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Size Matters: The Role of Nodule Size in Assessing Lithic Transportation—The Case of the Mount Reihan Flint Extraction and Axe/Adze Workshop, Dishon Basin, Eastern Galilee, Israel

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ABSTRACT
There has been much progress recently in reconstructing the transportation of lithic materials from quarry/extraction sites and workshops to occupation sites. The suggested "theoretical nodule," "cortex ratio," and "volume ratio" measures have proven useful, mainly when applied to cases in which relatively small initial nodules/cobbles were selected for knapping. However, these methods lose much of their relevance when dealing with the production of bifacials from large nodules. In this article, we present evidence from a newly discovered axe/adze workshop at Mount Reihan in the eastern Galilee, Israel, which boasts an almost complete *chaîne opératoire* of the production of Neolithic/Chalcolithic axes and adzes from large (mean weight 17.7 kg) flint nodules as a starting point. Measuring nodules, bifacial roughouts, and debitage enables us to propose a two-step method that is valid for the production of bifacials from large nodules: (1) weight of knapped waste is calculated as 80 per cent of the initial flint weight; (2) the 20 per cent weight that remains is divided between the rejected roughouts and the exported/transported items, following a ratio of 1 roughout: 2–3 exported tools.

KEYWORDS
Flint extraction; lithic transportation; Axe/Adze Workshop; nodule size; Neolithic/Chalcolithic; Israel

Introduction

Research of prehistoric south Levantine flint quarry/extraction and workshop sites has expanded substantially in recent years. This includes both Paleolithic complexes in the Dishon Valley, Mount Achbara, Sede Ilan, and Givat Rabbi East (see Finkel, Gopher, Ben-Yosef, & Barkai, 2018, map 1; Gopher & Barkai, 2011) and Neolithic sites such as those at Ramat Tamar (Schyle, 2007 and references therein), Kaiser Hill (Grosman & Goren-Inbar, 2016 and references therein), the newly discovered Mount Reihan (Finkel, Gopher, Ben-Yosef, & Barkai, 2017), and others.

Two questions that naturally result from such work are how to assess production at such sites quantitatively and how to calculate the number of target items transported from them. The methods available include measuring "theoretical nodule" (ratio of core to original nodule), "cortex ratio" (amount of cortex transported), and "volume ratio" (amount of volume transported). These methods have proven useful when applied to cases in which small initial nodules/cobbles were selected for knapping. However, these methods lose much of their applicability when dealing with the production of bifacial tools from large nodules (see below). The research problem is, therefore, how to quantify lithic transportation in a way that is relevant for our case.

This paper has three goals: first, to discuss methodological issues related to stone artifact transportation from extraction and workshop sites; second, to present data from a newly discovered Neolithic/Chalcolithic axe/adze extraction and workshop site at Mt. Reihan (henceforth RAW), Israel (described in Finkel et al., 2017), and discuss the implication of nodule size preferences and extraction efficiency (i.e. the number of axes/adzes produced from a nodule or the weight of axes/adzes compared to the weight of the original nodule); and, third, to suggest a method for measuring transportation from a quarry/workshop site based on our work at RAW.

Methods of Reconstructing Stone Artifact Transport Patterns Based on Debitage Assemblages

Assessing procurement activities and calculating the amount of lithic products transported from extraction and workshop sites to occupation sites has become an important element in assessing raw material preferences, mobility patterns, land use, inter-site connectivity, and other characteristics of hunter-gatherer groups and later early farming communities. In the early 2000s a

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few attempts were made to analyze artifact mobility using analytical and experimental methods (e.g. Beck et al., 2002; Dibble, Schurmans, Iovita, & McLaughlin, 2005; Ditchfield, 2016 and references within; Ditchfield, Holdaway, Allen, & McAlister, 2014; Douglass, 2010; Douglass, Holdaway, Fanning, & Shiner, 2008; Holdaway & Douglass, 2012; Holdaway, Wendrich, & Phillipps, 2010; Phillipps, 2012; Phillipps & Holdaway, 2016; Roth & Dibble, 1998; Schyle, 2007).

Dibble et al.'s (2005) research, based on experimental data, was the first to present the "cortex ratio" method, which demonstrated its effectiveness in detecting transportation of fully cortical flakes and flake-based artifacts. The ratio resulted from the division of the measured cortical surface of an assemblage of artifacts found in the extraction and workshop site by the expected cortical surface of the raw material used. This was based on geometrical models of nodule size and shape multiplied by the presumed number of nodules. If the observed amount of cortex in an assemblage was less than expected, the "cortex ratio" would be less than 1, suggesting that some of the products of the reduction process were transported. "cortex ratio" has limited relevance to our case because the transported artifacts were axes/adzes with almost no cortex (see below). The reduction process at RAW began with a large flake/blade, sometimes with a cortical dorsal face. However, since most of the reduction process took place on site, almost no cortex was transported and it is thus difficult to detect deviations from the 1:1 "cortex ratio."

Douglass tested and extended this method using weight as a measure for volume. He combined data from flake and core assemblages from silcrete and quartz surface scatters in six extraction and workshop sites in western New South Wales (Australia) and experimental work (Douglass, 2010; Douglass et al., 2008; Holdaway et al., 2010). Phillipps and Holdaway applied this method to 13 archaeological assemblages from different extraction and workshop sites in the Egyptian Neolithic Fayum and found that in some cases, core transportation was more relevant for transportation assessment than cortex loss. Therefore, they presented a new method using a measure they called "volume ratio," which detects transportation of volumetric artifacts with substantial volume. They compared the observed volume of stone assemblages in the extraction and workshop site to the total expected initial volume of the raw nodules/cobbles used to produce them (Phillipps, 2012; Phillipps & Holdaway, 2016).

"Volume ratio" is also of little use for RAW. The nodules at RAW are very large (both in weight and in volume) compared to the materials used to develop this measure. Nor is Ditchfield et al.'s (2014) adze-specific "volume ratio" very useful at RAW due to the different cobble/nodule size and shape.

Both methods are based on the challenging assumption that the number of cores found in the assemblage in an extraction and workshop site represent the initial number of nodules/cobbles used and therefore the initial average volume of a "theoretical nodule" can be assessed by dividing the total volume of the assemblage's artifacts by the number of cores found. Dibble et al. (2005) accurately stated the challenge of the "theoretical nodule" assumption:

> In other situations, it may be difficult or even impossible to determine accurately the sizes and shapes of the nodules that were exploited prehistorically. The problem is that existing local nodule sizes still remaining in the area of the site may or may not represent the range of sizes used in the past, especially if nodules were selected according to size criteria. If, for example, the largest nodules were consistently being selected, then the mean of the nodules remaining unworked could be less than the mean of the ones that were worked. In addition, if the local raw materials were extensively exploited for a considerable duration, the mean size of available nodules might actually decrease through time. (p. 557)

The assumption of a 1:1 ratio between nodules and cores (i.e. one core per nodule) might be justified if relatively small nodules are involved. Ditchfield et al. (2014) used a combination of "cortex ratio" and an adjusted "volume ratio" focused on adze production in a prehistoric adze workshop assemblage in the southern Cook Islands. But they added an additional assumption—that each cobble (= nodule) was used to produce two adzes. This might be relevant for the case they presented, but again, it probably is not sustainable for other cases. Recently, Ditchfield (2016) suggested a flake-to-core ratio and a non-cortical-to-cortical flake ratio; but since our case is focused on bifacial (axe/adze) production and not on flake production, these ratios are not discussed here. Detailed comments on bifacial production at RAW are available in Finkel et al. (2017).

Materials and Methods

We begin this section with a presentation of the site, then elaborate on the weight measurements of flint debitage, roughouts, and nodules (including experimentally knapped materials), and conclude with our calculations for the various aspects of the production.

The Mount Reihan Axe/Adze Workshop (RAW)

The Reihan Neolithic/Chalcolithic axe and adze workshop is located on one of the plateaus above the Dishon

Stream on the western mountain flank of the Eastern Upper Galilee (see Figure 1). The area is an erosive surface divided into mountainous plateaus at altitudes of 650–750 m above sea level (masl) with peaks up to 830 masl (Figure 2). The Dishon is a perennial stream with a few springs along its course. The stream flows sharply to the east into the Hula Valley. Geologically, the Eocene limestone and chalk of the Timrat Formation, which dominates the area, is rich in flint (Levitte & Sneh, 2013). Karrens containing flint nodules can still be seen today in the vicinity of the extraction and reduction (henceforth E&R) tailing piles.

RAW was discovered in a survey focused on Late Lower Paleolithic and Middle Paleolithic E&R localities (designated Localities 1–8 in Figure 2; and see Finkel, Gopher, & Barkai, 2016). The total area of the Neolithic/Chalcolithic extraction activities and the workshop area is estimated at 40,000 m^2 (Figure 3, marked in blue).

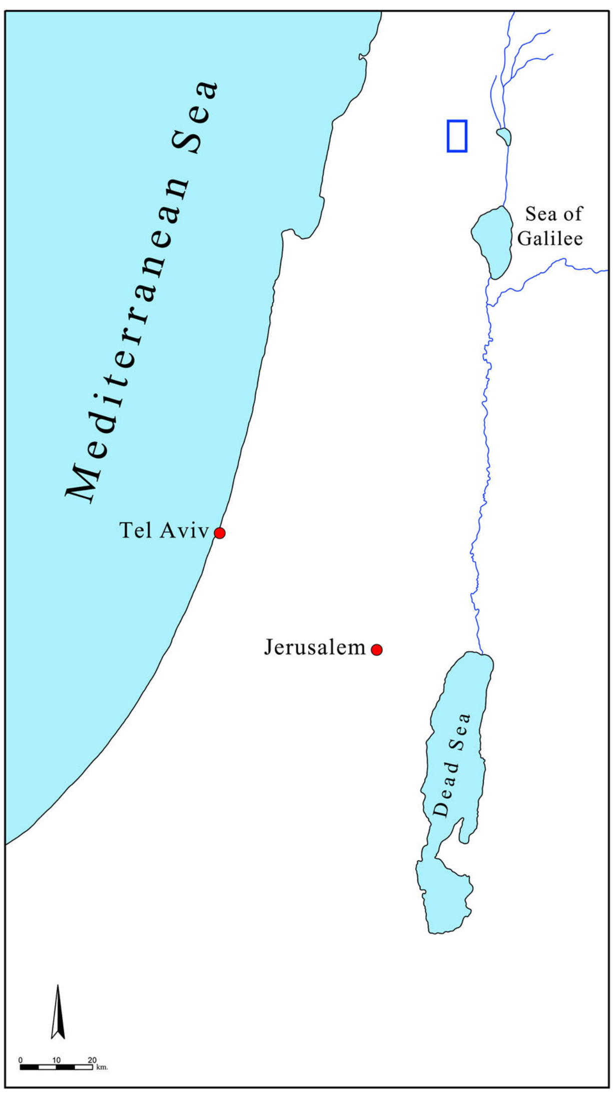


Figure 1. Southern Levant and the research area (marked by a blue square).

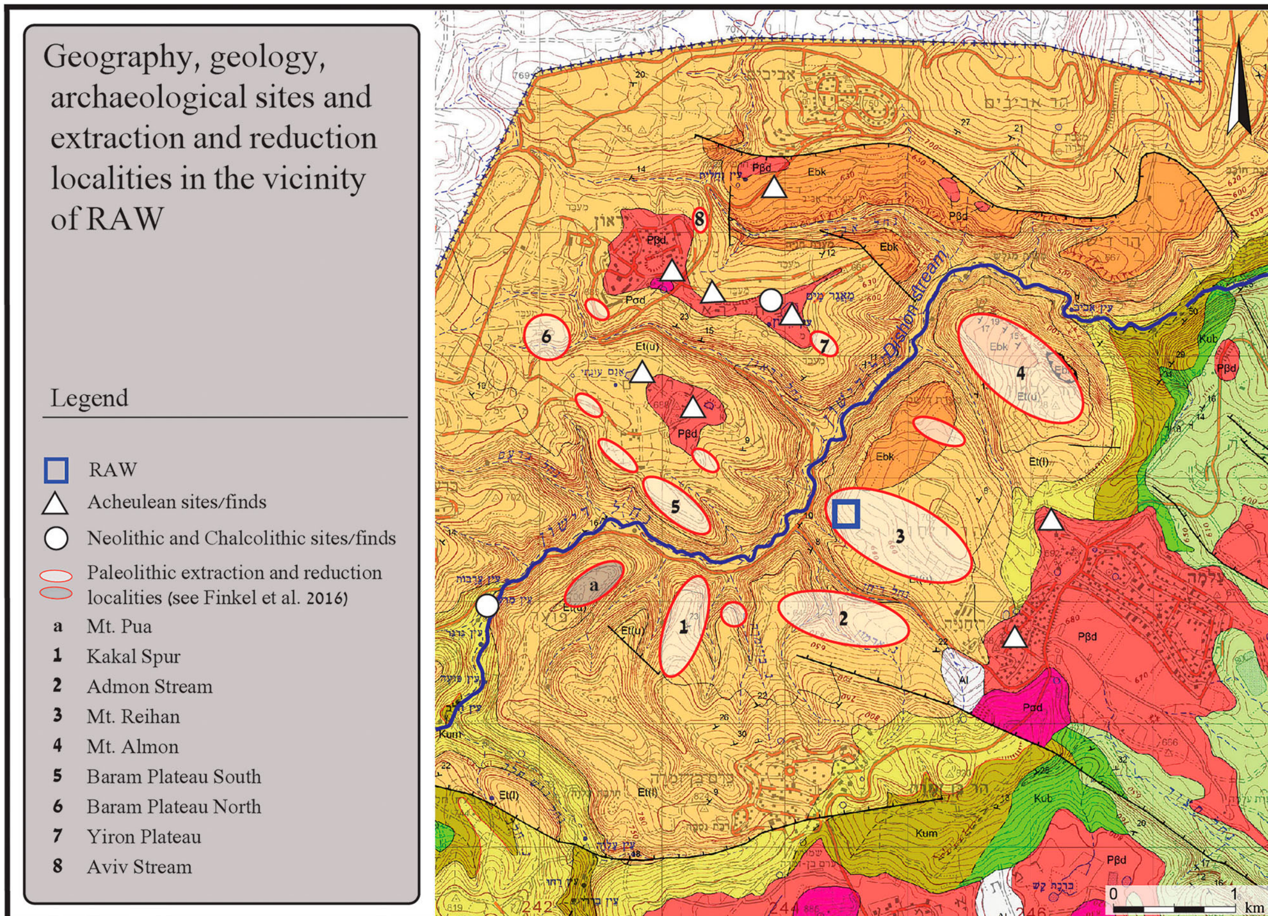
Two modes of flint procurement activities were discerned (Finkel et al., 2017): (1) the exploitation of exposed nodules in the open space (henceforth: surface workshop); (2) the extraction of nodules embedded in limestone karrens, which creates tailing piles composed of limestone waste and flint reduction debitage (for details regarding the tailing pile phenomenon, see Barkai & Gopher, 2011; Gopher & Barkai, 2011, 2014). Tailing piles vary in form and size (see Finkel et al., 2016 and references therein).

Fieldwork presented here was carried out in three areas:

- The area of the surface workshop: A 900-m^2 area was selected for surface collection (out of 40,000 m^2). Full artifact collection was performed in four 10×10 m squares (Figure 3(b): Squares 1, 2, 4, 5) including all flint items visible on the surface. The other five squares (Figure 3(b): Squares 3, 6, 7, 8, 9—500 m^2) were collected selectively by trained lithic analyzers taking only bifacial roughouts (Paleolithic and Neolithic/Chalcolithic) and Levallois-related items. Altogether 154 Neolithic/Chalcolithic bifacial roughouts, eight (Lower) Paleolithic bifaces and 23 Levallois cores were found in the 900-m^2 area (see Finkel et al., 2017).
- The area of the tailing piles: The pile selected, designated RAW 100 (Figure 3(b)), is one of five such piles within the workshop and is relatively large. In the ~200 m^2 of the pile's surface we conducted full collection from a 2×2 m square at the center of the pile, and only bifacial roughouts (Paleolithic and Neolithic/Chalcolithic) and Levallois-related items from the rest of the pile's surface. In total, we collected 38 Neolithic/Chalcolithic bifacial roughouts and seven Levallois cores (see Finkel et al., 2017).
- The area to the north of the surface workshop and tailing pile RAW 100 contained unexploited flint nodules (of the same flint known in the workshop and the pile) on the surface. No evidence of flint extraction or knapping was observed in this area. The area was divided into three sub-areas (see Figure 3(b)) representing the highest density of nodules: 200 m^2 marked as Area A; 300 m^2 marked as Area B; and the edge of a tree orchard marked as Area C. Nodules were collected and weighed.

The study area is situated on a plateau, inclining mildly from northeast to southwest, resulting in a minor effect of post-depositional processes on the entire area.

The production process of bifacial tools was traced from the complete selected nodule to the almost finished axe or adze, through four major reduction



STRATIGRAPHY סטרטיגרפיה

SYSTEM תקופה		SERIES - STAGE סדרה - דרגה	SYMBOL סימן	THICK. m עובי מ'	LITHOLOGY מסלע	LITHOSTRATIGRAPHY ליתוסטרטיגרפיה: MAPPING UNITS יחידות מיפוי		GROUP חבורה
QUATERNARY קוורטר		HOLOCENE הולוקן	Al	2+		Alluvium, colluvium, soil אלוביום, קולוביום, קרקע		
TERTIARY טרציר	NEOGENE ניאוגן	PLIOCENE פליוקן	Pσd			Dalton Scoria & Tuff סקוריה וטוף דלתון		
			Pβd			Dalton Basalt בזלת דלתון		
	PALEOGENE פליאוגן	EOCENE אאוקן	Ebk	100+		Bar Kokhba Formation תצורת בר כוכבא		AVEDAT עבדת
			Et(u)	100-150		Timrat Formation Upper Memeber תצורת תמרת פרט עליון		
			Et(l)	100-200		Timrat Formation Lower Memeber תצורת תמרת פרט תחתון		
		PALEOCENE פלאוקן	KTmgt	42-110		Mishash (chalk), Ghareb & Taqiye fms. תצ. מישאש (קירטון), ע'רב וטקייה		MOUNT SCOPUS הר הצופים
		SENONIAN סנון	Kum: Kuma	61		Menuha Fm. תצורת מנוחה	Ahihud Mbr. (incl. Kabri Marl)	
			Kum: Kumh				Har Zefat Mbr.	
		TURONIAN טורון	Kub	0-30		Bina Formation תצורת בענה		
			Kuyi	0-20		Yirka Formation תצורת ירכא		
			Kuy	0-40		Yanuh Formation תצ. ינוח		
			Kusa	142		Sakhnin Formation תצורת סחנין		

Figure 2. The research area in its geographical, geological, and archaeological settings (geological map: Levitte & Sneh, 2013).

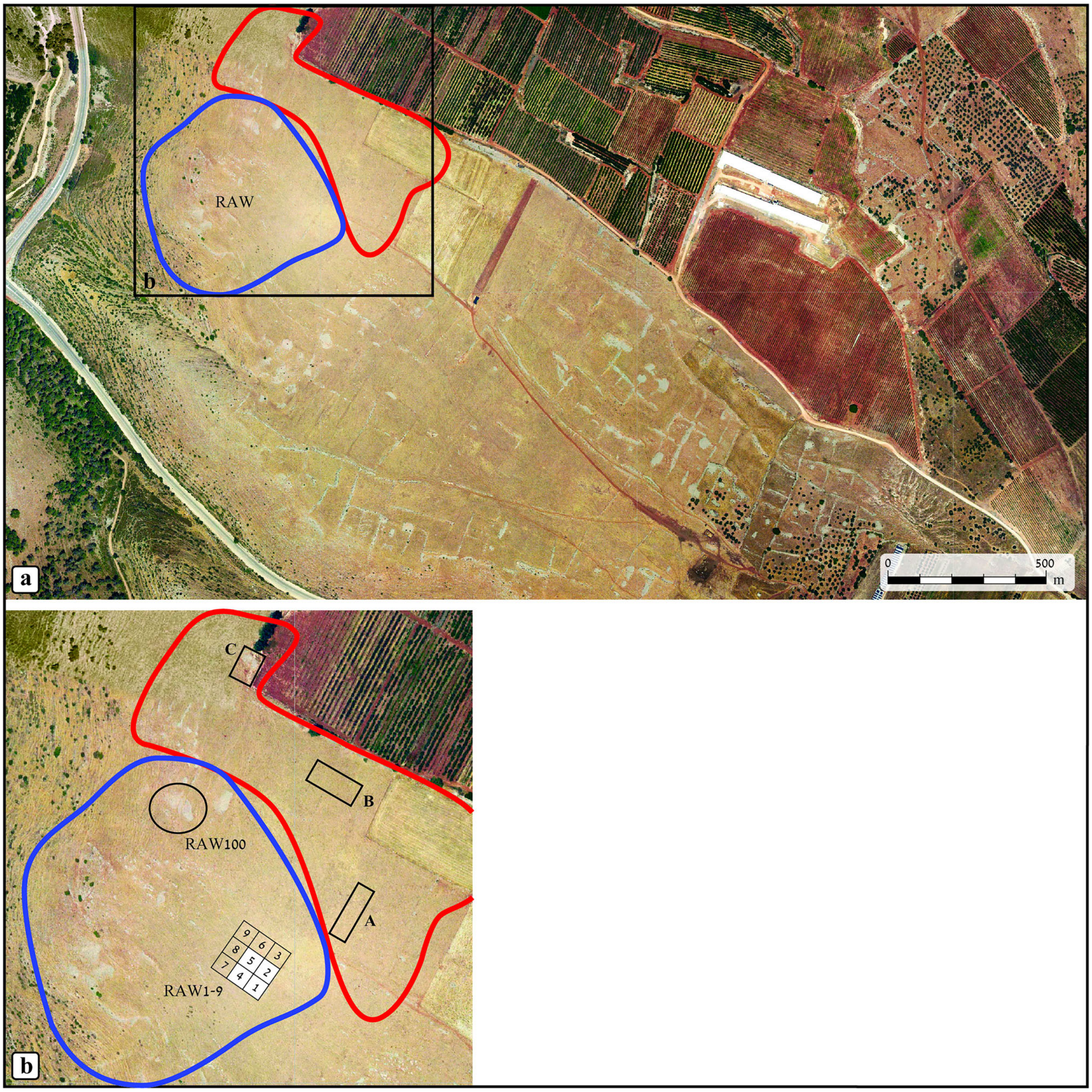


Figure 3. RAW research area: (a) the blue line marks the total area of RAW; (b) the red line marks the area where unexploited flint nodules were found.

stages (see Finkel et al., 2017). Although stray Lower and Middle Paleolithic finds are evident, RAW is clearly different from Lower and Middle Paleolithic E&R localities within the Dishon Complex. While at RAW the vast majority of items is Neolithic/Chalcolithic, at all the other E&R localities the situation is reversed—the vast majority of finds belong to the Lower and Middle Paleolithic, while Neolithic/Chalcolithic finds are either entirely missing or rare.

Why is the exploitation of surface exposed nodules seen only at RAW while it is missing at other Paleolithic E&R localities in the Dishon Complex? We believe that the extensive Lower and Middle Paleolithic extraction exhausted the near-surface flint-bearing karrens in the Dishon area. Today, only a few locations show flint nodules (usually small ones) embedded within the limestone karrens in the Dishon E&R Complex (Finkel et al., 2016), yet exposed nodules of various sizes can still be found on the surface in several other Paleolithic E&R localities in the area (e.g. Kakal Spur, Baram north, and Mount Pua; Figure 2). However, the largest area bearing large nodules found today at the Dishon Complex, exceeding the others by far, is RAW. The need for relatively large nodules for the production of bifacial tools and the nearly exhausted resource of hard-to-get primary "fresh" large nodules may be the reason for the return to sites that had been exploited earlier, where natural nodules had been found in abundance on the surface.

The extensive Neolithic/Chalcolithic exploitation, compared to stray Lower and Middle Paleolithic exploitation, and the fact that the Neolithic/Chalcolithic users of RAW exploited exposed, loose nodules while Paleolithic knappers did not, enables us to focus this paper on the Neolithic/Chalcolithic axe/adze production efficiency.

Another issue of concern is how to differentiate between products of experienced knappers and those of novices. Although we cannot offer a well-based estimate, we assume that novice knappers fail more often than experts; therefore, suffice it to say that broken roughouts (rejects) were found in eight out of nine squares (Finkel et al., 2017, table 4), indicating that novices had been at work. On the other hand, almost no finished tools were found in the workshop (all exported), which indicates expert knappers had been working there as well.

Field work was conducted in the spring and summer of 2015 at both RAW (Figure 3(a,b) marked in blue) and north of it, in an area with natural flint nodules and no evidence of E&R activities (Figure 3(a,b), marked in red).

The Flint Assemblages

Weight measurements are added to the previously reported flint assemblages of RAW, Squares 1, 2, 4, 5, and the 2 × 2 m square in tailing pile RAW 100 (Finkel et al., 2017, briefly summarized above). The term "size" used throughout this paper refers to both volume and weight, and is assessed through direct measurements of weight, transformed into volume using silcrete specific weight—which makes it comparable to the other methods.

(1) Mode of activity 1: surface workshop (Squares 1, 2, 4, 5, see Figure 3(b)). Here we measured:
   (1.1) The total weight of the assemblage (including bifacial roughouts) for each of the fully collected squares (1, 2, 4, 5). This enabled us to assess the number of exploited nodules within an average square (see details below).
   (1.2) The total weight of bifacial roughouts from Squares 1, 2, 4, 5.
   (1.3) The weight of the 50 largest cores (out of 124) found in Squares 1, 2, 4, 5 (400 m^2), in order to assess the weight ratio between cores and nodules (related to the "theoretical nodule" method (see details below).

(2) Mode of activity 2: E&R tailing pile RAW 100. Here we measured:
   (2.1) The total weight of the assemblage (including bifacial roughouts) collected from a 2 × 2 m square in the center of the pile.
   (2.2) The total weight of bifacial roughouts collected from the 2 × 2 m square in the center of the pile.

The weight of the assemblage was measured in buckets, with a 100-g resolution digital weigh-scale, leveled on a horizontal metal surface and after scaling by the known body weight of one of us (MF).

The Unexploited Nodules Within RAW

(1) Mode of activity 1, surface workshop: Here we measured the 10 largest unexploited nodules found in the 400 m^2 of Squares 1, 2, 4, 5 (Figure 4(d)), which represent the preference of the knappers by elimination (i.e. nodules larger than those found were exploited and thus were missing).
(2) Mode of activity 2, E&R tailing pile RAW 100: Here we measured the weight of the 10 largest unexploited nodules found in the ~200 m^2 surface of the tailing pile (Figure 4(c), that represent the preference of the knappers by elimination.

Nodules were each weighed independently and measured for length, width, and thickness.

The Unexploited Nodules North of RAW

Within the unexploited area north of RAW (Figure 3(a,b), marked in red), 50 of the largest nodules available on the surface were weighed in three sampled areas with the highest density of nodules (see Figure 3(b): 15 nodules from Area A; 25 nodules from Area B; 10 nodules from Area C. Each nodule was measured and weighed independently on the digital scale (see Figure 4(b)). In cases of broken nodules, a factor was added to the measured weight: D, damaged (~20% missing = factor of 1.2; 8 nodules out of 50); VD, very damaged (~35% missing = factor of 1.5; 5 nodules out of 50); half broken (~50% missing = factor of 2; 2 nodules out of 50).

Experimental Axe Production

In order to verify available observations and data from other sites (Schyle, 2007) concerning the weight ratio between axes and knapping debitage resulting from the production process, three axes were produced from

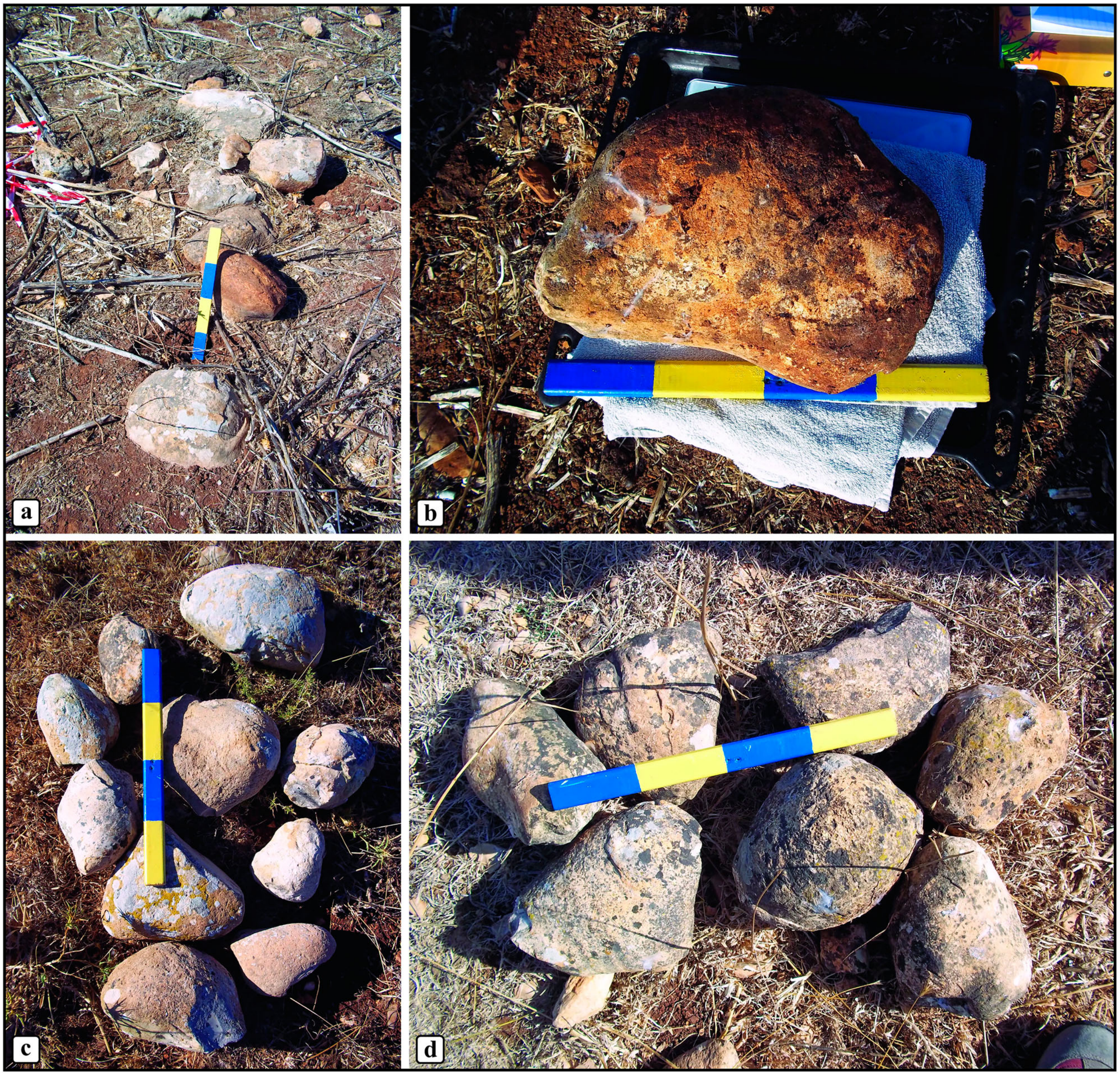


Figure 4. (a) A few large nodules from Area A; (b) large nodule from Area B; (c) 10 of the largest nodules from the 200 m^2 tailing pile RAW 100; (d) seven of the 10 largest nodules from the 400 m^2 of RAW Squares 1, 2, 4, 5 (scale = 40 cm).

small nodules taken from RAW by an archeologist and expert knapper, Dr Tosabanta Padhan. Although we are aware of the limitations of making only three bifacial replications, and of the fact that they were made from small nodules (and not from large nodules as is the case at RAW), we believe that the ratio between roughout and debitage weight we measured in this experiment provides a relevant set of data that may be valid for our needs.

Calculating Weight Ratios

Weights of nodules from RAW Squares 1, 2, 4, 5 and tailing pile RAW 100 as well as from the unexploited area lacking evidence for E&R, north of the former two, were compared to the weight of the flint assemblages collected from RAW Squares 1, 2, 4, 5 and from a 2 × 2 m square in the center of tailing pile RAW 100. Mean and standard deviation were calculated for each of the above-mentioned nodule measures. A few basic calculations were performed in order to estimate: (1) the knappers' preferred size of nodule; (2) the number of large nodules used at RAW Squares 1, 2, 4, 5 and tailing pile RAW 100; (3) the bifacial roughouts number produced from one large nodule; and more. These ratios enabled a comparison between RAW results and the "cortex ratio" and "volume ratio" methods. To transform

Table 1. Nodule weight by area—unexploited and exploited.

Weight (kg)	50 largest nodules from unexploited area north of RAW (total of 500 m^2—areas A + B + C)	10 largest nodules in RAW Squares 1, 2, 4, 5 (400 m^2) fully collected	10 largest nodules in RAW 100 (~200 m^2) pile
Mean nodule weight	17.7	5.3	3.6
Standard deviation	8.6	2.2	1.6
Lowest nodule weight	7.5	2.4	1.8
Highest nodule weight	41.5	8.3	7.3

nodule weight values to volume we multiplied the measured weight by silicate specific weight (2.46 according to Dibble et al., 2005). The number and mean values of cores were used to make similar comparisons.

Our assumption was that the relatively large unexploited nodules found north of RAW (Areas A, B and C) might represent available nodules exploited at the workshop for adze/axe production. Such large nodules are totally absent from the surface workshop (including Squares 1, 2, 4, 5) and the E&R tailing pile RAW 100, and we believe that these were targeted by Neolithic/Chalcolithic flint knappers at these localities for the production of axes/adzes.

We do not know why the large nodules found in the area north of RAW were unexploited by Neolithic/Chalcolithic knappers. We suggest, however, that some sort of management was in play. We base this proposition on the fact that no "islands" of unexploited large nodules were found within the 40,000 m^2 of RAW, and no E&R "islands" were found in the unexploited area north of it.

Results

Nodule weight is presented in Table 1, showing that the average weight of the 50 largest nodules in the unexploited area north of RAW (Figure 3(b)—Areas A, B, C) is approximately 3–4 times greater than the average weight of the nodules in the exploited area of RAW (Squares 1, 2, 4, 5; RAW 100 pile). It is notable that the average weight of unexploited nodules found near other E&R tailing piles in the Dishon Complex is similar.

As Table 2 (Column 3) demonstrates, the estimated number of large nodules exploited in 100 m^2 of RAW Squares 1, 2, 4, 5 workshop area is 5.5–8.1 nodules (average 6.9). This is similar to the number of large nodules (above 8 kg) found in an average 100 m^2 of unexploited area (38 nodules/500 m^2 (Figure 3(b))—areas A + B] = 7.6 nodules per 100 m^2). This supports our assumption that the large nodules found north of RAW represent the missing exploited nodules at RAW itself (see "Materials and Methods" above).

Other data relevant to "cortex ratio" and "volume ratio" that will be discussed below include:

(1) Cortex coverage of bifacial roughouts—A small amount of cortex was found on the early-stage bifacial roughouts (~10% of the total surface area) and even less on the more advanced roughout stages (~1% of the total surface area of the items) (Finkel et al., 2017, figs 8, 11).
(2) Cores—Significantly, in the bifacial tools' workshops, core numbers are not the preferred gauge by which

Table 2. Weights of debitage and bifacial roughouts and derived ratios of reduction efficiency.

Column	1	2	3	4	5	6
	A. Total weight of assemblage (kg)	**B.** Number and weight (in parentheses) of bifacial roughouts	**C.** Assessed number of exploited nodules	Reduction "efficiency"—roughouts/nodule weight (%)	Reduction "efficiency"—number of roughouts per nodule	Mean weight of a bifacial roughout (g)
RAW 1 (100 m^2)	134.4	21 (9.9)	7.6	7.4	2.8	470
RAW 2 (100 m^2)	118	17 (9)	6.7	7.6	2.5	530
RAW 4 (100 m^2)	142.1	21 (8.3)	8.1	5.8	2.6	395
RAW 5 (100 m^2)	95.6	20 (8.8)	5.5	9.2	3.64	440
Sum RAW 1, 2, 3, 5 (400 m^2**)**	**490.1**	**79** (**36**)	**27.7**	**7.3**	**2.85**	**455**
Mean values for 100 m^2	Waste (assemblage − roughouts) = 113.5 kg	~20 (9)	6.9			
RAW 100 (4 m^2)	32.1	9	1.8	12.5	4.9	440
RAW 100 normalized to 100 m^2	802.5	225	45.6	–	–	–

1. Debitage + bifacial roughouts collected from 10 × 10 square.
2. Collected from 10 × 10 square.
3. Calculated by total weight of assemblage (A)/mean unexploited nodule weight (17.7).
4. Bifacial roughouts weight/total assemblage weight (A).
5. Number of bifacial roughouts (B)/assessed number of exploited nodules (C).
6. Weight of roughouts/number of bifacial roughouts (B).

Table 3. Ratio between knapping waste and the initial weight of the large flint flake.

	Experiment 1 (Figure 3(b))	Experiment 2 (Figure 3(c))	Experiment 3 (Figure 3(d))
Knapping waste weight (g)	1169	1327	625
Axe weight (g)	308	302	246
Knapping waste (%)	79	81	71

to assess the original number of nodules, as is the case with other flake- or blade-based assemblages. It is possible that some of the cores represent the exhausted stage of much larger cores used in the production of large blanks used for bifacial tool shaping. This possibility has not been tested and seems, in our view, to be unlikely. However, we will address core number at RAW primarily because of its relevance for the "cortex" and "volume ratio" methods. The mean core weight of the 50 largest cores (out of 124) found at RAW Squares 1, 2, 4, 5 was 770 g (N = 50, SD 347). If our assumption that the large nodules were preferred for axe/adze production is correct, this would mean that an average core weighs ~4.35% of the original 17.7 kg average nodule weight (and therefore volume). A ratio of 124 cores to 27.7 nodules (Table 2, Column 3) results in 4.5 cores per nodule.

(3) The experimental axe production (Table 3; Figure 5), presents ~70–80% of knapping waste.

Discussion

This section begins with a discussion of the newly discovered Neolithic/Chalcolithic flint extraction and axe/adze workshop site vis-à-vis nodule size preferences and extraction efficiency. We then critically assess fundamental methodological issues related to stone artifact transportation from extraction and workshop

Figure 5. Experimental axe production. (a) expert knapper Dr Tosabanta Padhan in action; (b–d) axes and debitage.

sites to occupation sites, and end with our proposed method.

Nodule Size Preferences and Extraction Efficiency at RAW

Size Preference of Neolithic and Chalcolithic Flint Knappers

Table 1 shows the preference for large nodule size for axe and adze production. A ~7.5 kg minimal "weight line" can be drawn between the largest nodules found at the intensively exploited RAW Squares 1, 2, 4, 5 and RAW 100 tailing pile and the "smallest of the largest" 50 nodules found north of the E&R localities (in the unexploited area). Nodules lighter than 7.5 kg were also used in the workshop, most probably for production of trajectories other than bifacials; however, the heavier ones that were most probably available are missing from the E&R localities.

"Extraction and Reduction Efficiency" at RAW

Table 2 indicates that the ratio between bifacial roughout weight and the total weight of flint items found on RAW Squares 1, 2, 4, 5, and the ratio between bifacial roughout weight and the mean nodule weight found in the unexploited area (17.7 kg), are similar and range between 5.8 and 9.2 per cent of the total weight (and therefore volume). These numbers do not include the successful roughouts that were transported from the workshop to occupation sites. However, it should be kept in mind that the mean roughout weight presented in Table 2 is between 395 and 530 g and is influenced by the heavier, early-stage roughouts. The mean weight of the final-stage adzes and axes found in RAW Squares 1, 2, 4, 5 and the RAW 100 pile was 281 g for adzes ($N = 7$) and 256 g for axes ($N = 7$). We thus assume that the transported bifacials may have weighed over 200 g (Finkel et al., 2017, table 4—RO4). This is still heavier than bifacial tools discarded after use and resharpening at occupation sites such as Pre-Pottery Neolithic B Beisamoun in the Hula Valley, where the average axe weight of a bifacial was 161 g (Barkai, 2005, pp. 157–158), or at the Chalcolithic Peqi'in burial cave, where the average adze weight was 145 g (Barkai, 2005, pp. 270–271). In any case, it should be borne in mind that the transported bifacials are missing from the calculations made for the workshop presented above.

What is the ratio between the rejected roughouts found at RAW and the number of successful roughouts exported from the workshop?

For the calculation of ratios between knapping waste and roughouts and rejected roughouts to exported ones, we use Schyle's (2007) calculations conducted in the Ramat Tamar Neolithic flint E&R Complex in the Negev, southern Israel, oriented toward bifacial production. Based on lithic refitting, Schyle (2007, pp. 93–109) calculated that the ratio of waste weight to the total nodule weight was ~3:4 (69–75% waste for rejected roughouts; Schyle, 2007, p. 95) to ~4:5 (75–89% for exported roughouts; Schyle, 2007, p. 95). We decided to take an 80% waste weight, or a 20% roughout weight, as the basic measure for our calculation (see also Kimura & Girya 2016, p. 462, who obtained 76.6% waste in biface production experimental work at the Shirataki obsidian source). By using the total weight of flint waste produced during the E&R processes, the number of abandoned axe roughouts and the weight of the roughouts ready to be exported (found to be similar to ours—275 g at Ramat Tamar vs ~256 g for axes and ~281 g for adzes at RAW (Finkel et al., 2017, table 4)), Schyle calculated the exported roughouts to be between 50 and 64% of the total number of roughouts—a very low ratio in his view.

It should be emphasized here that Schyle's 75% waste is supported by our limited experimental data, presented in Table 3 (70–80%).

In our case, if a mean weight of 113.5 kg/100 m^2 of flint debitage in RAW 1, 2, 4, 5 (Table 2, Column 1) represents 80% waste, then ~30 kg of roughouts equals the missing 20%. Those 30 kg are divided into ~20 roughouts per 100 m^2 (Table 2, Column 2; and Finkel et al., 2017, table 3) weighing ~10 kg (Table 2, Column 2: 9 kg), leaving ~20 kg for exported roughouts. This would result in an estimate of ~70 roughouts (weighing 256–281 g—an average of ~275 g for exported roughouts) per 100 m^2. In this case the ratio of exports to rejects is 70/20 (or 77% successfully produced bifacials), close to Schyle's higher estimation of 64%. For further conclusions, we will continue to assume that for every rejected roughout, two (closer to Schyle's 64%) to three (closer to our 77%) successful preforms were transported to their destination to become usable axes/adzes. Altogether, for a 100-m^2 area at RAW, we can estimate 60–80 roughouts (rejected + exported) produced from 6.9 large average nodules (Table 2, Column 3), or ~8–11 roughouts per nodule.

Combining our data and the calculation above, we can suggest an overall "reduction efficiency" of ~17% at RAW: ~3 "heavy 500 g" rejected roughouts (1.5 kg) + ~6 "lightweight 250 g" exported bifacial tools (1.5 kg) (3 kg of roughouts/17.7 kg nodule = 17%), which is very close to Schyle's refitting-based 20%.

Another issue concerning the specific bifacial production at RAW discussed in Finkel et al. (2017), evident from the results, is the dramatically higher exploitation intensity at the RAW 100 tailing pile vis-à vis RAW Squares 1, 2, 4, 5 (Table 2, bottom rows).

Taking the size of RAW (40,000 m^2) and the estimate of 40–60 axe/adze roughouts exported from 100 m^2, the result would be 16,000–24,000 exported bifacials.

Taking into account the Lower and Middle Paleolithic finds at RAW (eight Paleolithic roughouts and 23 Levallois cores compared to 158 axe/adze roughouts; Finkel et al., 2017, table 4) we will decrease our proposal by 20 per cent to 13,000–19,000 exported bifacials.

Where did all those bifacials go? The potential distribution area of items produced at Neolithic and Chalcolithic RAW includes Neolithic Hagoshrim (20 km from RAW) which yielded 6854 bifacial tools as well as additional ones recovered during the excavations of the mid-1990s; Neolithic Beisamoun (12 km from RAW) yielded 5894 bifacial tools collected from the surface of the site (see Finkel et al., 2017, fig. 1 and table 1) and additional ones in recent excavations of the site. The very large number of bifacial tools from these two sites reflects intensive tree felling and woodworking activities during the Neolithic period (Barkai, 2005). Other Neolithic and Chalcolithic sites in the Hula Valley, Golan Heights, Upper and Western Galilee, show bifacial tools in the dozens (see Finkel et al., 2017, fig. 1 and table 1). All these sites were potential destinations for the large-scale bifacial production of RAW—to date the only Neolithic/Chalcolithic workshop found on the Eocene north–south "strip" of the Eastern Galilee. While relatively small patches of Eocene limestone and chalk formations have been found in the northern Golan Heights and in the Western Upper Galilee, no significant E&R activities have yet been detected there. A geochemical analysis presented by Finkel et al. (2017) provided evidence that axes/adzes found at Neolithic Beisamoun and Hagoshrim (12–20 km from RAW) are made of flint from the same geological formation as the knapping debitage found on tailing pile RAW 100, and therefore probably originated from this workshop.

The Limited Relevance of the "Cortex Ratio" and "Volume Ratio" Methods to RAW (and Workshop Sites with Large Nodules in General)

As presented above, it is our assertion that the "cortex ratio" and "volume ratio" methods are of little value in the case of RAW and other prehistoric sites situated within areas characterized by the availability of large flint nodules.

Here we will exemplify this by trying to use our data while employing those methods.

The Effect of the Relatively Large Size of Nodules at RAW on the Ratio between Cortex Area and Volume, and Subsequently on the Accuracy of the "Cortex Ratio" Method

Before we begin exploring the impact of nodule size on "cortex ratio," it should be noted that adzes and axes at RAW are shaped on flake/blade blanks that have only one cortical (dorsal) face and a plain ventral face. Blanks for axes/adzes produced from the inner part of the nodule are from the outset devoid of a cortex. This is not a major challenge when an adze is assumed to be knapped from a small nodule—resulting, for example, in two adzes per nodule—as in the case tested by Ditchfield et al. (2014) in the Cook Islands. But this situation is irrelevant to the case at RAW and other similar contexts.

The "theoretical nodule" weight in Dibble et al.'s (2005) experimental work was quite small—0.35 to 4.35 kg—compared to the mean nodule weight at RAW (17.7 kg). This was also the case for Douglass et al.'s (2008) experiments (3.7 kg for silcrete cobbles and 1.5 kg for quartz), yet the archaeological finds are even lighter—230–920 g for silcrete; 160–260 g for quartz (see also Douglass, 2010, table 9.1). Flint nodules at Fayum are very small as well (Seilah raw material location (n = 986): average 276 g, SD 174 g; eight nodules from different sites—mean 429 g, SD 92 g; Phillipps, 2012, p. 129, see also our Figure 6(b)). Greywacke cobbles in the Cook Islands were also quite small. The mean weight of half a cobble was 1245 g in the experimental assemblage and 402 g in the archeological assemblage (Ditchfield et al., 2014, pp. 515–516, tables 1 and 2; see our Figure 6(c)). Doubling those numbers for the cobble's full weight using a measured density of 2.65 g/cm^3 (not far from silicate density—2.46) still shows a low weight compared to the nodules at RAW.

Dibble et al. emphasize that 30 per cent under- or overestimation of the number of cores will result in only a 10 per cent change in the "cortex ratio." "On the other hand," they write, "the risk of seriously distorting the final results increases with smaller assemblages, for which under- or overestimating the number of nodules by only a few could represent a sizable percentage error" (Dibble et al., 2005, p. 553).

In order to examine the influence of a "theoretical nodule" size on cortex surface area in our case, we compared the average 5.3-kg nodule (representing the nodules that were left in the E&R localities) to our suggested 17.7-kg originally exploited nodules (Table 1). For the calculation of cortex surface area we used the spherical nodule surface equation ($S = 4\pi (3V/4\pi)^{2/3}$). The results (Table 4) show that taking the unexploited 5.3-kg nodules (mistakenly, as suggested above) as the original nodules instead of our calculated 17.7-kg nodules would result in a 230 per cent (3.3 times) over-estimation of the nodule number, and therefore an overestimation of 50 per cent more cortex surface area.

Figure 6. (a) A nodule from RAW; (b) a nodule from Seilah, Egypt (Phillipps, 2012, p. 129); (c) experimental cobble from the Cook Islands (Ditchfield et al., 2014, p. 514). Scales are approximately similar.

Our work justifies Dibble et al.'s (2005) concern presented in the introduction above. In our case, the possible bias is eliminated by using the nearby unexploited nodules, which most probably represent the original exploited ones at RAW (see Table 4).

The Ratio Between Core Weight/Volume and Nodule Size

The mean core volume in Kom K (Egypt) was 32.187 cm^3 (SD 29.7 cm^3; Phillipps, 2012, p. 150) which is 91% of the 35.39-cm^3 theoretical nodule volume (Phillipps, 2012,

Table 4. Cortex surface calculations, based on two assumptions concerning "theoretical nodule" weight: (1) the 5.3-kg untouched nodules found at RAW Squares 1, 2, 4, 5; (2) the 17.7-kg nodules found north of RAW.

Weight of "theoretical nodule" if calculated according to:	Number of nodules calculated as the ratio between 100 kg of assemblage to the "theoretical nodule" weight	Volume of one spherical nodule (cm^3)	Cortex surface of one spherical nodule (cm^2)	Total cortex surface of exploited "theoretical nodules" as calculated for 100 kg of assemblage (cm^2)
5.3 kg—mean 10 largest nodules found at RAW Squares 1, 2, 4, 5	18.87	2150	805.3	15196
17.7 kg—mean 50 largest nodules found north of RAW	5.68	7195	1802	10235

Note: We used the spherical nodule surface equation ($S = 4\pi\ (3\ V/4\ \pi)^2/^3$. V = weight/silcrete specific weight of 2.46 gr/cm^3 (Dibble et al., 2005, p. 549).

p. 163). In Australia (Douglass, 2010, p. 116, table 6.4), the core weight out of the total assemblage weight was found to be 17.7–47%, and higher for local sources (28–47%). These results are significantly different from our finds of the mean largest cores weighing ~4.35% of the original nodule.

When dealing with flake production industries, counting the number of transported cores will give a good measure of raw material transportation. When dealing with axe and adze production, where the transported item is a bifacial roughout, counting cores is probably not the best gauge for estimating the scale of production. In any case, compared to the above-mentioned results from Australia, the total core weight of RAW Squares 1, 2, 4, 5 was found to be 19.5 per cent of the total assemblage weight (based on more than four cores per nodule)—that is, on the lower part of the scale. When using a ratio of one core to one nodule, the total weight of the cores drops to 4.5 per cent.

The high ratio between core weight and total assemblage weight is at the heart of the concept of "volume ratio" (= flake volume + core volume: estimated nodule volume × core number). "Because cores have the highest volume-to-surface area ratio of any of the three major artifact classes (cores, flakes, and tools), it is logical that their transportation or addition will have a significant impact on total assemblage volume" (Phillipps & Holdaway, 2016, p. 533). This is applicable in cases of small initial nodules and relatively large cores as described in all the above-mentioned studies, or even for adzes made of small cobbles as in the case in the Cook Islands (where adze volume consists of 64% of the cobble volume), but its relevance to the case of RAW is limited. Taking out cores or a few (as calculated above, ~6) final reduction stage adzes (mean weight 281 g) or axes (mean 256 g) from the RAW assemblage will not be noticeable due to the low ratio between core/bifacial roughout and nodule weight. This becomes more complicated when comparing heavily cortex-covered cores like those found in the Neolithic Kom K site in Egypt (36.7% of cores have cortex coverage of 50–99%; 57.2% of cores have cortex coverage of 1–50%, 6.1% had none; Phillipps, 2012, p. 145, table 6.7) to RAW, where the cortex coverage of the first, roughest reduction-stage items was ~10% and on the last and finest stage ~1% only (see Finkel et al., 2017, figs 8, 11; and above).

Taking into account the weight and cortex area of the very large nodules at RAW, and since most of the reduction work was done on site, it is reasonable to assume that the concept of measuring either cortex loss or volume loss would relate to only marginal portions of these nodules and therefore would be difficult to detect and not especially useful for transportation calculations from RAW.

Another proposed method for estimating cobble/nodule size, presented by Phillipps and Holdaway (2016), suggests that "the use of the upper quartile core size measurements estimates the original cobble size by using the larger cores and assuming that these provide a closer estimate of original cobble size before flaking commenced" (p. 524). Again, this is irrelevant when dealing with a mean of 814 g for the first and roughest adze stage of reduction or of 590 g for the axes (Finkel et al., 2017, table 4—RO-1), and with 17.7-kg nodules.

Core Number as a Measure of the Number of "Theoretical Nodules"

The attempt to calculate the number of "theoretical nodules" from the number of cores, that forms the basis of all methods, is recognized as problematic by Dibble et al.—"This [ratio of core to a theoretical nodule] is not completely foolproof either, because one nodule could easily result in two or more cores, and in certain industries, large flakes may themselves be transformed into cores" (2005, p. 557)—and by Phillipps and Holdaway (2016)—"This raises the possibility that counting the numbers of cores present archeologically at the Fayum sites may not be a good measure of the number of cobbles that were originally flaked at these locations."

Using the total core number found at RAW Squares 1, 2, 4, 5 as an estimate for the number of "theoretical nodules" would result in 124 nodules weighing 3.95 kg each (490.1 kg of the total assemblage/124 cores), much closer to the mean nodule weight of 5.3 kg found on RAW Squares 1, 2, 4, 5, and significantly lower than the 17.7 kg of the calculated weight of the exploited nodules. This would lead to the false numbers mentioned above. Acknowledging the problem of relying on core numbers, researchers tried to find a better way to estimate the number of cores found in the assemblage. Douglass et al. (2008) reduced the core numbers by excluding "flake and bipolar cores as their presence would have unduly inflated expected cortex value" (p. 519). Phillipps and Holdaway (2016) presented the possibility that each core was reduced to a third of its original size, and therefore "this means that at the completion of experimental unifacial core reduction, multiplying this dimension by three times provides the approximate size of the original nodule" (p. 529).

In our case, most of the cores represent the inner parts of nodules and not, as in Fayum (Egypt) and Australia, only the outer cortical parts. Therefore, dividing 124 cores by 4.5 (i.e. assuming that each nodule reduction ended with 4.5 cores) is reasonable because of the large size of the nodules; it is, however, still half of the ratio of 8–11 roughouts to one nodule. This elucidates the difficulties in using core numbers (or rejected adze roughout numbers) as a guide for "theoretical nodule" numbers, which lies at the heart of both the "cortex ratio" and "volume ratio" methods.

Our Suggested Method for Bifacial Production from Large Nodules

Based on our direct weight and number measure of nodules, flaking debitage, and roughouts, we suggest that when dealing with bifacial production from large nodules, the best measure for assessing transportation of end products is a ratio of rejected roughouts to exported tools of 1:2–3, or a ratio of rejected and exported tool weight to waste weight of 1:4. Our proposal in not intended to be universal or to replace the "cortex ratio" or "volume ratio" based on the number of "theoretical nodule" methods presented above; rather, we suggest it as relevant for bifacials produced from large nodules.

Conclusions

In this paper we presented data from RAW—a newly discovered Neolithic/Chalcolithic axe/adze extraction and workshop site that combines flint assemblages from two modes of procurement activities—exploitation of loose nodules and the extraction of nodules from limestone karrens. The site presents an almost complete *chaîne opératoire* of Neolithic/Chalcolithic axe/adze production, and in situ unexploited large flint nodules in a nearby area. This relatively unique combination enabled us to conduct direct measurements based on a minimal number of assumptions, and to achieve one of the paper's goals—to offer an estimate of the reduction efficiency and nodule size preferences in the Neolithic/Chalcolithic bifacial production of this site. The results show that when dealing with Neolithic/Chalcolithic bifacials produced from large nodules, a weight ratio of 1:4 between end product and knapping waste (or 80 per cent waste) is a reasonable expected measure of reduction efficiency. Taking into account all the data, we estimate that 13,000–19,000 bifacials were exported from RAW. We also show that a "preference line" of ~7.5 kg can be drawn between the exploited and unexploited nodules.

As for the other goals of this paper, the finds at RAW provided an opportunity to test, almost directly, the "theoretical nodule," "cortex ratio," and "volume ratio" methods developed in recent years regarding transportation of items from extraction sites and workshops to occupation sites, and to justify some of the concerns raised by those who developed these methods. Our results demonstrate that: (1) calculating the number of "theoretical nodules" based on the observed number of cores or end products (e.g. axes/adzes) is relevant for small cobbles/nodules but not for large nodules; (2) the "cortex ratio" is irrelevant when the items (bifacial tools) transported from the workshop have little or no cortex; and (3) "volume ratio" loses its applicability in cases where the volume of the transported items is small in relation to the original nodule volume. Our results suggest that some of the assumptions of these methods, which are relevant for small cobbles/nodules, lose much of their applicability for large nodules. Based on information from an earlier study of a flint extraction quarry site and a nearby axe workshop site in southern Israel, and on our new data, we propose a two-step method: (1) weight of knapped waste is calculated as 80 per cent of the initial flint weight; (2) the 20 per cent weight remaining is divided between the rejected roughouts found on site and the exported/transported items, following a ratio of one roughout to 2–3 exported tools.

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No potential conflict of interest was reported by the authors.

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