Archaeobotanical evidence reveals the origins of bread 14,400 years ago in northeastern Jordan

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The origins of bread have long been associated with the emergence of agriculture and cereal domestication during the Neolithic in southwest Asia. In this study we analyze a total of 24 charred food remains from Shubayqa 1, a Natufian hunter-gatherer site located in northeastern Jordan and dated to 14.6–11.6 ka cal BP. Our finds provide empirical data to demonstrate that the preparation and consumption of bread-like products predated the emergence of agriculture by at least 4,000 years. The interdisciplinary analyses indicate the use of some of the "founder crops" of southwest Asian agriculture (e.g., *Triticum boeoticum*, wild einkorn) and root foods (e.g., *Bolboschoenus glaucus*, club-rush tubers) to produce flat bread-like products. The available archaeobotanical evidence for the Natufian period indicates that cereal exploitation was not common during this time, and it is most likely that cereal-based meals like bread become staples only when agriculture was firmly established.

southwest Asia | Epipaleolithic | hunter-gatherer | food | archaeobotany

Bread is one of the most important foodstuffs consumed in the modern world. The simplest bread recipe contains a mixture of flour and water to produce dough or batter that maybe fermented before it is baked, fried or steamed. The outcome of this modest process is a rather versatile staple that is found today on many kitchen tables around the world. Despite its importance in modern cuisine, the origins of bread are still largely unknown. Early finds of bread in Neolithic sites in Europe and southwest Asia (1, 2) have inevitably related its invention to fully-fledged agricultural communities that exploited domesticated plant species [at least since circa (c.) 9.1 ka cal BP]. However, in southwest Asia (Near East), where the wild ancestors of domesticated crops such as wheat and barley occur naturally, hunter-gatherers of the Upper Paleolithic period (c. 23 ka cal BP) were already producing flour from wild grasses (3), and some authors claim that the invention of brewing, groats, porridge, and unleavened bread could have occurred as early as the late Epipaleolithic or Natufian period (14.6–11.7 ka cal BP) (3–6). However, direct evidence for cereal-based meals predating the emergence of agriculture has not been reported.

Shubayqa 1 is a hunter-gatherer site dated to the early and late Natufian (from 14.6 to 11.6 ka cal BP) located in northeast Jordan, in an area known as the Black Desert (7) (Fig. 1). The site was found and briefly dug by Allison Bets in the 1990s, and archaeologists from the University of Copenhagen, under the auspices of the Department of Antiquities of Jordan, have conducted four excavation seasons at the site from 2012 to 2015. Along with el-Wad Terrace, Shubayqa 1 represents one of the oldest Natufian sites so far discovered in southwest Asia (7). The site consists of two well-preserved superimposed buildings, the earlier one being Structure 1 (Fig. 2), which is a semisubterranean building with a carefully built flagstone pavement made of local basalt stones. This structure comprises exclusively Natufian deposits with a rich finds assemblage of chipped stones (7), ground stone tools (8), animal bones (9), and plant remains (10).

Archaeobotanical investigations at Shubayqa 1 have thus far focused on the contents of two fireplaces built in sequential phases at the center of Structure 1. The oldest fireplace is a large (approximately 1 m in diameter) circular structure made of flat basalt stones (Fig. 2). The contents of the fireplace were left intact after its last use and were subsequently buried beneath a thick deposit that covered the building (approximately 0.5 m). In the next occupation phase of the site, the inhabitants built a new fireplace above the previous one in almost the same location, very similar in size and shape, using angular basal boulders. The contents of this fireplace were also left in situ after abandonment. Seven radiocarbon dates of short-lived charred plant remains from within the fireplaces indicate their use around 14.4–14.2 ka cal BP, which corresponds with the early Natufian period (7).

Systematic sampling and analyses of the full content of the fireplaces revealed an extraordinary archaeobotanical assemblage, with more than 65,000 well-preserved nonwoody plant macroremains belonging to at least 95 taxa (10). From these, club-rush tubers (*Bolboschoenus glaucus*) were most common and comprised approximately 50,000 remains. Other plants preserved in the fireplaces included crucifers (Cruciferae), small-seeded legumes (*Trigonella*/*Astragalus*), as well wild einkorn wheat (*Triticum boeoticum*/*urartu*), barley (*Hordeum spontaneum*), and oat (*Avena* sp.). In addition to these, the assemblage comprised at least 642 macroscopic (>2 mm) lumps of charred food remains. Charred food remains have rarely been recognized as a class of archaeobotanical material (i.e., artifact), and their analysis has not been systematic. However, food remains are

Significance

Despite being one of the most important foodstuffs consumed in the modern world, the origins of bread are still largely unknown. Here we report the earliest empirical evidence for the preparation of bread-like products by Natufian hunter-gatherers, 4,000 years before the emergence of the Neolithic agricultural way of life. The discovery of charred food remains has allowed for the reconstruction of the *chaîne opératoire* for the early production of bread-like products. Our results suggest the use of the wild ancestors of domesticated cereals (e.g. wild einkorn) and club-rush tubers to produce flat bread-like products. Cereal-based meals such as bread probably become staples when Neolithic farmers started to rely on the cultivation of domesticated cereal species for their subsistence.

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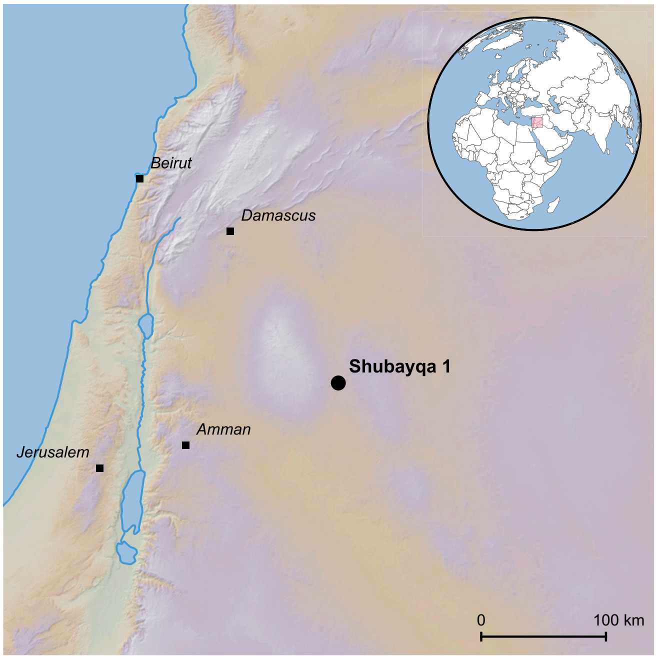

Fig. 1. Map showing the location of Shubayqa 1 in northeastern Jordan (illustrator: Joe Roe).

preserved in archaeological sites and provide empirical data on prehistoric plant-food selection, preparation, and consumption activities that would otherwise be very difficult to characterize. In this study we present the results of a total of 24 remains categorized as bread-like. The analyses carried out involved general description of the remains (i.e., size, texture, particles, and inclusions) using low-magnification microscopy, and their examination under scanning electronic microscopy (SEM) for the identification of plant particles (i.e., ingredients) and characterization of the matrix (number and types of voids) (2, 11–14). In addition to these, six specimens were subject to starch analyses (*Materials and Methods* and *SI Appendix, Supplementary Information Text*).

The Identification of Prehistoric Bread

The identification of "bread" or other cereal-based products in archaeology is not straightforward. There has been a tendency to use modern culinary terms to refer to ancient cereal-based products such as bread, often without the application of tested identification criteria and relying on the presence of cereal tissue and the overall shape of the remains to catalog them (11). The detailed tissue analysis of experimental cereal-based preparations has recently allowed for the establishment of new criteria to identify flat bread, dough, and porridge-like products in the archaeological record (2). After mixing flour and water, occluded gas cells of 0.01–0.1 mm develop in the dough. The molding of dough modifies the gas cell structures by making the small air bubbles burst, collide, and combine into big ones. If this dough is directly charred, it shows a hollow matrix with large closed voids (0.5–0.8 mm) covering more than 30% of the surface (2). The most dramatic change to the dough microstructure takes place during baking, when gas cells expand into an open network of pores or voids (15). If the dough has been cooked into flat bread and later charred, the matrix shows a low proportion of small (0.05–0.25 mm in size) micropores that cover 5–10% of the surface (ref. 2 and *SI Appendix*, Fig. S8).

At Shubayqa 1, a total of 24 food remains were categorized as bread-like products based on the estimation, quantification, measurement, and typological classification of plant particles and voids visible in the food matrix (*Materials and Methods*). From these, 22 were found in the oldest fireplace and 2 in the youngest. Macroscopically, all fragments showed a starchy, often vitrified, microstructure and irregular porous matrix, indicative of well-processed food components (Fig. 3*A* and *SI Appendix*, Figs. S1 and S8). The average size of the remains was between 4.4 mm width, 2.5 mm height, and 5.7 mm length (*SI Appendix*, Table S1). The basic classification system based on height measurements suggests that they probably represent unleavened flat bread-like products, as their height was <25 mm (13). This idea is supported by the size of the voids. In modern leavened breads, voids are >1 mm in size and commonly cover 40–70% of the matrix (14). The size of the voids of the bread-like remains from Shubayqa 1 was 0.15 mm on average and they were present in 16% of the matrix (*SI Appendix*, Table S2). These results are in agreement with finds identified as "flat breads" from several Neolithic and Roman age sites in Europe and Turkey (2, 11, 12).

Fig. 2. The site of Shubayqa 1 showing Structure 1 and one of the fireplaces (the oldest one) where the bread-like remains were discovered.

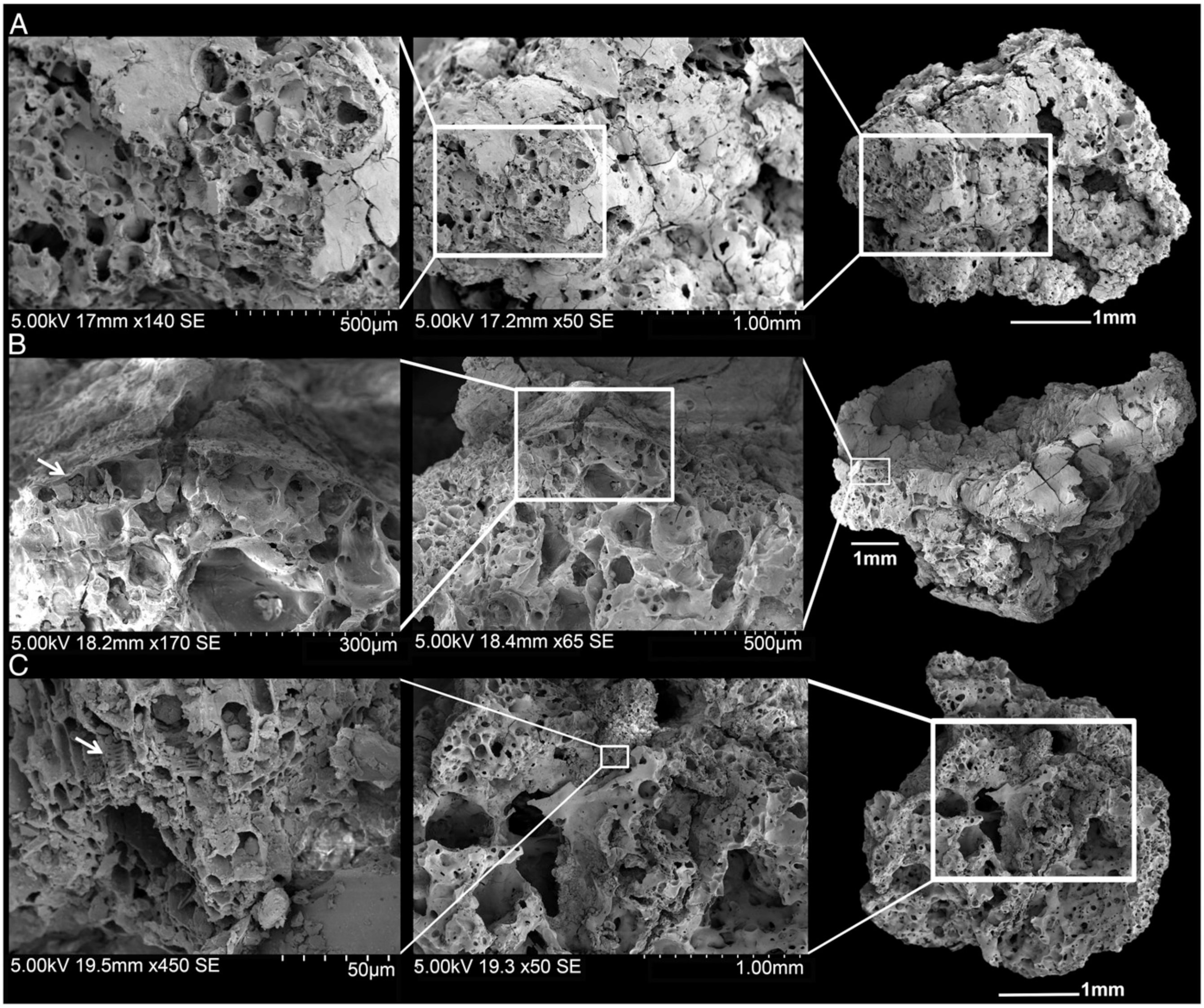

Fig. 3. Scanning electron microscope images of bread-like remains from Shubayqa 1. (*A*) Sample number 6 showing the typical porous matrix of bread with small closed voids. (*B*) Detail of an aleurone layer from sample number 17 (at least single celled). (*C*) Sample number 12 showing vascular tissue, the arrow marks the xylem vessels in longitudinal section (for additional images of the remains see *SI Appendix*, Figs. S2–S8).

The Plant Ingredients

In terms of the ingredients used in the food preparations from Shubayqa 1, the results indicate the presence of remains made of cereals and some others made of a mixture of cereals and noncereal components. From the 24 fragments, 15 showed cereal tissue, primarily pericarp tissue (longitudinal and transverse cells or bran layers), endosperm cell structures (aleurone layers) (Fig. 3 *B* and *C* and *SI Appendix*, Figs. S2–S4), and starch-containing cells (*SI Appendix*, Fig. S5). Fragments of longitudinal and transverse cells were the most common type of particles among the food remains (present in 11 of 24 remains) and measured from 50 to 2,000 μm in size, with an average size of 600 μm. In five of the remains, cereal grain cross-sections were identified. At least two specimens showed single-celled aleurone layers, typical of wheat species (*Triticum*), rye (*Secale*), millets (*Panicum* and *Setaria*), and oat (*Avena*), but the presence of double- or triple-layered aleurone found in grasses such as barley (*Hordeum*) cannot be completely excluded. In one of the remains analyzed for starch *Avena*-type was identified within the ingredients (*SI Appendix*, Table S3). The processing and consumption of large-seeded grasses in Shubayqa 1 is supported by the assemblage of plant macroremains found in association with the food remains. Approximately 46% of the grains of wild wheat and barley found in the fireplaces showed a bulging pattern on broken edges (10). This pattern is caused when the grains are ground before charring (16), and it is commonly linked to food production activities such as dehusking or bulgur/flour making (17). The evidence therefore suggests that several large-seeded grasses were most probably used in the food preparations from Shubayqa 1.

At least five of the bread-like remains showed the presence of noncereal components, including parenchyma cells, vascular tissue, and root-type starch (Fig. 3*C* and *SI Appendix*, Figs. S5–S7 and S10 and Tables S2 and S3). The vascular tissue preserved represents most likely club-rush tuber (*B. glaucus*), since more than 50,000 underground storage organs of this species were recovered in the two fireplaces (10). Ethnobotanical and experimental evidence indicates club-rush tubers are best consumed as gruel or flour to make bread, instead of boiling or steaming (18, 19). Pure club-rush tuber bread is brittle, crumbly, and flaky, but the addition of bread wheat (*Triticum aestivum*) flour (i.e.,

ANTHROPOLOGY

gluten) allows for the production of elastic dough that can be pressed onto the walls of a tandir-type oven structure and be baked (18). Evidence for cereal and club-rush tuber preparations have been identified at late Neolithic sites in Turkey (2) and The Netherlands (20). The finds from Shubayqa 1 suggest a considerably earlier date for their dietary use.

The *Chaîne Opératoire* for the Production of Bread-Like Products in Shubayqa 1

The measured sizes of the cereal and noncereal components suggest that the texture of the foodstuffs was controlled by repeated milling, sieving, and/or careful winnowing of the remains. Experimental studies indicate that without sieving, large bran fragments of 5-mm length and above occur in cereal food products (21). The metrical analyses of the particles from Shubayqa 1 show sizes between 0.05 and 2 mm (*SI Appendix*, Table S2). A total of 41.18% of the particles range within the modern dunst and flour category (i.e., <0.3 mm), 29.41% of the particles were classified as semolina (i.e., 0.3–1 mm in size), and the other 29.41% were particles >1 mm, or grist type. The overall number of measurable particles found in Shubayqa 1 is low, but the results indicate larger proportions of flour-type particles than bread-like remains at later Neolithic sites (e.g., ref. 11). Another difference is the absence of cereal chaff, whole grains, and other gritty matter, inclusions that tend to characterize later "staple" breads (11, 12, 22). It is possible that the flour used to make the bread-like remains at Shubayqa 1 was meticulously ground and carefully sieved to obtain a consistency similar to modern flours. Indeed, one of the main landmarks of Natufian culture is the intensive use of grinding and pounding tools (23), and Shubayqa 1 has yielded the largest assemblage of ground stone tools from secure late Epipaleolithic contents in the southern Levant (8). The prevalence of hand-stones and lower grinding implements at the site shows that grinding was a regularly practiced activity and suggests that the inhabitants were skilled in processing raw materials such as plants.

Starch analyses of the remains shows that five of the six remains analyzed had little or no starch, whereas one showed good preservation (*SI Appendix*, Figs. S9–S13 and Table S3). The absence of starch may be the combined result of grinding and baking as wet dough, as well as charring. These processes would have gelatinized the starches, leaving them susceptible to postdepositional processes and hydrolysis (24–27). Evidence for cooking damage is present in Shubayqa 1 in the form of completely or partially gelatinized starches (*SI Appendix*, Fig. S11); some of them showed "enlargement" of the hilum, which might be related to grinding (ref. 25 and *SI Appendix*, Fig. S9). Likewise, the presence of undamaged starch in the bread-like samples may also be explained by the carbonized state of the samples themselves. Indeed, several authors have suggested that carbonized food remains on the inside of prehistoric cooking pots may provide a good microenvironment for the preservation of starch and other microbotanical remains (28–37). The dough produced after grinding and mixing of flour and water would have been dense in comparison with modern spongy and porous breads made of bread wheat. Given the absence of oven remains at this site or others of this period (38), it is most likely that dough was placed in the ashes of a fireplace or on a hot stone to be baked.

The Production of Bread-Like Products During the Natufian

The reasons behind the production of bread-like products by the inhabitants of Shubayqa 1 are difficult to assess, but could be linked to nutritional, practical, or symbolic motivations (i.e., feasting). The modification processes that are involved in bread preparation (i.e., cereal dehusking, milling, drying, cooking, and baking) reduce noxious and indigestible components such as cellulose-rich chaff, improve starch accessibility and protein digestion, and produce a particular taste (12). The food remains were found in two in situ fireplaces, suggesting that the inhabitants of Shubayqa 1 produced bread-like products shortly before they abandoned the site. Its production could therefore be interpreted as a means of stocking up a rather light, nutritional, and easily transportable foodstuff that can additionally be stored dried for several months. However, it is also possible that bread was produced as a "special" food. Bread involves high production costs, including thorough dehusking and grinding of the cereals, as well as kneading and baking (5). It is suggested that the initial production of cereal-based foodstuffs, such as bread (and possibly also beer), could have been related to feasting behavior, where value-added luxury foods were employed to impress invited guests and secure prestige for the host (5). This interpretation finds some support in the archaeobotanical record, which shows that wild cereals were rarely exploited during the whole Epipaleolithic period (c. 23–11.7 ka cal BP) (39, 40). Most recent archaeobotanical evidence for the Natufian indicates that the small-seeded grasses, fruit and nuts, and root foods made the bulk of the diet (10, 39–42), with cereals being exploited to much lower extent, especially in comparison with later Pre-Pottery Neolithic periods (10). Consequently, and in contrast to the fact that bread is nowadays consumed on a daily basis, cereal-made products such as bread were probably not routinely consumed foodstuffs or dietary staples during the Natufian. The exploitation of cereals increased gradually between 11.5 and 9 ka cal BP, alongside evidence for the morphological domestication and increased investment in the manufacture of farming artifacts such as sickles (10, 40). At around 9 ka cal BP, domesticated cereal economies become widespread in southwest Asia (40), and bread remains, as well as specialized baking installations such as ovens, are regularly found in domestic contexts (2, 38). This would suggest that bread was transformed from a special occasion food to a daily staple when agriculture was more firmly established.

Conclusions

Previous studies have associated the production of bread with fully fledged agricultural groups of the Neolithic period. However, the discovery of charred food remains at Shubayqa 1 provides direct empirical data for the production of bread-like foodstuffs 4,000 y before agriculture emerged in southwest Asia. Our finds show the inhabitants exploited wild cereals, but also consumed root foods, plant resources whose economic value has largely been ignored due to their low archaeological visibility. Baking represents an important step forward in human subsistence and nutrition, and we here demonstrate that Natufian hunter-gatherers already practiced it. However, to explore when baking of foodstuffs such as bread developed the systematic analyses of charred food remains from contemporary, as well as previous Epipaleolithic hunter-gatherers sites should be carried out in the future.

Overall, our finds demonstrate that charred food remains are preserved in prehistoric sites in southwest Asia and their analysis provides firsthand and detailed information on the components of human diet and cooking technology very difficult to achieve by other means. The addition of these lines of evidence will enable a more critical and holistic evaluation of food consumption among hunter-gatherers and farmer-herders, providing unique insights to understand the transition from foraging to plant food production.

Materials and Methods

The whole contents of the two fireplaces were retrieved and sampled for plant macroremains. The charred bread-like products were recovered by dry sieving the soil samples with a 2 × 2 mm metal mesh. The dry sieving of the samples was carried out previous to flotation to pick out plant remains such as tubers and charred food remains that could have been subject to disintegration when entering in contact with water (10).

The initial analyses, including the general description and photography of the food fragments, were carried out using a stereobinocular microscope (Nikon binocular SMZ 1000) at magnification from 7× to 45× at the Universidad del País Vasco-Euskal Herriko Univertsitatea (UPV-EHU). A fraction of the food remains (a total of 49 remains) was chosen for further analysis and observation under SEM for the identification of their botanical composition and characterization of the matrix. SEM observations of the food remains were done using a Hitachi S-3400N scanning electron microscope housed at the Institute of Archaeology at University College London. For SEM observation, samples were cleaned from soil sediments with a brush to remove adhering soil or sediment, sputter coated with approximately 1 μm of gold. During the microscopic analyses, two main aspects were investigated: the identification of specific types of plant tissue contained in the matrix; and the examination of the microstructures, which are the outcome of the processing and cooking methods used for their preparation. From the 49 remains, a total of 24 showed clear characteristics of bread in terms of plant composition and type of matrix.

For the identification of the botanical composition of the food remains, this study is based on the tissue identification criteria developed by several authors (2, 11, 12, 43–46). The main edible plant tissues were considered and tested such as: layers present in the cereal kernels (pericarp and seed coat); chaff (epidermis of paleas and lemmas); other parenchyma tissues (pulses and tubers); vascular tissues (underground storage organs); and starch granules, which although not easily preserved in charred material, can provide vital information about food processing and preparation techniques (17, 22, 24).

Due to the low overall number of plant particles identified in the food preparations, a total of six bread-like remains were subject to starch analyses. For this purpose, a small subsample was taken from each food sample, leaving the larger portion for future analyses. The subsamples were lightly ground in a mortar and pestle and then mounted directly in entellan. The slides were scanned using a Zeiss Axio Imager.M2m microscope. The slides were scanned in their entirety at 20× for large or notable starches. One (if the number of starches were quite low) or two rows were selected and scanned at 40× from all of the slides to identify smaller starches and phytoliths. This method of counting provided an efficient presence/absence analysis. The samples were not weighed, as there was no analytical balance available at the time of analysis. Future analysis will be conducted on weighed samples, which will allow us to calculate absolute counts.

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ANTHROPOLOGY

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