# Archaeology of Ancient Egyptian Beer

**Delwen Samuel,** *McDonald Institute for Archaeological Research, University of Cambridge, Cambridge, England*

## ABSTRACT

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Beer was a staple food in ancient Egypt and important in all aspects of life, but until recently, very little of the brewing process has been well understood. An archaeological approach to the study of ancient Egyptian brewing has focused primarily on the desiccated remains of cereal-based, starchy beer and brewing by-products. The microstructure of these residues is outstandingly well preserved and can be studied using scanning electron microscopy. The state of the starch has been used to determine the ancient processes used for brewing. Strong evidence for malting comes from pitted and channeled starch granules present in most of the beer residues. Gelatinization indicates that cereals or cereal products were heated while moist, but the degree of heating and the level of moisture appear to have varied. Evidence is presented for different possible cereal processing methods, and the subsequent mixture of products to create the final beer. Arguments are presented against the traditional view that ancient Egyptian beer was made from bread and that dates were a standard ingredient.

Keywords: Ancient Egypt, Archaeology, Beer, Microscopy, Starch

## RESUMEN

La cerveza era un alimento básico en el antiguo Egipto y muy importante en todos los aspectos de la vida, sin embargo, hasta muy recientemente, muy poco acerca de su elaboración era conocido. Un enfoque arqueológico al estudio de los métados de elaboración de cerveza en el antiguo Egipto se ha concentrado en los restos desecados de cerveza de almidón de cereales y en los subproductos de su elaboración. La microestructura de estos residuos está excelentemente bien conservada y puede ser estudiada usando microscopía de barrido electrónico. El estado del almidón ha sido usado para determinar los antiguos procesos usados para elaborar cerveza. La presencia de almidón fragmentado en la mayoría de los residuos de cerveza sugiere la existencia de malteo de cereales. La gelatinización indica que los cereales o productos de cereales fueron calentados estando húmedos, pero el grado de calentamiento y el nivel de humedad parecen ser variables. Se presenta evidencia de posibles métodos diferentes de procesar cereales y de una mezcla posterior de estos productos para crear la cerveza final. Se presentan argumentos en contra del punto de vista tradicional de que la antigua cerveza egipcia era hecha a partir de pan y de que los dátiles eran un ingrediente estándar.

Ancient Egyptian inscriptions and documents make it clear that beer, together with bread, was a staple item of diet (12,27,29). Beer nourished the wealthy as well as the poor, was offered in temples to the gods, and was placed in tombs as a provision for the afterlife. It was drunk daily as a refreshing beverage and brewed specially for state occasions and local festivals. It was very likely a reliable source of potable liquid as well. Two cereals provided the base for ancient Egyptian wealth and the raw material for brewing: barley—both two row (*Hordeum distichum* L. emend. Lam.) and six row (*H. vulgare* L. emend. Lam.)—and an archaic form of wheat called emmer (*Triticum dicoccum* Schübl.). Grain production and distribution underpinned the economy and indeed the political organization of this ancient society (38). Brewing was both a regular domestic task and an important state activity. It permeated every aspect of life, and the study of ancient Egyptian brewing can thus provide access to a better understanding of the structure of ancient Egypt itself.

Traditionally, the study of beer in ancient Egypt has been approached through abundant artistic records. Ancient documentary information and ethnographic studies of a fermented Nubian beverage called bouza (41,45) have also played a role. The artistic evidence consists of statuettes and models that were placed in tombs, and the reliefs and paintings that decorated their walls, to recreate all of the provisions necessary for a comfortable existence in the afterlife. Because beer was so important, there are many brewing scenes. These representations, although often lively and detailed, are difficult to interpret. There is rarely an accompanying explanation of the activities portrayed, nor can we even be sure of the correct order of actions (55). The situation is further complicated because historical ancient Egyptian culture extended over nearly 3,000 years, during which time techniques changed gradually, although it can be difficult to pinpoint when and how these changes occurred.

Although there is vague general agreement, there has been no definite consensus of opinion on precisely how beer was brewed in ancient Egypt. Most interpretations vary in minor details or major aspects of production. For example, the use of malt has been much debated (41,55). This is partly because confirmation for its production has been sought in the interpretation of written evidence, and opinion on the meaning of particular cereal-related words varies (28,59,65). It is difficult to summarize current thought on ancient Egyptian brewing methods—itself an indication of how little is really understood.

The following is a generalized description of ancient brewing drawn from the scholarly literature. Beer loaves were formed from a richly yeasted dough that may or may not have been made from malt. This dough was lightly baked, and the resulting bread was crumbled and strained through a sieve with water. It may have been at this stage that ingredients such as dates or extra yeast were added. The dissolved bread, enriched by sugars from the dates, was then fermented in large vats; the liquid was decanted into jars, and these were finally sealed for storage or transport. This sequence bears some resemblance to that proposed for Sumerian brewing in ancient Mesopotamia (26,34).

There are a variety of problems with this view of ancient Egyptian brewing. Although it is often assumed that beer was made from barley (14,27), there is no real agreement on the meaning of inscriptions accompanying artistic depictions. Was beer made only with barley, or also with emmer, or with both as some scholars state? Were dates a standard ingredient, as hops are today? Were other flavorings used, and if so, what were they? Many lists of flavorings can be found in the literature (27,58), but their identification is not based on the direct evidence of material remains of the plants themselves.

There is not much known about the relative quantities of ingredients, although from documentary evidence we know beer was produced in differing strengths (38,50). How much labor was needed, and how long did beer take to produce? Such factors govern the economics of brewing today, and understanding them would provide archaeologists with insights into both beer production and the economic workings of ancient Egypt. The current generalized reconstruction of ancient brewing brings up other basic questions as well. For example, why is it necessary to strain crumbled bread through a sieve at all? Present interpretations of

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Journal of the American Society of Brewing Chemists 54 (1996) artistic representations showing ancient brewing do not adequately address either specific queries nor broader questions about ancient Egyptian life.

**Archaeological Approaches to Ancient Egyptian Brewing**

The ancient Egyptian beer project was set up to gain a more detailed understanding of brewery, and in doing so, to help in the identification or interpretation of archaeological evidence that may be related to brewing. Eventually, it should be possible to establish more firmly its place in the ancient Egyptian economy and society. The project has been sponsored by Scottish and Newcastle Breweries plc and carried out under the aegis of the Egypt Exploration Society. The fundamental aim is to develop a model that can accurately explain and interpret all of the brewing evidence that survives from ancient Egypt. The artistic corpus has been deliberately set aside because it has already been so intensively studied, yet has not yielded more than generalized—and contradictory—ideas. Furthermore, depictions are interpretations of the brewing process, created by contemporaries who left steps out, used one action to represent a sequence of activity, or very probably rendered processes schematically according to their own understanding of what was then a living process. It was not, after all, the function of reliefs and models to provide instructions for brewing.

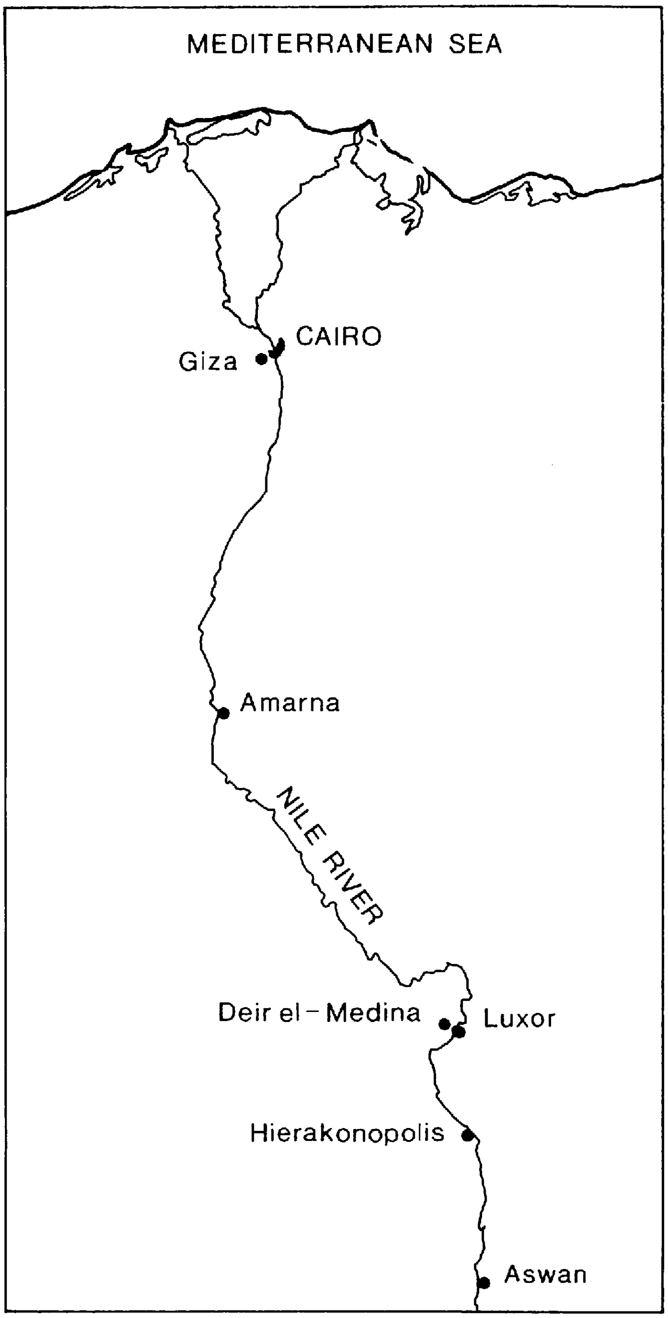


**Fig. 1.** Egypt, showing the location of sites mentioned in the text.

Archaeological remains are the material record of past human activities. Much of the record can be lost or scattered through, for example, reworking, disturbance, or different disposal places for different types of waste such as broken pottery vessels, and spent grain. Nevertheless, these remains are a direct link to events of the past. The archaeological evidence for ancient Egyptian brewing in particular is much richer than has been widely realized. The most important clues survive as a result of Egypt's extremely dry climate. Prepared food remains, rarely encountered in archaeology, have been well preserved by thorough desiccation in the arid Egyptian desert. The brewing project, therefore, is focusing on a detailed study of the ingredients and microstructure of ancient beer dregs and of the by-products generated in beer production.

The current focus is on brewing practices during a particular period of ancient Egyptian history, the New Kingdom (1550–1070 B.C.). Differences arising from the variety of brews, special occasions, and social factors must be taken into account. One way of attempting to deal with these variables is to compare remains from similar deposits. There are two New Kingdom village sites situated in the desert that have produced a good range of desiccated residues available for study (Fig. 1).

One of these ancient settlements is the Workmen's Village at Amarna. Amarna itself, in Middle Egypt, was for a brief time the capital of the country. The function of the village, and the reasons for its location nearly a mile from the edge of the main city well into the desert, are not fully understood (37). The other site, Deir el-Medina, is further south at Luxor. It is well known that this village housed the workers who built and decorated the tombs in the Valley of the Kings and Valley of the Queens (7,63). The people who lived in these villages accumulated the remains of beer and brewing by-products in two ways. They deliberately placed food, including beer, into tombs, as provisions intended for the journey to the afterlife. Such funerary offerings come from Deir el-Medina; none have been recorded from the Amarna village. The other source of brewery-related residues is the debris generated by people producing food for their own daily consumption.

Thus, dregs from funerary and settlement contexts are available for study, which, compared with caution, complement each other. Evidence from two desert villages almost certainly does not fully reflect New Kingdom brewing practices. As further material becomes available, information from the Amarna and Deir el-Medina villages can be supplemented, and the ideas they have generated can be confirmed or modified.

Funerary provisions often survive in relatively large quantities, but they are divorced from any association with production installations or equipment. It is not certain whether the vessels in which they are found were actually connected with the brewing, whether they were seen as symbolically important, or whether they happened to be conveniently available at the time they were needed.

In contrast, individual settlement residues are usually retrieved in very small amounts. Most commonly, they are thin crusts on broken pot shards (Fig. 2). Vast quantities of broken pots have been excavated from these sites. The majority of shards were very likely discarded when clay vessels broke. On a tiny proportion, the contents of the vessels' last use have adhered and survive to the present day. Thus, there is an association of contents to vessel type. All such pot fragments found so far have come from rubbish dumps, not in the houses where food preparation must have taken place, so that the connection with preparation areas is unknown.

Clearly, not all residues are derived from brewing. How is it possible to tell which are likely candidates for ancient beer? Two types of observation suggest a likely connection. First, brewing residues are more likely to have been either a liquid or a wet mass at the time of their production. This is indicated by a pattern of deposition on the shard or vessel that shows that the original contents have reduced substantially in volume compared to the surviving residue. For example, there may be a dark line on the interior wall of a vessel above a solid mass that has shrunk away into the base.

More definitively, the inclusion of bran or chaff fragments in residues demonstrates that cereal was an ingredient and strengthens the probability that brewing is involved. The assumption that most cereal-based residues that originally had a high water content were derived from brewing seems reasonable, because beer was the prime cereal food along with bread. It is possible that these types of residue came from mixing bowls for bread dough, but there are actually very few vessels that seem appropriate for such a function—they are not large, wide-mouthed bowls. Bread dough would also leave a different pattern of residue deposition because of its much lower water content.

Thus, shreds of chaff or bran in desiccated food crusts or pottery vessels suggest a cereal base, and such residues are good candidates for brewing remains. Observation of many residues has shown that ancient cooked starchy material has a medium to dark orange-brown color and a glossy or dense but matte appearance, while uncooked starch looks yellowish and powdery. Residues without cereal tissues but with similar color and texture are worth examining as well. Further detailed analysis of such residues has borne out these initial selection criteria, by the discovery of well preserved processed starch granules and yeast cells.

**Cereals Used for Brewing**

In the thin washes of residue that cling to discarded pot shards, chaff and bran fragments generally survive as tiny shreds embedded in an orange-brown colored matrix. The only way to identify such small pieces of cereal is to examine their cell patterns. The task is somewhat simplified, because barley and emmer were the only cereals grown in ancient Egypt (61). Thus, a distinction between only two cereal species is required. However, these two cultivated grasses have very similar cellular structures. Bran contains more distinctive tissue layers (66), but it is fragile, tends to preserve less well than chaff, and is more difficult to mount onto slides for microscopic examination. Differences between the cellular pattern of emmer and barley chaff have yet to be firmly established, but it is possible to make tentative identifications.

Tomb offerings generally contain larger quantities of desiccated food, and those examined so far tend to be coarse textured. Whole and nearly whole pieces of grain and chaff survive in the mass, and morphology can often be used to distinguish between barley and emmer. The differences between wheat and barley grain are widely recognized. Barley has chisel-shaped apical and embryo ends, a broad shallow ventral groove, and slightly ridged edges in transverse view. Wheat, in contrast, is rounded in cross section and has a narrow, deep ventral groove and blunter ends. The apical end generally bears a distinct brush of hairs, a feature much reduced in barley (66).

Archaeobotanists have also developed methods of separating the chaff (in the case of residues, mostly rachis internodes) of different cereal species on the basis of morphology (33). The barley rachis is generally more gracile and smooth with a distinct notch at each node. Wheat rachis internodes vary in diagnostic characteristics according to species, but all are much more robust than barley, and the nodes grade smoothly from one rachis section to the next. Emmer rachis fragments tend to retain the base of the glume, a very distinctive characteristic.

Whole grain, cereal chaff, and the shreds of cereal tissues have established that both emmer and barley were used for brewing. From the assemblage of residues examined so far, the pattern appears to be that generally either one or the other cereal was used, but occasionally the two were mixed together. The number of samples are currently too few to determine whether there was a preference for emmer or barley for brewing. The choice of cereal may have depended on the purpose of the beer. It is possible that one cereal was made more often into funerary offerings while the other was brewed for daily consumption. Many more samples, from a variety of locations, are required for any conclusive statement.

**The Search for Brewing Processes**

The study of food preparation demands more than a knowledge of the ingredients used, fundamental though that is. Processes must also be understood. These have been identified by the application of scanning electron microscopy (SEM) to the analysis of residues. The greatly magnified views of surfaces provided by this technique have shown that preservation of Egyptian desiccated beer dregs is outstanding, not only for the study of general morphology and cellular patterns, but for examination at the subcellular level as well. The processing information sought is preserved in the microstructure of starch granules. Yeast cells (Fig. 3) and possibly lactic acid bacteria, rarely detected in the archaeological record, have also been located.

It is well established that the structure of starch granules changes according to the conditions to which they are exposed. There are two changes of relevance to brewing. When grain germinates, amylase attack creates pits and channels on large, A-type granules. As enzymatic breakdown advances, only the shells of granules may be left, internally lined with concentric rings (13,48,49). The other process, gelatinization, occurs when starch is heated in the presence of moisture. Starch granules typically swell, deform, and, if enough water is present, eventually merge completely into one another (24,32,64). These morphological changes can be detected in the ancient starchy residues, providing invaluable direct data about ancient treatments.

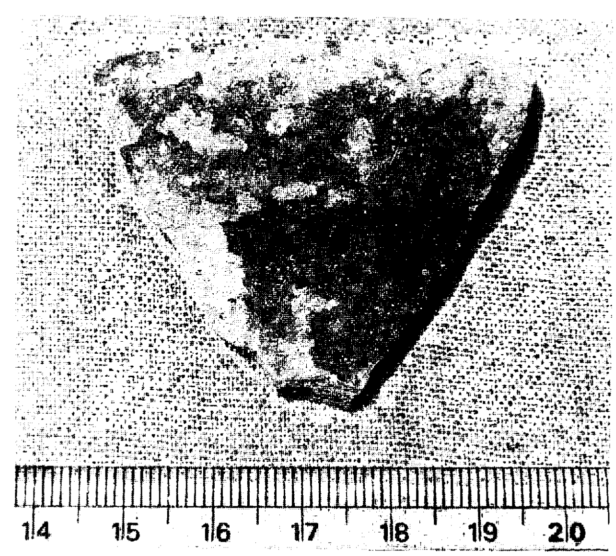


**Fig. 2.** The outer surface of a broken fragment of pottery vessel (shard) from a rubbish dump at the Amarna Workmen's Village. A desiccated crust of organic residue containing cereal chaff clings to it. The scale shows centimeters (sample TAVR92-58).

Before SEM studies of modern starch can be applied to ancient residues, however, a number of problems must be addressed. The use of microstructure to determine the steps in brewing production presents several challenges. First of all, these ancient residues are over 3,000 years old, and not surprisingly they are in less than perfect condition. They are frequently dusty and contain large amounts of particulate matter that can obscure areas of interest. Fungal hyphae have often invaded, after the foodstuff was either deposited in tomb or rubbish heap, but before complete desiccation. They are generally present in low densities, however.

Second, except under unusual circumstances, it is not possible to be sure of the brewing stage from which each sample is derived. The presence of abundant yeast or lactic acid bacteria is probably an indicator of later stages in brewing but does not confirm that the residue was actually beer. For example, yeast cells are present in one very chaffy mass that resembles mashing dregs, not the final brewing product. Chaff-rich jar contents look similar to the spent grains that are a by-product of modern brewing but the presence of yeast in at least one such mass suggests that a different processing sequence may have been used. The presence of yeast itself can be difficult to detect. If no bud scars are visible, yeast cells are indistinguishable morphologically from small, B-type starch granules. Thin coatings of redeposited material can severely obscure morphology.

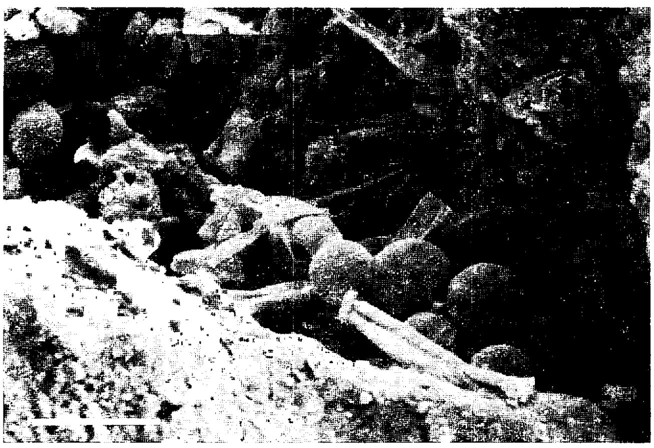

**Fig. 3.** Scanning electron micrograph of desiccated yeast cells preserved in residue on a pot shard excavated from a rubbish dump at the Amarna Workmen's Village. The yeast was actively budding at the time of desiccation. Scale bar = 10 µm (sample TAVR92-03).

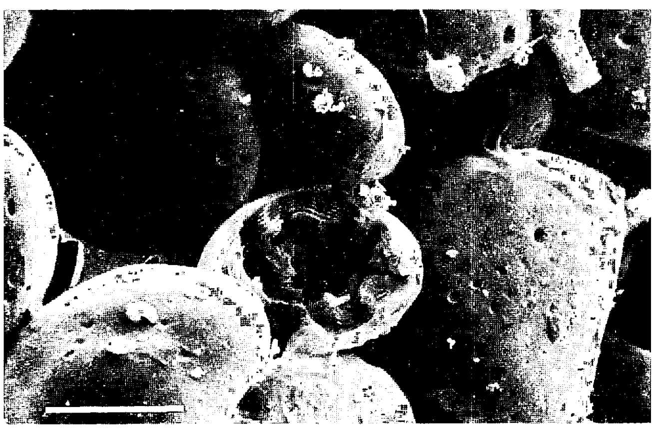

**Fig. 4.** Scanning electron micrograph of pitted and hollowed large A-type starch granules from a piece of ancient cereal endosperm. The sample comes from desiccated chaffy contents of a pottery jar, excavated from a tomb at the Deir el-Medina Workmen's Village. Scale bar = 10 µm (sample Inv. 044).

The type of vessel holding the residue may give clues. One possibility is that bowls were more likely to have been used as a drinking vessel, and thus to have contained the final beer product, than, say, a large open vat with many chaff fragments adhering. On the other hand, bowls may have been used as ladles to transfer the contents of one vessel to another.

Third, we know from offering lists, ration lists, medical texts, and administrative documents that there were many named beers (27,29). However, there are no data to show what distinguished them. Brewing residues may have derived from different types of beer for which production techniques differed and are therefore not directly comparable. There is no way to tell in advance whether residues come from the same sequence of production processes. The residues themselves show a range of variation in color, texture, and microstructure, making consistent patterns difficult to detect.

The final barrier to the interpretation of these residues is the problem of disentangling each step that affected the starch during brewing. Because starch granule populations are heterogeneous, and respond to any given processing step by gradations of change (2), the microstructure of one small part of a residue cannot be expected to represent the whole deposit nor even one grain of cereal. The order of processing steps is not a straightforward assessment, and possible mixtures of grain treated in different ways may be complicating the evidence further.

By examining each individual residue as thoroughly as possible, attempting to sample both representative and unusual portions of those residues, and using other available information, such as amounts of chaff or vessel type, it has been possible to overcome some of these difficulties. The examination of starch microstructure has permitted major advances to be made in the understanding of ancient Egyptian brewing.

**The Case for Malting**

The microstructure of numerous cereal residues clearly shows evidence for the attack of starch by amylases. Starch granules are frequently pitted and channeled (Fig. 4). In some cases, the empty outer shells are all that remain. This is the typical pattern caused by enzymatic attack.

The only processing step that could cause pitting and channeling is the germination of grain. Could this germination have been accidental? Sprouting in the ear can be a problem in wet climates (11,44), but in rainless Egypt, it can be eliminated as a possibility. Similarly, the lack of moisture outside the flood season except where water was deliberately directed also rules out accidental germination in store. It is hardly likely that the ancient Egyptians would have built their granaries on low lying, flood-prone ground.

Starch pitting and channeling might be a result of other processes unconnected with deliberate processing. Aging is one possibility. The passage of time cannot be experimentally replicated, making it difficult to disprove as an agent of starch breakdown. It is unclear what type of aging mechanism might replicate the results of enzymatic degradation so precisely. Although individual starch granules vary in their response to changing conditions (2), the very wide range of granule degradation that can occur within a single residue seems inconsistent with aging alone. Aging cannot be definitively ruled out, but it does not appear to offer a satisfactory explanation for observed morphology.

There are two possible sources of amylase that do not derive from cereal processing. Many residues contain fungal hyphae. It is possible that the larger accumulations of chaffy remains were attacked by grain weevils. The digestive processes of both types of organism include enzymatic breakdown of starch. Pests of grain and grain products have been found in preserved bread loaves (40,54), but virtually none have been observed on or in chaffy pot contents and none have been seen on thin starchy crusts on broken pots. Similarly, very little insect excreta (frass) has been seen. This supports the suggestion that most such residues were deposited as wet or damp masses, because grain weevils prefer dry conditions. The lack of frass and insect bodies or body parts suggests insects rarely attacked these residues.

It is more difficult to eliminate fungal infestation and possible fungal amylase production as a source of starch degradation. Although the presence of microorganisms cannot be eliminated on the basis of negative evidence, some residues that show extensive starch breakdown have no obvious or very little fungal growth. In some locations within residues where fungal hyphae are present, the surrounding starch granules are not pitted. Further, it is questionable whether the generally low densities in which such contaminants are present overall could be responsible for the extensive starch breakdown that is frequently observed throughout the starchy residues.

Although alternative routes for starch degradation cannot be completely ruled out, none seem to offer a fully satisfactory explanation for the appearance of pitted, channeled, and hollowed starch granules. On the other hand, such morphology is well explained by deliberate cereal germination and malting.

Support for this comes from a few loose grains retrieved from rubbish pits at the Amarna Workmen's village (Fig. 5). One barley grain still retains little rootlets, while two emmer grains have deep furrows down the dorsal side, caused by the elongating acrospires that have since broken off. These could not have sprouted unintentionally, because the only water available at the desert village was carried from a well about a kilometer away. They must have been deliberately germinated.

This evidence supports the view that malting was a basic part of the ancient Egyptian brewing procedure. This is not a new suggestion. Some Egyptologists have proposed that a particular word in the ancient Egyptian lexicon, pronounced "beshaw" (*bš3*), means malt (10,46,65). The word has a strong association with cereal in a wide variety of written sources. Direct evidence of the residues cannot determine the interpretation of a specific word, but it does corroborate this previous proposition that malting was an established process.

Similar conclusions based on microscopy were reached as early as 1929 (20) when Johannes Grüss studied ancient residue found in an amphora excavated by Henry Winlock of the Metropolitan Museum of Art in New York, dating to about 2000 B.C. This came from the tomb of a man named Wah at Thebes. Grüss also observed deeply channeled starch granules and concluded that they came from sprouted grain. Because he published in a specialist German brewing trade publication only, this work was unfortunately lost to Egyptological view.

**Malting Procedures**

If it is accepted that the degradation morphology of starch granules was caused by malting, it is possible to search for more details of the process. First, because only viable uncooked and undamaged grains will sprout, it must have been an early step. Second, germination of both emmer and barley must have taken place in the husk. This is standard procedure for barley today, and there is good reason to suppose that the ancient Egyptians did not remove the barley husk prior to sprouting either. Although it has been found that abraded barley has more even enzyme distribution and more rapid modification than untreated barley (49), preindustrial ancient Egyptian technology would not have been able to control abrasion precisely. There would be a high risk that grain would be damaged in the course of removing or shredding the chaff, which is tightly fused to the grain.

Sprouting in the husk, however, is not immediately obvious for emmer. This cereal is one of the glume wheats, which means that when the ears are threshed, they break up into individual packets called spikelets, each consisting of two grains tightly enclosed in several layers of chaff attached to the rachis internode. The proportion of chaff to grain in an emmer spikelet is far higher than that of hulled barley. The husk is much tougher and a marked impediment to water uptake. In experiments with free emmer grain and grain still in the spikelet, the latter took at least three days longer to chit (D. Samuel, *unpublished data*).

Detailed experiments have been carried out to determine ancient Egyptian methods of freeing emmer grain from its tightly enclosing chaff (53,54). These are based on both archaeological artifacts and ethnographic studies. Limestone mortars and wooden pestles have been found in houses at both the Deir el-Medina and Amarna ancient villages (6,35,36,51). Ethnographic analogies (25,30; M. Nesbitt and D. Samuel, *unpublished data*), chosen on the basis of similar cereal processing technology and, where possible, the same type of cereals, have provided key information on how these tools may have been used.

Drawing on such data, experiments have demonstrated that emmer grain was separated from chaff by pounding slightly damp spikelets in a limestone mortar with a wooden pestle. This effectively strips the chaff from the whole grain but in doing so, a high proportion of the grain embryos are damaged or torn off entirely. As with barley, therefore, to ensure that most emmer grains would germinate, they must have been sprouted in the spikelet.

Confirmation for this conclusion comes from the germinated emmer grains found at the Amarna Workmen's village. The dorsal side is clearly furrowed by the elongating acrospire. When emmer grains are sprouted without their chaff, the growing shoot curls away from the grain. It is only when the grain is enclosed in chaff that the acrospire is forced to push its way along the back of the grain, creating such a channeled appearance, as it does in hulled barley (D. Samuel, *unpublished data*).

This in turn means that further processing of both barley and emmer malt would have involved large quantities of chaff. Because most of the thin washes of starchy residue on broken pot-

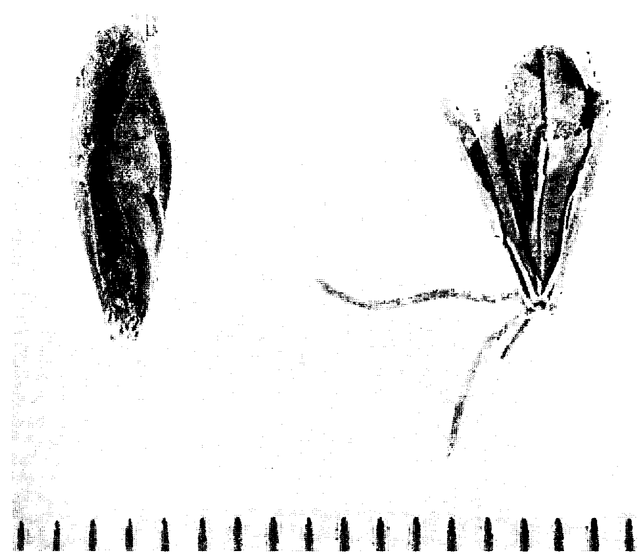

**Fig. 5.** Sprouted grains preserved by desiccation and retrieved from a rubbish dump at the Amarna Workmen's Village. The grain on the left is emmer, which has lost its rootlets and acrospire, but retains the furrow in the dorsal side created by the growing shoot. The grain on the left is barley, still partially retaining its chaff, and with the rootlets intact. The emmer grain is glassy in texture, indicating that it had been heated when still moist and prior to discard. The scale shows 1-mm intervals. Photo by Gwil Owen.

shards contain only a few tiny shreds of chaff, it appears that beer could not have been heavily contaminated by it. The use of sieves in brewing, as shown in artistic depictions, immediately becomes apparent. Rather than filtering crumbled bread as has been suggested (see above), it is far more likely that they were used to remove the large quantities of chaff from mashed malt. Whether chaff was removed before fermentation as is done today, or afterwards, remains to be fully established. Bitter flavors from the chaff may not have been a disadvantage in brews without hops.

It thus seems clear that both barley and emmer intended for beer were germinated in the husk. Can the length of malting time be estimated? There are many factors that affect rates of germination and attendant changes in the starchy endosperm. There is also a very wide range of possible germination regimes (1). As emmer in the spikelet takes longer to germinate than hulled barley, this may have been one factor in deciding from which cereal to brew.

At first sight, evidence from the residues appeared to indicate that the length of germination was controlled with great precision. In modern raw emmer and barley starchy endosperms, there is often a fairly substantial amount of protein matrix surrounding the starch granules (49). In many samples of ancient residue, some fragments of coherent endosperm are lacking protein matrix, and yet no sign of enzyme attack appears on the starch granules. Sprouting seemed to have proceeded just far enough so that proteases removed much of the storage protein from the starchy endosperm, but not far enough that amylases produced any pitting on the starch granules. The pattern appeared similar to that caused by sophisticated steeping regimes used today (1).

The reason for this was clarified when ancient whole raw grains were examined. Barley and emmer grains from archaeological contexts unconnected with processed residues were chosen that showed by their relatively pale color and fairly floury consistency that they had not been exposed to heat. They showed no sign of elongated or shriveled embryos, strongly suggesting that they had not been exposed to moisture. The starchy endosperm of the ancient barley grain examined to date contains much less protein than does modern barley grain. Protein in the ancient emmer seems to vary across the grain. In the subaleurone area, there is more protein matrix than is present in the ancient barley. Toward the center of the endosperm, however, the protein matrix is considerably thinner. All areas of the ancient emmer grain have less protein matrix than does modern emmer.

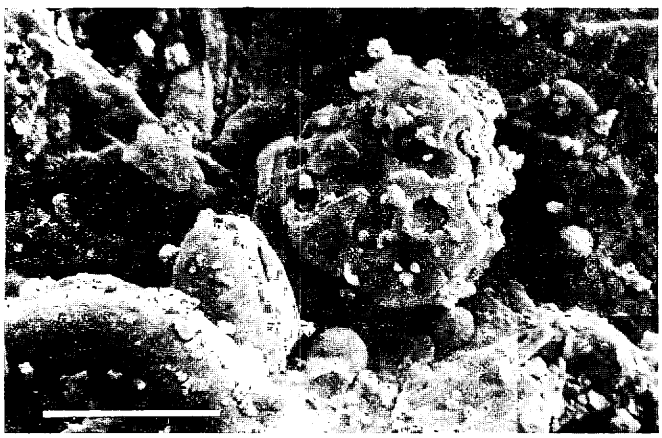

**Fig. 6.** Scanning electron micrograph of starch granules from desiccated residue adhering to a pottery shard excavated from a rubbish dump at the Amarna Workmen's Village. These large A-type granules have been redistributed from their original location within grain endosperm, and show evidence for different degrees of enzyme attack. The starch granule to the left of center shows no pitting, while the granule immediately adjacent to it on the right is heavily degraded. Note the possible bacteria in the background, upper right. Scale bar = 10 μm (sample TAVR92-56).

Unlike starch, age may be responsible for the overall sparse protein matrix. Recently, sodium dodecylsulfide polyacrylamide gel electrophoresis (SDS-PAGE) of ancient grain was carried out with modern tetraploid emmer and durum wheat grains as controls, according to techniques well established for cereal grains (9). The undifferentiated tracks produced, showing a complete lack of banding (D. Samuel, *unpublished data*), seem to be the result of a combination of random protein breakdown and cross-linking, perhaps with polyphenolic compounds (4). Thin sections of both unembedded and resin embedded ancient grains exposed to Coomassie blue and naphthalene black pick up the stains in the aleurone and in the matrix around the starch granules. This indicates that the proteinaceous material is still capable of the same histochemical reactions as its modern counterpart but without providing information on the types of changes it may have undergone. The intensity of staining in the ancient grain is less than that of the modern comparatives.

There are other possibilities for the lower density of endosperm protein that are not mutually exclusive with breakdown through aging. One reason may be that low storage protein content was a characteristic of these ancient grain varieties. It has been shown that drought after anthesis causes decreased absolute barley grain nitrogen content (8). Moisture available to field crops in ancient Egypt came from stored water in the soil after the annual floods. Water may have been limiting during the ripening phase and may have caused an overall reduction in grain nitrogen content.

There is enough evidence to say that, whatever the precise mechanism for low protein content, the reduced level in the ancient grain explains the lack of protein matrix found in emmer and barley endosperm chunks lodged in beer residues. Plainly, relative amounts of protein are not a good guide to the length of time that grain was malted.

Modification of starch granules may be affected by a variety of factors, apart from the length of time grain was exposed to moisture. These include temperature, moisture levels, and depth of the malt bed (49), none of which can now be ascertained for the ancient Egyptian system. In addition, the differences in degree of amylase attack from the embryo to the tip of the grain and the sub-aleurone to the interior central portion may be marked. Starch granules near the embryo may be heavily degraded, while the endosperm at the tip or interior of the grain may hardly be affected.

Complicating the effort to quantify the ancient Egyptian malting regime is the possibility that enzyme attack on starch granules resumed after grain germination had been halted by drying or gentle heating. Provided the grain or grain mash was not exposed to temperatures over 70°C—at which point α-amylase is inactivated (39,57)—when re-moistened, enzymes will continue to attack starch granules even though the embryo has been killed. This is the basis for modern mashing, and a similar procedure may have been used in ancient Egypt.

Perhaps the best indicator so far located for malting time is the germinated grain found from the Workmen's Village at Amarna. The length of rootlets visible on the barley grain and the extent of the dorsal furrows on the emmer grain indicate germination continued well beyond the chitting stage. A reasonable estimate might be that barley was sprouted for at least three to five days, and probably emmer was sprouted for a few days longer still, because of its much thicker chaff. Without any evidence for possible air rests, temperatures, and other relevant factors, it may not be possible to be any more precise.

The evidence is sufficient to show that, whatever the specific regimes employed, malting was a considerable investment in time and would have required adequate space. This adds a previously unappreciated dimension to the ancient brewing process. Now archaeologists can begin to look for installations or vessels that may have been used for malting. With such knowledge about malting, it may eventually be possible to determine whether specialized equipment and areas were used for state brewing at this period of ancient Egyptian history. Dedicated malting areas may well be found in larger domestic houses, and the mechanics of malting must be taken into account when considering how households functioned in smaller dwellings. Evidence for malting works would lead to reinterpretation of a part of the archaeological record that is currently unrecognized.

**Ancient Egyptian Brewing: Single System or Two-Part Process?**

Malting was apparently a key step in the ancient Egyptian brewing process. It is not yet clear, however, whether all grain destined for brewing was malted. Individual large A-type starch granules show the effects of enzyme attack more clearly than do small B-type granules. During the process of brewing, some A-type granules were dislodged from their original positions within the starchy endosperm. Once freed in suspension, they have become randomly deposited in the ancient residue remaining from the original brewing process. The redistributed A-type granules frequently show a range of modification, from no visible effects, to slight pitting, to heavy attack (Fig. 6). These starch granules could have come from incompletely modified cereal grains, or they may have come from a mixture of grain, some malted and some not. The most degraded granules that can still be recognized are battered-looking, hollowed, and channeled shells, which may have been attacked first in the endosperm and subsequently by free enzymes while suspended in water. Single residues may contain both these and pristine-looking starch. This suggests that ancient Egyptian beer may have been made with both malt and unsprouted grain.

SEM of beer-related residues discloses another process used by the ancient brewers. The exposure of cereal grain or a derivative (such as coarsely milled grist) to moisture and heat causes the starch to gelatinize. This creates a solid, glassy-looking matrix that can be seen in many of the residues. Some distribution patterns of gelatinized starch may also support the suggestion that grain was treated in different ways before being mixed together during beer making.

In apparently coherent pieces of endosperm within many of the ancient residues, there is a sharp transition between starch granules that retain their individual boundaries and completely gelatinized regions (Fig. 7). Heating has clearly had a markedly different effect across a very short distance. One possibility for this difference is that water had penetrated only partially through grains or grist. When heat was applied, endosperm that contained moisture became gelatinized, while immediately adjacent dry regions were unaffected. Alternatively, a rapid cooking method may have been used, such that heat did not penetrate evenly through the starchy endosperm.

A similar pattern of sharp transition between amorphous and granular areas within starchy endosperm has been observed in modern malts. Thomas (62) has described the case-hardening phenomenon, in which apparently liquefied sub-aleurone material is found immediately adjacent to unaffected starch granules in well-modified fractions of malt. He has suggested that this transformation is due to unspecified temperature, air flow, and humidity conditions during kilning, together with localized differences in protein quantity or quality. As discussed above, ancient emmer grains show variation in protein deposition across the endosperm, and this may contribute to sharp transitions within the starchy endosperm upon exposure to heat.

Like the variations in amylase attack on individual starch granules, some residues show extreme states of gelatinization. This is particularly so for the thin smears on pot shards from Amarna village rubbish dumps. The cause for this great variation within individual residues does not seem to be differential responses of starch granule populations to the same process. In one example, completely undistorted A-type starch granules are embedded in a matrix of totally gelatinized starch. In another, both unmodified and pitted A-type starch granules undistorted by heat are settled in a mass of gelatinized starch like raisins in a cake (Fig. 8).

The explanation for these observations may be that grain was treated in at least two different ways. One interpretation of the evidence is that grain was malted enough to cause pitting on only some starch granules, leaving others in the tip or interior of the grain unaffected by amylase. Some of this malted grain may have been heated while moist. In the process, some grain perhaps produced the same case hardening phenomenon observed today, while widespread portions of the starchy endosperm of other grain in the batch became thoroughly gelatinized. This may have resembled the specialty products made today by stewing green malt, known as caramalt and crystal malt (3). At the same time, a

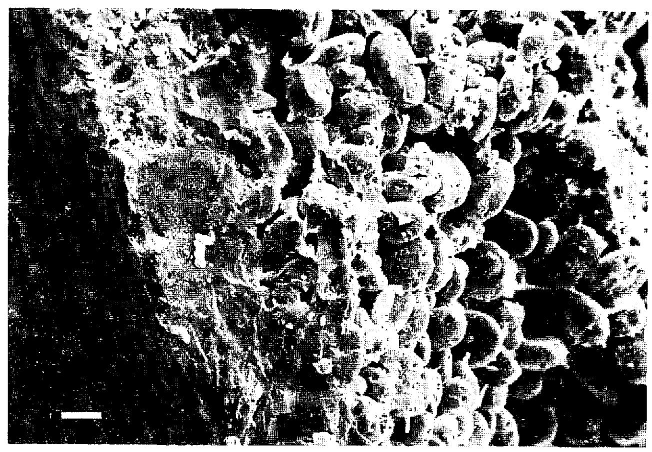

**Fig. 7.** Scanning electron micrograph of processed cereal starchy endosperm from desiccated chaffy contents of a pottery vessel excavated from a Deir el-Medina Workmen's Village tomb. There is a sharp transition zone from pitted but individual starch granules on the right, to a gelatinized, glassy mass on the left. Scale bar = 10 µm (sample Inv. 042).

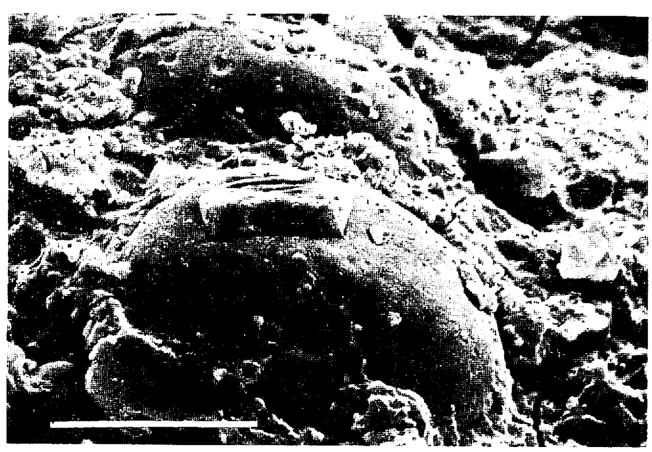

**Fig. 8.** Scanning electron micrograph of desiccated residue on a pot shard excavated from a rubbish dump at the Amarna Workmen's Village and shown in Fig. 2. The part of the residue shown consists of a mass of gelatinized starch in which pitted and unpitted starch granules, none of which are distorted by heating, are firmly embedded. Scale bar = 10 µm (sample TAVR92-58).

portion of malted grain may have been set aside and dried but not exposed to high temperatures.

Such a two-part system would be a good way to brew in the absence of the technical ability to regulate processes closely. Malted but uncooked grain would provide active enzyme capable of breaking down starch granules suspended in water, and gelatinized starch, into simple sugars available for yeast or lactic acid bacteria metabolism. The roasted, malted grains would impart a pleasant flavor, and the gelatinized starch would be easily susceptible to amylase attack. Contrary to traditional views of ancient Egyptian brewing, in this possible sequence, bread plays no role at all.

In sum, sampled residues show four possible grain treatments during brewing. Unheated, unsprouted grain or incompletely modified grain would have produced ungelatinized starch unmodified by enzymes. Sprouted grain, dried gently, probably produced ungelatinized starch modified by enzymes. Heated, moist, unsprouted grain could have produced gelatinized starch unmodified by enzymes, and heated, moist sprouted grain could have produced gelatinized starch modified by enzymes. Enzymatically modified starch, either ungelatinized or gelatinized, and starch granules, both unmodified and ungelatinized, have already been discussed. The fourth type of starch present in beer residues is unmodified but gelatinized. It is currently not possible to say whether this is derived from sprouted grain in which part of the starch was unaffected by amylase. It is possible that some brewing methods involved cooked grains that were not germinated first. Such treatment would provide a flavor different from that from an all-malt beer.

From the evidence of the residues, it seems very likely that the ancient Egyptians used a variety of techniques to kiln their germinated grain or to process unsprouted grain destined for brewing. Although this greatly complicates the task of untangling the processes that resulted in each individual residue, it would certainly create beers of different character. This might account for many of the named types of ancient Egyptian beer.

**Future Research**

The complexity of food preparation, and the dearth of precise information about past processing methods, means that a wide range of techniques should be applied to preserved residues to maximize knowledge about them. The results from scanning electron microscopy have been described in some detail, and electrophoretic work has been mentioned. Simple methodologies will also be worthwhile.

Ungelatinized starch appears birefringent when viewed with polarized light, while gelatinized but undistorted granules lose this property. The use of polarized light is a fairly crude technique, because loss of birefringence occurs before starch granules are fully gelatinized (19). Nevertheless, it indicates some exposure to heating under moist conditions, offering useful data unavailable from SEM.

Iodide ion has long been used as a starch-specific stain, usually in the form of iodine potassium iodide (IKI). This stain colors whole starch a deep purple-black. It also differentially stains the breakdown products of amylase attack, such that long-, medium-, and short-chain dextrins become mauve, bluish, and red-brown, respectively (31).

Some sampled residues have already been studied with polarized light and IKI stain. The results are proving very helpful in determining the state of the starch, complementing SEM data on enzyme attack and heating. Integrating these results and carrying out further analyses may help to answer some of the problems posed above. Other microscopy techniques are planned or are in progress. These include embedding and thin-sectioning samples of residue so that different histochemical tests may be applied. The study of ultra thin-sections with transmission electron microscopy may resolve ultrastructure and allow more precise identification of residue components. Immunocytochemical labeling may prove a sensitive way to identify not only cereal components but other possible ingredients as well. This method may help to pinpoint fermentation microorganisms more accurately, as they can be elusive if morphological criteria alone are applied.

A question that is still wide open for investigation is whether flavorings were added to beers. Many Egyptologists believe that dates were a basic ingredient for beer (15,29,56). The main evidence for this is the translation of a particular word "benner" (*bnr*), which occurs frequently in documentary and artistic sources dealing with beer. The ascribed meaning when associated with beer has generally been "dates," but another valid translation is "sweet thing" (16). This could be dates, but it could also be various other commodities—including malt. Some authors have considered the possibility that the word refers to some type of cereal (17,43). Maksoud and coworkers (42) have stated that remains of dates have been found in early beer residues from Hierakonopolis, dating to about 3,400–3,500 B.C. (18). There are no published confirmatory data.

Dates may have been a flavoring of ancient Egyptian beer, but archaeobotanical evidence suggests they were not a standard ingredient. If they were used in quantity for this staple food, there should be vast numbers of discarded date stones in the archaeological record. Dates and date stones have been found in tombs and settlement sites, but there is no record of their occurrence in the amounts that would indicate they were as important in brewing as cereal grain (60). Date stones were retrieved from recent excavations at the Amarna Workmen's village, within houses, rubbish dumps, and religious chapels, but in relatively low numbers, while very large quantities of cereal chaff have been recovered, particularly from rubbish deposits (D. Samuel, *unpublished data*, see also 52).

Other fruits and spices may well have been added to some kinds of beer, but there is little direct evidence of this so far. Microscopic study of residues for the ancient Egyptian beer project currently suggests that the basic recipe, at least for the artisan classes of ancient Egyptian society, did not include flavorings. The early Hierakonopolis beer residues are said to contain grape pips (42). Grüss (20) has stated that tissue from the bitter or Seville orange (*Citrus aurantium* L. var. *amara*) was found in other residues. But because this fruit was not grown in the Near East until post-Classical times (67), this identification cannot be trusted. Further work on many more residues is needed before the true status of "flavored" beers can be properly assessed.

Fermentative microorganisms are obviously a key requirement for brewing. Yeast has always been proposed as the prime fermentation agent for ancient Egyptian beer. Grüss (20–22) found yeast in numerous different residues, mostly from vessels placed in tombs. Substantial colonies of yeast cells have been observed in some brewing residues using SEM. Clumps of bacteria are also seen in some of the dregs. It is possible that these are lactic acid bacteria that can play an important role in fermentation. This remains to be confirmed because visual analysis is capable of detecting yeasts and bacteria, but morphology can give little information about their taxonomic affiliations, their metabolic pathways, and their wild or domesticated status.

These and other questions have a direct bearing both on the brewing process and the development of brewing in ancient Egypt. To answer them, recourse to the most sophisticated of modern techniques is required. Immunocytochemistry has a role to play in this area. Recent advances in the isolation and sequencing of ancient DNA from a wide variety of archaeological remains (5,23,47) make this a promising technique.

There is still much to learn about ancient beer making. The many types of ancient Egyptian beer, the probable differences that

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developed over time, and the complexity of brewing that is now beginning to emerge makes its study a stimulating challenge. Archaeological study, application of new and established scientific techniques, and the expertise of the modern brewing and food industries create a powerful and exciting combination—a synthesis that is slowly revealing the brewing arts of a distant past.

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