag.

As indicated from the survey results and previous excavations, only some of the slag at KAJ was crushed, which is also the case at Khirbat en-Nahas. This phenomenon is possibly the result of later slags being produced from a more efficient smelting technology. As smelting technologies improved, less copper would be lost/trapped in the slag. The decreased amount of copper, or even a reduced amount of visible copper, could potentially render the slag crushing process ineffective or inefficient and cause the abandonment of this step in the chaîne opératoire. This understanding is further supported by the excavations and stratigraphy in Areas B and C, where crushed slag is only directly associated with the earliest occupation of the site. There is also substantial evidence for the gradual improvement of copper production over the course of habitation at KAJ and in Faynan more generally (Ben-Yosef et al. 2019; Liss and Levy 2015). Given the site seems to have been abandoned, it is also possible the inhabitants simply did not reach the crushing step for some of the slag prior to leaving KAJ. However, this explanation is less likely, given the similar phenomenon at Khirbat en-Nahas, which continued to produce copper after KAJ.

Radiocarbon Dates

Ten new radiocarbon samples were selected from both the slag mound and building excavations to further contextualize KAJ in the Iron Age, bringing the total number to 19 from the site. Based on the dates and stratigraphy (Tables 1, 2), the construction and initial occupation of Building 2 likely begins approximately in the mid-11th century B.C. (elaborated on in greater detail below), and the structure was most likely abandoned with the site in the mid–late 10th century B.C. The radiocarbon results from the slag mound similarly indicate that the site was established in the mid-11th century B.C., contemporaneous with the construction of Building 2. Samples from the main production phase (Stratum C2a) at the top of the mound correlate with the last occupation of Building 2 in the late 10th century B.C. In general, this new suite of radiocarbon dates matches with those collected from Area A (Ben-Yosef et al. 2010), securely placing KAJ within the Early Iron Age between the 11th and 10th centuries B.C. (see Table 2 for a complete stratigraphy of all excavation areas and associated radiocarbon dates; graphs of the new radiocarbon dates are available in Supplemental Material 1).

Paleobotanical and Anthracological Analyses

Wood charcoal and macrobotanical remains were collected and recovered after dry sieving from 10 contexts at the site (three loci from the Area C slag mound and seven from rooms in Building 2). Additionally, material was collected from the soil samples (57 total) processed for flotation. Analysis of the macrobotanical remains recovered from flotation is still ongoing, so only results from the analysis of wood charcoal recovered from dry sieving are presented here. In total, 3,305 fragments have been analyzed, of which 90% have been identified (Table 3; Figure 11). Most of the assemblage consists of xerophytic, salt-tolerant plant taxa available from the nearby dry, brackish wadi channels and substrate around the Wadi al-Jariya catchment, although taxa which grow in well-watered wadi courses and upland areas (e.g., *Juniperus phoenicea* and *Pistacia atlantica*) are also present. Tamarisk (*Tamarix* sp.) is the most abundant taxon, particularly in contexts from the slag mound, and is present in all sampled contexts. These results share many similarities with wood charcoal assemblages from other Iron Age copper manufacturing sites in Faynan, including Khirbat en-Nahas and Faynan 5 (Baierle et al. 1989; Engel 1992, 1993; Engel and Frey 1996), which also consist largely of steppic plant taxa, and particularly favor tamarisk wood as a fuel source.

The KAJ assemblage also contains wood from several taxa with edible fruits, including carob (*Ceratonia siliqua*), date palm (*Phoenix dactylifera*), fig (*Ficus carica*), grape (*Vitis vinifera*), olive (*Olea europaea*), and pomegranate (*Punica granatum*). Fruit tree wood remains are present in both the Building 2 and slag mound contexts. Grape pips, figs, pomegranate, and date palm seeds were identified during preliminary analysis of KAJ's non-wood macrobotanical remains, and dried pomegranate fruits have been found elsewhere in the Faynan region in the Iron Age Wadi Fidan 40 cemetery (Levy, Adams, and Shafiq 1999). The wood remains most likely derive from cuttings of stems and vines removed as part of orchard management.

Table 1. Complete results from radiocarbon samples collected during the 2014 excavation season at KAJ.

Sample	Area	Room	Locus	Species	Notes	Age (B.P.)	Date (1σ)	Date (2σ)
KAJ1 AA105757X28659	B	3	543	*Phoenix dactylifera*	Whole seed	2763 ± 34	970–844 B.C. (68.2%)	997–832 B.C. (95.4%)
KAJ2 AA105758X28660	B	6	554	*Phoenix dactylifera*	Whole seed	2821 ± 32	1009–927 B.C. (68.2%)	1083–898 B.C. (95.4%)
KAJ3 AA105759X28661	B	4	544	*Phoenix dactylifera*	Whole seed	2896 ± 28	1118–1027 B.C. (68.2%)	1196–1001 B.C. (95.4%)
KAJ4 AA105760X28662	B	2	542	*Phoenix dactylifera*	Seed fragment (ca. 1/3)	2786 ± 29	979–901 B.C. (68.2%)	1007–846 B.C. (95.4%)
KAJ5 AA105761X28663	B	2	545	*Phoenix dactylifera*	Whole seed	2819 ± 34	1009–924 B.C. (68.2%)	1107–896 B.C. (95.4%)
KAJ6 AA105762X28664	B	1	565	*Phoenix dactylifera*	Whole seed	2836 ± 30	1026–931 B.C. (68.2%)	1107–912 B.C. (95.4%)
KAJ7 AA105763X28665	B	3	561	*Phoenix dactylifera*	Whole seed	2779 ± 29	978–895 B.C. (68.2%)	1002–845 B.C. (95.4%)
KAJ8 AA105765X28667	C	N/A	533	*Tamarix* sp.	Entire ca. 2 year old twig	2749 ± 47	932–832 B.C. (68.2%)	1001–813 B.C. (95.4%)
KAJ9 AA105764X28666	C	N/A	535	*Phoenix dactylifera*	Whole seed	2852 ± 30	1054–940 B.C. (68.2%)	1112–928 B.C. (95.4%)
KAJ10 AA105756X28658	C	N/A	549	*Retama raetam*	Entire small-diameter twig	2873 ± 33	1111–1005 B.C. (68.2%)	1190–931 B.C. (95.4%)

Table 2. Complete stratigraphy correlated across all excavation areas at Khirbat al-Jariya (Areas A, B, and C) (Area A stratigraphy and radiocarbon dates from Ben-Yosef et al. 2010).

Complete Stratigraphy and Correlation from KAJ 2006 and 2014 Excavation Seasons										
Strat.	Description	Radiocarbon Area A (1σ)	Area A	Description	Radiocarbon Area B (1σ)	Area B	Description	Radiocarbon Area C (1σ)	Area C	Description
I	Post-occupation	1113–997 B.C.	A1a	Top sediments of slag mound, copper production debris and aeolian loess	N/A	B1a	Modern, repurposed stones	N/A		Not present
		1125–1026 B.C.	A1b	Fill inside Structure 276, large boulders and stones	N/A	B1b B1c	Stone collapse Stone collapse with loess fill	N/A		
II	Final occupation and copper production phase	995–912 B.C.	A2	Occupation phase of Structure 276, copper production debris at top of mound	1009–927 B.C., 979-901 B.C., 1118–1027 B.C. 970–844 B.C.	B2a B2a/b	Final occupation phase in Building 2 Ambiguous loci associated with 2a or 2b	932–832 B.C.	C2a	Thick accumulation of copper production debris
III	Occupation following architectural restructuring of Building 2	994–915 B.C., 1108–934 B.C.	A3	Accumulation of copper production debris in slag mound	1009–924 B.C., 1026–931 B.C., 978–895 B.C.	B2b	Second occupation phase in Building 2 following architectural restructuring	N/A		Not present
IV	Initial occupation of site	995–919 B.C.	A4	Occupation phase with stone installations, floors, and tent dwelling?	N/A	B2c	Construction and initial occupation in Building 2	N/A	C2b	Thin debris accumulation
		1128–1026 B.C.	A5	Accumulation of domestic debris mixed with industrial remains				1054–940 B.C.	C2c	Occupation phase with domestic refuse
		1113–1012 B.C., 1114–1016 B.C.	A6	Occupation phase above bedrock with fine crushed slag, ore, ash, and pits				1111–1005 B.C.	C2d	Superimposed layers of crushed slag, nearby mounds of crushed slag
Bedrock										

Table 3. Absolute fragment counts (AFC), percentage abundance (%F), and percentage ubiquity (%U) of wood charcoal taxa sampled from KAJ (Smart and Hoffman 1988). Samples which had a strong resemblance to a particular taxon but which lacked sufficient criteria for secure identification are recorded with the prefix cf.

Taxa	AFC	%F	%U
Acacia sp.	22	0.7	30
Acacia tortilis	21	0.7	30
Acacia Total	43	1.4	50
Amaranthaceae-Chenopodioideae	140	4.7	70
Anabasis sp.	2	0.1	10
Ceratonia siliqua	525	17.7	70
cf. *Ceratonia siliqua*	14	0.5	20
Fabaceae	28	0.9	30
Fabaceae-Faboideae	10	0.3	10
Ficus sp.	45	1.5	30
Fagonia/Zygophyllum	8	0.3	10
Haloxylon persicum	44	1.5	40
Juniperus phoenicea	5	0.2	30
Nitraria retusa	38	1.3	50
Olea europaea	41	1.4	60
Phoenix dactylifera	179	6.0	50
Pistacia atlantica	276	9.3	20
Prosopis farcta	3	0.1	10
Punica granatum	253	8.5	70
Retama raetam	266	9.0	100
Tamarix sp.	1045	35.2	100
Vitis vinifera	3	0.1	10
Zygophyllum dumosum	3	0.1	10
Total identified	2971		
Indeterminate	334		
Total fragments	3305		

Periodic pruning promotes fruit production and rejuvenates older trees by removing dead and diseased branches and nonproductive shoots and branches, so that the tree's energy reserves are focused on producing fruiting buds and younger shoots that have high fruit yields. Pruning also allows sunlight to penetrate the branches of light-demanding olive, fig, and grape trees and vines, and maintains vegetation at a height and shape that facilitates efficient harvesting (Gucci and Cantini 2000; Flaishman, Rodov, and Stover 2008; Terral 2000).

Orchard and viticultural wood refuse provide a ready-made fuel source in traditional agricultural practice in Jordan today, including in the Faynan region (Lancaster and Lancaster 1999, 174–175), and fruit tree wood (particularly olive) has been identified as a fuel source in multiple archaeological sites in the Levant (Langgut et al. 2019; Terral 2000), including in metallurgical production sites like Khirbat en-Nahas and Tell Hammeh (Engel 1993; Veldhuijzen and Rehren 2007). While agricultural waste alone would not have satisfied the large fuel demands of an industrial-scale metallurgical operation like that found at KAJ, fruit tree cuttings would still have been a useful, supplementary source of wood.

The presence of both wood and fruit remains (with especially large quantities of date palm) indicate that KAJ's inhabitants had local access to cultivated fruit trees, which they consumed. While the immediate area around KAJ is steep, arid terrain that is unsuitable for cultivation, Wadis Faynan and Fidan have well-watered channels with soils conducive to agriculture. Remains of Iron Age field systems, likely watered via runoff farming regimes, and agricultural terraces have been identified in both areas (Knabb et al. 2016; Mattingly et al. 2007). Closer to KAJ, on Wadi Ghuwayba al-Ghani ("al-Ghani" is a descriptor meaning "the moist one"), one of the drainages of the Wadi al-Ghuwayba, modern Bedouin grow fruit trees, including olive and pomegranate, in agricultural gardens. Thus, the fruits and wood cuttings likely came to KAJ from orchards or fields growing in one of these water-rich locations in the Faynan landscape.

The wide variety of plant taxa collected by the inhabitants of KAJ suggests that fuel selection was less specialized toward specific taxa than it was in the later Roman and Middle Islamic Periods in the Faynan region (Baierle et al. 1989). However, the most prevalent wood taxa (e.g., *Tamarix* and *Retama raetam*) at KAJ nevertheless demonstrate knowledge of, and preference for, trees and shrubs that provide large quantities of fuel, burn well, and which could be easily transported to

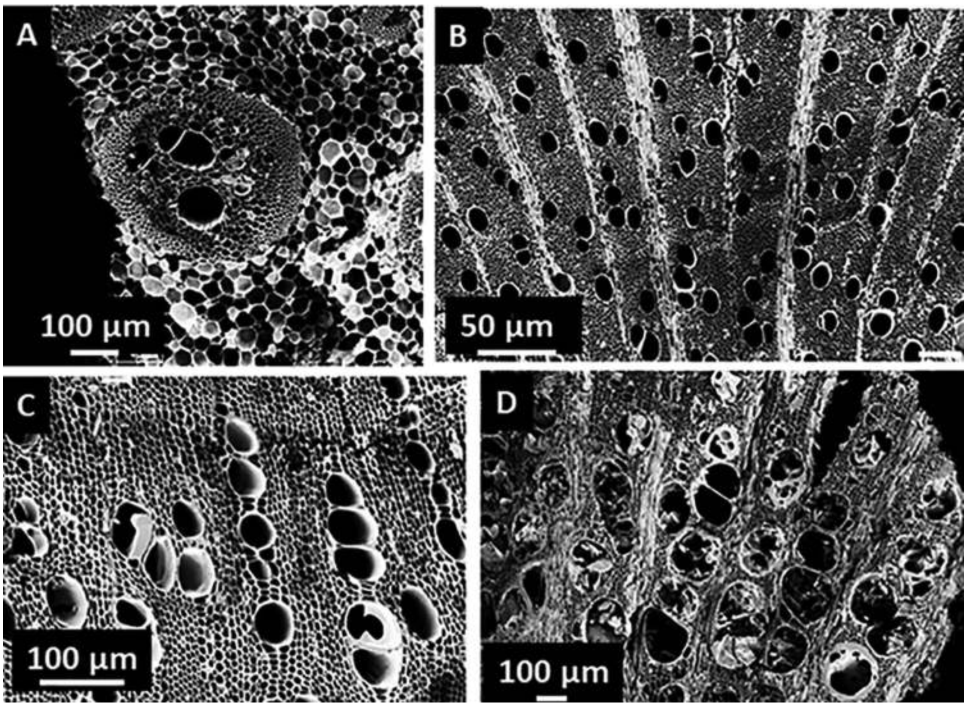

Figure 11. SEM microphotographs of taxa in the Khirbat al-Jariya wood charcoal assemblage, including transverse sections of: A) *Phoenix dactylifera*; B) *Tamarix*; C) *Punica granatum*; and, D) *Vitis vinifera*.

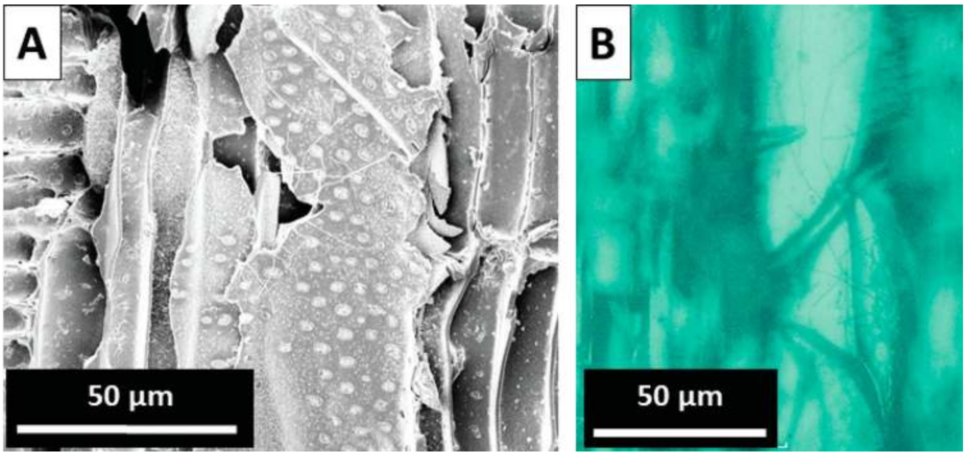

Figure 12. SEM and light microphotographs showing fungal hyphae in vessel and parenchyma elements of (A) *Acacia* cf. *tortilis* and (B) *Punica granatum*. The high incidence of fungal hyphae in many of the analyzed KAJ wood charcoal fragments indicates harvesting of deadwood (Moskal-del Hoyo, Wachowiak, and Blanchette 2010).

the site from nearby. KAJ's inhabitants further implemented collection strategies that promoted long-term sustainability of fuel sources by using highly regenerative taxa, like tamarisk, and harvesting deadwood (Figure 12). The use of wood fuel from fruit trees, as well as other taxa like acacia (*Acacia tortilis*) that provide fuel and additional products like animal fodder, also indicate that fuel collection at KAJ was integrated with the site's full suite of subsistence activities (additional images of wood anatomical features available in Supplemental Material 2).

Discussion

Excavations from both Areas B and C support a reinterpretation of KAJ. Based on the results from the 2006 season (primarily the discovery of potential tent postholes and evidence for small-scale copper production), the excavators suggested KAJ was an ephemeral settlement in its earliest stages established to opportunistically exploit local copper ores (Ben-Yosef et al. 2010, 743). In addition, it was proposed that significant architecture was only constructed in the 10th century B.C. with the development of a more substantial and sophisticated industry (Ben-Yosef et al. 2010, 743). However, the Building 2 excavation and dating seem to contradict this hypothesis. Based on the stratigraphy indicating two occupation phases on bedrock floors chronologically separated by the blocking of doorways, excavated radiocarbon samples from the bedrock must relate to the second occupation phase. These dates therefore post-date the first occupation of Building 2 and function as a terminus ante quem for its construction. As such, Building 2, the largest extant stone-constructed building at KAJ, was likely built in the mid-11th century B.C., at the very beginnings of the settlement. Due to the industrial nature of Building 2, it did not provide much clarification concerning the social dynamics of copper production, as originally hypothesized. However, the significance of this early construction at the site suggests KAJ was an integral part of the Early Iron Age Faynan copper production network from the outset of its settlement, representing development early in Production Phase 1 in Faynan (Ben-Yosef et al. 2019).

Following the initial construction and occupation in Building 2, the structure was architecturally modified by the aforementioned door blockages. The reason for this alteration is currently unclear. It may be associated with a change in function and/or control of the building, but it is impossible to determine from the current state of the archaeological record, based on the understanding that material culture from the first occupation was no longer present at the time of excavation, except in the minimally excavated eastern rooms. The doorway to the small structure excavated in 2006 was also intentionally blocked (Ben-Yosef et al. 2010, fig. 7); it is difficult to situate chronologically, but it was potentially associated with the same event in Building 2. A similar phenomenon was discovered at KEN, in which the guard chambers of the gatehouse connected to the fortress were intentionally narrowed (Levy et al. 2014, 96). However, this event has been attributed to the campaign of Sheshonq I, which has also been connected to the synchronous abandonment of KAJ (and the transition to Production Phase 3) (Levy, Ben-Yosef, and Najjar 2012, 210; Ben-Yosef et al. 2010, 744; Levy, Münger, and Najjar 2014; Ben-Yosef et al. 2019). Thus, these blocked doorways at KAJ are unique in their early date, and they are potentially evidence of a localized event. Future excavation in the unexcavated eastern rooms could provide additional insight.

Based on the material culture in Building 2 and the proximity of the two crushed slag mounds, the building might have been dedicated to slag processing and/or supervision of the operations; this draws a possible parallel to Area S at KEN, which also included a building rich with stone tools that was associated with slag crushing (Levy et al. 2014, 151–169; Levy, Bettilyon, and Burton 2016). The connection between a large, central building at the site and slag processing suggests it was a crucial component of metal production at KAJ. Secondary slag processing also links the metallurgical process at KAJ and KEN. Similar mounds of crushed slag were found on the outskirts of KEN, suggesting both sites employed a comparable chaîne opératoire (Ben-Yosef 2010, 329–331). These crushed slag deposits at KEN were initially difficult to date precisely within the Iron Age or to associate with a specific Production Phase, given the long and continuous copper smelting at the site from the 12th–9th centuries B.C. (Ben-Yosef 2010, 930). The crushed slag at KAJ can help refine the chronological attributions for these features, as KAJ was only inhabited during the 11th–10th centuries B.C. (during Production Phases 1 and 2). Furthermore, slag processing seems to stop during the later phases of copper production in Iron Age Faynan (Ben-Yosef 2010). Thus, it is possible to more generally date the crushed slag mounds at KEN to an early production phase in the 11th–10th centuries B.C. (Production Phase 1 and/or 2), contemporaneous with KAJ.

From the Area C slag mound probe, the material culture directly above bedrock was most likely associated with the initial occupation at KAJ and is similar to the Area A slag mound excavation. The crushed slag in this first layer reiterates the hypothesis that KAJ was established for the purpose of copper production and exploiting local ores, especially considering the presence of ancient mines near the site, the Wadi al-Jariya mines (Figure 1), and also the lack of nearby water or other natural resources (Ben-Yosef et al. 2010, 736). The significance of the accumulation of slag (roughly 80 cm) also suggests a more intensive early production period than seen at the bottom of the Area A slag mound, where there was only a thin layer of crushed slag (ca. 10 cm). Based on the radiocarbon dates, this earliest production is contemporaneous with the construction of Building 2 in the mid-11th century B.C. As such, along with the immediate construction of significant architecture, the inhabitants of KAJ were likely producing copper on a substantial scale early in the site's occupation, perhaps suggesting a more rapid development of copper production within Production Phase 1.

Above the layer of crushed slag, Area C transitioned to a possible domestic/habitation function, reflecting what was seen in Area A. Material culture from this layer was indicative of domestic refuse related to cooking, based on the bones and date seeds, and completely lacking slag. Following the unique and somewhat ambiguous deposit of compact tan sediment, the area once again functioned as a metallurgical dump. Here, the material record diverges slightly from Area A in the size of slag fragments found within this layer; tap slags with diameters up to 25 cm were collected, whereas previously excavated tap and furnace slags were typically less than 10 cm in diameter, with some samples reaching 15 cm (Ben-Yosef et al. 2010, 738; Ben-Yosef and Levy 2014b, 941–943). These slags are possibly indicative of intensification in production not represented by the Area A slag mound. From the radiocarbon dates and its presence on the surface of the site, it is possible to suggest that this thick metallurgical layer represents the final phase of intense copper production at KAJ associated with Phase 2 before abandonment, and it is likely linked with the final occupation in Building 2.

The paleobotanical and anthracological data help frame the site in a regional context as part of an interconnected industrial landscape. Evidence of cultivated fruit trees in the archaeological record indicates that subsistence for workers at the site likely depended on a provisioning network operating on a regional scale. The evidence for fruits at KAJ suggests a connection between the site and a perennial spring, the closest being Ain al-Ghuwayba (ca. 2.5 km away), which feeds the Wadi Ghuwayba al-Ghani and its present-day orchard. This spring is flanked on both sides of the wadi by a contemporaneous site, Khirbat al-Ghuwayba (KAG) (Figure 1), a small-scale Iron Age smelting site of about 7 ha in size and ca. 4 km from KEN (Ben-Yosef 2010, 430–450, 888; Ben-Yosef, Najjar, and Levy 2014, 848–850). The limited excavations at the site have not revealed much about its overall use during the Iron Age beyond some copper production. However, dating based on a radiocarbon sample, ceramics, and the archaeometallurgical assemblage suggests an Early Iron Age date for the site with typological similarities to KAJ, situating it within Production Phase 1 (Ben-Yosef, Najjar, and Levy 2014, 848). Thus, the settlements of KAJ and KAG, with comparable dating and material culture, are likely two components of an organized network centered at KEN in Phase 1. These three sites are also interconnected by wadis and within 4 km of each other, facilitating movement between them. Moreover, based on its proximity to the spring and the botanical evidence from KAJ, KAG may have had a role in provisioning copper producing sites in the region.

Overall, the results from KAJ show organization and coordination in the development of the site during Ben-Yosef and colleagues' (2019) Phase 1 in Faynan. The results from both Areas B and C seem to indicate that KAJ was a significant copper production site from its initial establishment, rather than an ephemeral and opportunistic site experiencing a gradual development in complexity and metallurgical activity. Taking into consideration the contemporaneous copper production at KEN, which likely began producing copper at the very beginning of Phase 1, settlement at KAJ should be reinterpreted as an organized expansion of the already active metallurgical industry in Faynan. The reason for this expansion is probably connected to the location of KAJ up the wadi from KEN, providing a greater proximity to the copper resources in this area of Faynan (Knabb et al. 2014; Figure 1). The consistencies in the copper production chaîne opératoire between KAJ and KEN also support this conclusion; inhabitants of both sites dedicated significant efforts to slag crushing, depositing mounds on the perimeter of the site, and used similar strategies/resources for charcoal. Thus, it is possible a subset of metalworkers from KEN with a shared technical knowledge established KAJ for easier access to the Wadi al-Jariya mines. Moreover, this new settlement at KAJ was probably provisioned by a regional network including KAG, based on the paleobotanical data. This connection further corroborates the expansion to KAJ was a coordinated endeavor and contributes to the developing understanding of the degree of political complexity in Faynan during the Iron Age.

The extension of copper smelting to KAJ also indicates that the demand for copper in the mid-11th century B.C. was significant enough to justify/incentivize an intensification of production, as KEN also continued to smelt copper during this period (and potentially also KAG on a much smaller scale). This understanding fits within the broader context of copper production in the eastern Mediterranean. In the Late Bronze Age, Cyprus was the primary supplier of copper to the southern Levant (Muhly 1989; Kassianidou 2012a; Kassianidou and Papasavvas 2012; Yahalom-Mack et al. 2014). However, industrial scale metal production in Cyprus declined with the transition to the Iron Age, possibly in conjunction with economic disruption at the end of the Late Bronze Age (Yahalom-Mack et al. 2014; Kassianidou 2012b, 2014; Cline 2014; Knapp and Manning 2016). The unmet demand for copper in the southern Levant and beyond could have provided the impetus for establishing mining and smelting centers in Faynan, the beginning of Phase 1 (Ben-Yosef et al. 2010, 2019). Ultimately, the Wadi Arabah would develop into the main source of copper to the region until the end of production in the Late Iron Age (Levy, Ben-Yosef, and Najjar 2014; Ben-Yosef et al. 2019). The metal produced in Faynan reached the Mediterranean via the Negev Desert, as evidenced by pottery analysis at sites in the Negev and a submerged copper cargo found at Neve

Yam (Yahalom-Mack et al. 2014; Martin and Finkelstein 2013; Martin et al. 2013; Yahalom-Mack and Segal 2018; Ben-Yosef and Sergi 2018). Moreover, this copper seems to have been available to a wide market at least as far as Greece (Kiderlen et al. 2016). The role of Faynan in the eastern Mediterranean economy and the demand for copper could also have contributed to the gradual technological developments seen over the course of production at KAJ, such as the larger slags in the final phases of copper smelting and the transition to Phase 2 (this is also evidenced through x-ray fluorescence analysis of slag samples from the site [Ben-Yosef et al. 2019; Ben-Yosef 2010; Liss and Levy 2015]). The new map of KAJ also reiterates the significant scale of production based on the identified slag deposits. Increases in technological sophistication, efficiency, and scale to maximize copper extraction could have been driven by the potential economic profits or other socio-political factors. Situating the excavation results within the context of Iron Age Faynan and the economy of the southern Levant in this way can help explain the reinterpretation of KAJ as a calculated expansion of the existing copper smelting industry and part of the development of the Iron Age industrial landscape.

Conclusions

Results from the 2014 excavation season at KAJ indicated a larger scale of production and more significant architecture in the earliest phases of the site's occupation than previous research suggested. Building 2 and substantial copper slag remains excavated in Area C both date to the mid-11th century B.C., contemporaneous with the earliest remains excavated by Ben-Yosef and colleagues (2010). Remapping the site revealed additional architectural and archaeometallurgical features at KAJ, while the paleobotanical and anthracological analysis situated the site as part of a regional network. As such, KAJ can be seen as a satellite production center representing one part of an organized expansion of ongoing production at KEN, as opposed to an early and opportunistic phase of Iron Age copper smelting. The demand for copper reaching widespread markets in the eastern Mediterranean, along with the nearby copper mines in the Wadi al-Jariya, likely provided the impetus for a coordinated effort to establish an additional smelting center. In sum, renewed excavations at KAJ revealed an expeditious development of copper smelting up the wadi from KEN, providing new insight concerning the development of the Iron Age Faynan industrial landscape.

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