The Sands of Time

The Desert Neolithic Settlement at Ayn Abū Nukhayla

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Digital Appendices 2.1, 16.1, 17.1-17.19, and 18.1 can be accessed at
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Chapter 17

Groundstones and Grinding Technology

Seiji Kadowaki

In an effort to better understand the role of grinding technology in the behaviors of the inhabitants of Ayn Abū Nukhayla, this study examines (1) the functions of the groundstone tool types, (2) the density of milling stones in the site and their proportions within the groundstone assemblage, (3) the groundstone tool morphometrics, (4) the motor habits associated with grinding motions , and (5) the transformation of groundstone tool morphology through use. These technological traits are shown to have been influenced by a complex set of factors involving the availability and variety of the raw material used in the fabrication of groundstone implements and the designs and sizes of the implements as they were linked to human motor habits and efficiency of use.

Introduction

Three seasons of excavations and surface collections in 2000, 2001, and 2005 resulted in the recovery of more than 400 groundstone artifacts (Table 17.1; See Digital Appendix 17.1 for the detailed information for each piece). Most of these samples (371 pieces) were found inside structures (loci) and assigned to one of the three phases of occupation. Other pieces were either excavated outside the loci (11 pieces) or collected on the surface (25 pieces), making their phase designation difficult. However, these surface collections are likely to have originated from the Neolithic deposits given that the site is dominated by PPNB occupations and the surface samples resemble those of this period in the range of tool types and general techno-morphological characteristics. Thus, all of these samples are included in the following examination of Neolithic groundstones from Ayn Abū Nukhayla.

The typological and technological analyses of groundstones in this study follow the behavioral sequence associated with the artifacts' life history from the acquisition of raw materials, through production to use. Groundstone artifacts are classified according to Wright's typology (1992a) in order to make systematic comparisons with the assemblages of other Early Neolithic sites. Based on this typological examination, in combination with the morphometric attributes of grinding tools, I also analyze the grinding technology of handstones and querns to obtain insights into the food-grinding strategy at the site. In these examinations, the samples from different phases are amalgamated to enlarge the sample size because the three phases do not differ from one another significantly in tool types or techno-morphological traits.

Raw Materials

Raw materials for groundstones were exploited mostly from the talus at the foot of the cliff located 60-80m west of the site (Digital Appendix 17.2). Here, clasts of different textures, sizes, and forms are derived from the Cambrian sandstones (Umm Ishrin and Salib Arkose) and Pre-Cambrian granite (Qara) formations. The source provides clasts of quartz rich sandstone, often cemented with hematite, with morphologies ranging from cobble, pebble, and boulder, to slab. Also encountered in the rock samples from the scree are granite, diorite, and siltstone.[1]

[1] The raw materials were identified by Dr. Dennis Kerr, Dr. Peter Michael, and Dr. Winton Cornell of the Department of Geosciences, the University of Tulsa.

Table 17.1 *Inventory of groundstone artifacts from Ayn Abū Nukhayla*

	Type Group	Type No.	Type Name	Phase I	Phase II	Phase III	Unphased	Unprovenienced		Totals	
		2	Boulder quern	1	0	2	0	0	3		
		7	Basin quern	1	1	23	1	10	36		
A	Grinding Slabs/ Querns	8	Unifacial punctuated quern	1	0	5	0	0	6	78	19.2%
		9	Bifacial punctuated quern	0	0	2	0	1	3		
		10	Fragment	0	1	15	0	2	18		
		11	Miscellaneous slab	0	0	12	0	0	12		
B	Mortars	12	Pebble mortar	0	1	1	0	0	2	5	1.2%
		20	Miscellaneous mortar	0	0	2	0	1	3		
		21	Bifacial Discoidal/Oval	0	1	1	0	0	2		
		22	Bifacial Discoidal/Lens	0	2	4	0	0	6		
		23	Bifacial Discoidal/Tapered	0	0	1	0	0	1		
		24a	Bifacial Discoidal/Planoconvex	0	0	2	0	0	2		
		24b	Bifacial Discoidal/Planoconvex	0	0	1	0	0	1		
		26	Bifacial Discoidal/Wedged	0	1	0	0	0	1		
		28	Bifacial Discoidal/Planoirregular	0	0	2	0	0	2		
		30a	Bifacial Ovate/Lens	0	0	4	0	0	4		
		30b	Bifacial Ovate/Lens	0	0	11	2	1	14		
		32	Bifacial Ovate/Planoconvex	0	0	7	0	0	7		
		33a	Bifacial Ovate/Flat	0	1	5	0	0	6		
		33b	Bifacial Ovate/Flat	2	0	7	0	1	10		
		34	Bifacial Ovate/Wedged	0	1	3	0	1	5		
		35	Bifacial Ovate/Triangular	0	0	2	0	0	2		
		36a	Bifacial Ovate/Planoirregular	0	0	3	0	0	3		
C	Handstones	36b	Bifacial Ovate/Planoirregular	0	0	3	0	0	3	176	43.2%
		38	Bifacial Loaf/Lens	0	1	2	0	0	3		

		40	Bifacial Loaf/Planoconvex	0	2	16	0	0	18		
		41a	Bifacial Loaf/Flat	0	0	1	0	0	1		
		41b	Bifacial Loaf/Flat	0	0	1	0	0	1		
		42	Bifacial Loaf/Wedged	0	0	4	0	0	4		
		43	Bifacial Loaf/Triangular	0	2	3	0	0	5		
		45	Bifacial Rectilinear/Oval	0	0	2	0	0	2		
		55	Irregular	5	4	6	1	0	16		
		56	Unifacial Discoidal	0	0	3	0	0	3		
		57	Unifacial Ovate	0	1	6	0	0	7		
		59	Unifacial Loaf	0	0	6	0	1	7		
		60	Fragment	1	6	23	0	3	33		
		61	Miscellaneous handstone	0	0	2	0	0	2		
		NA	Un-analyzed	0	0	5	0	0	5		
D	Pestles	63	Unipolar cylindrical	0	1	3	0	0	4	5	1.2%
		65	Unipolar conical	0	0	1	0	0	1		
E	Pounders	72	Irregular core	0	0	1	0	0	1	2	0.5%
		73	Spherical/Irregular	0	1	0	0	0	1		
F	Polishing Pebbles	78	Bifacial	1	0	1	0	0	2	2	0.5%
G	Worked Pebbles and Cobbles	80a	Ground cobble (granite)	0	0	2	1	1	4	86	21.1%
		80b	Ground pebble (quartzite)	1	6	13	1	1	22		
		81a	Ground sphere (larger)	0	0	5	0	0	5		
		81b	Ground sphere (smaller)	3	5	4	1	0	13		
		82	Pecked cobble	0	1	4	0	0	5		
		85a	Small slab abrader (red clay shale)	1	7	22	3	0	33		
		85b	Small slab abrader	1	3	0	0	0	4		
H	Ground Axes and Celts	93b	Ground knife	0	3	1	0	1	5	8	2.0%
		95	Flaked chopper	0	2	0	1	0	3		

Table 17.1 (cont.) *Inventory of groundstone artifacts from Ayn Abū Nukhayla*

	Type Group	Type No.	Type Name	Phase I	Phase II	Phase III	Unphased	Unprovenienced	Totals		
		97	Shaft straightener	1	0	3	0	0	4		
I	Grooved Stones	98	Cutmarked slab	0	1	3	0	0	4	10	2.5%
		100	Miscellaneous grooved stone	0	0	1	0	1	2		
J	Perforated Stones	101	Counterpoise Weight	0	1	3	0	0	4	6	1.5%
		105	Spindle whorl	0	1	1	0	0	2		
K	Stone Vessels	124	Body fragment	0	0	1	0	0	1	1	0.2%
L	Debitage	132	Pecked preform	1	2	5	0	0	8	23	5.7%
		134	Flake	1	4	10	0	0	15		
		136	Handstone/Slab fragment	1	0	0	0	0	1		
M	Unidentified Groundstone Fragments	138	Unknown fragment	0	0	1	0	0	1	5	1.2%
		139	Indeterminate	2	0	1	0	0	3		
Totals				24	63	284	11	25	407	407	100.0%

All handstones and most grinding querns are made of local sandstone, while only three grinding slabs are made on small boulders of granite (See Table 17.2 for the correlations between tool types and raw material types). Cobbles and pebbles of sandstone and granite were also used for grinding or pecking with little modification (e.g., worked pebbles and cobbles, Digital Appendix 17.3). Unmodified quartzite pebbles, often recovered from floor levels, may also have been brought from the foot of the talus for ad hoc uses (Type No. 80b, Digital Appendix 17.3:2-4). Excavations also recovered small fragments of clay shale modified by grinding into tabular forms with several facets (Type No. 85a, Digital Appendix 17.4, Digital Appendix 17.5:3). Clay shale was also used for some cutmarked slabs (Type No. 98, Figure 17.4:6-7). Another cutmarked slab is made of hornphers (Figure 17.4:5), and a fragment of a possible stone vessel (Type No. 124, Figure 17.5:6, Digital Appendix 17.5:4) is made of rhyolite. These types of igneous rocks also are likely of local origin.

A few of the groundstones recovered from the site are made of non-local materials. Soapstone was used for shaft straighteners (Type No. 97, Figure 17.4:1-4, Digital Appendix 17.5:2), while a piece of basaltic pumice was formed into a conical shape (Type No. 65, Figure 17.2:6, Digital Appendix 17.5:1). The nearest source of pumice is ca. 40-50km away on the Ma'an Plateau, while that of soapstone is unknown.

Production Technology

The raw materials received various types and degrees of modification before being used as tools. This involved several manufacturing stages following various reduction technologies, as suggested by ethnographic records (Hayden 1987; Cook 1973), studies of archaeological workshops (Hersh 1981; Hoffman and Doyel 1985; Roubet

Table 17.2 *Crosstab of raw material by tool type*

		Locally Available						Imported				
Type Group	Type Name	Sand-stone	Clay Shale	Quartz-ite	Granite	Rhyolite	Horn-phers	Flint	Soap-stone	Basaltic Pumice	Uniden-tified	Total
Grinding Slabs/Querns		75	0	0	3	0	0	0	0	0	0	78
Mortars		5	0	0	0	0	0	0	0	0	0	5
Handstones		171	0	0	0	0	0	0	0	0	5	176
Pestles		4	0	0	0	0	0	0	0	1	0	5
Pounders		0	0	1	0	0	0	1	0	0	0	2
Polishing Pebbles		2	0	0	0	0	0	0	0	0	0	2
Worked Pebbles and Cobbles	Ground cobble (80a)	1	0	0	1	0	0	0	0	0	2	4
	Ground pebble (80b)	2	0	20	0	0	0	0	0	0	0	22
	Ground sphere	18	0	0	0	0	0	0	0	0	0	18
	Pecked cobble	3	0	0	1	0	0	0	0	0	1	5
	Small slab abrader (85a)	0	33	0	0	0	0	0	0	0	0	33
	Small slab abrader (85b)	4	0	0	0	0	0	0	0	0	0	4
Ground Axes and Celts		7	0	1	0	0	0	0	0	0	0	8
Grooved Stones	Shaft straightener	0	0	0	0	0	0	0	4	0	0	4
	Cutmarked slab	1	2	0	0	0	1	0	0	0	0	4
	Misc. grooved stone	2	0	0	0	0	0	0	0	0	0	2
Perforated Stones		6	0	0	0	0	0	0	0	0	0	6
Stone Vessels		0	0	0	0	1	0	0	0	0	0	1
Debitage		23	0	0	0	0	0	0	0	0	0	23
Unidentifiable Fragments		5	0	0	0	0	0	0	0	0	0	5
Total		329	35	22	5	1	1	1	4	1	8	407

1989; Runnel 1981; Schneider 1996), and experimental manufacture (Hersh 1981; Wilke and Quintero 1996). The insights from these studies provide a basis for the expectations of production stages, techniques, and their material correlates (e.g., Wright 1992a:496). Each manufacturing stage is characterized by certain types of production techniques, debitage, products, and manufacturing tools.

Coarse Flaking

Many grinding querns from Ayn Abū Nukhayla show large flake scars on their lateral sides (Figure 17.1:7, 11), indicating that

Figure 17.1 *Grinding Slabs/Querns from Ayn Abū Nukhayla: (1-11) Basin Querns, (12) Unifacial Punctuated Quern, (13) Bifacial Punctuated Quern, (14-18) Miscellaneous Slabs.*

they received coarse flaking in the secondary reduction/roughout stage of the tool manufacture. However, the excavation did not recover any large flakes or coarse choppers that would have been linked to coarse flaking. This suggests that coarse flaking took place outside the excavated area, probably adjacent to the nearby source of raw material in an effort to reduce portage weight. This is consistent with several ethnographic records and archaeological data which indicate that primary production often occurs near the sources of raw materials (Hayden 1987; Hoffman and Doyel 1985; Roubet 1989; Schneider 1996).

Fine Flaking and Pecking

This production stage may have taken place on site as reflected in the recovery of debitage, including tool-preforms and flakes. According to Wright's (1992a:496) scheme of groundstone production, preforms should be left in the secondary reduction/roughout stage, which involves coarse flaking or pecking. However, the preforms of handstones from Ayn Abū Nukhayla do not appear to have received extensive modification such as coarse flaking, but they do appear to have been modified with fine flaking, pecking, and grinding (Digital Appendix 17.6:1-2). Fine flaking is also suggested by the small size (less than 4cm) of sandstone flakes from the site.

Traces of the pecking technique are visible on the lateral sides of various tool types such as handstones, pestles, mortars, and worked cobbles. The technique was probably employed in the retouch stage of the tool manufacture. The pecked marks are also left on the working surface of the handstones and the grinding querns, indicating the maintenance or rejuvenation of working surface for regaining a rough surface (Wright 1992a:134-135).

Possible manufacturing tools include small chopping tools (Digital Appendix 17.7:4-6), pounders (Digital Appendix 17.8:1-2), and several handstones with flaking scars, which probably resulted from their secondary use for pounding (Figure 17.3:6-7, 11). These fist-size tools were probably used for fine flaking or pecking. On the other hand, a heavy chopping tool (Digital Appendix 17.7:4) may have been used for coarse flaking. However, the tool's edge is still sharp without distinct battered marks that should have been left as a result of coarse flaking. The tool may have had different uses such as chopping softer materials.

Grinding, Drilling, and Incising

Although almost all groundstone tools have traces of grinding, it is difficult to assess to what extent the grinding technique was used in the tool production stage. The experimental manufacture of pestles by Wilke and Quintero (1996) shows that the grinding technique is required only in the last stage of manufacture for smoothing out the surface. Raw material can be modified mostly by the pecking technique. However, certain tool types appear to have received extensive grinding in their manufacture. These types are the shaft straighteners (Figure 17.4:1-4) and the spindle whorls (Figure 17.5:1-2). Both tool types are entirely covered with smooth surfaces and show no clear pecking mark.

Drilling was employed for the production of perforated stones, which include spindle whorls (Figure 17.5:1-2) and counterpoise weights (Figure 17.5:3-5). Drilling was probably performed with drills and perforators of chipped stones recovered from the site, but the task could also have been achieved by pecking with a chopper with a pointed end (Digital Appendix 17.7:5). All the perforations show bi-conical cross sections, indicating that both opposing surfaces were worked to make a hollow.

Grooves of the shaft straighteners (Figure 17.4:1-4) and some cutmarked slabs (Figure 17.4:5-8) are formally shaped and must have been intentionally fabricated rather than formed through use. Longitudinal striations on the surface of the grooves indicate that they were created by incising the surface probably with chipped stone blades.

Tool Typology

The typological description of the groundstone assemblage follows the classification system developed by Wright (1992a) (Table 17.1; Digital Appendix 17.1). It should be noted that the type list in Wright (1992a) is slightly different from that in Wright (1992b). This study employs the former version because it is applied to a number of prehistoric groundstone assemblages in Wright (1992a), from which this study cites data for comparison with Ayn Abū Nukhayla. In addition, several tool types in Wright's list were subdivided to fit the variability of the present assemblage.

Grinding Slabs/Querns

Grinding slabs/querns are defined as "the lower, stationary stone in a pair of tools used mainly for grinding. Most of the grinding action is in a plane parallel to the side on which the artifact rests" (Wright 1992a:625). Six types were identified in the assemblage (Table 17.1). They are Boulder Quern (No. 2), Basin Quern (No. 7), Unifacial Punctuated Slab/Quern (No. 8), Bifacial Punctured Slab/Quern (No. 9), Slab/ Quern Fragment (No. 10), and Miscellaneous Grinding Slab/Quern (No. 11). The basin quern is most frequent, accounting for ca. 46% of the grinding slabs/querns, and no formal grinding slab has so far been recovered.

No. 2: Boulder Quern. Large cobbles and small boulders are used as raw material without formal modification, and they have a shallow oval grinding surface located on a naturally flat surface. This tool type includes only three specimens that are all small and informally modified, indicating their expedient usage. Their shallow grinding surfaces suggest that they were used only for a short period and one specimen shows a series of pecked depressions on the grinding surface.

No. 7: Basin Quern. This type includes 36 pieces (Figure 17.1:1-11). They have an oval and concave working surface on one side, and only two pieces have working surfaces on opposed sides. Sandstone boulders are used as raw material. Most specimens show various sizes of flaking and pecking scars on their sides or around the periphery of the working surface, indicating that flaking and pecking techniques were employed in the tool manufacturing process (Figure 17.1:7, 11).

No. 8: Unifacial Punctuated Quern. The querns of this type are principally similar to the basin querns except for the presence of a hollow on the grinding surface, which is a worn-out penetration due to the prolonged use, maintenance, or ritualistic breakage by pecking (Figure 17.1:12).

No. 9: Bifacial Punctured Quern. Two opposed oval and concave working surfaces were worn through to the opposite surface (Figure 17.1:13). The lateral sides of the querns show flaking and pecking scars, which may have been left in the roughout or retouch stage of tool production.

No. 10: Slab/Quern Fragment. The pieces of this type retain concave surfaces that indicate their function as lower stones, but they are too fragmented to be identified at the level of the specific type. However, they are probably fragments of basin querns, which constitute the majority of the lower stones from the site.

No. 11: Miscellaneous Grinding Slab. The tools of this type are made of sandstone slabs and boulders, and the working surfaces are relatively flat. Five pieces from Locus 20 are tabular sandstones with little modification (Figure 17.1:15-17). They were recovered on the cobble floor in the western corner of the room. One specimen from Locus 25 is a large boulder with a flat surface on one side, while the other side is convex and retains traces of pecking (Figure 17.1:14). A piece from Locus 3 received a low degree of modification without distinct flaking or pecking marks (Figure 17.1:18). Although the type name indicates the function for grinding, the above pieces from the site are not likely to have been used for food grinding because the working surfaces show no clear traces of grinding.

Mortars

Mortars are defined as "a lower, stationary stone in a pair of tools used mainly for pounding" (Wright 1992a:626). Mortars constitute a small component of the assemblage (Table 17.1).

No. 12: Pebble Mortar. Two pieces of this type were recovered in Block II (Figure 17.2:1-2). They have a round outline formed by pecking and coarse grinding. Two shallow depressions are located on the opposing surfaces. The surface of the depression is coarsely ground with no distinct pounding marks. The working surfaces appear to be too shallow and too small for pounding task, and no pestle in the assemblage would fit within such small depressions (Figure 17.2:3-6). Thus, these small mortars probably had other functions than pounding.

No. 20: Miscellaneous Mortar. Two pieces from Block I and one from the surface are included in this type. The former two pieces are irregular in shape and show a few traces of pecking and coarse grinding on lateral sides. The working surface is slightly concave and exhibits its pounding marks. The piece from the surface has two small depressions on a sandstone slab. These depressions are shallow and show pecking marks.

Handstones

This tool category is defined as an "upper, mobile stone in a pair of grinding tools" (Wright 1992a:628). Handstones account for nearly half of the assemblage (Table 17.1) and comprise three major forms:discoid, ovate, and loaf. The discoid handstone has a subcircular shape (the ratio of length to width ≈ 1.0), while the ovate and the loaf handstones have an oval shape. The loaf handstone is larger and more elongated (the ratio of length to width ≈1.75-2.0) than the ovate one (the ratio of length to width ≈1.5-1.75; Wright 1992a:628-631). These handstones usually show signs of wear on both surfaces.

Wright (1992a:501-502) proposes several subtypes of handstones according to the combination of different plan forms and cross-section forms. Her list of subtypes is employed

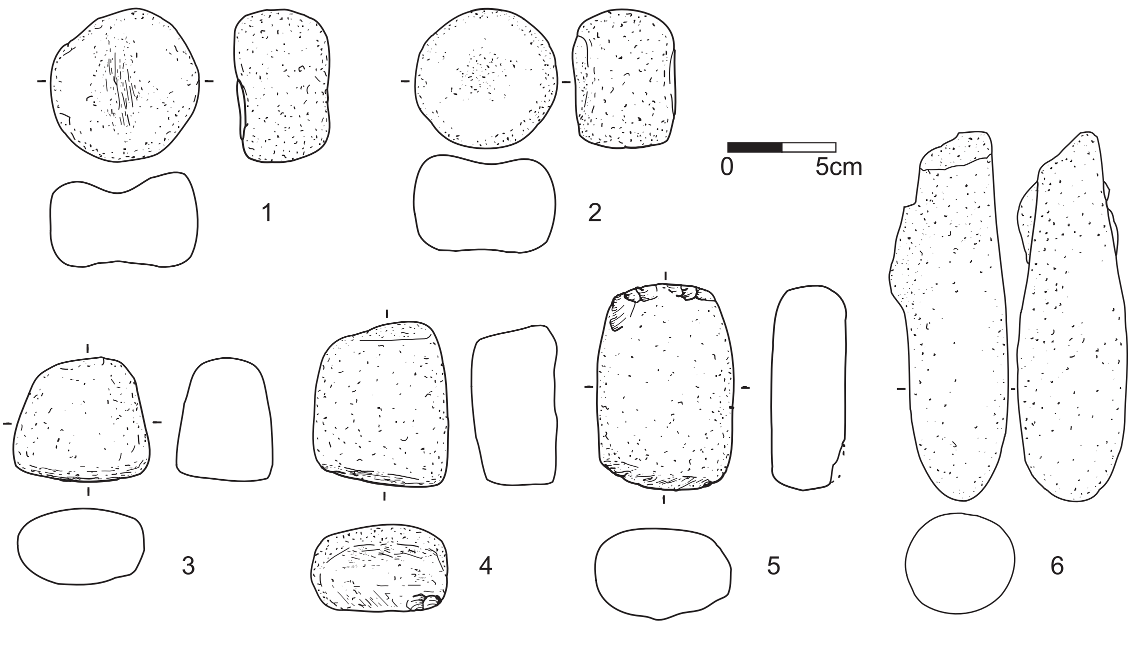

Figure 17.2 *Mortars and pestles from Ayn Abū Nukhayla: (1-2) Pebble Mortars, (3-5) Unipolar Cylindrical Pestles, (6) Unipolar Conical Pestle.*

here, but some modifications, with additional subdivisions, were made to fit the morphological variability of handstones from Ayn Abū Nukhayla. The following description will focus on the definition and the explanation of the subtypes modified by the author (See Digital Appendix 17.9 for the schematic illustration of the subtypes).

No. 24a and 24b: Bifacial Discoidal/Planoconvex. Wright originally defined this tool type as discoidal handstones with two opposed working faces that are flat and convex meeting at the sides. However, two pieces of the assemblage are thick and have round lateral sides instead of having the opposing faces meeting at the sides (Figure 17.3:1, 3). These pieces that do not fall in the original definition were grouped as No. 24a, while the specimens assuming the form of Wright's original definition are named No. 24b here.

No. 30a and 30b: Bifacial Ovate/Lens. Ovate handstones of this type have two opposing convex faces and straight sides (Wright 1992a:628), assuming lenticular cross section. The two opposing surfaces of No. 30b handstone are in parallel, while those of No. 30a are tilted (Figure 17.3:17).

No. 33a and 33b: Bifacial Ovate/Flat. Wright defines this type as ovate handstones with two flat parallel faces and approximately straight sides, but a number of specimens from the site show a weak ridge on the working surface, consisting of two beveled planes. Because the ridge is not developed enough to assume a triangular section, these pieces are grouped under the tool type of No. 33b. The form of the original definition is numbered as No. 33a.

No. 36a and 36b: Bifacial Ovate/Planoirregular. This type is originally defined as ovate handstones with two opposing faces that are flat and irregular, but some pieces of the assemblage have a convex surface instead of a flat one. They are classified as No. 36b, while the form of original definition is grouped as No. 36a.

No. 41a and 41b: Bifacial Loaf/Flat. This type is defined as loaf handstones whose "opposed faces are flat and parallel, and sides are straight" (Wright 1992a:629). Some specimens have a weak ridge on the working face, which is formed by two beveled planes. Because such beveling is not distinct enough to assume a triangular section, these pieces are grouped under the type of No. 41b (Figure 17.3:11), and the form of original definition is numbered as No. 41a.

Some handstones received a variety of secondary use. For example, flaking scars at the end surfaces of tools indicate the use of handstones for pounding (Figure 17.3:6, 7, 11), while incisions and small depressions left on working surfaces suggest their use as abraders for the production of bone tools or shell ornaments (Figure 17.3:14, 16-18).

Pestles

This class is defined as an "upper, mobile stone in a pair of pounding tools" (Wright 1992a:631). This tool category includes only five pieces and forms a small portion of the assemblage. Two types were identified.

No. 63: Unipolar Cylindrical Pestle. Plan shape is cylindrical, and the cross-section assumes an oval form. End surfaces show traces of grinding in addition to a few flaking scars, indicating that the tools were used for both grinding and pounding (Figure 17.2:3-5). These tools may have been used in a set with grinding querns instead of mortars because the mortars from the site are too small to fit the working surface of the pestles (Figure 17.2:1-2).

No. 65: Unipolar Conical Pestle. A single piece of this type has a conical shape (Figure 17.2:6; Digital Appendix 17.5:1), and its narrower end is missing with a part of irregular surface. This piece differs from other pestle not only in the shape but also in the raw material, which is porous basaltic pumice that was probably imported from a distance near Ma'an plateau. A broader end of the tool does not show clear

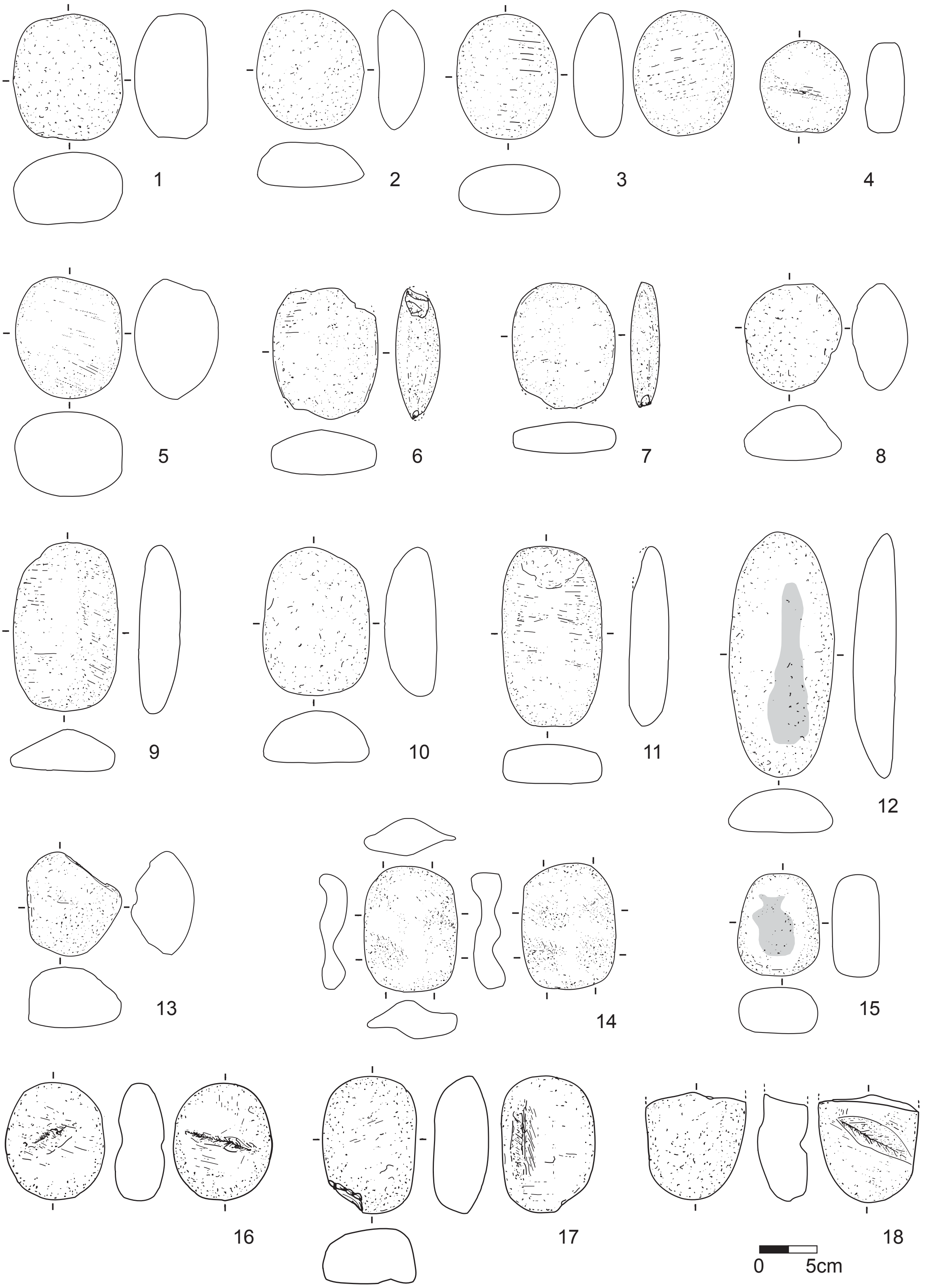

Figure 17.3 *Handstones from Ayn Abū Nukhayla: (1, 3) Bifacial Discoidal/Planoconvex, (2,8) Unifacial Discoidal, (4, 6-7) Bifacial Discoidal/Lens, (5) Bifacial Discoidal/Oval, (9) Bifacial Ovate/Triangular, (10) Unifacial Ovate, (11) Bifacial Loaf/Flat with beveled planes, (12) Bifacial Loaf/Planoconvex, (13) Irregular, (14) Miscellaneous with ground depressions, (15) Bifacial Rectilinear/Oval, (16) Bifacial Discoidal/Lens with incision, (17) Bifacial Ovate/Lens with incision, (18) Bifacial Loaf/Planoconvex with incision. Shaded areas indicate red stains on the surface.*

traces of use for pecking or grinding but is smoothly ground. The tool may not have actually functioned as a "pestle".

Pounders

The original definition of this type is a "core or unmodified angular nodule…almost always of flint, with heavy battering marks (crushing fractures) on any or all sides…. Forms range from irregular to spheroid. Easily held in one hand" (Wright 1992a:632).

One flint core was classified as an irregular core pounder (No. 72), but the edges of the core are ground instead of being battered (Digital Appendix 17.8:1). Another specimen of the pounder is a quartzite cobble that falls in the subtype of spherical/irregular pounder (No. 73). This piece is covered with battering marks and has a semispherical outline (Digital Appendix 17.8:2).

Polishing Pebbles

This category includes an "unmodified pebble or small cobble, generally waterworn or riverine. One or more brightly polished surfaces on a small flint or quartzite pebble (other raw materials occasionally encountered). … Surface plan shape variable, but always either slightly convex or flat in section" (Wright 1992a:633). Two specimens that are classified into this type are tabular sandstone pebbles with two opposing polished surfaces (No. 78) (Digital Appendix 17.8:3-4).

Worked Pebbles and Cobbles

This type is defined as "artifacts showing traces of reduction by ad hoc use but with diffuse use surfaces lacking clear patterning" (Wright 1992a:633). Because of the little modification of raw material, the morphological variability of this tool type depends on the shape and the size of raw material.

No. 80a and 80b: Ground Cobble/Pebble. These subtypes include unmodified cobbles or peb-

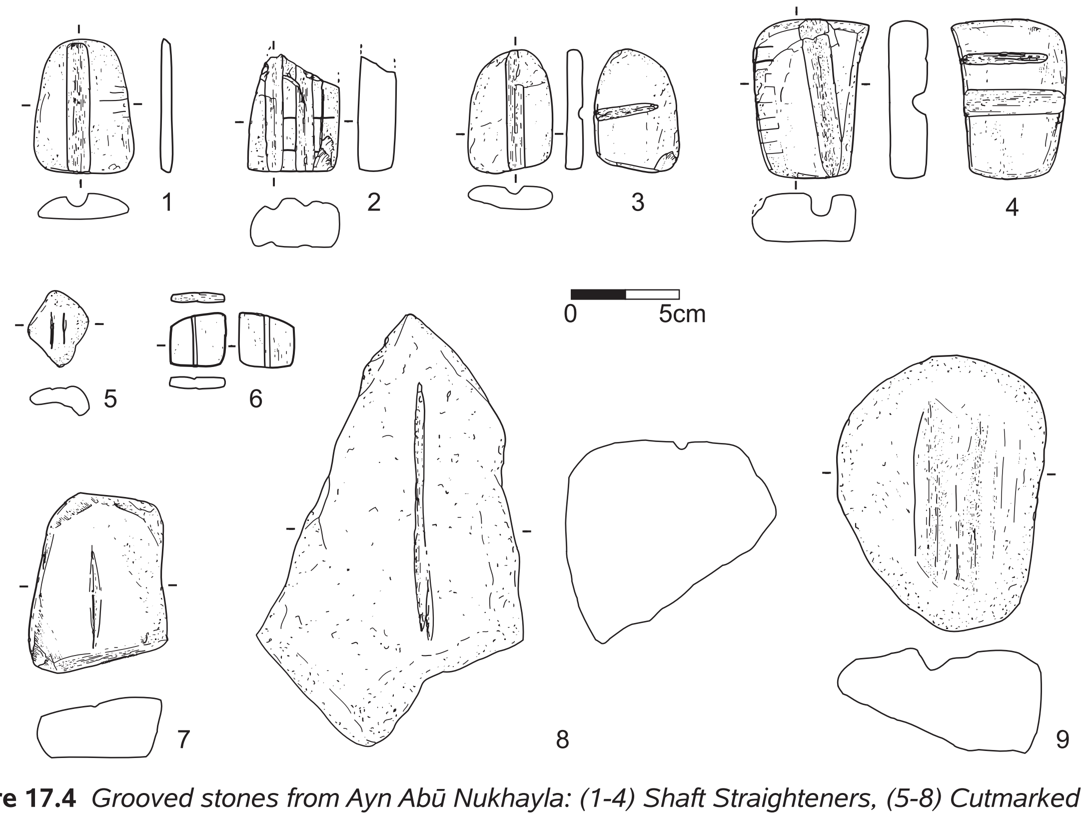

Figure 17.4 *Grooved stones from Ayn Abū Nukhayla: (1-4) Shaft Straighteners, (5-8) Cutmarked Slabs, (9) Miscellaneous Grooved Stone.*

bles with one or more ground surfaces, which show irregular shape and distribution (Wright 1992a:633). Specimens of No. 80a are cobbles of granite or sandstone (Digital Appendix 17.3:1) and are larger than No. 80b, which are mostly unmodified pebbles of quartzite (Digital Appendix 17.3:2-4). The ground surface of No.80a is clearer than that of No.80b.

No. 81: Ground Sphere. Artifacts of this type are entirely covered with ground surface and assume a nearly perfect sphere (Wright 1992a:633; Digital Appendix 17.3:5-10). They are mostly made of coarse sandstone cobbles or pebbles, and their size appears to distribute in two modes (Digital Appendix 17.10). Wright reports small ground spheres from Azraq 31, a Late Neolithic site, as "tokens" (Wright 1992a:238). Larger ground spheres were probably used as grinding tools in the pair with grinding querns since the outline of large ground spheres fits quite well with the concavity of the working surface of the basin querns.

No. 82: Pecked Cobble/Pebble. Artifacts of this type have pecked marks in addition to the ground surface (Digital Appendix 17.3:11-12). They are made of granite or sandstone cobbles, and are quite similar in shape and size to the ground cobbles of No. 80a except for the presence of pecking marks.

No. 85a and 85b: Small Slab Abrader. Both subtypes are tabular in shape, and show wear facets and abrasive scratches (Digital Appendices 17.4 and 17.5:3). The artifacts of No. 85a differ from No. 85b in their use of red clay shale, while those of No. 85b are made of light gray or beige sandstone. Given the irregular shape and the variability in size of the No. 85a pieces, they were probably used as a source of pigment rather than any kind of grinding tools. Indeed, several handstones retain red pigment on their surfaces (Figure 17.3:12, 15), indicating that clay-shale slabs were abraded against handstones to produce the powder of red pigment.

Ground Axes and Celts

The original definition of this type is "a stone tool with a cutting edge perpendicular to the long axis of the tool and manufactured partly via abrasion" (Wright 1992a:634), but it also includes a tool type (No. 93) that has a cutting edge along the long lateral edges.

No. 93a: Flaked "Knife" and No. 93b: Ground "Knife". The tool type of No. 93 is defined as "any elongated non-flint tool which is ground along the face but flaked along the long lateral edges. No evidence of polishing or grinding on the edges" (Wright 1992a:636). The finds from Ayn Abū Nukhayla (Digital Appendix 17.7:1-3) are elongated tabular sandstone, carefully ground over the entire surface, and one of their lateral edges tapers out, although it does not form a sharp cutting edge. Because the tapering edges were not formed by flaking but by grinding, the No. 93 was subdivided into No. 93a, which has a flaked edge, and No. 93b, which has a ground edge.

No. 95: Miscellaneous Flaked Chopper. This tool type (Wright 1992a:636) makes up another type of ground axes and celts, and three pieces in the assemblage fall in this type (Digital Appendix 17.7:4-6). They are chopper-chopping tools with a bifacially flaked edge made on sandstone or quartzite cobbles. The battered edges indicate the use for chopping, battering or pecking tasks. Heavy duty tools of this type may have been used for the production and maintenance of groundstone tools, as indicated by several ethnographical records and experimental studies (Hayden 1987; Hoffman and Doyel 1985; Roubet 1989).

Grooved Stones

The grooved stone is "any blank with a groove, defined as a concave use surface much longer than it is wide (more than 3 times as long), lenticular in plan and V-shaped or U-shaped in transverse section" (Wright 1992a:636). Three types of grooved stones are identifiable in the assemblage.

No. 97: Shaft Straightener. All four pieces included in this type have a squarish outline and U-shaped grooves, sometimes accompanied with several lines of incisions (Figure 17.4:1-4). Two of them have an angular cross section (Figure 17.4:2, 4) and have two grooves in parallel on a single plane, while the other two pieces are lenticular in cross-section and have only one groove on a single plane (Figure 17.4:1, 3). Shaft straighteners are exclusively made of soapstone (Digital Appendix 17.5:2).

No. 98: Cutmarked Slab. The type is characterized by the presence of "a long and very narrow cut mark, lenticular in plan, and always sharply angled V shape in transverse section" (Wright 1992a:637). Four pieces, identified as this type, are variable in shape and size. Two are red clay-shale slabs shaped into a square form by grinding, with narrow incisions cut longitudinally across the flat surface (Figure 17.4:6, 7). Another cutmarked slab is made of a small pebble of hornphers with two narrow parallel grooves (Figure 17.4:5). The last specimen of this type is an angular sandstone cobble that is much larger than the other three pieces. A long narrow groove is oriented longitudinally across the flat surface of the cobble (Figure 17.4:8).

No. 100: Miscellaneous Grooved Stone. One of the two pieces, included in this type, is a sandstone cobble with a couple of shallow grooves that appear to have been left through use (Figure 17.4:9). The other piece is made of a flat sandstone cobble and has two shallow grooves with a square cross section on a smoothly abraded plane.

Perforated Stones

The type is characterized by "the presence of either a perforation (which connects two sides of an artifact), or one or more drill marks (which do not fully penetrate opposing sides)" (Wright 1992a:637). Perforated stones from

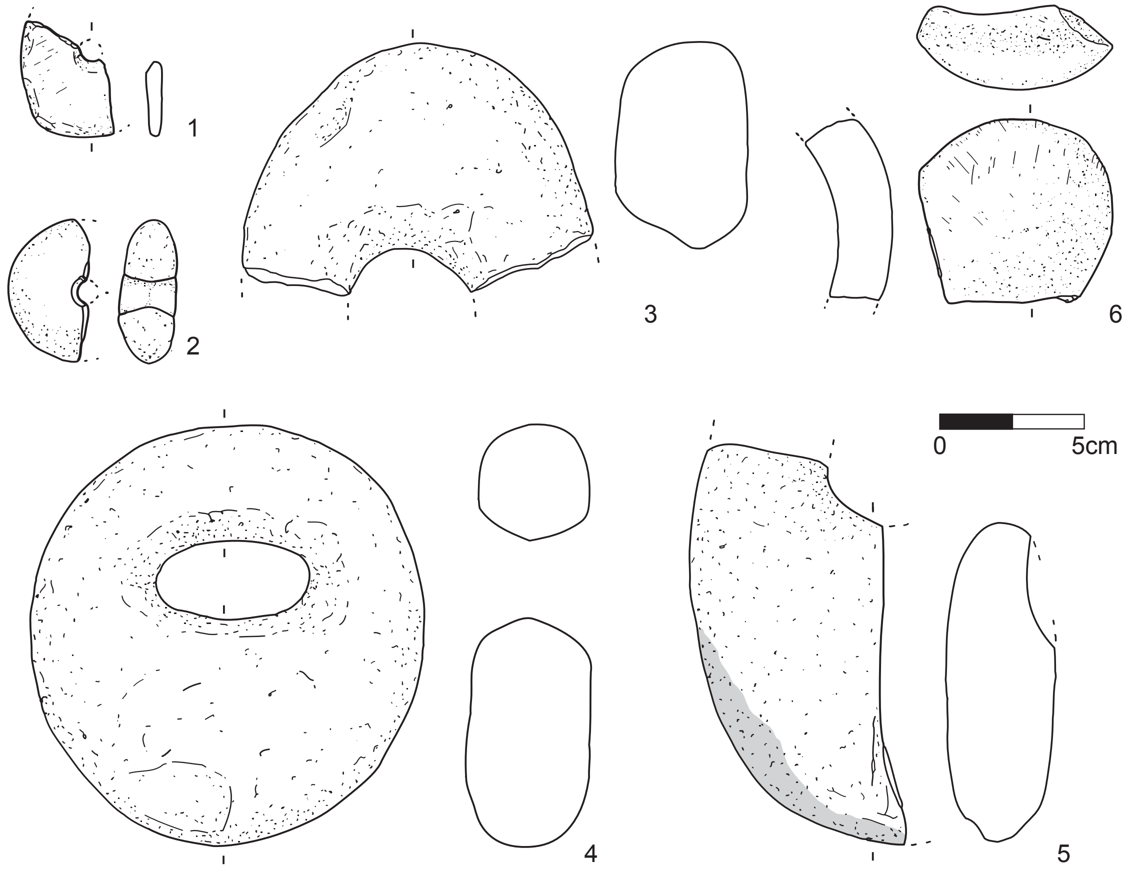

Figure 17.5 *Perforated stones and stone vessel from Ayn Abū Nukhayla: (1-2) Spindle Whorls, (3-5) Counterpoise Weights, (6) Body fragment of a stone vessel. Shaded areas indicate red stains on the surface.*

Ayn Abū Nukhayla are grouped into two types, which are the counterpoise weight (No. 101) and the spindle whorl (No. 105).

No. 101: Counterpoise Weight. One complete specimen is a sandstone cobble elaborately shaped into a discoidal shape by pecking, and an oval perforation is sunk near one end of the disc (Figure 17.5:4). At another end is located a trace of grinding. Two other specimens are broken fragments, but they appear to have had more elongated outline than the former discoidal piece (Figure 17.5:3, 5). One of them shows the stain of red pigment on the side as well as on the broken surface, indicating the re-use of the broken piece for pigment processing (Figure 17.5:5).

No. 105: Spindle Whorl. One of the two pieces in this type (Figure 17.5:2) has a discoidal outline and is lenticular in cross section, covered entirely with smoothed surface. A perforation in the center has a bi-conical cross section. The other piece (Figure 17.5:1) is a small fragment of discoidal sandstone slab. It shows clear traces of abrasion and a perforation with a bi-conical cross section.

Stone Vessel

No. 124. A possible body fragment of a stone vessel was recovered. (Figure 17.5:6; Digital Appendix 17.5:4) The specimen is made of rhyolite and has a smooth exterior surface that was finished by grinding. The piece may have originated from a closed-form vessel like a globular bowl (No. 113) because the wall is inverted with a consistent thickness. One of the broken surfaces is rounded with some traces of pecking and striations perpendicular to the edge, indicating that the fragment was re-used as a tool for pecking or scraping. The virtual absence of stone vessels at Ayn Abū Nukhayla contrasts to their frequent occurrences at other PPNB sites, particularly in the Mediterranean environmental zone (Wright 1992a:473-477).

Debitage

No. 132: Pecked Preform. Most pecked preforms in the assemblage appear to represent unfinished handstones (Digital Appendix 17.6:1-2). The preforms are shaped into ovate or rectangular forms, showing traces of pecking and grinding. Accidental breakage during the manufacture of the tools or the unsuitable forms may have caused the abandonment of the preforms. In addition, a single piece is an elliptic sandstone slab, whose periphery is roughly flaked and partly ground (Digital Appendix 17.6:3). Its peculiar flat shape and the trimmed edge suggest that it is a preform of a flaked/ground knife (No. 93).

No. 134: Flake. Several small flakes of sandstone were recovered, indicating that small-scale fabrication or the maintenance of groundstone implements took place in the excavated area.

Unidentifiable Ground Stone Fragments

No. 136: *Possible Handstone/Grinding Slab*. This is "a fragment with a single flat ground surface which could be either a handstone or grinding slab fragment" (Wright 1992a:642). Only one piece is included in this type.

No. 138: Unknown. This is an "unidentifiable ground stone fragment" (Wright 1992a:642). Only one piece is included in this type.

No. 139: Indeterminate. "Possible ground stone outil à posteriori but ambiguous" (Wright 1992a:642). Three pieces of irregular forms are included in this category. They show traces of flaking, pecking (Digital Appendix 17.6:4), or a small depression (Digital Appendix 17.6:5), indicating the uses for various activities.

Technological Analyses of Grinding Tools

This section examines the technology of food-grinding performed with handstones and grinding slabs/querns, which together account for more than 60% (N = 254) of the groundstone assemblage. The handstone and the grinding slab/quern are conventionally regarded as upper and lower grinding stones, particularly, for food processing. Thus, these tool types are often called "milling stones" or "millstones" (Bartlett 1933; Euler and Dobyns 1983; Wilke and Quintero 1996). On the basis of this general assumption, this study examines (1) the function of these tool types, (2) the density of milling stones in the site and the proportion of milling stones in the groundstone assemblage, (3) tool morphology and size, (4) motor habits, and (5) the transformation of tool morphology through use. The results of these analyses are discussed in terms of the grinding technology employed by the Neolithic inhabitants at Ayn Abū Nukhayla.

Function of Grinding Tools

Various ethnographic accounts and experimental uses of millstones suggest that they are primarily used for food preparation, and these observations conventionally provided the basis for the archaeological explanations of "millstones" (Bartlett 1933; Eddy 1964; Euler and Dobyns 1983; Hard 1990; Jones 1996; Kraybill 1977; Mauldin 1991, 1993; Morris 1990; Woodbury 1954; Wright 1992a, 1993). In the case of the Levantine prehistory, the link between the millstones and the food processing is considered quite strong as Wright (1992a, 1993) has shown through the diachronic development of milling tools from the Epipalaeolithic to the Neolithic period. According to her, mortars and pestles were prevalently used during the Natufian period, gradually supplanted by a set of grinding slabs/querns and handstones from the PPNA to the PPNB period. She further suggested that the increasing use of grinding slabs/querns and handstones resulted from the effort to reduce the particle size of plant foods for better digestion. She thought this was promoted for maximizing "the nutritional returns from limited 'catchments' close to settlements" as settlements became more sedentary and the climate deteriorated in the Late Natufian period (Wright 1992a, 1993:97). In this sense, the use of milling tools does not necessarily mean the dependence on the agricultural crops, but at least the ties of milling implements to the food preparation activity is indicated.

However, ethnographic data also indicate that there are other functions of milling implements than food processing, such as for hide processing (Adams 1988), the pulverization of temper and clay for pottery manufacture (Euler and Dobyns 1983), crushing pigments, and sharpening other tools (Schneider 1993). In fact, the processing of pigment by handstones is indicated by the adherence of red stains on some handstones (Figure 17.3:12, 15). Flaking scars at the end surfaces of handstones indicate their use for pounding (Figure 17.3:6-7, 11), while incisions and small depressions left on working surfaces suggest their use as abraders for the production of bone tools or shell ornaments (Figure 17.3:14, 16-18). These uses of handstones, nonetheless, appear to have resulted from their secondary use because the handstones show clear traces of grinding on their working surfaces.

More direct evidence on the function of millstones can be obtained by analyzing microscopic use-wear or residues from the tool surface (Adams 1996; Atchison and Fullagar 1998; Dubreuil 2004; Fullager *et al.* 2008; Roland Jones 1989). At Ayn Abū Nukhayla, phytoliths from inflorescences of wheat and cerealia-type pollen were recovered from the surfaces of handstones and grinding querns, suggesting their use for processing cereals (Portillo *et al.* 2009; Chapter 8). Phytoliths of wheat inflorescences were also concentrated in the areas where grinding querns were located on the building floors of Loci 2, 3, and 20 (Albert and Henry 2004; Portillo *et al.* 2009; Chapter 9). Thus, it is quite likely that primary functions of handstones and grinding querns at Ayn Abū Nukhayla included the processing of plant food, particularly cereal grains.

Density and Proportion of Milling Tools

The density of milling tools and their proportion to the total groundstone assemblage were compared between Ayn Abū Nukhayla and other PPNB sites. The groundstone data of the other PPNB sites were mostly obtained from Wright (1992a), whose use of a common classification system facilitated the intersite comparison. Other sources of data include Simmons and Najjar (2006) for Ghwair I, Gopher *et al.* (1995) for 'Ain Qadis I, and Gopher and Orelle (1995) for Munhata (see Table 4-2 in Kadowaki 2002 for the correspondence of the groundstone typology at Munhata to that of K. Wright).

The density is calculated by the number of millstones per square meter of excavated areas. The areas surveyed for surface collection are also included for the assemblages of Ba'ja (Gebel and Bienert 1997:247) and 'Ain Qadis (Gopher *et al.* 1995). Although a more accurate comparison would be the number of artifacts per cubic meter, such a comparison is difficult due to the lack of data on the thickness of excavated deposits at most sites. Thus, it should be noted that the tool density is likely to be overrepresented at sites with thick cultural deposits, such as at Basta, while it may be underrepresented at Ba'ja, which includes only

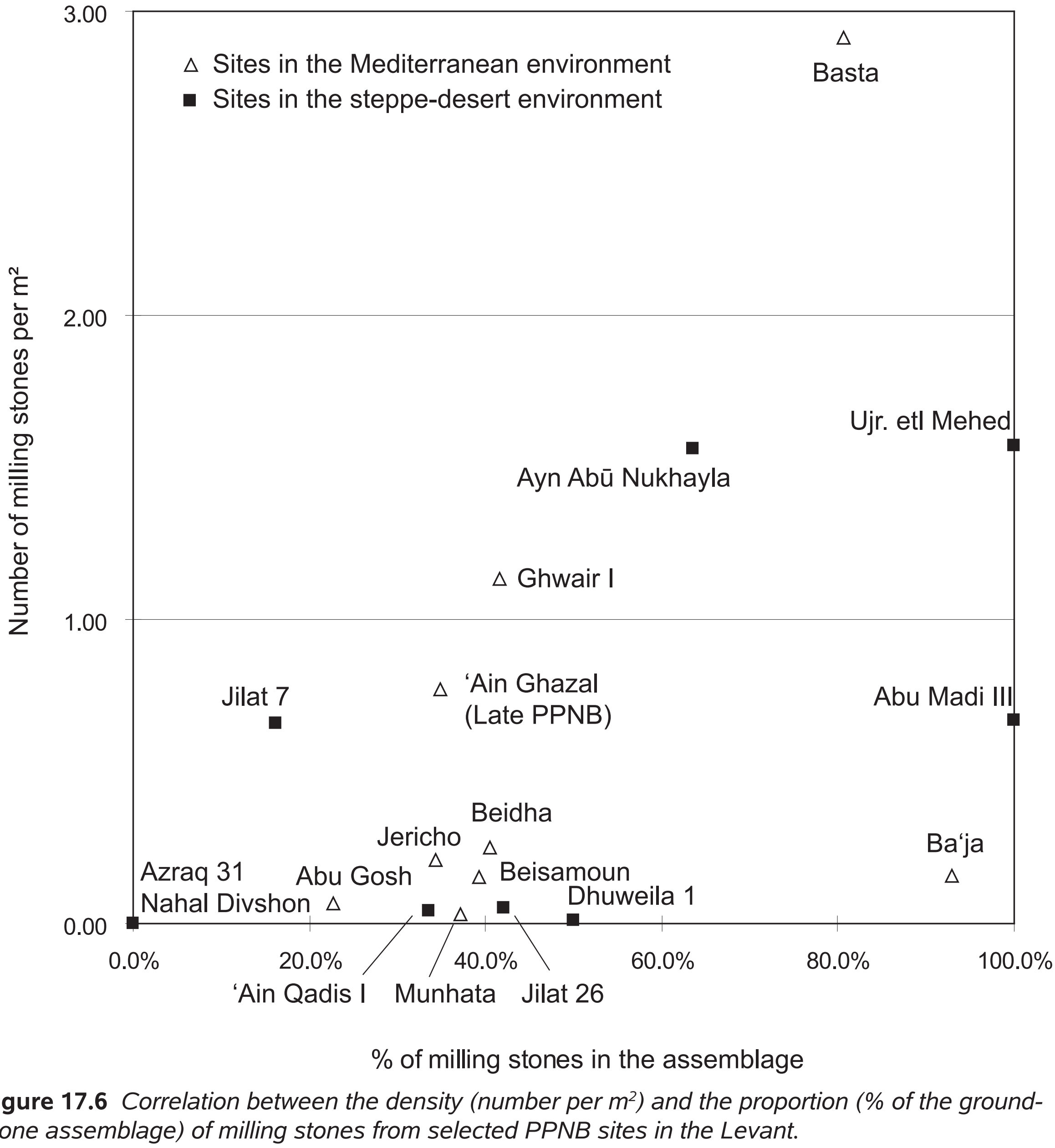

Figure 17.6 *Correlation between the density (number per m²) and the proportion (% of the groundstone assemblage) of milling stones from selected PPNB sites in the Levant.*

surface collections. The proportion of milling stones is obtained by the percentage of the six types of milling stones (grinding slabs/querns, handstones, mortars, bedrock mortars, pebble mortars, and pestles) in the total groundstone artifacts.

The density and proportion of millstones at Ayn Abū Nukhayla are relatively high among the PPNB sites as shown in Figure 17.6. It is remarkable that these figures are higher at Ayn Abū Nukhayla than at many agrarian villages located in the more favorable Mediterranean environmental zone. Moreover, the deposits at Ayn Abū Nukhayla are not significantly thicker than other PPNB sites and thus are unlikely to overrepresent its tool density. Instead, the occurrences of milling tools can be influenced by various factors, such as the wear rates of raw materials, the availability of raw materials, the site-functions, and the contexts of excavated areas. For example, if the grinding tools are made of raw materials that quickly wear out, the frequent maintenance and replacement of the tools should result in the high occurrences of milling tools. Based on the grinding experiments, Adams (1999) suggests that grinding tools made of granular materials, like sandstone, wear smooth more quickly than basalt tools. Because the smoothed surface needs to be pecked and roughened to regain the grinding efficiency (Adams 1999:486-487; Wight 1990:81-90), the maintenance of grinding surfaces accelerates the reduction of grinding tools, shortening their use life.

From this viewpoint, the high occurrences of milling tools at Ayn Abū Nukhayla can be partly explained as a result of the frequent use of locally available sandstone for handstones and basin querns (Table 17.2). The same explanation may also apply to the case of Baʻja and Basta, where local sandstone is a major raw material type of groundstone artifacts (Gebel and Bienert 1997:247-251; Wright 1992a:231; Nissen *et al.* 1987:108). Limestone is another common raw material at Basta and other PPNB sites, such as ʻAin Ghazal (Rollefson and Simmons 1988:399, 408), Jilat 7 (Wright 1992a:440), Jericho (Dorrell 1983:491, 520), Munhata (Gopher and Orelle 1995:71, 95), Abu Gosh (Lechevallier 1978:78), Beisamoun (Lechevallier 1978:178), and ʻAin Qadis (Gopher *et al.* 1995:30). However, these sites except for Basta are also characterized by the use of basalt for some handstones or grinding slabs/querns. Given the durability of basalt, the longer use-life of basalt grinding tools may have lowered the density and proportion of milling stones.

However, the use of locally available coarse sandstone for handstones and grinding slabs/querns at Beidha cannot explain its relatively low density and proportion of milling tools (Wright 1992a:207). This suggests that the durability of raw materials is not always a determining factor for the density and proportion of milling stones. On the other hand, these figures are high at Ujrat el Mehed and Abu Madi III, the interim report of which suggests that local granitic rocks were the major sources for grinding tools (Bar-Yosef 1984:154-155).

The distance to raw material sources may also affect the occurrences of the tools because the consumption of imported raw materials is often economized (Odell 2003:198-201). However, no significant difference is observable among the sites in the availability of raw materials, most of which are reported to have been obtained locally. One clear exception is the case at Jilat 7, where the tools were made of basalt that was imported from at least 45km away (Wright 1992a:225). Despite this great distance to the sources, the density of milling stones at Jilat 7 is relatively high. This is because a cache of groundstone artifacts was recovered in the small excavated area of 85m^2 (Wright 1992a:224). A concentration of handstones (N = 6, of which five are complete) was also recovered at Feature 1/Locus 2 in Ayn Abū Nukhayla (Kadowaki 2008), but the scale of this cache appears too small to have significantly increased the tool density at the site.

The high density and proportion of milling stones at Ayn Abū Nukhayla can also be related to the excavated contexts, most of which are indoor spaces surrounded by the densely distributed stone-walls of a "beehive structure" (Chapters 4 and 5). However, the excavation of the indoor space does not necessarily increase the recovery of artifacts because building floors often receive cleaning that removes obtrusive refuse to extramural middens. The maintenance of indoor space is usually rigorous at sedentary settlements in the Mediterranean environment (Goring-Morris 1994:438). On the other hand, at Ayn Abū Nukhayla, numerous artifacts were recovered inside the pithouses, particularly at floor levels, suggesting the low degree of area-maintenance (Chapter 18; Henry *et al.* 2011; Kadowaki 2008). Such conditions in the discard locations and the excavated contexts also may have affected the patterns in the density of milling stones.

Other probable reasons for the occurrences of milling stones are the site-function and the mobility of inhabitants. For example, no food-grinding tools were recovered at Nahal Divshon (Servello 1976) or in the PPNB contexts at Azraq 31 (Baird *et al.* 1992:18), which appear to have been temporary, hunting camps. On the other hand, "more than a dozen handstones" were recovered at a small occupation (ca. 20m^2) of Abu Madi III (Bar-Yosef 1984:155). Other sites have architectural remains of various scales and structures, which include what is interpreted as windbreaks at Dhuweila (Betts 1998:48), clusters of circular stone-walled buildings at Ayn Abū Nukhayla, at Phase A of Beidha (Byrd 2005), and at Ujrat el Mehed (Bar-Yosef 1984:153-154), somewhat standardized, rectilinear residential structures, called "pier houses", at 'Ain Ghazal (Rollefson 1997), in Phase C of Beidha (Byrd 2005), at Beisamoun (Lechevallier 1978:134-141), and at Jericho (Kenyon 1981), and large, compartmentalized building compounds at Basta (Nissen *et al.* 1987) and Ba'ja (Gebel and Bienert 1997).

Although this chapter is not intended to examine the functions of these sites in depth, it is noted that the patterns in the occurrences of milling stones in Figure 17.6 do not correspond to the dichotomous distinction between "farmers" in the Mediterranean environment and "mobile foragers" in the steppe-desert environment, which is expected from other archaeological records (Bar-Yosef 2001; Goring-Morris *et al.* 2009). This is because the use of milling stones was not restricted to sedentary, agrarian villages in the Mediterranean climate zone but also occurred at some sites in the arid environment, such as Ayn Abū Nukhayla, Jilat 7, Ujrat el Mehed, and Abu Madi III. These sites, except for Abu Madi III, are associated with stone-walled residential buildings with abundant remains of domestic activities and thus considered major settlements in the arid zone (Goring-Morris 1993:68-70). Such examples also include Nahal Issaron (Goring-Morris and Gopher 1983), Nahal Reuel (Ronen *et al.* 1999), and Wadi Tbeik (Bar-Yosef 1984).

It is also noted that these settlements are characterized by a dominance of grinding slabs/querns and handstones over mortars and pestles (Kadowaki 2002:Table 4-3; Wright 1992a). Based on an experimental study and ethnographic account, K. Wright suggested that mortars and pestles are effective in pounding seed foods especially for their dehusking, while the use of grinding slabs/querns and handstones reduces the grain size of seed foods for better digestion, which helps people maximize the nutritional return from a given amount of food resource (Wright 1992a). Given the advantage provided by the use of grinding slabs/querns and handstones, the high occurrence of the grinding tools in the arid zone may indicate the attempt to intensively exploit the available territory and the limited amount of the plant foods by increasing nutrient extractive efficiency (*cf.* Fullagar and Field 1997).

In sum, the variability in the density and the proportion of milling stones among the PPNB sites is likely to involve multiple factors, including the durability and availability of raw materials, the contexts of excavated areas, discard behaviors, site-functions, and available plant resources. Despite such diverse potential causes, the observed pattern can still help illustrate the grinding technology at Ayn Abū Nukhayla, which is characterized by the intensive use of locally available sandstone for the production of handstones and grinding querns. These milling implements were demanded by the inhabitants of the settlement probably for the efficient consumption of plant foods in this marginal, arid environment.

Tool Morphology and Size

The aim and scope of the following morphometric analyses draw on a number of ethnographic, experimental, and archaeological studies on food-grinding tools in the American Southwest and Mesoamerica (e.g., Adams 1999, 2002; Bartlet 1933; Eddy 1964; Euler and Dobyns 1983; Hard 1990; Hayden 1987; Horsfall 1987; Mauldin 1993; Stone 1994). These studies offer significant insights into the relationship between the tool morphology and the grinding technology. Among various technological implications of the tool form/size, this study focuses on the grinding efficiency, the ground material, the raw material availability, and the portability of tools. I selected several morphometric attributes that are particularly relevant to these factors. The selected attributes are examined by comparing Ayn Abū Nukhayla with other contemporary sites in the southern Levant. The analyses of handstones and grinding querns are followed by a discussion of the results in terms of the grinding technology.

Handstones. The selected attributes of handstones are length, the ratio of length to width, and the proportion of the three forms of handstones (discoid, ovate, and loaf). These data are available from only a few sites because many reports do not present the dimensional data of groundstone tools, and the handstone typology varies from one site to another. The data were taken from four PPNB sites (i.e., Beidha, Jilat 7, Baʿja, and Munhata) to be compared with those of Ayn Abū Nukhayla (Figure 17.7 and Digital Appendix 17.11). Only dimensional data are available from Munhata (Gopher and Orelle 1995), while only the proportion of the handstone types has been reported for Basta (Nissen *et al*. 1987).

The results of a *t*-test indicate that handstones at Ayn Abū Nukhayla are smaller than those of Beidha (t = 2.11, df = 24.7, 2-tailed p = 0.045), while they are larger than those of Munhata (t = 5.71, df = 97, 2-tailed p = 0.00). The length of handstones from Ayn Abū Nukhayla appear closer to that of Jilat 7, although the sample size

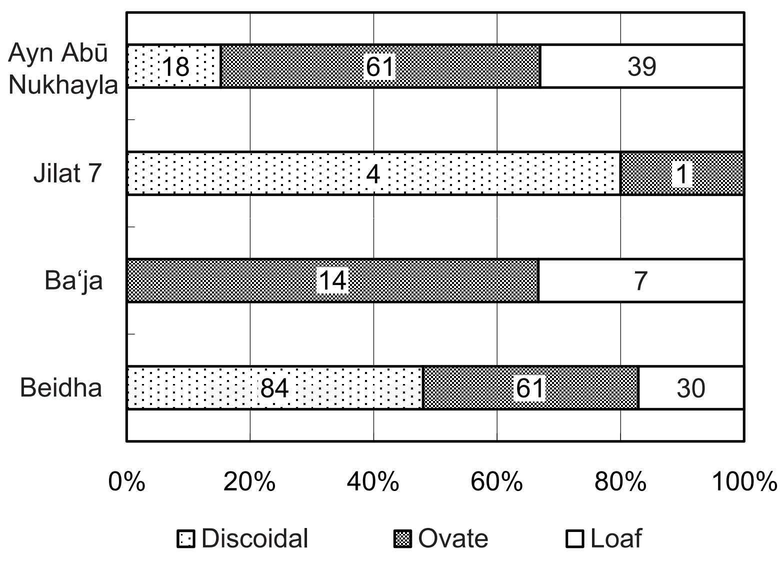

Figure 17.7 *Proportions of three types of handstones from selected PPNB sites (data for Jilat 7, Baʿja, and Beidha from Wright 1992a). Numbers in bars are the frequencies of each type.*

for the latter site is too small (N = 2) for statistical comparison. In addition, it is also noted that handstones from Baʿja and Basta appear to be even larger than Beidha. Ovate handstones from Baʿja range from 100 to 150mm, while the length of the loaf handstone is "similar to the widths of the saddle slabs" (Wright 1992a:232), which measure 222mm and 250mm on the drawings (Wright 1992a:Fig. 5-36a, b). Semi-oval handstones from Basta are also large, ranging from 95 to 350mm in length and from 42 to 104mm in width (Nissen *et al.* 1987).

The ratio of length to width was also statistically examined (Digital Appendix 17.11). The results show that the ratio does not differ between Ayn Abū Nukhayla and Beidha, but the ratio of Munhata is significantly smaller than Ayn Abū Nukhayla ($t = -2.91$, $df = 97$, 2-tailed $p = 0.005$). This indicates that the handstones of Ayn Abū Nukhayla are more elongated than those of Munhata. The abundance of the elongated handstones at Ayn Abū Nukhayla is also suggested by the proportions of the three handstone forms (discoid, ovate, and loaf). As shown in Figure 17.7, the handstones of Ayn Abū Nukhayla are characterized by the high proportion of the loaf handstones and the low ratio of the discoid form.

Grinding Querns. The forms of grinding slabs/querns were compared among some PPNB sites based on Wright's typology of the grinding slabs/querns. Wadi Jilat 7 and Baʿja are characterized by saddle-shaped slabs, while the basin querns are dominant at Ayn Abū Nukhayla (Digital Appendix 17.12). The abundance of saddle-shaped slabs is also mentioned in the preliminary report of Basta (Nissen *et al.* 1987). Beidha includes numerous trough grinding slabs/querns besides basin querns and saddle-shaped slabs. The trough grinding slabs/querns are "rectangular in plan and S-shaped in long section, curving downward from a 'shelf' at the high proximal end to an opening at the thin distal end" (Wright 1992a:626). The opening of the trough slabs/querns allows an easy access to the ground contents. The trough grinding slabs/querns are also abundant at Munhata (Gopher and Orelle 1995) and probably at Beisamoun (Lechevallier 1978).

The dimensional data of the grinding slabs/querns are available only from Beidha and Jilat 7 besides Ayn Abū Nukhayla (Digital Appendix 17.13). Although the small sample size does not allow statistical comparison, the length and width of grinding querns from Ayn Abū Nukhayla tend to be greater than those of grinding slabs/querns from Beidha. However, the length and width of the use surface do not seem to differ between them as much. In addition, the grinding querns and their use surfaces of Ayn Abū Nukhayla appear to be larger than those of Jilat 7 (Digital Appendix 17.13).

Discussion. Among the above sites, the small size of handstones and grinding slabs at Jilat 7 can be explained as a design to economize the use of imported basalt (*cf.* Stone 1994) and as mobile inhabitants' intent to increase the portability of the tools (Wright 1992a:225). However, such constraints on the raw material availability or the portability of tools did not exist at Ayn Abū Nukhayla, where a great volume of sandstone clasts of various sizes is available quite near the site. In fact, the size of grinding querns at Ayn Abū Nukhayla is greater than Beidha and Jilat 7.

On the other hand, the same explanation does not apply to the size of handstones. It is not immediately clear why handstones at Ayn Abū Nukhayla are smaller than those at Beidha, Baʿja, and Basta, sites where local sandstone was also available. The explanation for this may be related to the high occurrence of basin querns in that the concave surface of the basin querns can be formed by the use of handstones that are much shorter than the width of lower stones (see Digital Appendix 17.14 for the comparison of the size between handstones and basin querns). Moreover, the size of handstones need not be restricted as much in the case of trough querns, which open at one end, and saddle-shaped slabs. In fact, manos used with trough metates and flat/concave metates are usually larger than those associated with basin metates in the American Southwest (Adams 1993:332, 1998).

Based on grinding experiments, Adams (1999) suggests that the basin metate, which is comparable to the basin quern, was efficient in grinding dry or non-oily foods because the concave surface prevents them from spillage. The prevention of spillage may have been one of the factors in deciding the design of grinding tools at Ayn Abū Nukhayla, as the milling of cereal grains is indicated by microbotanic analyses (Albert and Henry 2004; Portillo *et al.* 2009; Chapters 8 and 9).

Another question tied to the analyses is the abundance of elongated handstones despite the dominance of basin querns. The loaf and ovate handstones excavated from the site are too long, and their outlines are too straight to fit the concave surfaces of the basin querns; too much space is left between the handstones and the grinding surfaces of the querns. On the other hand, the discoid handstones are short and have a convex surface, fitting well with the concave surface of basin querns. However, the low frequency of the discoid handstones does not match the dominance of the basin querns.

A similar situation is observable at Archaic sites in the Middle Santa Cruz Valley of the American Southwest (Adams 1998). Basin metates are the primary product there although the mano data indicates that they were used against flat/concave metates. Adams (1998:371-374) explains that the flat/concave metates existed at the site and were used for grinding, but they were subsequently removed from the site. According to her, the flat/concave metates were scavenged because they were more suitable to efficient grinding than the basin querns that were not selected for removal. She also pointed out that most metates may have been used and stored outside, which made them accessible for scavenging. However, at Ayn Abū Nukhayla, all grinding slabs/querns were recovered inside pithouses, often associated with concentrations of other artifacts and caches on house floors. This contextual evidence points to house floor assemblages in primary context that have not experienced extensive scavenging.

To investigate the problem in explaining the morphological variation of handstones and grinding querns, the following examines the grinding motion and the progressive transformation of tool morphology through use.

Grinding Motion

The forms of grinding slabs/querns are partly related to how handstones are moved on them. For example, Wright suggests that grinding slabs were used for lateral (reciprocal) grinding in a linear path, while grinding querns were used for rotary grinding in an oval or elliptical path (Wright 1992a:625). On the other hand, the grinding experiments by Adams (1996:23-24, 1999) indicate that basin metates, comparable to basin querns, can be used with manos moved in not only circular but also reciprocal paths, while trough and flat/concave metates are used with reciprocal strokes of manos. In addition to the two ways of handstone-strokes, i.e., circular and linear strokes, this study also takes into account the rocking motion (Bartlett 1933), thus defining the four kinds of motions, which are (1) the rotating motion with the rocking motion, (2) the rotating motion without the rocking motion, (3) the one-axis reciprocal stroke with the rocking motion, and (4) the one-axis reciprocal stroke without the rocking motion.

Adams (1996) described how these different motions affect the wear patterns of handstones. For example, she proposes that the rocking motion causes particular wear facets on handstones depending on whether they are used in circular strokes or in back-and-forth strokes. If handstones are used in the rotating motion with rocking motion, that part of the handstone under the palm receives more pressure than the other parts, thus being more heav-

Table 17.3 *Abrasive scratches on the three types of handstones from Ayn Abū Nukhayla*

	Transverse		Random		Unclear		Total	
Handstone Type	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Discoidal	10	55.6	3	16.7	5	27.8	18	100.0
Ovate	42	68.9	11	18.0	8	13.1	61	100.0
Loaf	32	82.1	0	0.0	7	17.9	39	100.0
Total	84	71.2	14	11.9	20	16.9	118	100.0

ily abraded. If handstones are used in reciprocal back-and-forth strokes with the rocking motion, wear facets develop on proximal and distal edges, forming a triangular cross section. On the other hand, if handstones are used without the rocking motion either in the rotating or reciprocal motion, the entire surface of the grinding surface will be evenly abraded. Adams (1996) also mentions that abrasive scratches are informative in determining whether handstones were moved in the rotating motion or in the reciprocal motion.

Evidence from Handstones. Abrasive scratches on the working surface of the handstones were examined, and two patterns of scratches were observed. The first pattern consists of scratches running transversally to the long axis (Digital Appendix 17.15), while the second one shows scratches running in the random direction. As shown in Table 17.3, the transversal scratches are more frequently seen in all handstone forms, while the latter pattern is observable only in the ovate and the discoid forms. This indicates that loaf shaped handstones were exclusively moved with the back-and-forth strokes, while ovate and discoid handstones were occasionally moved in multiple directions, including the rotating motion.

Wear facets on the grinding surfaces of handstones were also examined. Only three ovate handstones show a wear facet that may have been left by the rotating strokes with the rocking motion (Digital Appendix 17.16). The periphery of the grinding surface is partly heavily worn, possibly having received the stronger pressure from the palm. Some of the ovate and loaf handstones have a triangular cross-section (including the tool types of No. 35, 43, 33b, and 41b; Figure 17.3:9, 11). This suggests that the rocking motion was combined with the back-and-forth motion more frequently than with the rotating motion.

The above observations on the macroscopic use-wear of handstones indicate that the reciprocal back-and-forth motion was frequently employed at Ayn Abū Nukhayla, particularly with loaf handstones, while the rotating motion was occasionally employed with ovate and discoidal handstones. The rocking motion was rarely associated with the rotating motion and more frequently employed with the reciprocal motion of loaf and ovate handstones.

Evidence from Grinding Querns. According to Wright's proposition, the high proportion of basin querns in the assemblage indicates that most of the grinding at Ayn Abū Nukhayla was done with the rotary motion of handstones. However, the working surfaces of some basin querns show macroscopic linear scratches running in parallel to the long axis of the querns (Figure 17.1:7-8, 12; Digital Appendix 17.17), and only one quern retains the circular trajectory of abrasive scratches (Figure 17.1:10; Digital Appendix 17.18). This indicates the frequent employment of reciprocal back-and-forth motion.

It is also noted that the shape of the working surface of the querns is an elongated oval, which does not provide enough space for the rotary motion. The size of the working surface of the querns was compared with the size of handstones in order to estimate the space available

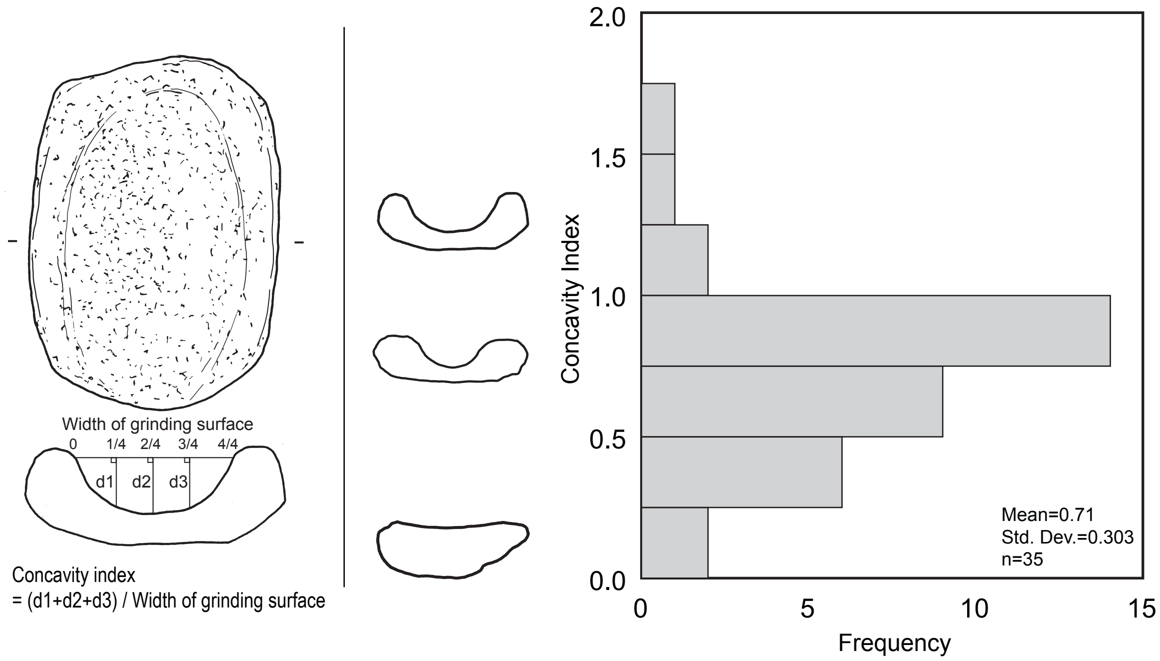

Figure 17.8 *Concavity Index of the grinding surface of basin querns from Ayn Abū Nukhayla (Left: Definition, Right: Distribution).*

for handstones to be moved on the surface of the querns (Digital Appendix 17.14). Because the handstones were held perpendicular to the user, the length of the handstones was compared with the width of the querns and the width of the handstones was compared with the length of the working surface of the querns. The result suggests that there is little space available for the handstones to be moved in a transversal direction compared to the space available for a back and forth direction.

This observation is consistent with the evidence from handstones described above. Use-wear and morphometric attributes of handstones and grinding querns collectively suggest that the one-axis back-and-forth motion was more frequently employed than the rotary motion at Ayn Abū Nukhayla.

Reduction of Grinding Tools through Use

The grinding surfaces of the basin querns at Ayn Abū Nukhayla show a considerable variation in their concavity. Some have quite deep

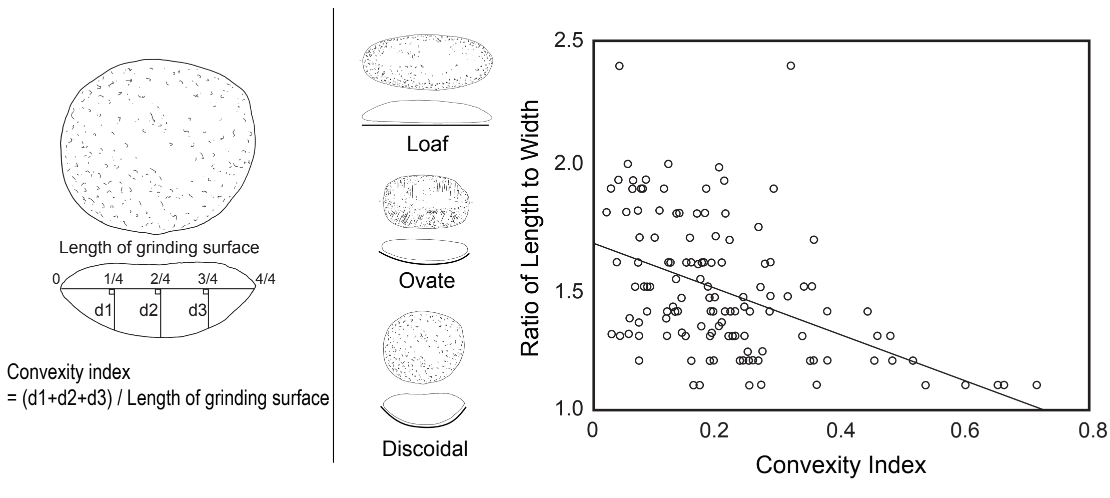

Figure 17.9 *Convexity Index of the grinding surface of handstones from Ayn Abū Nukhayla (Left: Definition, Right: Correlation between the index and the plan form of the handstones).*

basins, resembling those of the unifacial punctuated quern (Figure 17.1:12), while others have less concave surfaces, similar to the flat/concave metates in the American Southwest (Figure 17.1:11). Such variations in the concavity of the grinding surface were examined by measuring the relative concavity (Concavity Index), proposed by Wright (1992a:657-658). Following her methods, I measured the depth relative to the width of grinding surface as shown in Figure 17.8. The results show a unimodal distribution of the concavity indices, indicating that the concavity of the grinding surface gradually varies, instead of falling within distinct intervals.

The question is whether the concavity of basin querns was intentionally created or formed as a result of use. Although the handstones may have been designed to be smaller than the width of the basin querns, the uni-modal variation of the surface concavity is likely the result of the reduction through use. This is because the milling tools made of granular rocks, such as sandstone, have to be occasionally maintained by pecking the grinding surface for regaining a rough surface (Adams 1999; Wright 1992a:134-135) and this pecking results in the loss of the volume of the tools (Wright 1990).

The uni-modal variation of the concavity of basin querns is mirrored in the convexity of handstones. The measurements of their convexity (Figure 17.9) also distribute in unimode. Moreover, the convexity of handstones has a statistically significant negative correlation with the ratio of length to width ($R^2 = 0.211$, F value = 35.9, $p = 0.00$). This suggests that the grinding surface of handstones tends to be flatter as their plan form becomes more elongated. In other words, loaf handstones tend to have flatter grinding surfaces than ovate handstones, and the greater convexity of grinding surfaces is associated with discoidal handstones.

The above observations indicate that different forms of handstones were used against the same type of lower stones, the basin quern, according to the concavity of the basin querns. For example, loaf handstones may have been used against querns with relatively flat grinding surfaces. As the concavity of the grinding surface became more pronounced, the loaf form was replaced with the ovate and then discoid forms. Such a sequential use of the different forms of handstones, however, does not appear to have been caused by the transformation of handstones from the loaf through ovate to discoid forms as a result of use and maintenance. This is because the discoid handstones are significantly thicker than the ovate and loaf handstones (Kadowaki 2002:Table 3-2). It is likely that the different forms of handstones were manufactured according to the progressive development of the concavity of the querns in an effort to maximize the contact surface between the handstone and quern.

In addition, all discoid handstones from the site are complete, while loaf handstones include more broken pieces than the other two forms (Digital Appendix 17.19). This suggests that the loaf handstones were prone to breakage due to its elongated form, or they include many exhausted pieces that were abandoned after a long period of use. In contrast, the discoid handstones appear to have experienced less exhaustion than the loaf handstones.

Summary: Grinding Technology at Ayn Abū Nukhayla

The above examinations of handstones and querns can collectively provide some insights into the grinding technology. As mentioned earlier, the results of the phytolith and pollen analyses show that the grinding activities at Ayn Abū Nukhayla involved the processing of cereal grains, specifically wheat (Albert and Henry 2004; Portillo *et al.* 2009; Chapters 8 and 9).

The density of milling tools and their proportion in the groundstone assemblage are relatively high at Ayn Abū Nukhayla in comparison to other PPNB sites. The high frequencies of handstones and querns suggest that the inhabitants of the site attempted to maximize the nutrient returns of the limited amount of plant foods in the steppe environment through intensive milling. The recovery of abundant grinding tools is also compatible with the hypothesis that cereal cultivation was undertaken at the *qa*ʿ or mudflat near the site (Henry *et al.* 2003:25).

On the other hand, the quantity of grinding tools can also be influenced by the conditions of raw materials. For example, the inhabitants of the site exploited the nearby talus scree as local raw material sources, and this may have contributed to higher frequencies of the tools. The tool density may also have been enhanced by the use of sandstone that wears out quickly and necessitates the frequent maintenance of the grinding surface. The relatively short use-life of sandstone tools may have caused more frequent replacements of the milling implements, resulting in their greater abundance.

The proximity of raw material sources should also have contributed to the large size of grinding querns at Ayn Abū Nukhayla, which are as large as those at Beidha and larger than at Jilat 7. However, the same condition does not explain the relatively small size of handstones at Ayn Abū Nukhayla. The handstones could have been made larger to achieve more efficient grinding, as indicated by grinding experiments (Mauldin 1993). The length of handstones, however, is smaller than the width of grinding querns at Ayn Abū Nukhayla (Digital Appendix 17.14). Such a restriction of the size of handstones is likely to have contributed to the formation of the basin querns, which frequently occur at the site.

The dominance of basin querns characterizes the grinding technology at Ayn Abū Nukhayla because other types of slabs/querns, such as trough and saddle forms, are prevalent at Beidha, Baʿja, and Basta, where sandstone was locally available likewise. While the basin quern is advantageous in preventing the ground foods from spillage, the morphology of slabs/querns may also be related to the technique for processing grains (e.g., wet- or dry-grinding), the range of processed foods (e.g., oily or non-oily), and the motor habits of those using the implements (Adams 1999). Among these factors, the motor habits were examined through the observations of macroscopic use-wear on both handstones and querns. The results suggest that the handstones were mostly moved in a linear path on the basin querns at Ayn Abū Nukhayla. The linear motion allows a grinder to put his/her weight on handstones with both hands in each stroke to provide strong pressure, thus leading to more efficient grinding than the circular strokes (Adams 1993, 1999, 2002; Bartlet 1933). Interestingly, Molleson's (2000) osteo-archaeological analysis of the Neolithic population at Abu Hureyra revealed musculoskeletal stress markers and arthritic patterns consistent with women who used a two-handed, reciprocal motion in milling while kneeling adjacent to a quern.

The identification of use-wear that is consistent between handstones and querns suggests that they were used together as a set. However, the outlines of most ovate and loaf handstones from the site do not fit the concavity of the querns. As discussed earlier, the different forms of handstones were probably used against the same type of lower stones, the basin quern, as its grinding surface progressively developed a concavity during its use-life. The transformation of the querns indicates their prolonged use-life and a great intensity of grinding tasks performed at the site. At the same time, the wear rates of the tools would have been accelerated by the use of sandstone as a raw material.

In sum, the grinding technology at Ayn Abū Nukhayla is characterized by several observations suggested in the above analyses. They are (1) the high frequency of milling stones, (2) the large size of querns, (3) the dominance of basin querns, (4) the linear grinding motion, and (5) the transformation of querns through use paralleled by an evolution of handstone morphology. As discussed above, these technological traits have been not only influenced by the conditions of raw materials, such as the proximity of raw material sources and the use of sandstone, but also reflect the effectiveness and intensity of food-grinding performed by the occupants of Ayn Abū Nukhayla, whose attempt for the efficient exploitation of the surrounding steppe resources included the cultivation of cereals.