AN ARCHAEOLOGICAL STUDY OF BAKING AND BREAD IN NEW KINGDOM EGYPT

Volume 1

Delwen Samuel

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Darwin College, University of Cambridge

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AN ARCHAEOLOGICAL STUDY OF BAKING AND BREAD
IN NEW KINGDOM EGYPT
Delwen Samuel, Darwin College

This research applies a multi-disciplinary approach based on the archaeological record, to bread, a staple item of diet in ancient Egypt. Desiccated ancient loaves and artefacts connected with post-storage crop processing at settlement sites are the prime sources of data. They have been interpreted with reference to appropriate ethnographic analogies and to information about starch microstructure and its transformation under different processing techniques.

These sources of evidence, together with experimental replication, have established that New Kingdom Egyptians obtained clean grain from emmer spikelets by dampening and pounding the spikelets in limestone mortars with wooden pestles, which shredded the chaff and freed whole grain. The mixture was dried, winnowed and sieved. The whole grain was then milled on a saddle quern, on which any desired grade of flour could be produced. This work has disproved the widely quoted hypothesis that addition of grit was needed to mill flour with the saddle quern. Identification and distribution of cereal processing artefacts have been linked to household self-sufficiency and general transport of cereal commodities.

The study of actual ancient loaves has established a range of shapes, how they were formed, and that shape is not related to recipe. Emmer wheat was the cereal used for the great majority of the loaves examined, including those now held at the British Museum, the Louvre, and the Egyptian Museum, Turin. Occasional ingredients include fig, coriander, and date. Barley was not an intentional addition.

The analysis of starch from ancient loaves by optical and scanning electron microscopy has shown different patterns of germination and gelatinization, leading to the development of three different models for baking in New Kingdom Egypt. Bread was baked from untreated raw emmer, or from germinated emmer which was then air-dried and milled, or thirdly, from germinated emmer which was roasted prior to milling. These results have implications for the nutritional quality of bread, and for reinterpretation of the archaeological record.
DECLARATION

This work is based on research carried out between 1990 and 1993 at the University of Cambridge and the archaeological site of Amarna, Egypt. I worked on my own and this dissertation is the result of my own work. It includes nothing which is the outcome of work done in collaboration. It contains nothing which is the same as anything submitted by me for a degree at any other University. The text does not exceed the word limit as laid down in University and Departmental regulations.
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CHAPTER 1: TOWARDS THE ARCHAEOLOGICAL STUDY OF FOOD PREPARATION

I. The search for an archaeological theory of food studies

Archaeological studies of food provision are evolving rapidly. The most basic question about food in the past - the resources which were available and exploited - is being addressed through the analysis of plant and animal remains found in the archaeological record. Although these artefacts are frequently classified as environmental indicators (see, for example, Renfrew and Bahn, 1991: 42), they are most often applied, explicitly or implicitly, to broader questions of diet, economy, or other general themes (Luff and Rowley-Conwy, in press). The analysis of bioarchaeological remains was a rare feature of early archaeological studies but the central place of zooarchaeology and archaeobotany for the interpretation of ancient life is beginning to gain acceptance.

Zooarchaeological and archaeobotanical identifications are essential to the study of past subsistence. Yet as Sherratt points out (1991: 221), the study of edible resources is just the start of an understanding of food. Available resources and the dictates of human nutrition are the foundations upon which food is elaborated in its many different styles. Provision of food is a cultural pursuit. Everyday life is deeply affected by it for in most societies, perhaps with the exception of the technologically advanced, highly diversified modern nations, the majority of people are directly occupied for much of their time with obtaining, preparing, and consuming food. Differential access to resources, including the tools and technology, as well as ingredients,
may help to define social stratification. The supply and distribution of food and food-related commodities are linchpins of any economic system. Diet affects nutrition and pathology, with their positive and negative effects on a population. Food is often integral to ritual and religious activity.

The potential for dietary exploration has greatly expanded in the last two decades. Much of this has resulted from new technologies developed by other disciplines and applied to archaeology. Three areas of research serve to illustrate this development.

One example is the study of certain elements and their isotopes in human tissue, such as nitrogen, strontium, and carbon. These have been used to assess the relative dietary contribution of specific resources. Nitrogen and strontium isotope ratios indicate the relative amounts of marine resources in the diet, while carbon isotope ratios trace the importance of key food crops, including rice and maize (van der Merwe, 1992). Another example is analyses of coprolites and gut contents, which give direct evidence about what was actually consumed (Bryant, 1974; Hillman, 1986; Holden, 1986; Scaife, 1986; Wales and Evans 1988). Thirdly, chemical analysis has been used both for identification of poorly preserved or morphologically indeterminate plant material (Hillman et al., 1993: 104-106), as well as to identify visible or invisible residues adhering to ceramic vessels or sherd (Hill and Evans, 1989; Deal, 1990; Evershed et al., 1992).

While the application of techniques to study ancient food provision constantly evolves and expands, there has been little attempt within
archaeology to develop a coherent theory of food in culture, or as part of culture. Such a theory would help to unify and focus the many different aspects of the study, as well as to strengthen the concept that food provision is an important descriptor of human culture. One discipline which can help in the development of a theoretical framework is social anthropology.

Because food is a basic concern for all human societies, it has been a subject of interest in anthropology for many years (Messer, 1984; LaBianca, 1991). Goody (1982: 10–39) provides an overview of a number of methodologies which have been applied, and the areas of human life which have been explored through the study of food. There is an active school of thought which argues that human biological and nutritional needs are solely responsible for food choice, and sees cultural precepts and perceptions as mechanisms for embedding or perpetuating these nutritional needs (Harris and Ross, 1987). Anthropological work on food in human society has clearly demonstrated the importance of cuisine and consumption beyond the fundamental physiological need for nutrition.

Goody’s discussion of food and cooking is placed within the context of household and class. Food is related to the central human process of production, and thus inextricably and directly to economic organization, and its implications for social stratification and political power (1982: 37). Another example is Richards' study (1939) on food and diet amongst the Bemba in Rhodesia, a study which is in fact a classic and comprehensive examination of the economic and sociological structures in a society. This kind of work is closely allied to the
topics which archaeologists investigate. Goody brings together and elaborates a theoretical framework for the study of food provision, in which different cultural factors tend to predominate at each stage. This scheme is best presented in tabular form (Table 1.1), as adapted from Goody (1982: 37). Obviously, these divisions are not rigid, and elements of each grade into one other. Nevertheless, this structure is useful for considering the many complex aspects which make up food provision.

Previous archaeological investigations of food provision can be related to the framework elaborated by Goody, thereby explicitly articulating the cultural factors which are involved. For example, analysis of plant and animal macro-remains focuses on site-based resource procurement, with its primarily economic relevance. Since most recovered material derives from waste, such work must also address the process of disposal, with its social and ritual implications. So far, organic chemistry has been used mainly for identification of resources, and is thus also involved with the study of procurement. The relatively rare opportunity to look at what was actually eaten, that is, consumption, with its potential for exploration of social differentiation, has been provided by the analysis of tissues and organic molecules in gut contents and coprolites. Investigations of isotope distributions explore questions of procurement, distribution, and consumption, with their potential to explore both economic and political questions.

A comparison of this selective overview with Goody's framework shows that the archaeological study of the preparation of food, and all that entails by way of decisions and actions based on the dictates of
culture, has been largely neglected. The prime reason for this is the perishable nature of the evidence: the prepared food ready for, but prior to, consumption. The organic nature of food means that it is subject to decay, and if not eaten, it is unlikely to be preserved in the archaeological record. Exceptional conditions have permitted the recovery of quantities of actual prepared food, for example at Pompeii sealed by volcanic mud (Mayeske, 1979; 1988); extremely arid environments as in Egypt (Emery, 1962); and regions of permafrost (Rudenko, 1970: 60-61).

Because of recent developments in analytical equipment, the study of food preparation need not necessarily be restricted to these unusual locations. Analytical techniques are now capable of dealing with minute traces of material, making it possible to detect and analyse tiny quantities of organic residue lodged and sealed in the fabric of pottery vessels. One way this might be used to look at ancient food preparation is to link particular vessels with specific functions (Sherratt, 1987: 83). This type of research question has not yet been taken up.

The study of food preparation has been largely neglected by archaeologists, but its capacity to provide information about the past is in urgent need of exploration. However it is approached, the food preparation stage provides unique information about social and economic cultural factors. The preparation of food is also closely related to technological development (Forbes, 1965: 51). This can be integrated with other sources of information derived from other stages
of food provision, to gain a true understanding of the place of food in culture.

II. Thesis scope: bread in ancient Egypt

By working in a region with excellent organic preservation, the problem of organic decay is much reduced. Egypt, with its very dry atmosphere, is one such place. Here a highly developed, literate culture flourished for well over two and a half millennia, generating plenty of debris, cast-offs, offerings, and abandoned products, which have often survived through desiccation in remarkably good condition. Along with every other conceivable type of organic material, food and food remains have often been found, particularly in tombs from pre-Dynastic times (prior to c. 3,000 BC) into the Greco-Roman period (beginning in 332 BC), but also at settlement sites, even when targeted retrieval of such material has been lacking. Ancient Egyptian culture has been intensively investigated for more than two centuries, providing a large corpus of cultural information to which the place of food can be related.

These circumstances make ancient Egypt an excellent location for a case study of food and its preparation.

In any culture, the subject of food - or food preparation alone - is vast. Any hope of dealing with it adequately demands focus on a specific topic. A fruitful area of research centres around dietary staples. Staples form the core of nutrition, the items to which most time is devoted, and which absorb the main food-related resources. They are therefore of fundamental economic importance. They may be
expected to occupy a central place in the perceptions of their makers and consumers. Depending on the society and its structure, staples may be differentiated amongst social classes. Differentiation or stability of staples within a culture relates to the structure of that society.

In ancient Egypt, cereals were the primary agricultural product. Cereal remains found in tombs and from settlement sites dating to the Pharaonic era (c. 3000 BC - 332 BC) are virtually all emmer wheat (*Triticum dicoccum* Schübl.), two-row barley (*Hordeum distichum* L. emend. Lam.), or six-row barley (*H. vulgare* L. emend. Lam.) (Täckholm et al., 1941: 241, 285-287; Germer, 1985: 207-214). (The scientific naming system used here, and throughout this thesis, is the traditional binomial nomenclature, summarized by van Zeist, 1984.) The staple items of diet made from these cereal crops are well known from written evidence. Tomb and temple offering lists, administrative records including ration lists, and other documentation, all show that the principal food commodities were bread and beer (Drenkhahn, 1975: 871). The two products are closely related, and thus ideally studied together. Because of the large quantity of evidence generated during this research, this thesis deals only with bread.

The nature of bread is easily understood intuitively, but is difficult to define with precision. At its simplest, bread is a baked product (cooked by dry heat without direct exposure to fire), whose principal ingredient is cereal flour. The preparation of bread involves a number of steps, along with a range of resources. Not only is cereal required, but also the tools for preparing it, the ovens to bake in,
and the fuel to bake with. Grain and water are the only essential ingredients for bread, but there are many other potential ingredients which may have been used. This research focuses on the processing of cereals after storage, and their subsequent preparation into bread. Where there is evidence for other ingredients, these are examined. The tools and technology needed to produce bread are also explored.

III. Thesis scope: time frame

The time frame of any archaeological study may be either diachronic or synchronic. The long span of the Pharaonic period differed greatly in political and economic structure over the course of about 3,000 years, as traditions evolved and contacts developed with other peoples. In order to pursue a detailed multi-disciplinary synthesis of baking methods, this study is primarily synchronic in approach, focusing mainly on the New Kingdom period (c. 1550-1070 BC).

The site of Amarna, Middle Egypt was built on a plain which had never been previously settled, and after only 15 to 20 years, was wholly abandoned upon the death of its founder. Its remarkably short lifespan provides a tight frame of reference, irrespective of its precise absolute dating. The site is conventionally dated to about 1350 BC. Stretching over more than 7 kilometres along the east bank of the Nile, it was for a brief time the capital city of Egypt, under the Pharaoh Akhenaten. It encompasses all levels of urban society, with habitations ranging from the palace of Pharaoh, estates of the nobles, houses of the moderately well off, to the humblest dwellings of the poor. About a kilometre to the east of the city edge, a walled village with surrounding chapels, animal pens, rubbish dumps, and other
installations is set in one of the valleys of a low spur of hills. A good descriptive overview of this site has been written by Kemp (in press).

Amarna is the main point of reference for this study of baking in New Kingdom Egypt. The synchronic framework provided by Amarna and other New Kingdom evidence has been supplemented by evidence from other periods, where confirmatory or supplementary information is required or available and can usefully be integrated into the inquiry.

IV. Thesis aims

The central aim of this research is to elucidate, step by step and in detail, ancient Egyptian processing of harvested cereals into bread, focusing on New Kingdom practice. Before the broad social and economic implications of food preparation can be addressed, the resources and methods which were used need to be clearly understood. My intention is to provide a framework of dependable data so that bread making, a key activity because it involved production of a staple, can then be integrated into these and other aspects of ancient Egyptian culture. I aim to lay accurate and detailed foundations for further studies.

Part of the process of producing dependable data about bread and baking is the accurate assessment of the relevant archaeological record. Although a wide variety of tools and installations have been recovered from earlier excavations, including Amarna, their significance and function are often unclear. One of the stated goals for the current excavation work at Amarna is the clarification of
recorded features of domestic life (Kemp, 1987b: 24-25). This research will permit archaeological work to move beyond simply describing artefacts and installations, into interpretation.

My specific inquiries revolve around the resources used for baking from the time cereals were removed from store to the finished loaf, and how they were manipulated. The resources considered include not only the ingredients, but the tools and installations used to prepare them. Thus, not only is the cereal considered, but also mortars, querns, ceramic vessels, and ovens. This type of information goes some way towards establishing the economic network required for bread production, and opens up the study of social questions such as differential access to resources. Particular questions which I will address are listed below.

1) From previously gathered archaeobotanical evidence (Täckholm, et al., 1941; Germer, 1985) we know that there were two basic cereals grown in ancient Egypt, emmer wheat and barley. Were both of these cereals used or preferred for bread in the New Kingdom, or was one of greater importance?

2) The only essential ingredients in bread are flour and water. Were other ingredients added to bread, and if so, what were they? In particular, the use of yeast or other leavening agents cannot be assumed. Were different ingredients used for different types of bread?

3) What were the technological procedures used to prepare and bake
bread? What equipment was used, and how did these transform the ingredients at each stage of the preparation and baking process? What by-products were generated?

4) Linked to (3), the steps required, is the question of the different jobs or functions people may have performed. What are the time and labour requirements? What are the implications for organization of the baking process?

5) Where within the community did the whole baking process occur? Were different steps carried out in different areas?

I have explicitly left aside religious or ritual aspects of bread and baking. This is a specialized area of study, most of which is best approached through documentary sources, rather than archaeological evidence.

V. Methodological approach
A. Rationale for a biological framework
Humans manipulate the resources available to them, in order to satisfy the fundamental need to eat, within a biological framework. At the most basic level, food provides the nutrition which permits human life to continue. From this central fact, it is decision making based on cultural rules which result in the apparently limitless variations and elaborations of food provision. Biological processes, however, form a
baseline which constrain these variations, and therefore impose a boundary which limits speculation and hypothesis. Since past activities are not directly observable, this limitation is particularly important for archaeological studies. As Barker and Gamble (1985: 6) have pointed out, an understanding of the basic biological properties of bioarchaeological data needs to be established before questions of process and change can be addressed.

For cereal preparation, the biological facts of cereal morphology and biochemistry set the limits within which humans must operate to obtain nutrition. Many traditional ideas about ancient Egyptian bread are actually untenable for good biological reasons. Assumptions have been made based on modern bread baking, which uses a different type of cereal from that of the ancient Egyptians. Bread wheat (*Triticum aestivum* L.) – used now – and emmer wheat vary in a number of morphological and biochemical properties. As a result, the two wheats require different processing methods, and yield dissimilar products. The significance of these biological facts has not previously been recognized. The underlying but explicit organizational theme which I have used to explore bread production in ancient Egypt is therefore biological.

B. Rationale for a multi-disciplinary approach

Food preparation is complex, and demands the application of a wide range of methodologies in order to understand how it was undertaken in the past. One type of evidence alone may supply good information about some aspects, but by the nature of the incomplete record of the past, each class of information contains many gaps. With an inter-
disciplinary approach, it is possible to apply information generated from a number of sources to make informed inferences about areas for which there is no direct evidence. A wide variety of data improves the ability to build up precise and detailed models about the past, and to find methods by which they may be tested. One good example of this type of approach is the study of Chinese food habits and dining in the Han period (Pirazzoli-T'serstevens, 1991).

This research accordingly draws upon a number of different areas which are relevant to the study of baking. The subject has been traditionally approached through examination of the ancient Egyptian artistic record. Apart from a description of previous work in Chapter 2, I have avoided reference to tomb reliefs, models and statuettes for two reasons. It is very difficult for the modern viewer to look at ancient representations as they were conceived by the artist, for one inevitably tends to impose an interpretation based on one's own past experience. It is therefore doubtful whether observation of the artistic evidence alone provides clear information about past processes. (See Samuel, 1993, for further discussion of this point.) Ikram (1992: 1-2) also presents a critique on the use of the artistic evidence alone to study ancient activity. The second reason is that because the artistic corpus has been so well studied, any other work which includes it is in danger of attempting to fit the results into a preconceived pattern. This may be highly misleading, however, and the solution is to avoid use of such data until other sources of evidence have been fully investigated.
The sources of evidence which I have drawn upon are primarily archaeological. I have explored the artefacts and installations related to cereal preparation and baking which have been found at the site of Amarna, and have also referred to material excavated from Deir el-Medina, a Workmen's village of similar date at Thebes. I have drawn upon evidence from the pottery, but have not undertaken a detailed consideration of it, since this is a specialized topic, well covered by others (see Ch. 6 for references). Direct evidence for baking comes from the loaves which were placed in tombs as food offerings, and are now preserved thanks to Egypt's extremely arid climate. I have studied them by visual means, including microscopy. I have not used chemical analysis. Although potentially richly informative, it has not been possible in the time available to develop an analytical approach which takes into account the excellence of preservation, and the possible range of ingredients which might be present. Ethnoarchaeological work has proven to be particularly important for the analysis of ancient Egyptian cereal processing, and the lack of modern day emmer and barley bread making has left a number of questions about baking unanswered. Experimental reconstruction has been vital to understand the use of ancient equipment and the behaviour of both cereals and dough; further development of this approach may help to address many of the areas which are still puzzling. I have used very little of the documentary evidence. This is another specialist area, and is best re-examined by an Egyptologist making use of this archaeological study.
VI. Thesis overview

Chapter 2 examines the previous investigations which have been undertaken on ancient Egyptian bread baking, and demonstrates the heavy bias towards use of the artistic record. Chapter 3 then lays down the foundations of the biological approach which I have used, by examining the structure of the cereal grain, with a focus on emmer wheat in particular, and by an extensive survey of starch. All the topics discussed in Chapter 3, such as enzyme degradation of starch, and the morphological changes which occur when starch is exposed to heat and moisture, are critical to the interpretation of data relating to ancient loaves, discussed in Chapter 6. Chapter 4 gathers together descriptions of the various analytical methodologies which I have applied.

Chapter 5 goes on to use a variety of evidence to establish the nature of ancient Egyptian cereal processing, from spikelets to flour. This chapter uses data primarily from settlement archaeology, ethnoarchaeology, and experimentation. Chapter 6 is a detailed study of dough preparation and bread baking. Much of the direct evidence comes from desiccated tomb loaves. Finally, Chapter 7 presents the general conclusions which have resulted from this research, and places these in context by suggesting lines of future work.
CHAPTER 2: PREVIOUS WORK

I. Introduction

Egyptologists have given some attention to baking in Dynastic Egypt. Discussions of the process have been based primarily on the abundant artistic depictions, which show various actions connected with cereal processing, dough making and baking. These scenes are nearly always accompanied by brewing as well. The apparent links between the two activities, baking and brewing, can be difficult to separate, and this often holds true for modern interpretations. In this overview of previous work, I have made no attempt to cite comprehensively the profusion of references describing individual depictions. Where appropriate, I have referred to relevant publications, but have concentrated on syntheses of ancient Egyptian baking practice, particularly where these relate to New Kingdom times.

Other sources of evidence have played a subsidiary role. Contemporary traditional Egyptian practice is sometimes used as an analogue for activities discerned in artistic scenes. There are no ancient Egyptian documents which describe how bread was prepared. Much later, Classical authors were more forthcoming, and their writings have sometimes been applied to discussions of practice in Pharaonic times. Material evidence from archaeological excavations has very rarely been used in general discussions of bread preparation, and then only makes a brief appearance (e.g. Kemp, 1989: 120-124). In archaeological reports, installations and equipment such as ovens, querns, and mortars are described, but any discussion about their use is related back to the tomb scenes. The best source of direct
evidence, the desiccated loaves of bread discovered in many tombs, has very rarely been examined.

II. The nature of the artistic record

In ancient Egypt, the function of tomb decoration was to provide for the afterlife. Until the late New Kingdom, the ancient Egyptians aspired to a life after death which incorporated the ideal essentials and pleasures of the world they lived in. Tomb art was intended to portray, and thus create, that ideal. As bread was a staple, baking scenes were popular.

There were three main methods of depiction. Reliefs and paintings on tomb walls show large or small baking scenes, frequently accompanied by brewing. Statuettes, usually of limestone, portray individuals performing a specific action. Statuettes grade into models, in which two, three, or many wooden figures are represented, carrying out the tasks required to bake and brew. Over time, the favoured types of representation changed.

A. Predynastic to Old Kingdom, c. 4000 BC-2134 BC

The first known images which seem to be connected with cereal food preparation are two predynastic clay figurines. Although conventionally interpreted as figures working with vats of beer, it is possible that they were intended to represent dough working. One, dating to c. 4000-3500 BC, depicts a woman standing in a vat (Berlin Museum, Inv. Nr. 13832-3; Breasted, 1948: 32, Pl. 31a; Kaiser 1967: 12, Pl. 64), while the other shows a figure of indeterminate gender reaching into a large vat, and dates to c. 3500 BC (Cairo Museum, JE
38908; Needler, 1984: 381, Pl. 85). The next representations are not known to occur until probably the 4th Dynasty (c. 2575-2465 BC), with two stone statuettes, apparently engaged in sieving and brewing, from the tomb of Meres'ankh III at Giza, now at the Boston Museum of Fine Arts (30.1458; 27-5-6). A large wooden figure, now in the Museum of Athens (accession number not available), is attributed to the 4th Dynasty, and represents a woman kneeling over a millstone (Capart, 1905: no page number, Pl. 53). This particular statuette is unusual in its dimensions and material, but as a class of objects, individual statuettes are typical of the Old Kingdom (c. 2575-2134 BC). Groups were often placed together in one tomb, so that a full suite of actions is portrayed. One good example is the assemblage from the 5th Dynasty tomb of Nikauhathor, at Giza, now in the Cairo Museum (JE 72227-31, 72234, 87820; Hassan, 1944: 48, Pl. 10 A & B; Hassan, 1950: 177-181, Pl. 74-80).

The Old Kingdom was also a particularly prolific time for wall reliefs of baking. Because of their relatively large numbers, Old Kingdom practice has been the main focus for many discussions of ancient Egyptian baking. There are well over two dozen Old Kingdom wall reliefs, but probably the most famous is in the tomb of Ti, at Saqqara (#60; D22) (see e.g. Epron et al., 1939: Pl. 66-67, 70-71).

B. First Intermediate Period and Middle Kingdom, c. 2134-1640 BC
During the First Intermediate Period and Middle Kingdom, wall scenes continue, but are far less common. The relief tradition is much attenuated and occurs only on isolated stelae. One example is a stela fragment from tomb T7, at Balat (Dakhla Oasis), from the First
Intermediate Period (Valloggia and Henein, 1986: 81-82, Pl. 61, 81).
Another stela, of a man called Ab, or Ib, is from Riqqa (near Meidum), Middle Egypt, probably dating to the First Intermediate Period, with three carved figures grinding (now in the Ny Carlsberg Museum, A680; Engelbach, 1915: 13, Pl. 5, 6).

Of the few known wall paintings, six come from Beni Hassan, Middle Egypt (Newberry, 1893a: 30-31, 68, Pl 12, 29; 1893b: 48, 55-56, Pl. 6, 12; Wilkinson and Hill, 1983: 68-69), but probably the best known is that of Antefoker (#60) at Thebes, dating to the 12th Dynasty (1991-c.1783 BC) (Wreszinski, 1923: Pl. 217, 220, 221; Davies and Gardiner, 1920: 14-16, Pl. 8-9A, 11-12A). In contrast, there are more than thirty different extant wooden models or figurines engaged in baking (and brewing).

C. New Kingdom, c. 1550-1070 BC
By New Kingdom times, representations of many specific tasks required in the afterlife are uncommon. They were replaced by generalized ushabti servant figures, intended to perform any tasks demanded of them (Breasted, 1948: 22). Curiously, a few isolated examples of statuettes reappear, always engaged in milling. It is not now known where they are from. They are all of stone, except one bronze example, and far from representing servants, are often named persons of high rank, such as a king's scribe, priest, or royal wife.
The eight known examples are listed and described by Breasted (1948: 23-24), and the general form with some examples, is discussed by Gardiner (1906).
Vandier (1964: 305, 307) lists twelve New Kingdom tomb paintings depicting baking and brewing; of these, three show brewing only, and one is unpublished. One other is mentioned but not described by Vandier, and there is one known baking relief which is not from a tomb (Cooney, 1965: 73). This brings the total published New Kingdom wall depictions of baking to seven. They are listed in Table 2.1.

III. Previous studies of baking from the artistic record

A. Descriptions of primary data

Numerous descriptions of individual paintings, reliefs, statuettes and models have been published in accounts of excavated tombs. Virtually all of these deal with the depicted figures one by one in order, rarely attempting to look for the probable flow of action, but frequently referring to other known parallels. Often the emphasis is on points of dress, colour, or other art historical details. Within excavation reports, several authors have broadened their scope to look at baking practice in general, using a few or many artistic examples.

B. Syntheses of primary sources

Wall paintings and reliefs have attracted most attention, largely ignoring statuettes and Middle Kingdom models. Perhaps this is because wall depictions frequently have written labels, while none occur with models. A few are found on Old Kingdom statuettes, in addition to the New Kingdom millers inscribed with extracts from chapter 6 of the Book of the Dead. However, one of the earliest general descriptions of baking activity, by Borchardt (1897), focused on Old Kingdom statuettes, mainly those which were at that time in
the Cairo Museum collection. Borchardt re-identified some depictions, including a figure previously described as weeping, which he recognized as a person tending to a hearth or oven (1897: 125).

Three detailed investigations into ancient baking (and brewing) deal almost entirely with Old Kingdom methods. Firstly, a lengthy investigation by Montet (1925: 230-254) is part of a broader discussion of Old Kingdom tomb scenes of domestic life. The scenes of Ti's tomb are extensively cited, but several other tombs scenes are also used. Secondly, the detailed treatise by Wild (1966) concentrates on the reliefs in the tomb of Ti, examining the meanings of hieroglyphic labels, the actions of each figure, the use of vessels, tools and installations, and the order in which different activities may have occurred. Parallels with Middle Kingdom and New Kingdom scenes, as well as other Old Kingdom representations, are drawn, especially to try to establish the meanings of particular words. Finally, Faltings (1993) aims to be comprehensive in her use of both wall reliefs, and statuettes, from the Old Kingdom. These three studies are not discussed further here, since the time frame of this work is specifically the New Kingdom.

Wreszinski (1926) devoted an article to the subject of baking alone. He studied only wall paintings, choosing the clearest, and using accompanying inscriptions (1926: 1). In effect, much of the data comes from the Old Kingdom, since this is the period with most bakery wall scenes. Wreszinski apparently considered that baking practice remained essentially unchanged throughout the Dynastic era, and uses scenes from all three periods together.
Two authors survey baking and brewing scenes, according to period, using wall depictions exclusively as their frame of reference. Klebs (1915, 1922, 1934) published three volumes on reliefs and wall paintings, from the Old, Middle, and New Kingdoms, respectively. Within this broad undertaking, she discussed baking practice (1915: 67, 92-94; 1922: 94, 119-121; 1934: 171-179). In his examination of baking and brewing scenes, Vandier (1964: 272-318) also looked at each period separately.

Wreszinski's (1926) generalized reconstruction of the baking process, as well as the specifically New Kingdom methods described by Klebs (1934) and Vandier (1964) are presented as flowcharts in Table 2.2.

The information in the Lexikon der Ägyptologie may be considered a fair summary of scholarly thought on cereal preparation and baking. Wild (1975: 594) states that there was a gradual improvement in the method of obtaining fine, clean flour, by cleaning and pounding the grain, sifting and sieving, and successive grindings. He says (1975: 597) that dough was placed against the internal oven wall during baking, and reasserts the idea first raised by Klebs (1934: 135) - see below, section IV.B.1 - that more fluid dough dribbled down to form paddle-shaped loaves, as illustrated in the tomb of Nebamun (see Ch. 6.D.5). He discusses a number of different baking methods.

C. Previous general descriptions

Many general descriptions of ancient Egyptian baking have been written, and I have chosen to select only a few fairly recent,
representative examples. None is related to a particular period and references are rarely given. These accounts, ranging from scholarly semi-popular to popular, are important because they exemplify the current general conception about ancient Egyptian baking practice. Thus they are worth quoting at some length. They have been summarized for comparison in Table 2.3.


"At first, after winnowing, grinding and pounding were performed on a saddle quern by means of a round or roller-shaped stone... The crushed grain was then cribbled and sieved through sieves made of rush or papyrus. Actually most flour in antiquity was simply whole meal... examination of specimens of bread found in tombs shows that a lot of grit was allowed through.... workers are often seen in tomb illustrations kneading dough with their hands and, in large households, with their feet... Fermentation was started by adding sour dough, leaven, or yeast.... The dough so prepared was then baked. At first, baking was on an open fire or over ashes. A rudimentary oven was subsequently contrived by lighting a fire between a few vertically placed stones with an overlying horizontal slab. Sometimes... the dough was baked in pre-heated moulds. Later, came cylindrical ovens inside of which a fire was lit. Some of these ovens were open above; when the oven was sufficiently hot, the dough loaf was pressed against the inside of the heated walls. This gave flat curved loaves."


"The techniques of bread-making are easily understood thanks to tomb representations dating from the Old Kingdom. The grain (mostly emmer but also barley) was first cleaned by sieving... it was then ground in a mortar with a long-handled pestle that enabled greater pressure to be exerted; the resulting flour was sieved once again to remove impurities. This was followed by the important grinding phase.... The flour thus obtained was then mixed with water, frequently being trodden in huge vats if large quantities were involved, otherwise on stone slabs at an angle to enable surplus water to drain off. There is no specific evidence for the process of leavening the bread, which must have taken place while it was still dough.... Leavened or unleavened, the dough was now ready for baking. The methods of baking varied according to time, place, and social context. The simplest method consisted in putting the bread directly on the fire, in the burning embers or on slabs of stone placed over the flames. In the Old Kingdom, common use was made of moulds (equipped with a cover): these were heated to the desired temperature before being filled. In the New Kingdom, bakers mainly used cylindrical ovens where the loaves were attached to the internal
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walls of the oven. Similar procedures were followed in the manufacture of sweet breads."


"Reliefs, models and paintings of all periods show that flour was milled daily in quantity in Egyptian households. First the grain was crushed in a limestone mortar set into the floor. Then it was milled on a sloping stone... by means of a rubbing stone.... Once the grain had been ground it was passed through rushwork sieves. These were inefficient and the flour obtained was coarse and contained amounts of whole or partly crushed grain.... The grain was often parched, that is, soaked to soften the tough outer layers and then dried on mats in the sun before milling.... Unleavened dough could be shaped by hand and cooked directly on a flat stone placed over the fire, on the baking floor inside a clay oven, or even by being slapped on to the pottery wall of the oven itself. Some loaves were simply cooked in the ashes of the fire."


"Reliefs and models demonstrate the initial crushing of the grain... with stone pestles on flat limestone mortars. The coarse product was then ground again... with a spherical or ovoid roller over a low stone saddle quern with a central depression.... For finer grinding tall cylindrical or conical mortars were used... with long pestles.... Even though it was sometimes passed through papyrus or net sieves, flour made in mortars or crushers contained a good deal of sand and stone impurities.... The flour was never thoroughly milled or sieved, so that uncrushed germs and even whole grains remained in the bread, averaging about five per cubic centimetre.... Breadmaking began with the mixing of the dough, which was kneaded with both hands... on a low, flat stone surface, or else with the feet in a large container. Some yeast, salt, spices, milk and sometimes butter and eggs were added to the flour; after mixing, the dough was left to rise before being put into conical baking-forms or patted into various shapes and baked without a mould. In the earliest days bread was baked on an open fire, or in the embers. Later on a simple hob was made by setting a large flat stone on top of three upright ones and starting a fire underneath. From the Old Kingdom onwards, thick conical ceramic "bread-moulds" came into fashion. These were pre-heated on the open fire, then wiped with fat and filled with the dough which baked evenly right through, thanks to the accumulated heat. Middle Kingdom models already feature tall tapering bread-ovens with a firebox at the bottom, a grating and a domed upper compartment that was open at the top. Lumps of risen dough were placed on ledges inside the dome when it was hot."

D. Use of Classical authors

Comments by Classical authors about Egyptian bakery are sometimes quoted. Such references occur in general accounts of ancient Egyptian
food (e.g. Murray, 1963: 87), and in descriptions of bread baking in Pharaonic times (e.g. Darby et al., 1977: 506, 509, 517). Classical authors cited include Herodotus (mid 5th c. BC), Pliny (1st c. AD), Strabo (64 BC-AD 22), and Athenaeus (fl. c. AD 200).

IV. Critique of previous studies based on the artistic evidence

A. Deficiencies

1. Lack of real consensus

Current interpretations of ancient Egyptian baking practice, reconstructed through the artistic record, contain a multitude of discrepancies. As Währen (1961: 1) has stated, most people quote the same sources when discussing types of bread, yet, although these accounts draw upon the same pool of data, they do not tally. Points which vary include the function of the mortar and pestle, the stage at which sieving occurred, and the texture of the final product. Even the interpretation of individual scenes may be radically different. One good New Kingdom example is in the tomb of Nebamun (#17, Thebes). According to Wreszinski (1923: Pl. 125), one particular sequence involves activity around hearths and ovens; Säve-Söderbergh (1957: 24-25) describes grinding, sieving and pounding taking place.

A classic misinterpretation of tomb scenes concerns the notion that flat bread was baked on the exterior walls of cylindrical ovens (Borchardt, 1916: 530; Wilson, 1988b: 13; Hepper, 1992: 93). Although no longer used in Egypt today (it would be interesting to know why), such ovens, called tannours, are common elsewhere in the Near East, clearly demonstrating how round flat breads could have been produced in the past (Währen, 1960, 91; 1961: 3; Samuel, 1989: 25)
Most other authors specify that bread was baked in some way on the pre-heated interior oven walls (see also Ch. 6.VIII.D.5).

2. **Missing data**

There appears to be an implicit assumption in most discussions of ancient Egyptian bakery, that artistic depictions provide all the information which need be known about it. A spectrum of questions may be posed which this type of source does not address, questions which bear on broader social and economic themes, as well as the interpretation of the archaeological record and documentary sources. These queries may best be presented as a list. Many of them correspond to the aims of this research, presented in Ch. 1.IV.

i) What are the detailed and precise methods of preparation? It is clear that the artistic evidence has failed to provide any coherent detailed understanding of the full sequence of cereal preparation, nor of bakery methods, although individual stages are apparently understood.

ii) Which commodities are being used? As archaeobotanical evidence has shown (see Ch. 1.II), the cereals of ancient Egypt are emmer wheat and barley: which was favoured, if either? What other ingredients were added to bread? When scenes lack inscriptions (which is the case for all Middle Kingdom models) no information of this type is conveyed. When labels are provided, the identity of ingredients can still be highly problematic, as is demonstrated in section B.2 below.
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iii) The cereal most familiar to Western culture today is free threshing wheat, but this was not grown by the ancient Egyptians. What are the requirements of processing imposed by emmer and barley morphology? This point is discussed further in section B.3 below.

iv) What are the by-products of cereal processing, and how did the ancient Egyptians make use of them or dispose of them?

v) How much time was taken to produce given quantities at each stage, and how much labour was needed?

vi) What was the texture, palatability, flavour, nutritional content, and digestibility of the resulting product?

vii) Apart from loaf shape, how did bakery products differ?

B. Reasons for problems with the use of artistic depictions

1. Restricted data

None of the numerous accounts of baking in Pharaonic Egypt has been comprehensive in its use of the artistic sources, although Faltings (1993) has aimed to cover all Old Kingdom depictions. The only two authors to consider baking throughout this era, as well as New Kingdom practices in particular, considered the topic only within the context of reliefs and paintings. Their explicit focus excluded the examination of statuettes or models; neither did they consider any other type of supporting evidence, such as ethnographic or archaeological information. Other accounts, when describing individual
tombs and their contents, have made some use of evidence beyond depiction.

Rigourous exclusion of other types of evidence is untenable. One result is the odd method of baking flat round bread on cylindrical oven walls suggested by Klebs (1934: 174-175) and echoed by Vandier (1964: 310). It is worth quoting Klebs' discussion of the problem at length, to illustrate the depth of misunderstanding which has resulted from the use of artistic data alone.

"The bread and cakes were put into the oven when the flames were reduced to embers and the walls of the oven were slightly hot.... Where does (the baker) place the loaves? (In the depiction of Nebamun, #17, Thebes) we can see that the baker reaches into the inside wall of the oven. I think he uses the warm walls of the oven as baking trays. There must have been nails or something similar to attach the bread. I had this idea when I looked at the painting with the two kinds of bread, having just been taken out of the oven and lying next to it.... The thin baked loaves of bread or cake are round and show dark marks on the edge or in the middle which must stem from nails. Each bread would have been placed between four nails and hung on one nail. The rising hot air usually prevents them from sinking. If the dough was too liquid it did sink and the result was bread in the form of a drop. The dark marks are not visible in thick bread because the nail did not pierce it.... After the oven was filled with bread it was covered to first increase the heat and then to let it decrease very slowly until the bread is ready. How else could one bake bread in an oven that is hollow and the flames reach sometimes through the top of the oven?" [Translation by Denise Gilgen]

Vandier (1964: 310) was also perplexed about the use of cylindrical ovens for baking. He subscribed to Klebs' interpretation of the baking regime, but did not seem fully convinced by her invocation of nails on the oven walls to hold the bread in place. He admitted, however, that he had no better solution to offer (1964: 311). Certainly by Vandier's time, ethnographic information in publications dealing specifically with ancient Egyptian baking, was available which clearly shows how round
flattened pieces of dough adhere and bake directly on the heated internal walls of cylindrical ovens (Währen, 1960, 1961).

2. Problems with translations

One of the New Kingdom bread making depictions most frequently mentioned is the extensive passage scene in the tomb of Rekhmire (#100, Thebes, c. 1479-1401 BC). It has been described by Virey (1889: 46-48, Pl. 1, 9, 11, 12), Newberry (1900: 35, Pl 12-14), Wreszinski (1923: Pl. 324-326), and Davies (1943: 43-45, Pl. 48-51). Although the inscriptions indicate that bread making is involved, the main commodity which is being processed remained unidentified until recently.

Virey (1889: 46) called it wheat. For this particular scene, Newberry (1900: 35) only referred to it as uah-grain. In the lists of offerings from various districts, however, uah is translated as durrah—presumably sorghum or millet (1900: Pl. 6: 30-32). Wreszinski (1923: Pl. 325) also regarded it as a cereal. Davies (1943: 43) believed that the dark red colour indicates it is a pea or bean, and used the term w'h bean, or beans. The translation for w'h in the Wörterbuch (Erman and Grapow, 1926: 289) is "a cereal" ("eine Körnerfrucht"). Vandier (1964: 312) states that ouah is not a cereal, but nevertheless processing is exactly the same, and so this scene can be included in a general discussion of New Kingdom bakery. The term w'h has also been translated as carob bean (Faulkner, 1986: 58).

The identity of this mysterious item has been firmly established by the find of jars marked with the label w'h, and filled with tiger nuts.
the rhizomes of *Cyperus esculentus* L. (Edel, 1970: 22; Wilson, 1988a: 215). It would seem somewhat rash to assume that an unknown ingredient was treated exactly like cereals. Since *w*h turns out to be nothing like cereals, and is, as Wilson (1988b: 216) points out, totally unsuitable for bread making in the same way as cereals, this scene is not actually a good source of information for standard cereal bakery. Undoubtedly, it does contain many interesting parallels.

3. Lack of familiarity with the commodities involved

The processing requirements of hulled cereals, which include emmer and barley, seem to have been misunderstood, and this has led to misinterpretation of the artistic record. Chapter 5 investigates ancient Egyptian cereal processing using evidence from archaeology, ethnography, and experimentation. The central point, as Germer (1986: 1209) specifies for emmer, is that upon threshing, persistent chaff is still retained by hulled cereals (see Ch. 3.II) and further steps are required both to remove it, and to separate out the clean grain.

It is sometimes difficult to determine whether there is a general confusion between chaff and bran. In descriptions of cereal processing, cereal husk is sometimes mentioned, but not defined or described. One example is Davies' (1913: 35) examination of a scene from the tomb of Dagi (#103, Thebes, late 11th Dynasty, c. 2040-1991 BC), in which two men are pounding. He compares them to men "one sees... in the bazaars of Cairo today, pounding the husk of the grain with heavy pestles in a mortar". Given that emmer had long since ceased to be grown in Egypt (Täckholm *et al.*, 1941: 241), what was
it that Davies had observed in Cairo eighty years ago? Had he seen hulled barley being stripped of chaff, or wheat being stripped of bran, or the processing of some other commodity altogether? Whatever meaning is intended by husk (e.g. Davies, 1913: 35), l'enveloppe (e.g. Vandier, 1964: 273) or Hülse (Klebs, 1934: 176), the matter tends to vanish in general descriptions.

There are other misconceptions about the characteristics of cereals. For instance, Germer (1986: 1209) states that emmer contains more gluten protein than barley, making it especially suited to bread making. As discussed in Ch. 3.VIII.C.2, this is not correct.

4. Assumptions about continuity over time
Change in baking practices over time are dealt with variably in the literature. Work which makes use of primary sources - that is, direct observation of tomb scenes - tends to take change over time into account (for example, Klebs, 1915; 1922; 1934; Vandier, 1964; Wild, 1975). (Geographical similarity is implicitly assumed, with ancient Egyptian culture seen as a coherent entity. This may, of course, not always hold true.) General discussions rarely refer to changes.

Reference to Classical authors implies that no change occurred between the Pharaonic period and Graeco-Roman times. The only Greek author who wrote about Egypt prior to the take over by the Greeks was Herodotus. Even he arrived after the end of indigenous rule, when Persia had control of the country. Later writings may well be misleading or inaccurate if taken as a guide to ancient Egyptian cereal food preparation.
At least two major changes, directly affecting this process, had occurred since the end of the Pharaonic era. Firstly, the installation of a Greek administration led to the introduction of free threshing wheat, bringing Egypt into line with crops used throughout the Mediterranean and Near East for several millennia (Täckholm et al., 1941: 240; Zohary and Hopf, 1988: 42-45). Within 150 years, the change to free threshing wheat was virtually total (Crawford, 1979: 140).

Secondly, tools and technology also differed. The rotary quern was introduced into Egypt in Hellenistic times (Forbes, 1954: 274; 1965: 60). Without more archaeological evidence, it is not possible to say how quickly or extensively the transition was made from traditional to introduced milling technology. The extent to which other traditional ancient Egyptian baking practices continued or died away is currently completely unknown - especially as it has not been well established what they were in the first place.

Finally, casual reference is often made to modern ethnographic practices, without establishing the validity of the ethnographic parallel. For example, Garstang (1907: 63-64) describes a model from the tomb of Antef at Beni Hassan (#1, 11th Dynasty, c. 2134-1640 BC, current location unknown). He compares two women figures "apparently engaged in pounding the grain" to contemporary Nubian methods of bread making "which was probably also a custom in primitive Egypt". The Nubian practice is interesting, but varies in key points: the cereal used is durrah - presumably millet or sorghum;
the tool use differs - the cereal is pounded on a stone slab with a smooth stone. The application of ethnography can be essential to interpret the archaeological record, but the aptness of the analogy must be demonstrated.

V. Previous studies of ancient loaves

Relatively large numbers of bread loaves placed in tombs have been preserved by desiccation. Surprisingly, hardly anyone has looked at them in detail.

Perhaps the first person to do so was Prof. Dr. L. Wittmack. He was given a broken cone-shaped loaf to investigate and used microscopy to examine. He observed that it contained epidermis cells of cereal husk. His next test I quote in his own charming words:

"When I... added iodine, I found to my greatest surprise that the crumbs turned blue just as is the case for modern starch. When I noted this I exclaimed: Well, indeed, then does starch deserve its name, meaning strength, and most wonderfully has it retained that property for more than 4000 years." (Wittmack, 1905: 6).

At the request of Ludwig Borchardt, Grüss (1932) undertook microscopy studies of five loaves or remains of loaves held at the Berlin Museum. These analyses followed the methodology of his pioneering but little known work on beer residues (Grüss, 1928, 1929a, 1929b, 1929c, 1930). Borchardt (1932: 73) expressed the hope that the results of this work would stimulate other curators, with ancient Egyptian loaves in their care, to mount similar investigations. He pointed out that since all five Berlin loaves are made of emmer, the word which had until then been translated as "wheat" in the modern sense (i.e. bread wheat) may have been misinterpreted, and
called for further verification. Sadly, this suggestion was not taken up. Grüss' analyses (1932) are discussed in more detail in Ch. 6.V.D.

Borchardt (1932: 73) has provided the only detailed description of an ancient loaf, accompanied by illustrations. He was interested in establishing why the bread, which is round with a broad central cavity, was shaped as it is. He looked at archaeological evidence, in the form of "ovens" excavated at Amarna, and compared them to the ovens used in contemporary Egyptian villages, describing modern baking methods in some detail (1932: 75-76). This admirable approach was flawed, however, because a key archaeological structure, complete with evidence for an internal floor (1932: Pl. 4) which he thought was an oven, is in fact now known to be a pottery kiln (Nicholson, 1989b: 72; 1992: 67). Borchardt submitted to the Egyptological urge to compare the Berlin loaf to bread shapes in the artistic record, but only after his description of the real bread, and his detailed ethnographic account.

Wahren (1960: 94; 1961: 3, 8, 13, 15) also made use of ancient Egyptian desiccated loaves, and provided some measurements of them. They mainly serve an illustrative role in his typology of bread shapes, based largely on the artistic depictions. He has provided some ethnographic observations, demonstrating how round flat breads are today baked on the interior sides of cylindrical ovens (tannours), and the curved shape this method of baking imparts to the loaves (Wahren, 1960: 91; 1961: 3). Darby et al. (1977: 517-522) include a brief discussion of real ancient bread shapes, and provide a number of useful photographs.
Leek, a dentist, was interested in bread, as he hoped it might indicate the reasons for the markedly worn teeth of the ancient Egyptians. Accordingly, he submitted thirteen samples for various analyses (Leek, 1972b). He concentrated on the inorganic contents which were detected, and concluded that such abrasive particles in bread were responsible for all the attrition seen on ancient Egyptian teeth (1972b: 132). I will return to this subject in Ch. 6.III.C. Leek (1973) subsequently decided to do further work on the bread samples he acquired. He organized investigations to check for the presence of lichens (no evidence for them was found - 1973: 202) and insect remains (cereal infesting species were located in four out of seven samples - 1973: 203). Reaction to iodine (see Ch. 3.VII.5) and protein content were also carried out (1973: 203); results of the former are discussed further in Ch. 6.V.D.

The few studies made on actual ancient loaves have yielded new and valuable results, limited only by their restricted extent. The intense scholarly attention on artistic depictions in particular seems now to have reached an impasse in its ability to add any real understanding to ancient Egyptian cereal processing. The potential for archaeological inquiry has been left almost untapped. The investigations presented in succeeding chapters set aside the artistic record and follow in this path.
CHAPTER 3: THE EMMER SPIKELET; STARCH AND ITS FUNCTIONS IN BREAD

I. Introduction

Starch is the energy storage molecule of most plants. In cereals it is concentrated in the grain, and this is used by humans as a prime source of nutrition. The raw cereal is transformed and broken down during processing. In anticipation of results presented in later chapters, barley, although one of the two main cereal crops of ancient Egypt, is not dealt with here; the focus is on emmer wheat.

The aim of this chapter is twofold. Firstly, it presents the structure of the emmer spikelet, and the effects this has on processing requirements. Then, it goes on to link starch structure and morphology with specific physico-chemical states. Without some understanding of starch, data from ancient residues are likely to be misinterpreted. Starch structure, transformation, and breakdown are highly complex, and become even more so when starch is one constituent (although the major component) of a heterogeneous food mixture. Furthermore, many aspects still remain unresolved. The methods of analysis which have been developed to cope with starch are numerous (Shetty et al., 1974: 364; Lyne, 1976: 133; Atwell et al., 1988). This chapter focuses on evidence from microscopy, as it provides data directly comparable to the work I have done on ancient starch. Other studies are discussed as appropriate when they explain the biochemical basis for observed transformations in ancient material.
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In order to address some questions about the effects of starch processing on emmer, it has been necessary to look at analogous systems. Of the cereals, the structure and germination of bread wheat (*Triticum aestivum* L.) has been most intensively studied (Eskin, 1990: 167), because of its great importance as a commercial crop for bread making. Wheat is not parboiled or cooked whole on a commercial basis in the Western world. In order to obtain information about the effect of this process on starch in the whole grain, I have referred to parboiling of rice. It has not been possible for me to investigate emmer and emmer starch along the lines of the biochemical and physico-chemical studies which have been carried out on bread wheat, rice, and other cereals of commerce. This would be a full research project in itself.

II. Emmer spikelet structure and its effect on cereal processing

The cereal ear, like all grass structures, is complex (Bor and Guest, 1968: 1). The reader is referred to Fig. 3.1, which illustrates all the components of the ear, or spike, discussed in this section.

All cereal ears are made up of individual spikelets, which alternate on either side of a central axis. This axis is called a rachis, itself made up of rachis segments. The individual rachis segment also forms the base of a spikelet (Bor and Guest, 1968: 7, 9; Charles, 1984: 17, 19). Attached to the rachis segment are the layers of chaff which surround and protect the grain.

The number of grains within the spikelet vary according to the species. Emmer wheat (*Triticum dicoccum*) normally has two grains per
spikelet (Renfrew, 1973: 51), while bread wheat (T. aestivum) and hard or macaroni wheat (T. durum Desf.) may have two to six grains in each spikelet (1973: 53, 60).

Each grain within the spikelet is surrounded by a chaff envelope made up of two elements: the lemma, which lies adjacent to the back (dorsal side) of the grain; and the palea, which curves around the front (ventral side). The lemmas and paleas are thin and flexible, and are collectively referred to as the light chaff. In the wheats, two large thickened glumes encase all the grains with their individual light chaff envelopes. The glumes, together with the rachis segments, are known as the heavy chaff.

Wheat can be divided into two groups on the basis of morphology. They are known as the glume wheats, which include emmer, and the free threshing, or naked, wheats, which include bread and hard wheats. The different morphologies directly affect the methods required to process them. They can be characterized as follows:

1. Glume wheats have semi-tough rachises;
   Naked wheats have tough rachises.
2. Glume wheats have tough glumes (the light chaff is much less so);
   Naked wheats have brittle glumes and light chaff.

When naked wheats are harvested and threshed, the central axis remains more or less intact, because the individual rachis segments remain attached to one another. The bases of the glumes, lemmas and paleas detach from the rachis segment, and the grain within is
released. This produces a mixture of partially broken rachises, and free glumes, lemmas and paleas (see Fig. 3.1) as well as chopped straw. In traditional, non-mechanized systems, the freed grain is separated from the loose chaff elements and chopped straw by a series of winnowing and sieving steps (Hillman, 1985: 2-3).

In contrast, threshing a glume wheat such as emmer produces a mass of individual spikelets mixed with chopped straw. This is the case even if emmer is reaped with a combine harvester. Because the glumes are tough and remain firmly attached to each separate rachis segment, the grain is trapped within the spikelets. After removing the chopped straw by winnowing and sieving, extra processing steps must be used to break apart the spikelets and release the grain. The sequence of emmer processing is discussed in detail in Ch. 5.II.A, and 5.IV.

To summarize, glume wheats such as emmer require extra steps along with appropriate tools to obtain cleaned grain, which are not needed for free threshing wheats.

III. The cereal grain
Fig. 3.2 shows the various parts of the cereal grain, and the relationship of the tissues to one another.

The grain endosperm is enclosed in the bran and consists of two parts. Directly beneath the bran lies the aleurone layer. Aleurone cells tend to be cuboid with thick walls (Winton and Winton, 1932: 197), and contain a variety of compounds but no starch (Palmer, 1989: 122). They have a distinctive granular interior texture as seen
under the SEM (Fig. 3.3). Although structurally part of the endosperm, when milled the aleurone adheres to the pericarp and testa layers and becomes part of the bran fraction (Barnes, 1989: 373).

The starch endosperm cells make up the bulk of the cereal grain by weight and volume. They vary in size, but follow a distinct pattern. Those in the outer endosperm, particularly in the dorsal region of the grain, are long and slender ("needle-shaped") in cross section, while towards the centre they become more or less polygonal (Horder et al., 1954: 31). In wheat these cells are comparatively small near the aleurone, becoming two to three times as large in the central endosperm (Percival, 1921: 11). The relative proportions of cell shapes vary amongst species and variety, and seem to be related to hardness of the endosperm (see below). Cell wall patterns can be studied in a number of ways, including light microscopy, scanning electron microscopy (SEM), and fluorescence microscopy (Winton and Winton, 1932: 191; Aranyi and Hawrylewicz, 1969: 230; Fulcher and Wong, 1980: 15-17).

The starch granules are embedded in a protein matrix, and packed within starchy endosperm cells. The amount, distribution, and composition of protein surrounding the granules differ according to variety. Although the protein fraction makes up a small proportion of the total starchy endosperm (Palmer, 1989: 71), it affects a number of bread making stages, including milling, dough formation, and the type of final baked product (see Section VIII). Details of starch granule morphology are presented in Section IV.
A distinction between the texture of cereal grains has long been recognized, as "hard" or "soft" varieties. They have variously been referred to as hard, flinty, or horny, and soft, mealy, or floury. In the case of emmer, Percival (1921: 191) records that some emmer varieties are flinty, while others are mealy. The characteristic is particularly relevant to milling and the resulting type of baked product (Barnes, 1989: 374). Various investigators have explored the physico-chemical basis of the phenomenon.

Greer and Hinton (1950: 747) confirm earlier work by other investigators, which shows that the starch endosperm of hard wheat fractures along the lines of the cell walls, producing flour particles which consist mainly of whole single starchy endosperm cells, or groups of 2 or more of these cells. Soft wheat starchy endosperm, in contrast, fractures across and through cells, tearing them open and releasing the starch granules and protein to form flour with a structureless mass.

Grain hardness is genetically determined, and is now thought to be due to the adhesion of starch granules and protein matrix within starchy endosperm cells (Barnes, 1989: 374). The texture of the grain derives from a specific protein associated with the starch granule surface. If this protein is present the grain is soft, if absent, the grain is hard (1989: 387).

The effect of hard and soft endosperm texture on various aspects of cereal processing will be noted under the relevant sections below.
IV. Morphology of the starch granule

Wheat starch granules fall into two main size categories. The larger ones, called A-type, are lenticular, and range from about 15-40 μm in diameter. The smaller, spherical granules, known as B-type, are about 1-10 μm in diameter. The large granules are relatively few in number - about 3-4% of the total - but make the greatest contribution by weight - between 50-70% (Lineback and Rasper, 1988: 297).

A well known characteristic of starch granules is their birefringence in water, which produces a Maltese cross under polarized light, more or less in the centre of the granule. This phenomenon is an important and widely used diagnostic criterion to identify starch granules. The absence of the cross is a useful marker which indicates whether starch has been gelatinized through exposure to heat and moisture (section VI.D).

V. Some biochemical aspects of starch
A. Introduction

Starch is actually a highly complex group of molecules, and varies between and within plant species. Banks and Greenwood (1975: 2) suggest that each granule in one population of starch (e.g. from a single grain) is probably unique with regard to its fine structure and properties. In addition, the behaviour of a given starch granule at any one time is affected by all of its previous history (Blanshard, 1979: 147). This effectively prevents the formulation of many general statements about starch (Greenwood, 1979: 129).
Nevertheless, a great deal of work has been done on the fine structure of starch and the way in which the polymers of granules are arranged. Biochemically, starch is a complex carbohydrate, made up of polymer chains formed by repeating units of the simple sugar glucose. Work done in the 1940s (Banks and Greenwood, 1975: 1) established that starch is a heterogeneous material, made up of two main polymer types called amylose and amylopectin. Although the relative proportions of amylose and amylopectin vary in cereal starch, depending on species and variety, it is generally agreed that cereal starches typically contain 25-28% amylose (Greenwood and Munro, 1979: 60; Lineback and Rasper, 1988: 290).

The structure of glucose, the building block of starch, is shown in Fig. 3.4. The carbon atoms which make up the glucose ring are conventionally numbered 1 to 6. This system is indicated in Fig. 3.4, and is needed to describe the difference between the two polymers of starch.

B. The structure of amylose

Amylose is a linear molecule made up of α-D-glucose units linked together via the first and fourth carbon of each glucose ring (known as α,1-4 linkage). There are about 2,000 glucose units in each amylose chain (Barnes, 1989: 376). Fig. 3.5 shows the structure of amylose.

Enzymatic work has established that a very small number of amylose molecules have a branch chain of α,1-4 glucose units, linked to the main chain by an α,1-6 linkage (Banks and Greenwood, 1975: 15).
The actual proportion of branch points is uncertain, but minute (Manners, 1979: 76), and most discussions treat amylose as an essentially linear molecule.

When iodide ion is added to pure amylose in aqueous solution, the molecule stains deep purple to purple-black (Manners, 1979: 75).

C. The structure of amylopectin

Like amylose, amylopectin is made up of glucose unit chains, but in contrast, it is a highly branched molecule containing many tens of thousands of glucose units. The precise size of the molecule depends on the plant source (Banks and Greenwood, 1975: 44). Chemical analysis shows that amylopectin chains are made up of $\alpha,1\rightarrow4$ linked glucose units, ranging from 10 to 100 units per chain, with an average of 20-25 units (Manners, 1979: 77). About 5% of the glucose unit linkages are $\alpha,1\rightarrow6$, forming the branch points in the molecule (Barnes, 1989: 376). Fig. 3.6 shows a portion of amylopectin. In aqueous solution, pure amylopectin stains violet-purple in the presence of iodide ion (Manners, 1979: 75).

VI. Physico-chemical behaviour of starch

A. Introduction

There are two ways of examining the physical and chemical behaviour of starch under various conditions: as an extract of granules, and within a processed system of some kind, for example in dough and baked bread. Both approaches present problems and advantages. In a processed system, a complex set of factors will affect the starch. It is difficult to determine the effects of the different parameters, and it
can be hard to observe the starch granules themselves (Lineback and Wongsrikasem, 1980: 71). However, looking at starch within a system does reflect its behaviour in an actual processing situation. It is easier to study extracts of starch in dilute aqueous suspension, where the only variable is temperature (1980: 71), and where its effect is relatively easy to measure. On the other hand, the starch is examined in isolation and does not necessarily behave as it would within a food. To assess the behaviour of starch as it is exposed to different moisture and heat regimes, and for the studies of enzymatic degradation of starch, discussed in Section VI, both methods have been used to determine how starch is affected.

B. Exposure to cold water

Whole, undamaged starch is insoluble in cold water (Greenwood, 1979: 132). Water is absorbed, and the granule swells up by about 20% without loss of birefringence (Lineback and Rasper, 1988: 304). Upon drying, the granule returns to its original appearance. If starch granules have been damaged (see Section VII.B), in cold water they will swell to a much greater extent (Lyne, 1976: 163).

C. Exposure to dry heat

Using SEM, Hansen and Jones (1977: 1238) have studied the morphological changes which occur when flour starch is exposed to different conditions. When flour of 13% moisture (normal for ordinary dry flour) was heated to 108°C, 150°C, and 174°C, the protein fraction aggregated into clumps. The starch morphology was largely unaffected. At 150°C the starch granules began to appear somewhat irregular in shape, and at 174°C the granule surfaces looked rough.
and uneven. At this temperature they had lost their birefringence (1977: 1237). There are discrepancies in the literature about minimum water levels needed to effect a change in starch. Wootton and Chaudhry (1980: 1784) record that a minimum ratio of water to wheat starch of 0.45 (45%) is required for any appreciable change to occur, while Ghiasi et al. (1982: 258) report that no change occurs at a moisture content of less than 30%. Eventually, dry starch is pyrolysed - chemically decomposed - at very high temperatures (Blanshard, 1979: 140).

D. Exposure to heat in the presence of water

1. Morphological changes in excess water

This paragraph is based mainly on French (1973: 1055). When starch is suspended in water and gradually heated to about 55°C, the individual granules swell and absorb 50% or more of their weight in water. At these relatively low temperatures, swelling is reversible, and after cooling and drying, the starch granules appear essentially unaltered in morphology or structure. However, if the starch suspension is heated to temperatures between 60 to 80°C, most starches undergo irreversible swelling and they lose their molecular order (as seen by the loss of birefringence). The granules will continue to swell until, in dispersions containing 5% or more starch, dilated balloon-like swollen granules occupy the entire volume of the dispersion.

The marked swelling of the starch granules leads to a marked increase in viscosity. If the heating is prolonged, and particularly if it is affected by any mechanical agitation such as stirring, the granule
structure is broken down completely, and there is a corresponding drop in viscosity (Greenwood, 1979: 132). These irreversible changes in a given starch granule population do not take place all at once at a particular temperature, but occur over a range, generally of 5-10°C (Banks and Greenwood, 1975: 260), because each individual starch granule has its own susceptibility to temperature change (Rockland et al., 1977: 1205).

This process of swelling, loss of birefringence, distortion, and eventual disruption is known as gelatinization and pasting. The numerous methods developed for studying starch behaviour have led to definitions of gelatinization and pasting on a study-by-study basis. In 1988 a sub-committee of the American Association of Cereal Chemists proposed standard definitions, based on a survey of their membership (Atwell et al., 1988).

Their proposed definition of starch gelatinization is:

"the collapse (disruption) of molecular orders within the starch granule manifested in irreversible changes in properties such as granular swelling, native crystallite melting, loss of birefringence, and starch solubilization. The point of initial gelatinization and the range over which it occurs is governed by starch concentration, method of observation, granule type and heterogeneities within the granule population under study."

The primary change occurring in gelatinization is the disruption of molecular order.

The proposed definition of pasting is:

"the phenomenon following gelatinization in the dissolution of starch. It involves granular
swelling, exudation of molecular components from the granule, and eventually, total disruption of the granules."

Granular swelling and loss of molecular components are continued from the gelatinization stage.

In any one population of granules, the larger granules seem to gelatinize more quickly than small granules, at the lower end of the gelatinization temperature range (Banks and Greenwood 1975: 260; Rockland et al., 1977: 1205; Kulp, 1973: 669).

The loss of birefringence is a widely used, simple, and rapid diagnostic tool for assessing starch gelatinization, but it is restricted to the initial stages of gelatinization (Lineback and Wongsrikasem, 1980: 73). Many wheat starch granules in aqueous solution completely lose birefringence before 65°C, but maximum swelling of the granules occurs at higher temperatures. Goering et al. (1974: 764) note that swelling is accompanied by an increase in viscosity of a starch-water slurry, but a rapid increase in viscosity is not obtained until temperatures rise 12 to 23°C beyond the stage when 98% of granules have lost birefringence. They also investigated this discrepancy by comparing the temperatures at which granules from many different starch sources lost birefringence, and the temperatures at which a starch-water slurry was completely susceptible to breakdown by the enzyme glucoamylase (an enzyme incapable of breaking down whole raw starch granules). Table 3.1 presents their comparative data for wheat starch which demonstrates the temperature differential.

Using the scanning electron microscope, Hoseney et al. (1977: 56) examined changes in starch morphology which occur when granules are
heated in excess water. They gradually heated a simple 10% wheat starch-water solution and removed samples at successive temperature intervals. They found that at 25°C and 50°C essentially all granules were fully intact except for those which had been mechanically damaged. Many of the larger granules had surface indentations marking the location of smaller granules pressed against them in the tightly packed endosperm. At 60°C, just below the expected start of gelatinization, some smaller granules were dimpled or doughnut shaped while a few larger granules had collapsed or folded. This may have been an artefact of the drying procedure on the swollen granules. At 70°C, most granules were deformed, and few large granules showed the surface indentations caused by adpressed small granules. When temperatures reached 80 to 90°C, virtually all granules had collapsed. A 22% flour-in-water suspension treated in the same way showed much the same pattern of starch swelling and folding, but more foreign matter was seen to adhere to the granules. This was presumed to be endosperm protein.

Work done by Rockland et al. (1977: 1205) on Lima bean starch in water showed that morphological changes during gelatinization were similar to those noted by Hoseney et al. (1977) for wheat starch. Rockland et al. (1977: 1205) have characterized the published micrographs of granule morphological changes as: 1) swollen, 2) dimpled or indented, 3) (American) doughnut-shaped, 4) rubber-raft shaped, 5) pancake, 6) dispersed or diaphanous (see Fig. 3.7). Using optical microscopy, they (1977: 1206) observed that ungelatinized or partially gelatinized granules classified within the first 3 stages of enlargement (S-1 to S-3) had birefringent outer circumferences, but
the central area was not. Air-dried preparations of partially
gelatinized starch which progressed beyond stage 4 (rubber-raft
shaped) showed some return of birefringence. Completely gelatinized
granules showed no detectable reversible birefringence under the light
microscope and under phase-contrast appeared as diaphanous or
membrane-like structures.

For the interpretation of ancient starch residues, I have drawn
extensively on the work of Hoseney et al. (1977), and insofar as
wheat and bean starch behave in similar ways, on the work of
Rockland et al. (1977).

Experiments have shown (Bean and Yamazaki, 1978: 941; Hoseney et
al., 1977: 58; Rockland et al. 1977: 1207) that the addition of
substances such as sucrose or salt into an aqueous suspension of
starch raises the temperature at which gelatinization commences, and
that the temperature range of starch gelatinization is reduced.

2. Morphological changes in limited water systems

The changes which occur in the starch granule during processing are
dependent on both temperature and the amount of water available.
Derby et al. (1975: 707) have examined the effect of water limitation
on starch transformation. Using optical microscopy, the granule
appearance of starch suspensions was recorded at different dilutions
and a constant temperature of 100°C. A moisture content of 32% was
too low to cause any swelling or loss of birefringence. They found
that as the moisture content of the suspension increased, the
percentage loss of birefringence increased, granules progressively
folded and collapsed, until at 60% moisture, the fully gelatinized granules began to disintegrate and disperse. Hoseney et al. (1977: 58) have obtained similar results using scanning electron microscopy and a constant moisture system at varying temperatures. In contrast to excess water dispersions, wheat starch at 35% moisture (forming a dough) heated to 70°C still retained the packing indentations on large granule surfaces, and very few granules were deformed. At 90°C, most of the granules collapsed, but the extent of deformation and foreign matter was much less than starch in an excess water suspension at this temperature.

Ghiasi et al. (1982: 259) have established that the onset of gelatinization of wheat starch in limited water conditions occurred at the same temperature as excess water dispersions (57°C). Although all starch granules in excess water had lost their birefringence by 64°C, a further increase of 23°C was required for the same effect when water was limited.

3. Morphological changes of starch granules in whole cereal grains

Studies of starch gelatinization within whole starchy grains or seeds are mainly confined to rice, which is commonly cooked whole. Bakshi and Singh (1980: 1389, 1390) found that dehusked unpolished rice (brown rice) absorbed water three times as quickly, and became gelatinized in a quarter of the time, as rice still in the hull (i.e. lemma and palea not removed). Experimental evidence (Bakshi and Singh, 1980: 1392; Suzuki et al., 1976: 1182-1183) indicates that below a certain temperature (dependent on previous treatment), the cooking rate of whole grain is limited by the interactions of water with
components of the rice endosperm, including starch granules and protein. Above this temperature, the diffusion of water through the outer cooked layer to the interface of the uncooked core limits the cooking rate.

Earlier work (Bakshi and Singh, 1980: 1387) has established that the process of parboiling (soaking grain in water, steaming, and drying) causes starch gelatinization and disintegration of endosperm protein, which expands to fill any interior spaces, thus packing the gelatinized starch closely together. During this process, increased heat leads to a greater expansion of the grain, a darkened colour, and an increase in soluble starch content. Rockland et al. (1977: 1212) have found that initial gelatinization of bean starch dispersions occurred on average 5 to 6°C degrees lower than bean starch in the endosperm, while temperatures at which the last granules were gelatinized in excess water were about 10 to 16°C lower than those of intracellular starch. In other words, starch gelatinizes in the whole grain over a much wider temperature range than when it is free in suspension.

VII. Wheat germination and enzymatic starch breakdown
A. Initial events
When the wheat grain is exposed to sufficient moisture, a cascade of complex biochemical reactions mediated by enzymes is stimulated, leading to germination. The actual rate of growth varies according to temperature and moisture levels, as well as the cereal variety. Palmer (1989: 84, Table 14) summarizes enzyme development in the germinating endosperm. Based on figures for dehusked barley (which, according to Palmer (1989: 143), shows signs of sprouting after 18–20
hours), grain in the spikelet may start to sprout after about 24 hours exposure to moisture.

In the germinating cereal grain, the protein matrix and the cell walls must be broken down to allow starch degrading enzymes to contact the starch granules. The loosely packed matrix of protein and small starch granules in soft endosperm grain may facilitate enzyme distribution and action, whereas the closely packed protein and starch granules in hard endosperm grain seems to slow down enzymatic rates (Palmer, 1989: 152).

Protein breakdown begins early in the germination process (Bamforth and Quain, 1989: 332) caused by proteases - protein-attacking enzymes - released into the starchy endosperm from the aleurone (Palmer, 1989: 151). Palmer's (1987: 106) SEM work has shown that localized fragments of cell wall may remain in the starchy endosperm even after extensive enzyme action. This may be due to differences in the morphology and structure of endosperm cell walls.

B. Enzymatic degradation of starch

Plant starch acts as food reserves in insoluble form, and so the plant, having laid down the granules, also needs a mechanism to break them down when reserves are needed (French, 1973: 1056). Starch breakdown, or degradation, is accomplished by enzymes called amylases, which are either synthesized as required, or synthesized and stored for later mobilization. Their action on starch eventually produces the sugar maltose, which is composed of two linked glucose molecules.
1. Alpha-amylase

Alpha-amylase randomly breaks most of the α,1-4 linkages of amylose and amylopectin. The exceptions are those adjacent to α,1-6 linkages, or at the ends of chains (Eskin, 1990: 304; Banks and Greenwood, 1975: 212; Manners, 1974: 52). Fig. 3.8 summarizes its action on amylose and amylopectin. In summary, the action of α-amylase on amylose produces a mixture of linear chains several glucose units in length, and the simple sugars maltotriose (made of three linked glucose molecules), maltose (made of two linked glucose molecules), and glucose. On amylopectin, α-amylase attack results in the same products plus branched limit-dextrins (Manners, 1974: 53; Greenwood and Munro, 1979: 60).

Most α-amylase is synthesized after the grain is moistened, when plant hormones are released which stimulate the aleurone layer. There are trace amounts of α-amylase present in the ungerminated grains (Linko and Linko, 1986: 105).

The initial attack on starch granules within the germinating grain is carried out entirely by α-amylase (MacLeod, 1979: 219). It appears this is the only plant amylase capable of degrading the intact granule (Manners, 1974: 53). The texture of the starch granules is too fine for the enzyme to penetrate by diffusion into the interior, so α-amylase acts firstly at the surface (French, 1973: 1054). This may occur at a fissure or structural imperfection, eventually spreading laterally to produce pits on large granules. The centre of the granule is much less resistant to enzyme hydrolysis than any other region.
(Banks and Greenwood, 1975: 258). Wheat $\alpha$-amylase appears to attack granules preferentially at the equatorial plane, perhaps because it is a point of weakness. However, other wheat granules are attacked randomly over the surface (1975: 258), producing a typical pitted appearance under the optical or scanning electron microscope.

2. Beta-amylase

Beta-amylase successively removes maltose molecules from the non-reducing chain ends of amylose and amylopectin (Banks and Greenwood, 1975: 191; Eskin, 1990: 305; Manners, 1979: 76; Bamforth and Quain, 1989: 343; Greenwood and Munro, 1979: 60; Briggs et al. 1981: 70). This enzyme can entirely breakdown amylose into maltose, but it is incapable of by-passing the $\alpha$-1-6 branch linkages of amylopectin. As a result, when incubated with amylopectin in vitro, it produces maltose and a large limit dextrin of about half the weight of the amylopectin molecule. Fig. 3.8 shows a schematic representation of $\beta$-amylase on amylose and amylopectin.

Beta-amylase has no effect on whole starch granules (MacLeod, 1979: 219; Banks and Greenwood, 1975: 255). Within the sprouting grain, it breaks down intermediate dextrins which are first released from the granule by the action of $\alpha$-amylase (see Figure 3.12b). It is produced and laid down in the cereal grain during development (Eskin, 1990: 306).

3. Limit dextrinase

The third main enzyme which is active during the initial steps of starch breakdown in sprouting wheat or barley is limit dextrinase.
This acts on the α,1-6 branch links of amylopectin and branched dextrins - see Fig. 3.8 (Manners, 1974: 55; Banks and Greenwood, 1975: 233). Like α-amylase, there is very little limit dextrinase in ungerminated grain and it is mostly produced when the grain begins to sprout.

4. Other enzymes

The three amylases discussed above are the prime facilitators of starch breakdown in the germinating cereal grain (Palmer, 1989: 155), with α- and β-amylase predominant (1989: 162). The plant amylases are by no means the only enzymes able to degrade starch. Organisms both large and small have developed starch degrading enzymes in order to make use of this food reserve for their own nutritional needs. Human starch digestion is discussed briefly in Section IX below. Numerous micro-organisms also produce starch degrading enzymes which can act directly on intact granules (e.g. Odunfa, 1985: 161-162). Therefore, the typical pitting and corrosion of starch granules in food residues cannot automatically be attributed solely to germination enzymes.

5. Monitoring the extent of starch degradation

A qualitative assessment of the extent to which enzymes have broken down starch into dextrins can be made using the starch–iodide reaction (Radley, 1943: 129). Iodide can be applied to whole starch in an aqueous solution of iodine potassium iodide (IKI). This stains starch granules deep purple–black. As starch is degraded, iodide will stain the breakdown products different colours, according to the length of the glucose chains. Thus, the long dextrin chains produced
by the initial action of α-amylase turn purple when exposed to IKI. The shorter chains generated as enzyme action proceeds, stain successively blue-violet, violet, red, reddish brown, and finally, the shortest dextrins which will pick up stain, about 8 or 12 glucose units long, turn pale red. Dextrins below 6 glucose units, and the simple sugars maltotriose, maltose, and glucose, do not stain at all (Radley, 1943: 128).

This highly useful diagnostic tool works perfectly on ancient starch residues, and I have applied it to the analysis of ancient bread (Ch. 6.V).

C. Morphological changes in the endosperm during germination

Aleurone cell walls become pitted when germination commences (Pomeranz, 1972: 6, 18). Within the starchy endosperm there is no rigid sequence of tissue breakdown, but a general pattern has been observed. As germination extends over several days, cell walls are more thoroughly broken down than storage proteins, while starch hydrolysis takes place more gradually (Fretzdorff et al., 1982: 786; Palmer, 1989: 155). Endosperm modification begins in the embryo region and progresses up the grain towards the distal tip, gradually advancing more quickly adjacent to the aleurone layer (Briggs et al., 1981: 59). After some days growth, this differential pattern of tissue breakdown causes the area of the starchy endosperm near the embryo to be most extensively modified. Endosperm modification decreases towards the distal tip and towards the centre of the endosperm (Fretzdorff et al., 1982: 786; Palmer, 1972: 329; Palmer, 1989: 165; Dronzek et al., 1972: 235).
This acts on the α,1-6 branch links of amylopectin and branched dextrins - see Fig. 3.8 (Manners, 1974: 55; Banks and Greenwood, 1975: 233). Like α-amylase, there is very little limit dextrinase in ungerminated grain and it is mostly produced when the grain begins to sprout.

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by the initial action of \( \alpha \)-amylase turn purple when exposed to IKI. The shorter chains generated as enzyme action proceeds, stain successively blue-violet, violet, red, reddish brown, and finally, the shortest dextrins which will pick up stain, about 8 or 12 glucose units long, turn pale red. Dextrins below 6 glucose units, and the simple sugars maltotriose, maltose, and glucose, do not stain at all (Radley, 1943: 128).

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Palmer (1972: 329, 330) has observed that after five days of germination, there is no difference in the rate of enzymatic attack between large and small wheat starch granules. This may be because of thick protein deposits surrounding the small wheat granules, which may hamper enzyme access. Dronzek et al. (1972: 234) have recorded that after eight days of wheat embryo growth, both large and small starch granules are severely degraded and that large granules appear to be more heavily attacked than small granules.

Large and small starch granules attacked by amylases look different (Galliard and Bowler, 1987: 63). Large wheat starch granules are usually initially broached along the equatorial plane, followed by penetration of enzymes to the interior: an inside-to-outside pattern of digestion (1987: 63; Palmer, 1989: 154). A large starch granule may be extensively degraded inside, leaving little but a hollow shell, but the surface may look nearly intact except for a few small pits. Small granules show a pattern of surface erosion which results in small circular spots randomly distributed over their surfaces and their eventual degradation into the core. The photomicrograph published by Dronzek et al. (1972: 236, Figure 3) shows both eroded large and small granules but little adhering protein.

As with storage proteins, there is some evidence for a more rapid breakdown of soft endosperm starch granules compared to hard endosperm granules (Kikuchi et al., 1982: 1689). This is probably due to the difference in enzyme accessibility to its substrate.
VIII. Starch and bread

A. Introduction

Most discussions on bread biochemistry focus on products made from bread wheat (*T. aestivum*). While much of this information is applicable to the study of ancient bread baking, especially that concerning starch transformations, some of it is not. Bread wheat is alone among cereals in containing marked quantities of specific proteins, which can impart unique visco-elastic properties to dough; this has a direct effect on the baked bread (see below, Section C.2). The term "quality" used in the baking literature mainly refers to the attainment of the ideal development of these properties and the production of a well risen, spongy textured bread. Such loaves are totally different to those obtained from emmer bread (Singh et al., 1983: 1135). The detailed characteristics of dough and bread made from emmer are unknown; the basic research has not been done because this is not a commercially used cereal.

B. Starch and flour

The milling process both creates flour and influences the state of its starch. The result in turn has an effect on subsequent baking properties.

The individual starch granules in flour are not free, but are embedded in a protein matrix associated with other compounds, such as lipids (Greenwood, 1979: 135). The arrangement and form of starch granules in flour can be seen using scanning electron microscopy. Aranyi and Hawrylewicz (1969: 231) have shown that within each flour particle, the starch is arranged just as it is in the endosperm. Milling
does not change the chemical composition of flour, but does result in physical changes which are of prime importance to baking (Barnes, 1989: 381).

The action of milling disrupts the structure of some starch granules. This process is known as starch damage. In damaged starch granules, there is a change in the structural order of the starch (Greenwood, 1979: 136). They are not cracked, but are flattened, with a faint outline, leading to the term "ghosts" to describe them (Radley, 1943: 378). Splitting or radial cracking of granules which can sometimes be seen is not part of the phenomenon known as starch damage (Barnes, 1989: 381). Evers (1979: 158) shows a micrograph of damaged granules.

The proportion of damaged starch in milled flour depends both on milling technique and the texture of the grain being converted to flour (Collins, 1982: 12). The proportions of damaged granules in flour have been recorded as 1.6 to 4% (Kulp, 1972: 703) up to 5 to 8% (Ponte and Reed, 1982: 265). Flour from hard wheat has a greater number of damaged granules because of its greater inherent resistance to crushing, and therefore the greater force which must be applied to reduce it to flour (Barnes, 1989: 387).

The significance of starch damage is discussed below in the section on starch and dough, because the effects on bread begin when water is added to flour.
C. Starch and dough

1. Dough formation

When water is added to flour and mixed, a dough is formed and starch granules become evenly distributed within it (Aranyi and Hawrylewicz 1969: 233). In dough made from bread wheat, the protein forms a continuous smooth network called gluten, in which the starch granules are embedded (1969: 233).

Dough formation has two stages (Stear, 1990: 1). The first phase involves distribution of water and moistening of flour particles. Starch is very hydrophilic (Alsberg, 1928: 89), and the ability of starch to bind water is increased by milling (Kulp, 1972: 705). Intact starch granules in a dough may adsorb from 30 to 50% of their weight in water, while damaged granules may adsorb up to 70 to 100% (Eskin, 1990: 352; Stear, 1990: 1). The greater the starch damage, the greater the water adsorption capacity of the entire dough, and thus, the more water required to create a malleable texture (Obuchowski, 1984: 456; Eskin, 1990: 352). Since there is a higher rate of starch damage in hard wheat flours, these require more water to make up a workable dough. In addition to starch, pentosans and some proteins adsorb water. Flour doughs typically contain from 0.6 to 0.8 grams of water per gram of dry flour; about half of this is bound with the flour and the rest exists in the free state (Ablett, 1986: 32, 34). Mixing reorganizes the dough structure, but does not change this ratio of bound and free water.

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Simple sugars, mineral salts, soluble proteins, and other components dissolve in the free water, and this, together with swelling, is the
second stage of dough formation (Stear, 1990: 1). There are small quantities of simple sugars in the wheat grain, including sucrose, maltose, and glucose (Horder et al., 1954: 36; Ponte and Reed, 1982: 264). In bread wheat, 25% of the pentosans are soluble; they swell up to 800% by volume (Stear, 1990: 1), and are very viscous in solution (Eskin, 1990: 344). Conflicting experimental results make their exact role in bread structure uncertain (1990: 347).

Starch molecules from damaged granules dissolve in the water component which is a free liquid in the dough. Amylopectin rather than amylose seems to form most of the dissolved starch fraction (Galliard and Bowler, 1987: 65). Upon wetting, the damaged granules and their leached components are attacked by the cereal amylases (Linko and Linko, 1986: 107). This occurs even in ungerminated grain, because there are small amounts of stored enzyme. There are ample quantities of β-amylase present in the flour and dough for rapid degradation (Kulp, 1993: 154), but the concentration of α-amylase is low, which limits the overall rate at which degradation occurs (Ponte and Reed, 1982: 264). Long dry periods at harvest time can decrease the α-amylase level in grain still further (Collins, 1982: 12), while wheats grown in warm dry climates often have low overall enzymatic activity (Linko and Linko, 1986: 107).

Enzymatic action on raw uninjured starch is very slow, but can be very rapid on mechanically damaged granules (Alsberg, 1928: 91). Enzymatic activity on damaged granules produces simple sugars, and has important consequences for yeast fermentation. The amount of conversion of starch to sugar depends on the quantity of damaged
granules, the amount and type of amylase present, and the ease of access of enzyme to starch (Alsberg, 1928: 92).

In sum, a bread dough consists of three phases (Stear, 1990: 7). Firstly, the solids include most of the starch constituents, the insoluble proteins, and other insoluble items such as bran fragments. Secondly, some of the dough water is present as a free liquid, which dissolves the water soluble components and in which yeast cells are suspended (Brown, 1993: 40). Thirdly, trapped gases are adsorbed by these different components during mixing.

2. Dough proteins: Gluten

Gluten plays a crucial role in the structure of bread made from bread wheat, and as a result, strongly influences our ideas of what bread is and should be. It is briefly discussed, therefore, to establish its function in bread, and what bread is like in its absence.

The main storage proteins of the starchy endosperm in wheat, barley, and maize are a general class of molecules called prolamines, defined by their solubility in alcohol, their high content of the amino acids proline and glutamine, and their deficiency in the essential amino acid lysine (Eskin, 1990: 181; Miflin et al., 1983: 256). Wheat prolamin have the specific name gliadins and glutenins (Schofield, 1986: 15). Gliadins and glutenins have slightly different molecular formations in different wheat species (Horder et al., 1954: 38; Miflin et al., 1983: 312). When water is added to bread wheat flour and mixed, a smooth protein network is formed called gluten. It is not a constituent of the wheat grain or the flour; gluten forms from the glutenin and gliadin
of bread wheat alone, and only upon wetting and sufficient mixing (Barnes, 1989: 377).

It appears to be the differences in the glutenin fraction which largely account for the differences in gluten quality between bread wheat varieties (Schofield, 1986: 16), although gliadins are also implicated; the roles of the two protein fractions are not fully resolved (Eskin, 1990: 337). There are similar proteins to the *Triticum aestivum* gliadins and glutenins in wheat species, and other food cereals (Miflin *et al.*, 1983: 284, 312), but with the borderline exception of rye, when the flours from these cereals are mixed into dough, they do not behave in the same way as bread wheat gluten (Frazier and Daniels, 1986: 300). There are records in the literature (Miflin *et al.*, 1983: 257; Chamberlain, 1982: 48) that barley will also form a small amount of gluten, and that it is more cohesive and elastic than that of rye.

Bread wheat gluten has unique viscous, elastic, and cohesive properties. Its formation and development in the dough, through a series of intermolecular bonds, forms small bubbles which fill and expand with gas generated from yeast metabolism. This ultimately results in bread with a large volume and spongy texture, composed of a network of heat-transformed starch and protein, surrounding evenly sized and spaced gas bubbles. Apart from speciality breads, such as pumpernickel and pitta bread, this is the form and texture most British people consider ideal in bread.

The gliadins and glutenins of emmer do not form an elastic network when mixed into dough, and that of barley is borderline. Therefore,
the subject of gluten development is not discussed further. For a
good discussion of how gluten may operate in dough systems, see
Schofield, 1986. Because the cereals of ancient Egypt effectively lack
 gluten-forming proteins, the bread made from them will not resemble,
in puffed and rounded shape, in large size, or in spongy texture, the
bread we eat today.

D. Fermentation

One of the essential ingredients of bread as we know it today is
yeast. It serves three functions: to leaven the bread through the
production of carbon dioxide; by rising and moving the dough to help
the formation of gluten; and to create flavour (van Dam, 1986: 126;
Dough fermentation commences during mixing, continues throughout
processing, and finally ceases after the early phases of baking
(Shear, 1990: 479). In this section, the metabolism and enzymatic
action of yeast will be presented, before examining these three
functions. Sour dough systems will also be considered.

1. Yeast metabolism

The baker's yeast used in modern times is a unicellular fungus called
Saccharomyces cerevisiae (van Dam, 1986: 118). It reproduces
asexually by budding (Brown, 1982: 61; Stear, 1990: 471) although it
is also capable of sexual reproduction. When yeast is added to dough
it grows anaerobically, a process known as fermentation. This involves
the conversion of monosaccharides to glucose, which is used for yeast
metabolism, producing carbon dioxide and ethanol (Brown, 1982: 63).
The growth rate of yeast under optimal conditions is one new cell every three hours. During fermentative metabolism, this rate is much lower, but yeast is still actively growing, mainly replenishing cell material such as enzymes and replacement of wastes (1982: 75). The increase in dough size seen during proving is due to carbon dioxide evolution, not yeast reproduction.

*Saccharomyces cerevisae* cannot feed directly on starch (Stear, 1990: 467). When yeast is metabolizing anaerobically, it preferentially uses the simple sugars glucose, fructose, and sucrose (van Dam, 1986: 122; Brown, 1993: 67). In the dough system, there are two sources of fermentable sugars: those naturally present in the flour, and the maltose produced by amylase action on damaged starch (see Section B above). The low level of monosaccharides present in flour is not enough to sustain yeast activity throughout dough development, but if supplementary sucrose or fructose is added, the yeast will metabolize these in preference to amylase-produced maltose. If yeast runs out of these sugars and the only simple carbohydrate available is maltose, the yeast enzyme maltase, located inside the cell, converts it to glucose. This enzyme will not be activated until there are no alternative monosaccharides available to the yeast (Brown, 1993: 71; Stear, 1990: 480). In doughs where amylase activity is limited and no other sugar source is available, this may be the step which limits the rate of fermentation (van Dam, 1986: 127), but the carbohydrate-amylase complex will produce fermentable sugars throughout dough processing (Stear, 1990: 484). Adding extra simple sugars to dough will not encourage the yeast rate of metabolism to increase (Brown, 1982: 74).
The optimal temperature for yeast varies between 25-28°C (Prihoda et al., 1993: 31) and 24-30°C (Stear, 1990: 467). It can grow between 20 to 40°C. Beyond 40°C, however, yeast is progressively killed and all are killed at about 50°C (Brown, 1982: 71). Some components may depress yeast activity if they are present in the dough above certain concentrations. This is due to increased osmotic pressure, whereby water migrates out of the yeast cell into the dough free-water phase. Ingredients which can have this effect are salt, fat, and sugar in concentrations above 5% (Brown, 1982: 74; Ponte and Reed, 1982: 252).

Yeast produces carbon dioxide and ethanol through a sequence of steps (van Dam, 1986: 126), mediated by the enzyme complex zymase (Stear, 1990: 480). Both by-products play their part in bread making. In bread wheat doughs, carbon dioxide is trapped in gas cells by the elastic network of gluten and expands the bread, creating a spongy texture. It is this aeration which is the leavening process (van Dam, 1986: 126). The expansion and dough stretching helps to develop the gluten. The ethanol, and a whole series of metabolites and precursor products of yeast fermentation, are essential to flavour development in the final loaf (Ponte and Reed, 1982: 260). An important source of flavour is the free amino acids, which result from yeast growth, reacting with sugars in the dough produced from amylase activity, and browning the crust through what is known as Maillard reactions (Brown, 1982: 71; 1993: 40; Stear, 1990: 479).
The gas cells in dough are first formed by air incorporated into dough during mixing. These are inflated by carbon dioxide generated by yeast growth (Barnes, 1989: 407). In doughs made from non-gluten sources, the carbon dioxide evolved from yeast fermentation is not readily held in the dough, but some aeration is nonetheless achieved. The viscous network formed by water-adsorbing pentosans helps to keep some gas retained (Prihoda et al., 1993: 23).

2. Sour dough and lactic acid bacteria

Another system of bread leavening, which is less common in Britain though very important in other parts of the world, is sour dough. This is distinguished by a rich lactic acid bacteria content. The very large number of different bacteria found in bread systems fall into two categories, depending on their enzyme systems, and the type of metabolites they produce (Prihoda et al., 1993: 31). Both types produce lactic acid, which imparts the desirable flavour to sour dough breads (Stear, 1990: 484, 492). Many lactic acid bacteria can ferment maltose and fructose (Ponte and Reed, 1982: 284). The optimal temperature for growth is 35 to 40°C, at the higher end of the yeast range (Prihoda et al., 1993: 31).

Sour dough breads are made from a starter culture. This "mother dough" can be prepared in a number of ways, but typically involves gradual additions of flour and several fermenting steps (Stear, 1990: 493). This extended procedure allows the production of the intensive flavours typical of sour dough breads (1990: 494). The starter dough has to be carefully managed for optimal inoculation. If taken too soon, there will not be enough micro-organisms to flavour and develop the
dough; if too late, acidity levels may build up to levels which may inhibit and damage the microbes (1990: 496). The progress of fermentation can be monitored by the experienced baker through smell: a mild, aromatic odour indicates plenty of desirable lactic acid, while a sharp pungent smell means fermentation has progressed too far, with production of excessive acetic acid (1990: 505).

As a result of lactic acid bacteria activity, the dough system changes. The pH drops substantially. This creates an environment hostile to contaminating microflora which produce off-flavours, or toxic by-products (Prihoda et al., 1993: 31). There is some evidence that greater acidity facilitates protein swelling and starch gelatinization. The increased acidity has important consequences for breads made from non-gluten forming cereals. Because cereal amylase activity is inhibited, more starch is available for gelatinization. In these breads, gelatinized starch, rather than protein, is the main structural material (Brown, 1993: 63).

Characterization of yeasted and sour dough bread microflora shows that the two systems contain both yeasts and bacteria, and that both are probably important to the flavour of the final baked product. The difference is one of proportion: commercial yeasts have been found to contain between 10,000 to several million bacteria per gram (about 5%) of lactic acid bacteria, while sour doughs contain both yeasts and bacteria in a ratio of about 1:4-6 (Ponte and Reed, 1982: 284; Sugihara, 1985: 249). Up to 40 different yeast strains and 260 different Lactobacilli strains have been identified from various cultures (Stear, 1990: 495). Some systems have a variety of yeasts and
bacteria, while the San Francisco sour dough system, for example, has been found to contain one species of yeast and one species of bacteria (Sugihara, 1985: 251).

The latter system has been studied in some detail, to find out how it maintains a constant ratio and type of microflora. Wood and Hodge (1985: 283ff) hypothesize that there are a number of factors which maintain the integrity of the system over time, and that these probably apply to other sour dough systems, although they have yet to be studied in such detail. They conclude that the stability of established sour doughs is not really understood, but that the microflora appear highly adapted to their environments and to each other, creating a self-protecting and self-regulating system. The preferential use of maltose by lactic acid bacteria, for example, means that yeasts and bacteria do not compete for carbohydrate (Stear, 1990: 496). Resistance to infection by other micro-organisms is helped by anaerobic conditions and low pH.

A number of authors suggest that traditional leavening systems, before the advent of controlled conditions and the production of pure yeast cultures, would have been a mixture of lactic acid bacteria and yeast, creating a sour dough system (van Dam, 1986: 117; Sugihara, 1985: 249; Wood and Hodge, 1985: 280). The early method of adding yeast to dough was to add a piece of old dough to the new mixture. Sugihara (1985: 255) describes a traditional Egyptian bread making method for "shamsi" bread, in which the dough passes through four separate fermentations. Although the microflora of this type of dough has not been analysed, he states that the method undoubtedly favours
a sour dough of lactic bacteria and yeasts. Brown (1982: 58) comments that it was not until AD 1700 that yeast from beer dregs was used to leaven bread, but the technique was unreliable and tended to produce a bitter flavour.

E. Baking

There are three processes which occur during baking. These are oven proofing, crumb formation, and crust formation (Stear, 1990: 543). The times and temperatures at which these processes take place vary according to the ingredients and formulation of the dough (1990: 541), and all interact with and are affected by each other. As a result, the final baked product can vary enormously. Figure 3.9 shows some of the events which occur in a relatively simple dough system at different temperatures during baking.

Oven proofing occurs when dough is placed in a hot oven. The temperature within the dough rises and both cereal and yeast enzymes become more active. The dough expands sharply as gas cells rapidly expand with carbon dioxide and water vapour (Barnes, 1989: 404). Both $\alpha$- and $\beta$-amylase rapidly degrade the starch which begins to gelatinize around 60°C (Stear, 1990: 541; Medcalf and Gilles, 1968: 385). The extent of starch breakdown partly depends on pH and may be less extensive in sour dough breads, as these enzymes are inhibited in acidic conditions (Brown, 1993: 63). The dextrins and sugars produced by cereal amylases can increase by 15% in ordinary flour dough, and by 50% or more in sprouted grain dough during baking. The yeast enzymes also operate more quickly at the elevated temperatures of early baking, but they have only about 10 minutes of
enhanced activity before they are killed by temperatures rising above 55°C (van Dam, 1988: 127).

The crumb is formed by a number of complex factors. As the temperature rises, the liquid water in dough, and the water bound to proteins and pentosans, is transferred to the starch granules (Eskin, 1990: 358; Stear, 1990: 541). This allows gelatinization to occur. The granules swell, become flexible and stretch, passing through the stages of deformation noted by Rockland et al. (1977) for Lima bean starch. Some amylose may be leached out. However, because the amount of water in the system is limited, the individual granules do not become disrupted, but maintain some degree of structural integrity (Alsberg, 1928: 95; Lineback and Wongsrikasem, 1980: 73; Medcalf and Gilles, 1968: 385). The extent of gelatinization will also depend on the presence of other ingredients which compete for water. The addition of fat and sugar decreases the degree of starch deformation, and elevates the temperature at which gelatinization occurs within the dough (Lineback and Wongsrikasem, 1980: 71, 73; Hoseney et al., 1977: 60; Blanshard, 1986: 11). The extent of gelatinization is also affected by loaf size. For example, Wotton and Chaudhry (1980: 1784) compared thin crisp bread to bulky bread made from very similar formulations. They found that the percentage gelatinization in crisp bread was only 33% compared to 60% for bread, because of the rapid loss of water from the thin dough sheet.

In addition to gelatinized starch, the crumb is formed of coagulated proteins, leached amylose and some amylopectin, pentosans, and other ingredients such as fat, if it has been added (Blanshard, 1986: 11).
When cooled, these form a rubbery network containing gelatinized or partially gelatinized starch granules (1986: 13). The crumb composition can be seen using SEM. This shows that the gas cell walls of bread baked from gluten-rich bread wheat have a continuous protein network, while those of gluten-poor rye bread are pocked with holes over half the surface of the gas cells (Angold, 1979: 135-136).

Unlike the interior, which maintains a more or less constant moisture content throughout baking, the crust loses water rapidly. The initial high temperatures mean that gelatinization is more rapid (Zanoni et al., 1991: 1702), but as water is driven off, the process ceases, so that the crust has more ungelatinized, undeformed starch than the interior at the end of baking (Varriano-Marston et al., 1977: 463; Olsson and Skjöldebrand, 1984: 349). The combination of low moisture and elevated temperatures at the loaf surface causes a complex series of bread aroma substances to form primarily in this region. After cooling, however, these components diffuse into the adjacent crumb layers (Stear, 1990: 542).

**IX. Starch and cereals as human food**

The human alimentary tract cannot easily digest raw starch. MacDonald (1979: 332) suggests that a surrounding protein matrix makes starch granules inaccessible to amylolytic enzymes, and thus almost indigestible, with consequent uncomfortable results. Cooking transforms starch into a form which can be readily broken down by digestive amylases. Even though in many cooked starch foods, the granules retain some structural integrity and the amylose and amylopectin are not necessarily soluble, sufficient disruption occurs to
render them accessible to enzymatic attack (Galliard, 1987: 3). Other factors which can affect starch digestion are the botanical source of starch and the form in which it is ingested (Manners, 1979: 89; Flourié, 1989: 57).

Human saliva contains the amylolytic enzyme ptyalin (Horder et al., 1954: 103) which begins to digest starch in the mouth. This enzyme is inactivated by very low stomach pH, but may continue starch breakdown if it is protected within the food bolus, and if large quantities of food temporarily reduce the level of stomach acidity (Flourié, 1989: 49). The main site of starch digestion is in the small intestine, where pancreatic α-amylase breaks starch into maltose, maltotriose, and small branched dextrins. These in turn are degraded by carbohydrases in the mature columnar epithelial cells of the intestinal villi, releasing glucose which is absorbed into the bloodstream (1989: 49-50; Horder et al., 1954: 104).

Apart from a rich store of carbohydrates, and some proteins, cereals contain a very high content of the B vitamins and vitamin E. However, the B vitamins are destroyed by heat, and their original levels may be reduced by up to 20% during baking, with practically none surviving in the crust. Vitamin E is present in whole wheat bread (Horder et al., 1954: 45, 56, 128, 134).

Cereals are poor in the essential amino acid lysine (1954: 128; Hamad and Fields, 1979: 457), as well as the sulphur-containing amino acids (Au and Fields, 1989: 652). When cereals are germinated, the quantities of these amino acids increase significantly. Hamad and
Fields (1979: 457-458) have found that a five day germination of wheat resulted in nearly a fivefold increase in available lysine. In addition, they (1979: 459) have determined that lactic acid fermentation of ground wheat gruel increases available lysine by a factor of three. Germinated cereals in the diet may help to enhance nutrition if a full range of the essential amino acids is not readily available.
CHAPTER 4: ANALYTICAL METHODOLOGIES

I. Introduction

This thesis uses a multi-disciplinary approach, encompassing a number of methodologies. Whole bread loaves have been examined, and some specimens analysed with scanning electron microscopy (SEM), and optical microscopy. Reference material has been prepared to help interpret the microscopy data. Archaeological evidence connected with cereal processing and baking, with particular reference to the two New Kingdom Workmen's villages of Amarna and Deir el-Medina, has been surveyed. Appropriate ethnographic parallels have been consulted. All these sources have contributed to the development of cereal processing and baking models, which have been tested through experimentation.

II. Study of desiccated tomb loaves

All bread loaves examined as part of this research have been preserved by desiccation, and are now housed in museums. Many museums have restrictions on sampling, but some permitted the artefacts to be handled. Therefore, records of form and structure are more extensive than microscopy analysis.

The documentation for each loaf varies. One problem has been lack of provenance information, as many ancient loaves were collected casually and later donated to museums. Well preserved but unprovenanced loaves have been included in the study, since the number of loaves with detailed recorded provenance is quite small. Most examined loaves are well preserved, with the exception of a few at the Musée du
Louvre. Thirty-six loaves were handled and recorded in detail, while others were only observed through museum cases.

Recording sheets (Fig. 4.1) were used for most loaves. It was often not possible to take photographs because of study conditions, particularly low light levels, but sketches were made. Where possible, loaves were examined with a low power microscope, or, if this was not available, with a hand lens.

III. Scanning electron microscopy (SEM)
The scanning electron microscope generates high resolution images of surface topology at high magnifications (Troughton and Sampson, 1973: x; Gejl-Hansen and Flink, 1976: 483). For optimum use, samples must be thoroughly dry, surfaces should be clean, and preparation should insure that no electrical charge builds up while viewing.

All handling equipment (forceps, etc.) was rigourously cleaned between each sample, to prevent contamination. Each sample was scrutinized under a low power optical microscope, and items from it selected on the basis of colour, texture, and any observed inclusions. Some were chosen because they appeared to be representative of the whole sample. Others seemed unusual in colour, texture, or form. The weight of bread for SEM work generally varied from less than half a milligram, to approximately 2 mg, although lesser or greater amounts were also used, depending on sample size and composition. Once mounted on an SEM stub with double-sided sticky tape, the surface of each item was gently dusted by blowing air from a pipette-tipped hose attached to a rubber bulb. This removed dust and loose particles.
which might cause a build up of charge, or obscure the real surface of interest. This procedure successfully solved early problems with charge build up in the SEM chamber. A sketch of each item on the stub was made, along with relevant annotations on colour and texture, as this information is lost once the stubs are sputter coated.

After the application of silver dag paint, stubs were dried in a 30°C oven for at least 3 hours (usually longer) to drive off the solvent. They were then sputter coated. A 500 nm thick coating of gold/palladium was applied at first. When the charging problem was solved, the coating was gradually reduced to 250-300 nm. Stubs were then ready for scanning.

Samples were examined using the JEOL-35 scanning electron microscope at the Department of Anatomy, University of Cambridge. Magnifications up to about 10,000 times normally marked the upper limit which I used, because when the electron beam is focused beyond this, starch is vaporized, and the sample destroyed. In practice, it was rarely necessary to use such high magnifications. Photographs were taken on 35 mm Ilford black and white 50 ASA film.

Printed images were compared with reference material (see below), micrographs from various publications (see Chapter 3.V, VI for references), and shown to various specialists for identification.

IV. Optical microscopy

Optical microscopy provides information, particularly about the nature of starch in food residues (described below), which supplements the
results obtained by SEM. Indeed, high power optical microscopy is an essential adjunct to the interpretation of starch transformations, for neither technique used on its own can provide all pertinent data about the state of starch (Roger Angold, pers. comm.).

Permanent methods of mounting and recording are best, but slides used to study the nature of starch with optical microscopy cannot be kept. The samples are mounted in water, various stains can be applied sequentially, and the final stain, while providing vital data, obliterates much of the material on the slide. Apart from detailed note-taking, photography can preserve a record of observations, but the unavoidable movement of material on the slide makes it impossible to photograph the same materials exposed to different stains. The slides themselves must be discarded after observations are made.

Unlike SEM, temporary mounts divorce food residue particles from their context, and destroy the relationship of the different constituents to each other. Dispersal, however, serves a useful function. Items do not obscure each other, and each can be observed individually. Also, the optical microscope can focus through depth, and the three-dimensional structure of translucent tissues can be observed (Spencer, 1982: ix).

The minimum amount of sample needed is about 1 mg. Less than this, although theoretically usable, becomes very difficult to manipulate on the slide, and tends to be lost from the mount. Although very small samples can be examined, the fact that there is a lower limit on the amount which will provide useful information, combined with the
temporary and ultimately destructive nature of the preparation, makes this technique better suited as a supplement to SEM work, rather than a starting point.

The following procedure is based on techniques demonstrated to me by Roger Angold at the Rank, Hovis, McDougall laboratories in High Wycombe.

1) All handling equipment (forceps, etc.) was rigourously cleaned and dried between each sample to prevent contamination. New slides and coverslips were used for each sample.

2) As with selection of material for SEM mounts, a representative crumb of material was selected from the whole available sample using a low power microscope. Where sample sizes permitted, a generous amount (up to five times as much as required for SEM work) was taken, as this enhanced the ability to obtain detailed and reliable information from the procedure. On the other hand, too much material prevented good dispersal and accurate observation of individual items. About 2-5 mg of material was ideal.

3) The selected crumb was placed in the centre of a glass slide. It was carefully crushed with a small metal spatula, and scraped into a heap.

4) One drop of distilled water was added to the crushed powder with a pasteur pipette and this water-powder mixture then covered with a glass coverslip.
5) Each slide was examined with direct transmitted light at a magnification of between 200 and 400. Starch granules were easily visible if present. Other constituents were observed, such as fragments of bran tissue.

6) The slide was then observed with polarizing transmitted light. Starch granules which were not gelatinized show a typical Maltese cross under cross polarization, and have an opaque whitish colour. This appearance is called birefringence. The small, B-type, starch granules were difficult to see under ordinary light, but popped out like tiny stars with startling clarity under cross polarization. If exposed to enzyme attack, they still exhibited this diagnostic character to some degree, unless the break down had affected most of the starch granule. Starch granules which had been gelatinized did not have a Maltese cross under polarizing light, and were transparent. Partial gelatinization resulted in a partial cross and partial transparency. It was quite possible to have a distorted granule exhibiting the Maltese cross and appearing opaque white, while a perfectly formed one lacked a cross and became transparent under cross polarization.

7) A drop of dilute methylene blue (1:200-300) was added at one edge of the coverslip. The stain had to be irrigated across the mount by placing a piece of absorbent paper, such as filter paper, against the opposite edge of the coverslip. This dragged the stain towards the paper. It also tended to drag some of the specimen out of the mount, hence the need to begin with a reasonable amount of material. Some
care was required to prevent the mount drying out under the coverslip. Liquid was easily be replenished by adding a drop of distilled water with a pasteur pipette.

Methylene blue is a general stain for fungi, and should stain yeast cells. No convincing staining results were obtained, however, even with samples in which yeast was observed with the SEM. Another, more specific stain is needed. Although methylene blue generally perfused only lightly throughout starch granules, sometimes enhancing internal structural details such as pitting, the birefringent effect of cross polarizing light was lost.

8) Methylene blue was irrigated out. A drop or two of iodine potassium iodide (IKI) was added and irrigated under the coverslip. This is a standard stain for starch and can also be used to detect enzymatic starch breakdown (Radley, 1943: 128), as described in Ch. 3.VII.B.5. In addition, IKI allows starch gelatinization and dispersal to be detected. Individual granules were easily picked out by their dark silhouettes, but if present, gelatinized and dispersed starch, invisible otherwise, picked up the stain and could be observed in long streams, nets, or clouds across the slide. Gelatinized, non-dispersed starch appeared as a coherent, dark purple mass.

Iodine potassium iodide also temporarily enhanced the structure of some other constituents such as cereal tissues. Once this stain was applied, all starchy material progressively darkened until internal structure was completely obscured. The slide was then discarded.
It is unfortunate that, because of technical difficulties with the microscope camera, I have been unable to provide any high power light micrographs of ancient bread samples.

V. Preparation of reference material

Modern emmer was prepared as reference material to compare with scanning electron and optical microscopy images of ancient samples. Germination and heating were the two processes examined.

An initial experiment with emmer showed that there is usually a marked difference in germination between naked grain, and grain still in the spikelet (hulled grain). The first signs of germination for hulled grain were seen after about three days of exposure to moisture (samples were dissected out of the spikelet to monitor germination). Naked grains started to sprout after 24 hours. Germination was indicated by extension of the plumule (embryo leaf shoot) and coleorhiza (root sheath). Hulled grains have much more uneven germination rates than naked grains.

For reference microscopy, grain germinated in the spikelet was used. The following regime was applied:

CONTROL: no exposure to water.
C: 12 hour immersion in water.
D: 24 hour immersion in water.
E: 24 hour immersion, 24 hour damp air rest.
F: 24 hour immersion, 48 hour damp air rest.
After exposure to moisture, the spikelets were dried by heating in a drying cabinet. Control spikelets were placed in the drying cabinet at the same time as Group D and left for nearly four days. The embryo had to be dried quickly so that growth ceased, but heat had to be regulated to prevent starch gelatinization. A maximum temperature of 65°C was aimed for but not always achieved, as Figure 4.2 shows. As a result, groups C and D were exposed to temperatures at which gelatinization may have begun. This has been taken into account when assessing the results of SEM and staining on reference material. Because saturated and dry starch behave differently when exposed to heat (see Ch. 3.VI), the control spikelets do not indicate whether drying temperatures were too high.

The germination and drying procedure was intended to produce grain in which the starch was affected only by different sprouting periods. The effect of heat was studied separately. Each group of germinated and dried spikelets was divided into three sets: i) no further heating was applied (no heat = N/H); ii) dry spikelets were exposed to heat (dry heat = D/H); iii) spikelets were re-soaked and exposed to heat (wet heat = W/H).

Because starch is affected differently by heat depending on whether it is dry or moist, dry and wet spikelets were treated differently. Dry spikelets were exposed to temperatures of about 150°C, up to a maximum (very briefly) of 160°C, for 20 minutes. Soaked spikelets were exposed to temperatures up to 86°C, also for 20 minutes.
One spikelet from each of the three sets (N/H, D/H, W/H) from all five groups was chosen more or less randomly. The exception was Group F (24 hour immersion, 48 hour damp rest), for which spikelets with well defined rootlets were chosen, as an indication of reasonably advanced germination. Also, grains exposed to dry heat were rejected if they were blackened as this suggested heating beyond temperatures used for bread baking.

A grain from each set was snapped in half transversely at about the mid-point. The embryo half was then mounted on an SEM stub, providing a cross section of the grain at the mid-point. Fig. 4.3 shows starch from an emmer grain which was not exposed to any heat or moisture.

Two comments can be made about this reference material. Firstly, dry heating, even at 160°C, did not gelatinize starch in any of the groups (see Fig. 4.4). The only exception was a minority of granules in Group C (12 hours immersion), but as can be seen from Fig. 4.2, this may have been caused by drying down initially at too high a temperature. This result supports the interpretation that gelatinized starch seen in ancient samples must have been heated when retaining some degree of moisture. Fig. 4.5 shows the effects of heating wet starch in the grain; some gelatinization has occurred.

Secondly, very few pitted and channelled starch granules were seen in SEM images of Groups E and F. To examine this further, another grain from both groups was split longitudinally and viewed under the SEM. It was then possible to observe whether starch attack occurred
anywhere along the length of the grain. Starch granules near the embryo were pitted and channelled, but enzymatic attack had not progressed very far through the endosperm. This explains the apparent lack of pitting and channelling in cross sections of grain from groups E and F. Further carefully controlled work is needed to monitor the degree of morphological change over time of hulled germinating emmer, if morphological structure is to be used as a guide to times to which ancient starch was exposed to germination. This type of study is difficult because the complex interaction of ambient temperature, moisture level, degree of exposure to air, as well as genetic differences amongst variety, all affect rates of germination.

Better reference material would be obtained by eliminating the gap between germination and heating regimes for wet heated grains. Starch would then be definitely fully saturated, and gelatinization more precisely controlled. If heating cannot follow on from germination immediately, more careful monitoring of drying down, and better hydration prior to heating would undoubtedly improve results.

The lack of enzymatic action on starch granules at the mid-point of the grain indicates that starch breakdown of grain in the spikelet may be slower than published data suggest for naked grains (see Palmer, 1989: 143, for example). This is supported by the difference in time for the root sheath to extend in naked and hulled emmer grains (see above). Slicing the grain into more cross sections for SEM study would help to monitor the extent of enzymatic attack. In practice this is difficult. If grains are cut rather than snapped, the blade smears the starch granules and no structure is seen. Careful longitudinal
sectioning, with cross sections made wherever possible, may be the best compromise.

VI. Archaeological material

Archaeological data mainly came from two comparable sources: the Workmen's village at Amarna, Middle Egypt, and the Workmen's village at Deir el-Medina, Thebes. Both villages date to New Kingdom times. Deir el-Medina was inhabited from the reign of Thutmosis I (c. 1504-1492 BC) until well into the 20th Dynasty (later than 1165 BC), while the Amarna village was occupied only during the existence of the main city, for about 20 years around 1350 BC. It is known that the Deir el-Medina village was built and supported by the state to house the tomb builders who worked in the Valley of the Kings (Bierbrier, 1982: 9). The exact reasons for the existence of the village at Amarna are uncertain, but the inhabitants may have also been engaged in tomb building (Kemp, 1987b: 43-49).

Amarna has had a long history of excavation, and archaeological work is currently taking place there. The Workmen's village was excavated in two seasons by Peet and Woolley in 1921 and 1922 (Peet, 1921; Woolley, 1922; Peet and Woolley, 1923: 51-91), and most recently between 1979 and 1986 (Kemp, 1987b: 21). I have worked there since 1987, after excavation at the village ceased, but it is still possible to see much of the excavated areas. Most of the artefacts from these recent excavations are stored on site and are available for study. I am therefore personally familiar with many of the cereal processing artefacts, and have had the opportunity to examine directly
installations such as ovens, mortar emplacements, and quern emplacements.

Deir el-Medina was excavated over the course of three decades by five different missions between 1906 and 1935 (Bruyère, 1939: Pl. XXVI). The site can now be visited, but I have not had the opportunity to see it. Bruyère published a series of excavation reports about the site, and the artefacts are still in the process of being published. I have relied primarily on Bruyère's excavation publications for data about this village.

Information about Amarna is thus more complete than Deir el-Medina, not only because I am more familiar with the former, but because it has been dug recently with far more attention to detail than was the case earlier this century.

Installations and artefacts related to baking and bread have frequently been ignored or mis-identified. To establish accurate identifications which must precede any analytical study, publications for the two sites have been reassessed, based on observations I have made on artefacts from Amarna. These include material from the Workmen's village, but also from elsewhere at the site. Specifically, I have looked at mortars, mortar emplacements, quern stones and their emplacements, and ovens. No sieves or identifiable winnowing baskets have been found in the recent Amarna excavations, but some examples were uncovered at Deir el-Medina. I have discussed the pottery, but have not made a detailed study of it, which is a specialist task
already well covered by Pamela Rose and Paul Nicholson, the site ceramicists.

When particular objects are identified, it is possible to look at their distribution. This has been undertaken to a certain extent. The Deir el-Medina material is difficult to assess because of incomplete and relatively imprecise recording. The distribution of cereal-related remains at the Amarna village is part of a wider study, which because of time and space limitations has only been briefly mentioned within this thesis.

VII. Ethnography

Ethnography has provided key information, but no ethnographic work was carried out specifically for this research. Assemblages of equipment and associated artefacts may be well preserved, artistic depictions indicating their use may be available, and authentic equipment may be available for experimental reconstruction. Without some reference to similar contemporary approaches, the chances of the researcher putting these elements together accurately, with no experience in the use of archaic cereals and traditional equipment, are low. There are too many gaps in the evidence, and the elusive, transitory linking actions, which may be all-important, can never be preserved.

Milling methods which are probably analogous to ancient Egyptian practice, using the saddle quern, are now to be found only in sub-Saharan Africa, and some published studies are available (see Section 5.II.C). Some ethnographic data, both published (see Section 5.II.B),
and personally observed, from contemporary Turkish emmer processing were also applied.

VIII. Experimentation

Experimental archaeology can test ideas and hypotheses about ancient practices, particularly if it draws upon a wide range of evidence. Experimental archaeology also actively explores construction and use of equipment. When trying to replicate a sequence of actions, inaccurate assumptions and gaps in knowledge often become obvious. One of the valuable results of experimental archaeology is exposure of errors in interpretation. Without some ability to test, it can be difficult to establish flaws in interpretation stemming from an incomplete archaeological record.

Experimental work is best undertaken after several sources of evidence have been examined because reliable and convincing data on which to base experimental work are required. There are bound to be missing links, but these will be fewer when a wide range of relevant evidence is first investigated, which is then all applied to experimental reconstruction.

The sources of evidence discussed above have been used to build up models of ancient Egyptian cereal processing and baking. Experiments were then set up to test these models, to examine the use of the ancient equipment, and to determine what further evidence was required to improve the models. This work was carried out at Amarna, since authentic tools are readily available, and replica tools are easily made there. The original installations on which replicas were based
were also generally accessible for comparison. Cereal processing was replicated in full, while brief trials on baking were carried out.

To test the models, equipment first needed to be assembled. Where possible, the ancient tools themselves were used. Since limestone mortars and granite querns are durable, and many of those found at the site of Amarna were in good condition, one of each was used in experimental work. They were set up in replica emplacements modelled on archaeological finds from the Workmen's village.

The experimental quern emplacement (Fig. 5.37) was based on the dimensions and materials of the archaeological quern emplacement found in West Street, house 2/3, located in the north-west corner of the south annexe (Kemp, 1987a: 5, 9), and the emplacement in the front room south of Gate St. 8 - see Fig. 5.8 (Kemp, 1986a: 3-5). Although these emplacements did not survive intact, their dimensions were clear from the surviving foundations and the outlines of the complete emplacements on the adjacent walls. A photograph of an excellently preserved kitchen from earlier excavations at Amarna was also invaluable (Peet, 1921: Pl. XXVII.2). The experimental mortar emplacement was copied from the installation in Gate Street 9, Front Room South (Kemp, 1987a: 30, 36), and a replica pestle was made to use with it (Fig. 5.13). The replica oven was based on one found in the Main Chapel annexe (Kemp, 1987a: 56). I also examined other exposed chapel ovens (|1328|, Chapel 528, Kemp, 1985: 45; and |2810|, Chapel 556, Kemp, 1987a: 73). The construction of these installations and tools is described in the relevant sections of Chapter 6.
Some pieces of equipment were neither ancient examples nor accurate replicas. These were the sieve, the winnowing basket, and vessels for mixing dough. The latter should have made no difference to replication, but experiments were hampered by lack of an adequate sieve and winnowing basket. Bread moulds were not used; I decided to work on the simplest baking procedures before proceeding to mould-baked bread. Time constraints and the collapse of the replica oven restricted baking experiments.

The National Institute of Agricultural Botany, Cambridge grew on small stocks of emmer originally obtained from northern Turkey, providing abundant spikelets for experimental work.
CHAPTER 5: EMMER PROCESSING FROM SPIKELETS TO FLOUR

I. Introduction

As discussed below in section IV.A, and as will become clear in Chapter 6, all the evidence which I have examined points to the use of emmer for bread making. This does not imply that barley was never made into bread in New Kingdom Egypt, but because of the available ancient evidence, I have focused here on emmer exclusively. The chapter takes as its starting point the spikelets in bulk, and traces how the New Kingdom Egyptians obtained clean grain and emmer flour.

I have chosen to discuss first ethnographic studies of emmer processing, and cereal milling on saddle querns. These ethnographic parallels were selected with the archaeological evidence in mind, which is discussed in the subsequent section.

The most extensively excavated archaeological settlement sites dating to the New Kingdom, with relatively detailed publications, are the villages of Deir el-Medina in Upper Egypt, and the Workmen's village at Amarna in Middle Egypt. The evidence from these sites is considered in detail, and an analysis is made of the location of processing steps. Other settlement sites such as 18th Dynasty Gurob (Petrie, 1890), are described in too little detail to attempt reconstruction of cereal processing distribution, or even to determine whether the relevant installations were recovered.

To link archaeological and ethnographic evidence, and to test the resulting hypotheses about ancient cereal processing, I have
undertaken a series of cereal processing experiments. They have been designed so that wherever possible, the actual ancient Egyptian tools were used, or replicas constructed of the same materials and to the same specifications. Also critical is the manipulation of the same cereal species which were grown in ancient Egypt. Experiments were carried out with emmer wheat.

In drawing together this chapter, it has not always been straightforward to separate the information derived from each type of approach, and to discuss it in isolation. Working out the sequence of ancient Egyptian cereal processing has involved continual cross-reference between the sources of evidence, using each to fill in gaps left by the others. The final section of this chapter uses all this information to present a model of ancient Egyptian cereal processing in the New Kingdom and to demonstrate its potential to answer wider social and economic issues.

II. Ethnographic evidence
A. Introduction
Ethnographic investigations have been used to clarify two separate stages of the ancient Egyptian cereal processing sequence. Firstly, the methods are explored by which the ancient Egyptians most probably divested emmer grain of its tightly enclosing chaff. Here, the analogy has been selected by the use of the same commodity – emmer wheat spikelets – and similar tools. The ancient tools are described in the following section (III).
Secondly, ethnography has helped in the study of saddle quern milling. Today the Old World regions where hand milling is still practiced include North Africa, the Near and Far East, where the rotary quern is employed, while in sub-Saharan Africa the saddle quern is used. It is the latter area where relevant ethnographic analogies are found. The parallel is based on the similarity of the tools and their use for grain milling, but the exact commodities cannot be matched. Sub-Saharan cereals are primarily the Old World subtropical crops millet and sorghum, as well as New World maize (Harlan, 1989).

B. Dehusking emmer
A detailed ethnographic description of emmer dehusking is provided by Hillman (1984b). This forms part of his comprehensive survey of emmer harvesting, bulk processing to obtain semi-clean spikelets for storage, and the subsequent, smaller scale food processing sequence, especially bulghur production (parboiled cracked wheat). In presenting this sequence, he has brought together numerous recent and historical ethnographic observations, including his own. I have largely relied on this study to summarize how clean grain may be obtained from emmer spikelets.

As described in Ch. 3.II, when glume wheats, of which emmer is one, are threshed, a mixture of chopped straw and spikelets is produced. Once the spikelets have been separated from the straw, they must be breached to free the grain inside. Two methods of tearing apart emmer spikelets have been observed in non-mechanized processing systems. In mountainous regions of Turkey and Spain, the spikelets
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As described in Ch. 3.II, when glume wheats, of which emmer is one, are threshed, a mixture of chopped straw and spikelets is produced. Once the spikelets have been separated from the straw, they must be breached to free the grain inside. Two methods of tearing apart emmer spikelets have been observed in non-mechanized processing systems. In mountainous regions of Turkey and Spain, the spikelets
are sheared apart by milling in a water driven rotary mill with stones set about 3 mm apart (Delwen Samuel, Mark Nesbitt: personal observation; Leonor Peña-Chocarro, pers. comm.; Hillman, 1984b: 138). This clearly cannot be the system used by the ancient Egyptians, who had no rotary mills (Forbes, 1954: 274; 1965: 60) and no fast running streams.

The second way that emmer spikelets have been traditionally processed is by pounding them with a mortar and pestle (Hillman, 1984b: 129). This results in a mixture of free grain and fragmented chaff which can then be winnowed and sieved in a manner similar to freshly threshed naked wheats, to obtain clean grain.

The use of the mortar and pestle or mallet for dehusking emmer in the recent past is widespread in those regions which still grow it (Harlan, 1967: 199). The mallet appears to be used with larger mortars, and the pestle with small mortars. The mortar may be made of wood or stone, although wood is apparently preferred when it is available. The mallet is always made of wood, but stone pestles have been observed for debranning rice. The mortar size varies according to use; it may be as small as 10 cm in diameter for processing limited amounts of spikelets indoors, or massive permanent installations for bulk processing an entire year's grain supply.

Prior to pounding, the spikelets may be parched, to render the chaff brittle. Pounding with mortar and pestle produces a mixture of free grain and fragmented chaff. Hillman (1984b: 130) does not record to what extent the grains are crushed or whole, but he does state that
Turkish farmers near Kizilcahamam debran rice with mortars and pestles both made of basalt, with very little crushing of the grains. Harlan (1967: 199) has reported that experimental pounding of parched spikelets broke up the grain more than unparched spikelets.

The mixture of heavy and light chaff and grain is then separated by a series of winnowing and sieving steps. The first winnowing may use small winnowing forks or shovels, or winnowing baskets. The result of this action is separation of the light chaff from the heavy chaff and grain. If there are substantial numbers of whole spikelets left the latter mixture is put through a medium-coarse sieve and the spikelets are recycled back to the pounding stage. The grain/heavy chaff mixture is passed through a fine sieve which removes small pieces of heavy chaff and weed seeds, retaining the grain fraction and larger pieces of chaff. The latter settle in a layer above the grain and can be scooped off. After this, some villages wash the grain by immersing it in water. Wild grasses and grains infested with weevils or fungal growth float off because of the trapped air they contain. The washed grain is spread out to dry on mats. At this stage, with or without washing, the semi-cleaned grain may be stored.

Whether or not the emmer processing sequence includes storage of cleaned grain, when this grain is taken for food processing, it still needs further cleaning. This is done by more sieving and winnowing steps which may be repeated several times, but in smaller batches than at first, obtaining progressively cleaner grain each time. There may be a final winnowing to remove light particles which have so far persisted in the grain. Finally, the all-but-cleaned grain is hand
sorted. This extracts contaminants of the same size and mass as the grain, which are not removed by either winnowing or sieving. These include grains of darnel grass (*Lolium temulentum* L.), small stones, and pieces of dense chaff. The process is generally carried out at low wooden tables, with the picked out contaminants dropped on a mat beneath. The result is thoroughly cleaned grain.

**C. Milling with saddle querns**

During Pharaonic times, the saddle quern was used for milling, and this type of quern has been recovered from excavations. Ethnographic studies of Old World saddle quern use come from sub-Saharan Africa. Richards (1939: 92) has briefly described millet grinding by women of the Bemba tribe, where the dehusked, whole cereal is ground in a rock hollow. This is apparently very hard work, but the time required to produce a given amount of grain is not recorded. Fortes (1949) notes that it takes about one hour to grind enough grain for a main meal on a saddle quern amongst the Tallensi, but does not record the amount. Quantities and times were not mentioned by Burckhardt (1822: 219), who observed grinding on saddle querns in Nubia in the early years of the last century, but he did provide a fairly detailed description. There, sorghum was used. It was placed on a saddle quern sloping away from the grinder, with a hole at the opposite end to hold a jar or bowl for flour. The grinder knelt at the upper end, and added water to the grain, so that a wet paste, rather than a dry flour, was produced. The paste was later baked. It is unclear why the sorghum was ground wet rather than dry. The possibility that ancient Egyptians milled wet grain is considered in Ch. 6.V.C.5.
More recently, a detailed account of grinding on saddle querns by the nomadic Mahria of the northern Darfur (north-central east Sudan), has been given by Uta Holter (Schön and Holter, 1990: 362, 363). Millet is ground dry by women in two steps, with different hand stones, to produce coarse and then fine flour. A shallow plaited bowl is placed at the far end to collect flour, and a little grass broom is used to sweep the quern stone clean after use. The quern stone is not emplaced in a permanent or semi-permanent structure, but when in use, is raised above ground level with stones or sand. It is set at an angle, so that the upper end, behind which the woman kneels, is about 19 cm high, and the lower end about 8 cm off the ground.

The grain is placed on the upper quarter of the stone, both hands grasp the grindstone, and the grain and flour are milled in a straight line, or sometimes with a diagonal motion across the stone, down towards the end where the flour falls into the bowl. Now and again the grains which escape to the edges are pushed back to the middle just in front of the hand stone.

There are two types of millet which are ground, unfermented and fermented. There is no explanation of what fermenting involves, but presumably water is employed at some stage. Four and a half kilograms of dry millet takes 75 minutes to grind in two stages; 40 minutes for the coarse milling and 35 minutes for the fine milling. This will make enough for two meals to feed 8 people, mostly adults. Fermented millet takes 40 minutes altogether to grind 3 kilograms. Unfortunately, it is not stated whether fermented millet is ground wet
or dry. The times taken to grind millet, a small seeded cereal, may be less than that required to mill emmer grain.

III. Archaeological evidence

A. Aims

This section provides a detailed consideration of the tools connected with cereal processing, which have been recovered from, or may have been used at, the two Workmen's villages of Deir el-Medina and Amarna. It has two main goals.

i) Identification of tools. The identification of artefacts is a basic prerequisite to any analysis or interpretation of the archaeological record. In the past, many of the tools and installations connected with cereal processing have been either overlooked, or mis-identified. I have considered the material from the Amarna Workmen's village exhaustively, and in detail for Deir el-Medina, in order to establish firm and unequivocal identifications of artefacts, which in turn lead to accurate identifications of their functions.

ii) Distribution of artefacts. Once identifications have been established, their distributions are considered. Because of the different excavation histories of the two sites, this can be achieved with more certainty for Amarna than for Deir el-Medina, but unresolved gaps still remain.

This section, then, focuses on determining the distribution of firmly identified cereal processing tools. This allows the confident exploration of other, broader, aims, in conjunction with other sources of
evidence. In section V, I have explored wider issues, connected with social interactions as Goody's scheme suggests (see Table 1.1), and economic questions.

B. Frame of reference

Since cereal processing is a fundamental part of food production, one would expect to find its associated tools and installations at settlement sites. Two of the best preserved ancient Egyptian villages are the 18th Dynasty settlements of Amarna's Workmen's village, and the village of Deir el-Medina, on the West Bank at Thebes. They are comparable because they were set up to serve the state directly, and many of their supplies were provided by the state. The circumstances of their foundation meant they were located outside the fertile Nile flood plain, and their layouts were highly structured (Kemp, 1987b: 43). As a result of their arid setting, they are very well preserved, and accessible for excavation. They are almost certainly not representative of ancient Egyptian villages in general. There is no reason to suppose, however, that once supplies were received, cereal preparation methods were any different from those households which brought in their own harvests.

Both sites have been extensively excavated and published in some detail. They include not only houses with a walled village, but various buildings outside the walls. At Deir el-Medina, dwellings were sometimes later established in tomb chapel courts, and at Amarna, ovens were built in some of the chapel complexes. In the latter case, especially, it is not possible to be sure with what frequency they were used, and their context suggests some element of ceremonial use.
For the following discussion, I have largely confined my attention to the houses within the walls of the villages. This focuses the enquiry on domestic activity and daily consumption. Some reference has been made to finds from elsewhere, when they provide supplementary information.

The relevant excavation report for the Deir el-Medina walled village is Bruyère (1939: 72-78, 237-335). The literature for the Workmen’s village at Amarna is more scattered. For the earlier work, Peet and Woolley (1923: 51-91) is the main report, supplemented by Peet (1921) and Woolley (1922). The more recent excavations within the village walls are covered in Kemp (1986a, 1987a, and 1987b), together with some unpublished excavation data. To avoid tedious repetition, page number references to Bruyère’s 1939 Deir el-Medina publication are noted below as (DelM, 000), while references from taken Peet and Woolley (1923) are referred to as (WV, 000). References from other publications are referred to conventionally.

In the following discussion, the names Deir el-Medina and Amarna refer specifically to the respective walled villages, unless noted otherwise. I have used the same room terminology as used in the original reports. Houses at Deir el-Medina are referred to by their quarter and number, and those at Amarna by their street and number, as assigned by the excavators. Readers should refer to the village plans (Figs. 5.1 and 5.2) throughout.

Ethnographic analogues help to identify the types of tools associated with dehusking, cleaning, and milling glume wheats. Those which
might be predicted to survive in the archaeological record under normal conditions of preservation (where organic materials perish), are the tools made of stone, which could be mortars and pestles, and almost certainly querns, as well as the structures into which they may have been set. Artefacts made of organic materials, which could conceivably be expected to survive under desiccating conditions in Egypt, are wooden pestles, winnowing tools, and sieves. All such excavated artefacts from the village at Amarna are listed in Appendix A, while those from Deir el-Medina are listed in Appendix B.

A number of problems arise when trying to assess the presence and ancient distribution of artefacts associated with cereal processing. Both Deir el-Medina and the Workmen's village at Amarna were excavated in more than one stage. At Amarna the first stage was undertaken by Peet and Woolley in 1921 and 1922, and reported by them in a chapter of their 1923 publication. The work done followed the general pattern of excavation at that time: a rapid clearance to gain an overview of the settlement plan, the recording of most of the major features, and a selection of artefacts. The painstaking excavation and detailed recording common to modern techniques of excavation were not applied. As a result, it is impossible to piece together a complete record of particular features of interest, whatever they might be, because many were not recorded. Another difficulty is that descriptions of the same type of features across the excavated areas are not always uniform, sometimes making the reconstruction of earlier evidence uncertain.
The second phase of excavation at the Workmen's village, undertaken in the 1980s under the direction of Barry Kemp, concentrated on detailed excavation and recording. In assessing evidence from these excavations, a difficulty of a different kind is encountered. Between the 1920s and 1980s, the site of the Workmen's village suffered from extensive illicit digging. All five areas within the walled village investigated in the 1980s had been severely disturbed and turned over, although sections within these areas sometimes survived unscathed, and a great deal of rich evidence has been gathered nevertheless. However, this disturbance makes it difficult to know whether a "missing" feature in one of these places had never been there, or whether it had been removed or destroyed.

The walled village of Deir el-Medina was excavated over the course of two decades by five different groups (Bruyère, 1939: Pl. XXVI). Bruyère (1939) discusses much of the evidence uncovered by all of these investigators, but inevitably much of the detail and observation which comes from a co-ordinated approach must have been lost. The recorded distribution of tools and installations connected with cereal processing seems to have little to do with who did the digging. Like Amarna, the archaeological record at Deir el-Medina has suffered from pillaging, and also from floods.

C. Winnowing tools and sieves

There are three stages at which winnowing and sieving take place after harvest. The first occurs at the threshing floor, after threshing and prior to storage. Since the entire harvest is being processed, this stage is large scale and the winnowing is wind-assisted. The
action separates spikelets from chopped straw, straw nodes, weed seeds, and weed heads (Hillman, 1984b: 124-125). During pre-storage winnowing, the ancient Egyptians appear to have used winnowing forks and winnowing fans (e.g. Stead, 1986: 27-29), although they may also have used shallow baskets as employed in traditional Nubian millet cleaning during the harvest (Fernea, 1974: Pl. 24). This stage is not considered further here since it is part of the harvesting sequence, except to point out that, if the scale of spikelet cleaning at harvest differed substantially from the scale of separating grain from spikelet chaff, the tools were likely to have differed also.

The second and third winnowing and sieving stages take place after spikelet storage, and they are part of the processing which produces clean grain from whole spikelets. It is this post-storage work which is considered here. The second stage cleans the whole spikelets prior to further processing, while the third stage cleans the loose chaff produced by pounding, from the released grain.

Winnowing tools and sieves are the most perishable items used in the cereal processing sequence. Hillman (1984b: 131) records that the tools used to winnow fine chaff free of pounded spikelets are small (wooden) winnowing forks and shovels, winnowing baskets, sieves used as winnowing baskets, or special winnowing trays with an unperforated sheet of hide. No artefacts answering to the description of small winnowing forks or hide trays have been noted at either Deir el-Medina or Amarna.
Although Peet and Woolley (1923: 61) make the intriguing casual comment that winnowing fans were kept in the front hall of the Amarna village houses, not a single individual example is mentioned. They may be the type commonly associated with the large scale winnowing of threshed sheaves. This would imply that some Amarna villagers were involved in harvest activities, a suggestion which has not been made before, and cannot be assessed without more precise information about these particular artefacts.

The type of sieve which must have been used for ancient cereal processing would have resembled that illustrated in Harlan (1967: 200) from Ethiopia, used in modern times for cleaning pounded emmer spikelets. It is not described in the text, but the photograph shows that the mesh size is relatively even and consistent, and the sieve is deep enough to hold a reasonable volume of material, for the sides are made of six successive coils, curving up to make a deep rim. No diameter measurement nor scale is given.

Five sieves are recorded from the older excavations of the Amarna Workmen's village, but no mesh sizes are recorded. One whole sieve and two fragments come from the kitchen of Gate St. 12 (WV, 74). The complete sieve has a diameter of 21 cm, while one incomplete sieve has a diameter of 42 cm. The dimension of the other fragment is not recorded. This house was not fully excavated, and the publication does not record whether there was a mortar or any installations in this room. Although the plan shows a circle, it may very well not represent a mortar, and so one cannot say whether these sieves are associated with pounding. The sieve from East St. 12 (WV, 72), 33 cm
in diameter, was found in the front room, where a mortar was set into a boulder-paved area. The sieve from Main St. 8 (WV, 79) has a diameter of 23.5 cm, and was found in the front room, along with a "shallow stone circular bowl" which was probably a mortar (see below, Section D.1.a). Although these artefacts were near mortars, there are really too few, poorly described examples to draw any conclusions about the use of these particular sieves in the cereal processing sequence. The recent excavations have produced only a few sieve fragments, most of which look suspiciously late (Willeke Wendrich, pers. comm.).

An added difficulty with the earlier material is that the mesh sizes have not been recorded, but this dimension is directly relevant to sieve function. Mesh size is critical to satisfactory sieving, and each stage requires a different mesh gauge which is carefully and accurately woven by sieve-makers (Hillman, 1981: 155). The whole sieve found in Gate St. 12 (diameter 21 cm), and illustrated in Peet and Woolley, 1923: Plate XXII, 2, is now at the British Museum, where I have been able to examine it. The rim has a maximum depth of no more than 1 cm, so that the sieve would have had a very restricted capacity to contain anything. The width of gaps between the rigid passive cross pieces varies between 2.5 and 3 mm in the central part of the sieve, while the width of gaps between the twined cross pieces varies more, ranging between 0.5 and 4 mm, but with most about 2.5 cm apart. The combination of small diameter, lack of depth, and inconsistent mesh size suggests that this particular sieve was not used for grain cleaning, and may have been best suited to straining liquids.
At Deir el-Medina, apart from one general comment on the discovery of riddles (coarse sieves) and winnowing baskets in the sector covering houses NE.XV to NE.XIX, and SE.I to SE.III (DelM, 262), this type of artefact is not mentioned in the site publication, and unfortunately none is illustrated. Isolated finds of plaited mats were made and recorded in the report; these too are neither described nor illustrated. The plaiting technique, however, is most commonly, if not exclusively, associated with Graeco-Roman material, and this term may well have been wrongly applied (W. Wendrich, pers. comm.).

A catalogue of Deir el-Medina basketry material has been published, but it does not give precise provenances (Gourlay, 1981). Material included may come from the walled village, but may also originate from tombs. As far as can be judged from the photographs, material may date from the 18th Dynasty to the Graeco-Roman period (W. Wendrich, pers. comm.).

Two sieves and several baskets are illustrated in Gourlay's (1981) catalogue. The deep sieve illustrated in Fig. 5.3 (10.177; 1981: 129, Pl. IX, B) seems to be very similar to the modern day emmer processing sieve from Ethiopia illustrated by Harlan (1967: 200). It has a maximum diameter of 40 cm, a rim made up of 4 to 5 coils, and the whole has an interior depth of 6.3 cm. It would be well suited to hold a large quantity of loose pounded spikelets. It is difficult to assess the evenness of the woven centre; the description says only that the alternating cross ties are irregular. The shallow sieve (10.175; Gourlay, 1981: 129, Pl. IXA), on the other hand, is similar
to that from Amarna now in the British Museum, but it has an even smaller maximum external diameter of 16 cm, and a thickness of just over 1 cm; it must have been more suited to straining liquids than cereal processing.

There are several shallow baskets illustrated in Gourlay (1981). Of those illustrated, the baskets most likely to have been used for winnowing have wide diameters and a shallow, flaring rim. Thus, baskets 10.9, shown in Fig. 5.4 (1981: 73-74, Pl. VI.E) and 10.250 (1981: 153, Pl. XVIII) would have been better suited to winnowing pounded spikelets than 10.8, a deeper basket with a more steeply sloping rim, shown in Fig. 5.5 (1981: 73, Pl. VI.D). This distinction is based on the assumption that winnowing chaff from pounded spikelets was done on a small scale, without wind assistance, as described in section IV.E, below, and mentioned by Hillman (1984b: 134).

Numerous mats and baskets were also found at the Workmen's village at Amarna during the earlier excavations but again, little detail is available. Some examples are, however, illustrated (WV, Pl. XVII, #6 and Pl. XXI show some specimens), indicating the wide variety of shapes and sizes which were made, and the difficulty of drawing any conclusions about form or function from a general term. Basket 22.129 from the living-room of Main St. 10 (WV, 81) seems to resemble the deep, steeply sloping rimmed basket 10.8 from Deir el-Medina, and does not suggest a winnowing form.
A tomb find convincingly resembling a winnowing basket is illustrated by Schäfer (1908: 172) and Kaiser (1967: Fig. 290), and shown in Fig. 5.6. The exact provenance is unknown, but it comes from the New Kingdom necropolis at Dra' Abu el-Naga'. This basket is definitely coiled, not plaited (W. Wendrich, pers. comm.), but nevertheless, no date can confidently be assigned, and it may actually come from a much later period (Barry Kemp, pers. comm.). Schäfer (1908: 172) describes it as a large oval basket, about 50 cm in diameter, made of palm bast. Along one long side the broad lip is upright, while along the short sides it slopes down so that the other long side of the basket has no lip. This lipless edge is reinforced by a stitched border.

The Egyptian dealers from whom it was acquired suggested that it was a winnowing basket, and baskets of this form were also used in the last century in Germany in the grain cleaning process. Although Schäfer (1908: 172) says that Borchardt saw it in use in Germany for cleaning wheat of stones and similar impurities, it would work admirably for winnowing light chaff from pounded spikelets. As no other baskets of similar form are known, it is not possible to say whether this type of basket was used in Pharaonic Egypt, whether it was widespread, nor whether any similar examples were found at Deir el-Medina or Amarna.
D. Mortars and mortar emplacements

1. Identification of mortars

a. Workmen's village, Amarna

At the Amarna village, the earlier excavations frequently uncovered mortars, and several were also retrieved from the later excavations. Most of these hard white limestone tools have similar dimensions, ranging between 20 and 30 cm in diameter, with very few larger examples. Published measurements probably refer to exterior diameters, but this is not clear. The only mortar for which complete measurements have been made is from the front room south of Gate St. 9 (find # 7294), excavated in 1986 (Kemp, 1987a: 32) - see Table 5.1. It is a good example of Amarna mortars, and is illustrated in Fig. 5.7. Like it, most mortars are carefully shaped both inside and outside, but the exterior is left quite roughly chiselled. The exterior profile is a somewhat tapered, deep bowl shape, the widest circumference often slightly below the rim. The walls are very thick, and the base even stouter, so that the interior curve is distinctly rounded. Recent excavations also uncovered one mortar in Long Wall St. 6 (unpublished), and two in West St. 2/3 (Kemp, 1987a: 6-9).

Amongst the available measurements, there are three which are anomalous. A mortar from the front hall of Main St. 7 measures 45 cm in diameter (WV, 78), while that from the front room of Long Wall St. 6 (find # 48, excavated in 1977, unpublished data) has a maximum exterior diameter of 75 cm. This mortar was fashioned from a large chunk of limestone, with the outer surface left unshaped. It is rare that the exterior is left entirely unworked. Both examples are unusually large. The third anomalous example comes from the front
hall of East St. 12 (WV, 72, find 22/64). It is only 13 cm in diameter, with an interior hollow of 4 cm; it is thus much too small to have been used for cereal processing. In overall shape it is cylindrical (unpublished drawing), and thus quite different from the tapering bowl shape of the larger mortars. It must have been used either for processing very small amounts of material, perhaps condiments or medicines, or an entirely different purpose.

One of the problems in the earlier publications is the distinction between limestone mortars and limestone bowls called jar stands (Peet and Woolley, 1923: 64-65). Both are set into the floor. The distinction is based on interior surface texture: stone mortars are said to have a smooth texture at the bottom of the interior hollow. The upper part of their sides might be comparatively rough; while jar-stands are rough at the bottom with smooth rims.

Without the actual specimens, these identifications are difficult to assess. For example, exactly what type of texture is meant by "rough"? The Gate St. 9 mortar is more or less smooth throughout the interior surface, but is rough in parts, especially the sides, due to imperfections and voids in the stone (see Fig. 5.7). The action of pounding siliceous spikelets in a mortar would wear the whole interior mortar surface smooth and even polished, although the rim might be less exposed to wear (see below, Section IV.C). It is difficult to imagine, on the other hand, that repeated removal and replacement of pottery jars would have the same smoothing effect on the limestone surface, especially as the curve of the jar is unlikely to correspond closely to the interior curve of the limestone bowl. A jar which is left
in position would probably cause little wear. Peet and Woolley's jar stands often had built-up rims of stone and mud brick, which would tend to protect the surface from any wear caused by a propped jar.

A large jar supported by just such a construction in Main St. opposite house 4 (Woolley, 1922: 51, Pl. IX, upper) argues for the identification of smooth-rimmed limestone bowls as jar stands, especially when they are rimmed with stone or mud. This was the only example of a jar in-situ on a limestone vessel and it indicates that limestone bowls set in the ground could be used in this way. Offsetting this find is the recovery of a wooden pounder beside another mud-rimmed limestone bowl in the same street, opposite house 8 (WV, 68). Although this evidence is not conclusive one way or the other, it seems unlikely that time and care would be taken to construct and shape a limestone bowl, both inside and out, for use solely as a jar stand, especially as ceramic jar stands in a range of sizes are well known (Type I; WV, 137, Pl. XLVI, also Pl. XVII.3). This does not preclude their use as handy jar stands when not needed for pounding cereal. Without rejecting other possible uses, it can be concluded that the jar stands, as labelled by Peet and Woolley, were probably mortars and are referred to as such in later sections.

Identifications of other limestone vessels are also problematic. For example, a number have been described as shallow circular stone bowls. When measurements are given, such as the bowl of 25 cm diameter found in the front hall of Main St. 8, they fall within the size range of mortars. Most, if not all, of these are probably mortars as well, especially if they are made of limestone. In a site-wide
survey of Amarna (unpublished data), I have not come across any non-limestone mortars. I have also included this vessel type in my later discussions of mortars.

The function of an hourglass-shaped limestone artefact, found in the living-room of Gate St. 11 (WV, 73, Pl. XIV, #6, right), is uncertain. It is described as a vase-stand and looks as if it were designed to be free standing. The photograph shows a flanged upper interior, similar to the interior surface of the mortar from Gate St. 9. The object, however, seems more carefully shaped than the usual mortar, and has a much thinner, more delicate rim. Although it was retrieved from a living-room, an unusual location for mortars (see below), this may not be of great significance as it may have been moved. However, its notably thin rim, probably rules it out for use as a cereal processing mortar.

Two objects, possibly similar to the "vase-stand" of Gate St. 11, were found in the front hall of East St. 11. These are described as "hourglass shaped stone ring-stands" (WV, 72), and it is unclear whether they are hollow rings, or have solid bases like the vessel found in Gate St. 11. The excavators themselves do not make the comparison. One seems to have been set into the floor, as mortars commonly were, and furthermore, again as for mortars, was within a part of the floor paved with boulders, surrounded by a semi-circular coping of stones. The other vessel was apparently loose. The description is too vague to ascribe an identification with any certainty and I have not considered these artefacts to be mortars.
In summary, in the earlier Amarna publications, mortars probably include most of the vessels described as limestone jar stands and shallow limestone bowls, but are unlikely to have been hourglass-shaped vessels.

b. Deir el-Medina

The two different types of limestone vessel found at Deir el-Medina are called mortars and troughs, and examples of both are illustrated in photographs (DelM, 74, Fig. 22 and Fig. 23). There are no published drawings. Mortars are not described, but the illustration shows that the exterior is roughly tapered. The rim is thick and flat, rough on the exterior edge, but more smoothed at the interior edge. The interior surface is difficult to assess, but it is certainly more smoothed than the outside. The degree of interior curvature cannot be seen clearly. It appears to be more curved than the outside profile. The published photograph of two mortars suggests that one at least is slightly flanged inside, like the mortar from Gate St. 9 at Amarna.

Dimensions for only two mortars are provided. One, in house SE.VII, is 40 cm in diameter and 45 cm high (DelM, 273). The other mortar, found in SW.IV, is unusual. It is fashioned out of a square block, with a round hollow in the centre. The sides of the square measure 52 cm, and the block is 30 cm deep. The interior hollow is 25 cm deep, and the interior diameter of the mortar at the top is 37 cm. This is considerably larger than the mortar from Gate St. 9 at Amarna.

Photographs of some mortars at Deir el-Medina, as they can be seen today, were kindly provided by Barry Kemp and show an array of
shapes and sizes. Some have an interior flange, and the interior surfaces of many are relatively smooth. Some exteriors seem to have been shaped with some care, while others have been left very rough, with very thick walls, similar to the mortar recovered from Long Wall St. 6 at Amarna. It is not possible to suggest an explanation for this variation in exterior treatment without detailed examination. As far as it is possible to tell, the interior dimensions of these mortars are broadly similar.

The second type of limestone vessel at Deir el-Medina is called a trough ("auge"), and the photograph of two examples (DelM, 74, Fig. 23) shows that these are quite distinct from, and thus not confused with, mortars. The surface texture is very rough, both inside and out. They are broad and shallow, some have holes at the base of the interior hollow to drain away liquid, and they tend to be semi-rectangular or somewhat irregular in shape. Thus, the identification of mortars by Bruyère seems secure and unlikely to be confused with anything else.

2. Identification of mortar emplacements at both villages
There is little information about the method of mortar emplacement at Deir el-Medina. It is not possible to tell from the publication whether most mortars were loose, or their position simply not recorded. The few mortars whose positions are specifically mentioned are embedded in the ground, with the rims more or less flush with the floor surface. The two limestone mortars in NE.III were surrounded by a margin of little stones (DelM, 244). One or two were evidently not emplaced.
Mortar emplacement at Amarna has been clarified by the recovery of several during recent excavations. Although disturbed by illicit digging, it is clear that the mortar in front room south of Gate St. 9 had been set into the ground, so that its lip was more or less flush with the floor surface (Kemp, 1987a: 32, 36: Fig. 3.5). The floor around the emplacement was more elaborate than house floors in general, with stones set in marl mortar, covered smoothly with marl plaster, and then alluvial mud plaster (1987a: 30, 32).

Two mortars have been recovered from West St. 2/3. One, at the back of the southern annexe - area viii (Kemp, 1987a: 6) was too badly disturbed to obtain any information about its emplacement. The other, however, is very informative. It was found in the north-west corner of the front room (Kemp, 1987a: 8, Fig. 1.7). The base was partially embedded in the floor, but most of the body was secured by a mud brick and mud plaster construction. The surround rose well above the rim, filling in the space between the corner of the house and the mortar, while mud plaster covered the upper interior of the mortar. On the side of the mortar opposite the corner, where the person who was doing the pounding would have stood, a gap of about 25 cm was left in the mud brick and plaster surround.

The rich assemblage of desiccated plant remains surrounding the installation (Samuel, 1989: 280-286) confirm that this particular mortar was used to process cereal. The assemblage is almost entirely composed of emmer chaff, shredded to varying degrees by the pounding action. Nearly half the recovered plant remains by volume is composed of fine chaff, which cannot be identified down to species on
morphological grounds alone. However, all types of large emmer chaff have been identified (Samuel, 1989: 281). These include some whole spikelets still containing grain, whole but empty spikelets, over 160 rachis internodes, in excess of 60 spikelet forks, and more than 150 glume bases. The earlier identification of an "einkorn-like" spikelet fork is incorrect and is in fact a sub-basal emmer spikelet fork. Although no emmer grain has been recovered from this sample, several beards have been found. It is possible that they were once attached to whole grains which were subsequently consumed by insects or rodents.

Apart from emmer chaff, other species are also represented by a few remains. There is a small admixture of barley, probably a contaminant of the emmer, some grass and other weed seeds, and a few pieces of safflower seed (*Carthamus tinctorius* L.). These may not all have been associated directly with the emmer spikelets pounded in the mortar. For example, oil-rich safflower seeds may have been processed separately from, and in addition to, emmer spikelets. A few miscellaneous items not obviously part of a grain consignment, perhaps part of an accumulation of plant materials on the floor of the room brought in by various means, include small fragments of *Tamarix* twigs, other unidentified twig fragments, bark, and leaf pieces.

The elaborate emplacement of this mortar is unusual but not unique. As mentioned, a similar but less elaborate mortar edging has been found at Deir el-Medina. Peet and Woolley (1923) mention a number of limestone vessels with a built-up surround, calling them jar stands. One from Long Wall St. 7 is illustrated by them (WV, 83, Fig. 12),
described as a mortar which was probably a jar stand. Perhaps the bottom of the vessel interior was smooth, but the manner in which it was emplaced suggested use as a jar stand. In view of the unequivocal mortar emplacement at West St. 2/3, this particular limestone vessel, as well as the others which were surrounded by mud brick or stones and mud plaster, were very likely emplaced mortars.

As far as can be determined from the earlier reports of the Amarna village, the most common method of emplacement was to set the vessel into the ground so that the rims were either flush with the floor level or slightly protruding. Less commonly, mortars were set into the ground and provided with a stone or mud brick surround. Fewer still were arranged as with the mortar in the front room of West St. 2/3, with the base set more or less at floor level and a surround built up around it. Some mortars seem not to have been emplaced at all, but were found loose, although it is difficult to be sure of this.

The older reports hint at mortar emplacements with missing mortars. One is a depression located in the south-west room of East St. 1 (WV, 70). The excavators suggested this may have been for a stone bowl. The hollow has a diameter of 45 cm and a depth of 25 cm, which corresponds well to the dimensions of a mortar. A second possible trace is the round depression in the front room of West St. 13 (WV, 86), originally tentatively associated with a column base. Its location, however, is unusual for a column in village houses. No dimensions are given, but the fact that a wooden pestle was also found here is suggestive, although inconclusive. Finally, the other depression, also said to be for a column base, was found in the living-room of West
St. 15 (WV, 86), and here dimensions are provided. The diameter is 30 cm and the depth is 8 cm, which, combined with the location, certainly better fit a column base. With more detail, such as profiles of these depressions, or a description of the floor construction, a greater degree of confidence in identification might have been possible.

Ambiguous records which may refer to mortars or emplacements occur for several houses. Usually, when the published report states an area was screened off for bread making, it also states that a mortar was found within this area. Three houses, East St. 11 (WV, 72), Gate St. 12 (WV, 74), and West St. 9 (WV, 88), are described as having a screened-off area, but no mortar is mentioned. Is this an oversight, or can it be taken that no mortars were actually found? In the summary of the East St. 10 kitchen (WV, 71), a "bread-making area" is described, no mortar is mentioned in the text or shown on the plan, but a mortar was in fact found here. The room is described separately in detail as representative of kitchens in general at the Workmen's village (WV, 64), and here, the mortar is mentioned. Also, Pl. XVII, #6 shows this area with the mortar embedded flush with the floor surface.

No conclusions can be drawn, but these examples indicate the level of uncertainty which accompanies any attempt to reconstruct the full layout and holdings of the village houses at Amarna.
3. General presence of mortars

a. Deir el-Medina

Looking for the extent of mortar installation across the village of Deir el-Medina is complicated by the different excavators involved, inconsistent recording, and damage or destruction to many houses by illicit digging or floods. The absence of installations of any sort in these areas may indicate they were never there, or they were destroyed, and it is now impossible to distinguish between the two. On the other hand, a large heavy object such a limestone mortar may be uprooted, but it is unlikely to vanish as a result of flooding.

Disregarding the houses which have been damaged or destroyed and which therefore cannot be accurately assessed, there are still a large number with no mortars. Many occur in the north-west quarter, where other domestic installations are also missing. Five houses contain ovens and/or quern emplacements, indicating that cereal processing and baking took place there, but no mortar. These are houses NE.I, NW.I, NW.III, NW.XII, and C.VI. (The number is higher if damaged and destroyed houses are taken into account. Two damaged houses shown separately on the plan may be one large house, in which case the one large house has all cereal processing installations. These are NE.XVII and NE.XVIII.)

The numbers are low, but puzzling. There are three possible explanations. Some mortars may have been broken, and not recorded by earlier excavators, thus distorting the numbers downwards. Certain inhabitants may have taken their mortars with them when the village was abandoned. In view of the large number of mortars left
behind, it seems a less likely possibility. Thirdly, mortars (and other equipment) may have been shared amongst households. It is, however, difficult to think of possible reasons for sharing mortars in particular. None of the houses with other cereal processing installations except mortars are particularly small and thus lacking in space. Indeed, NE.I is one of the largest.

Altogether, slightly more than half the houses at Deir el-Medina have mortars. Of the houses which do contain mortars, twenty three (34% of all houses) have just one, NE.XIII has fragments (the total number was not estimated by the excavator), and thirteen (19% of all houses) have either two or three mortars. The possible reasons for multiple mortars are discussed below.

b. Workmen's village, Amarna

The situation at the Workmen's village, Amarna, is clearer, although not without problems. Kemp (1987a: 40-46) has summarized the location of food preparation installations, amongst other features, at the Workmen's village. Included in his survey are mortars and quern emplacements. His survey looks at overall diversity within households, whereas the discussion here is concerned with cereal processing installations in particular. Kemp (1987a: 41) counts a total of 25 mortar emplacements from the earlier excavations, as well as 2 from West St. 2/3, and perhaps 1 each from Main St. 8 and East St. 1. Kemp considers the shallow stone circular bowl of 25 cm diameter from Main St. 8 as a possible mortar.
It has been shown that any attempt to decide upon a precise figure is hampered by incomplete information and uncertainties in identification. On the assumption that most limestone bowl-like vessels are in fact mortars, excluding the hourglass-shaped items found in the living-room of Gate St. 11, the total number of mortars recovered from the Workmen's village by both expeditions is actually 34. Several features immediately become apparent. Firstly, unlike Deir el-Medina, 6 mortars are in the streets. Secondly, two mortars were recovered from living-rooms. Thirdly, some houses have more than one mortar.

It seems reasonable to look upon the village streets as extensions of house work space. A worker standing beside the wall would not be blocking the street, and siting a mortar outside the house would free more space indoors. It would also allow communal access to one mortar, as discussed below. Of the six street mortars, four were rimmed with mud or stone surrounds, while two were not.

Limestone vessels in living-rooms are rare, and only occurred in two houses. One is Main St. 7, where it is described as a pot stand let into the floor (WV, 78), and the other is Long Wall St. 10. In this case, the mortar appeared to be loose, and therefore, may have been moved from its working position. The rarity of mortars in living-rooms places a question mark over the function of the limestone vessel in Main St. 7.

Five houses - 14% of the totally excavated houses, excluding the yard of West St. 13 - contain more than one mortar, a situation which also occurs at Deir el-Medina. Experiments have shown (see below, IV)
that the time taken to process a given volume of emmer spikelets in a mortar is substantially less than the time needed to grind cleaned grain produced from those spikelets. No more than one mortar ought to be needed to supply grain to one quern. The suggestion is reinforced by the processing gap between pounding and grinding; grain freed by pounding must first be winnowed and sieved before it can be ground.

There are two possible reasons why one household should possess more than one mortar. One is that, in some houses, emmer spikelets were pounded in bulk to obtain a larger volume of grain than was ground at one time, and that this task was shared amongst members of the household. A second possibility is that other commodities were also pounded in mortars, and it was desirable to use different mortars for different types of material. One example is oil-bearing seeds crushed for oil: oily chaff may be more difficult to winnow and sieve. If this is the case, it would seem either a specialized task, or non-essential to have separate mortars since the minority of houses (at both Amarna and Deir el-Medina) have more than one mortar. Evidence which tends to undermine this suggestion are the few pieces of safflower seed found amongst the assemblage surrounding the emplaced mortar in the front room of West St. 2/3.

The archaeological evidence currently does not allow us to assess how likely these two suggestions might be. The best way of testing them would be to examine plant remains recovered from around mortars. Unfortunately, the opportunity to do this is probably now lost, for Deir el-Medina is completely excavated, and the unexcavated portions
of the Workmen's village at Amarna are badly disturbed. Nevertheless, the one plant assemblage associated with a mortar recovered during recent work shows that the remaining unexcavated houses may still retain valuable archaeobotanical evidence, and should be borne in mind by any future archaeologist.

A number of houses cannot be assessed for the presence of mortars because they were not completely excavated, or the contents were not fully published. The houses where the status of mortars (and other installations) is in doubt are: Gate St. 11 and 12 (front rooms not completely excavated), Long Wall St. 1 (front and central rooms not excavated), Main St. 2 and West St. 15 (no description of front rooms provided). The plan of Main St. 2 shows three different types of circle. It would be unwise to draw a conclusion from the plan alone, as circles are used to indicate items other than limestone vessels. Nothing is shown on the plan for West St. 15. One more house which was fully excavated and described, but which may or may not have contained a mortar, is East St. 1. Here, the excavators suggest (WV, 70) that a depression in the south-west corner of the house may have been for a stone bowl.

Of the excavated or partially excavated houses, there are nine altogether which appear to have had no mortars. If this was the case, one explanation is that these houses originally did contain mortars, but they were subsequently removed, leaving no trace because they had not been emplaced, or the emplacement was too ephemeral to be preserved or recognized. Recent excavators, with perhaps a greater awareness of what might be recovered, did not find a mortar in Gate
St. 8. Much of the floor, especially in the front of the house, was badly disturbed by illicit digging, so it is possible that a emplacement may have been destroyed. Gate St. 9, however, next door, also affected by illicit disturbance, did contain a mortar. Although it was removed from its original location, the emplacement was fortuitously partially preserved. It is not possible to be certain that some houses never had mortars, but it is worth considering the possibility.

Of all the fully excavated houses, the nine apparently without mortars are Gate St. 8, Main St. 3, 4, and 5, Long Wall St. 12, and West St. 13, 19, 21, and 26. Kemp (1987a: 42) states that some of the houses were probably not normal residences. He includes amongst these Main St. 3, Long Wall St. 8, and West St. 23. Towards the end of village occupation West St. 23 was apparently not a house at all, but an animal pen (1987a: 42), and Kemp (1987a: 44) suggests that the owner lived in West St. 26 opposite. In addition, Kemp (1987a: 44) suggests that Main St. 3 was not used as a house, but perhaps as a workshop for the neighbouring Main St. 2, because it lacks nearly all the domestic features of other houses, including stairs, mortar and quern emplacement, and oven. Also, it was decorated with wall paintings, a rare occurrence in the village. Long Wall St. 8 is anomalous because it has an unusual ground plan, with, uniquely, the oven in one of the front rooms.

If these houses never had mortars, did their inhabitants have access to others? Little can be added to the discussion of Main St. 3. The people of Main St. 4 and 5 would have had easy access to the mortar set in the street just opposite their front doors. People in West St. 13
may have used the mortar just down the street in front of West St. 15, which neighboured 13 plus its extra courtyard (WV, 86). If the plan can be relied upon, and no mortar was found in the front room of West St. 15, the street mortar may have been used by that household as well.

Turning to the northern end of West St., house 23 seems to have been given over to animal keeping, but has a mortar just inside the front door. If the house was used or owned by the inhabitants of West St. 26, as Kemp suggests, they may have sited their mortar there, rather than their own house. This installation may have been shared with the occupants of West St. 21, who also did not have a mortar. The situation for West St. 19 is unclear. As discussed above, it is not certain whether this house was lacking a mortar. If it was, the occupants may have used the mortar inside West St. 23, or the mortar in the street beside West St. 15. West St. 19 is about equidistant between the two.

This leaves two houses, Long Wall St. 12, and Gate St. 8 which apparently neither had mortars within them nor had nearby communal mortars. Both had quern emplacements (see below, Section F), showing that the occupants processed cereal into flour. Gate Street seems not to have been fully excavated by Peet and Woolley, so the possibility remains open that a mortar emplacement was in the street further south. Perhaps the occupants of these two houses had the use of a mortar within another house. In view of the apparent rarity of this arrangement (much more than at Deir el-Medina), it seems unsatisfactory - but see below, Section V.C.5.
E. Pestles, and their association with mortars

Pestles are rare at either village. This may be because of differential preservation for wooden ones, or because they are easily portable. Bruyère (DelM, 74) mentions finds of short granite pestles at Deir el-Medina, but no wooden ones. The only location specified in the description of Deir el-Medina houses is SE.IX (DelM, 276), where apparently a number were found, but unfortunately neither a description nor precise find spots are available. One mortar was found in the south-east corner of the east central room of this house.

More pestles are noted from the Workmen's village at Amarna, all from the earlier excavations. Both stone and wooden pestles were recovered, but there is little accompanying description. Stone pestles are referred to as pounders, and no dimensions are provided. Wooden pestles are referred to as either pestles or pounders; whether this is meant to convey any distinction is unknown. Length does not seem a distinguishing criterion: the wooden "pounder" from the front hall of West St. 13 was 55 cm long (WV, 86).

A very well preserved wooden pestle from the front hall of Main St. 6 is illustrated in WV, Plate XIX, #1, right. From this figure, it can be calculated that the length measures about 89 cm. The pestle is an elongated drop shape, fashioned by a chisel, whose marks can be seen over most of the surface. The upper 14 cm or so, where the pestle would have been grasped, is smooth and looks almost polished, no doubt from extensive handling. This section is barely 3 cm in diameter, but the base, just before it curves at the bottom, has a
diameter of just over 8.5 cm. The photograph shows some cracks, but it is not possible to say whether these were present while the pestle was in use. The whole length is slightly warped. This is likely to be original, not a subsequent deformation of age. The type of wood it was made from is unknown. It was likely to be hard and relatively dense, to withstand the pounding action, and as an essential and standard tool, was surely made of an indigenous Egyptian species.

In their overview of village houses, Peet and Woolley (1923: 61) mention that pestles were stored in the front hall. However, no particular pattern is seen in the house-by-house descriptions. Does this mean there were more recovered pestles than the report mentions?

None of the four stone pounders, or pestles, was found in the same room as a mortar. The association of stone pounders with mortars within a house is unclear. Two were found in the south-west corner of East St. 1, where only a depression of mortar-like dimensions was found (WV, 70). Another was found in the kitchen of Long Wall St. 1 (WV, 82), a house which was mostly left unexcavated. The fourth stone pounder was found in the kitchen of Main St. 10 (WV, 81). No mortars were found there, but two were uncovered in the front hall.

Of the six wooden pestles, half were directly associated with mortars in the same room, or in the case of one, found right beside the mortar opposite Main St. 8 (WV, 68). One of these was the fine specimen illustrated in WV, Pl. XIX #1, found by the mortar in Main St. 6 front hall (WV, 77, 78). Two pestles were from the same house, Main St. 8, one in the living-room and one in the kitchen (WV, 79).
Only one mortar was found in this house, in the front hall. Altogether, pestle numbers are far too low to determine whether houses with more than one mortar had more than one pestle, and thus the ability to bulk process a greater quantity of spikelets at once.

The suggestion that some households shared the same mortar is supported by the find of a wooden pestle in the front hall of West St. 13, which contained no mortar (WV, 86). The nearby mortar in the street is on "public" ground, making access to it straightforward.

Where pestles are found, they are usually associated with mortars, as would be expected. The discovery of two stone pounders in East St. 1 tends to strengthen the suggestion that a mortar had once been in the same room, and the discovery of a wooden pestle beside the mortar in Main St. outside house 8 reinforces the hypothesis that this type of rimmed limestone vessel did function as a mortar.

F. Quern stones
The saddle quern can be described in general terms as a stone slab, perhaps shaped on the sides and underside, but often roughly, while the upper working surface is more or less flattened. It is used in conjunction with a hand stone, which may be of varying shape and size, but has at least one more or less flattened surface against which grain is milled. This somewhat unprepossessing appearance may explain a frequent lack of interest in saddle querns on the part of archaeologists (Sumner, 1967: 4-5), some of whom may not have recognized them in excavations. Peet and Woolley (1923) record five saddle querns, unfortunately with no illustration, but with two brief
descriptions which makes their identification of these artefacts seem reliable.

The quern from the front hall of Main St. 6 is described as "a flat granite rubbing quern, 45 cm by 20 cm" (WV, 77), and that from the front hall of Main St. 8 as a "flat saddle quern of red sandstone, 34 cm by 18 cm" (WV, 79). These dimensions correspond well to the querns I have examined which were found during a survey of the entire site of Amarna (Delwen Samuel, unpublished data). The other three artefacts of this kind are not described; two are simply called querns and one, a rough millstone.

The identification of other possible querns from the earlier Amarna report is, as usual, affected by a vagueness of terminology. Three objects are referred to as stone rubbers, but no drawing, description, or measurements are provided for any of them. They cannot be ruled out on the grounds of terminology, as this is notoriously inconsistent. Of these other possible querns, one is called a limestone rubber, and is probably not a quern. Limestone does not appear to be a material used for querns at Amarna, and is an inferior stone for this type of tool. The other two simply cannot be assessed on the basis of the single adjectives they are accorded: black and granite rubbers respectively.

Two whole querns and one fragment were found in the course of recent excavations within the boundaries of the walled Amarna village. They are listed in Appendix A.
Bruyère (1939: 74) provides a general description of the Deir el-Medina kitchens, in which he states that most contained a granite milling stone and granite hand stone. The actual instances recorded in the house-by-house descriptions are relatively few; altogether, he mentions grinding stones specifically from eight different houses. This suggests more were found but not mentioned specifically in the excavation report. He also states that dough was mixed and kneaded on granite slabs (DelM, 75). The criteria used to distinguish the two, grinding slabs and mixing slabs, are not defined. In my opinion, identification of such stone slabs for mixing or kneading is incorrect, and my reasons for this are given in the next section. Kneading slabs as designated by Bruyère are much more likely to be saddle querns.

The numbers of querns abandoned at Deir el-Medina and Amarna may be unusual, and may perhaps be indicative of rapid departure by the inhabitants. Since saddle querns as a class of artefact tend to be ignored in excavation reports, it may be difficult to assess from other site reports how many whole and fragmented querns are normally found. One would certainly expect quern fragments broken during use, but these are even less likely than whole querns to be recognized or noted.

As the location of quern stones is directly related to the location of quern emplacements, this subject is discussed below.
G. Quern emplacements

1. Description

During the 1985 excavations at the Amarna Workmen's village, a distinctive, box-like structure was uncovered in Gate St. 8 (Kemp, 1987a: 3, Fig 1.3). Many installations like it, some in a much better state of preservation, have been found in both the earlier excavations at the Amarna village and at Deir el-Medina. A further example was subsequently excavated in 1986 in West St. 2/3 (Kemp, 1987a: 5-6).

At both Amarna and Deir el-Medina, each of these structures is invariably built against a structural wall, and often but not necessarily set into a corner (see Fig. 5.8). Three low panels of mud brick and the structural wall form a hollow box, but one panel, perpendicular to the wall, is built up higher than the other two. Thus, the two lower panels are generally about 30-40 cm high, while the third rises about 30 cm further. This mud brick box was filled with stones and mud, often with a top layer of ash (Kemp, 1987b: 26). The better preserved examples from Amarna and Deir el-Medina demonstrate that the sloping upper surface was covered in a layer of gypsum or mud plaster.

On both sides of this box, there are usually very shallow separate compartments against the structural wall, but sometimes this occurs only on one side. These compartments are delineated by a coping of mud plaster which is generally 10-15 cm high. The surfaces are often plastered with one or more layers of gypsum.

Some of these installations are shown in Bruyère (1939: 75, Fig. 24; Pl. XIII), while Peet (1921: Pl. XXVII) illustrates a very good
specimen from Gate St. 11, and one example from Main St. 5 is drawn in Peet and Woolley (1923: 77, Fig. 11).

2. Identification

Kemp (1986a: 3; 1987a: 6) concludes that such constructions are quern emplacements. Bruyère (1939: 75-77), however, has identified them as kneading troughs. Sist (1987: 56) states that bread dough was mixed on stone slabs set at an angle to enable surplus water to drain off. Although not explicitly stated, this idea seems to be related to Bruyère's interpretation. (Both Kemp and Bruyère draw upon the artistic record to support their different views.)

The identification of these installations as kneading troughs, and the accompanying stone slabs as mixing or kneading stones, is surely not correct. There are four grounds for this. Sist's interpretation can be rejected on biological grounds. In excess water, starch granules disperse into suspension creating a slurry, not a coherent, workable dough.

Secondly, the action of extensive kneading is pointless for emmer or barley dough, because there is no protein which forms visco-elastic gluten (see Chapter 3, Section VIII.C.2). Therefore, a special kneading installation is unnecessary. A long, narrow stone is poorly adapted for mixing or kneading in any case. The action used during mixing is not a linear back and forth movement, but a multidirectional motion, for which a bowl or squarish surface is more appropriate. Kneading also, though using in large part a back and forth movement, also requires a reasonable working width for turning the dough.
The third reason to reject the interpretation of kneading slabs concerns the materials used. Bruyère (DelM, 75) states that the kneading and mixing stones are made of granite, but does not indicate the nature of their surface texture. If the surfaces are polished, they would be serviceable for kneading. Otherwise, even a fine textured granite would not be suitable for mixing dough, for the mixture would stick to or become embedded in the interstices of the stone, and might even pull out crystals, so that rock particles become embedded in the dough. Despite Leek's (1972b) discovery of grit in ancient Egyptian bread, this seems most unlikely to have been a deliberate procedure.

Finally, the setting of the emplacements argues against their use for kneading or mixing. Even if the granite slabs were polished, their angled setting in the emplacements would be awkward for mixing. This action would involve a lifting motion while the body is extended, a manoeuvre liable to be extremely hard on the back. On the other hand, as has been shown experimentally (see below, Section IV.F.2), the installation is very well suited for grinding. This involves a back and forth rocking motion without lifting the hands away from the grindstone. Kemp's identification of these box-like structures as quern emplacements best concurs with the evidence.

Locating quern emplacements at Deir el-Medina is straightforward, because uniform terminology is used, and the village plan (DelM, Pl VII, Pl. XXIX) uses consistent representation. The task is more difficult for the earlier excavations of the village at Amarna. The excavators were puzzled by them (Peet, 1921: 178; WV, 61, 64), and
called them different things. A description of their appearance is provided in the overview of the typical village house (WV, 61, 64), but other examples in the house-by-house description do not always conform to this. Some element of interpretation, and indeed guesswork, is frequently necessary when trying to decide whether a given house contained a quern emplacement.

The usual term to describe what is actually a quern emplacement, is "box hearth". This designation was given because of the scorch marks sometimes seen above the installations on structural walls, and the layer of ash, just below the gypsum or mud plaster coating on the top sloping surface. Miller (1987: 14-16) convincingly argues that placing ash beneath the plastered surface of the quern emplacement was a method of insect control, preventing infestation by acting as a desiccant. Many tiny particles of cereal endosperm would have collected on the emplacement. It would have been difficult to clean thoroughly, attracting weevils and similar insect pests. The fire on the emplacement itself would kill insects in all stages of development, and destroy food particles attracting them (Kemp, 1987a: 6; 1987b: 26).

In the earlier excavation reports, sometimes the installation is not given a name but described. Wherever a box or compartment or bin with a shallow bin beside it, both areas whitewashed, is described, this too is very probably a quern emplacement. More uncertain are descriptions such as "a double manger or bin" (Long Wall St. 7, north west corner of front hall, WV, 83), and, in the front hall of West St. 13, a "brick manger (?) 0.50 m high; in south-east corner brick
platform 0.05 m high, perhaps base of bin". The double nature of these structures suggests that they should be considered quern emplacements also. One installation, which is described as a box hearth, can less easily be assigned to the quern emplacement category. This is built on the south wall of the kitchen in East St. 12, which is described as a "box hearth 0.30 m deep with stoke-hole in west side" (WV, 73). It is the stoke hole, with no obvious reason to be in a quern emplacement, which makes its actual function uncertain.

No plant remains directly associated with quern emplacements have been recovered. Bruyère (1953: 96) mentions a "little heap of wheat" beside one emplacement in a tomb house at Deir el-Medina outside the walled village. This is yet another intriguing comment, but the relationship between the two is not made clear, nor is there any further detail about the wheat.

One reason for the earlier confusion about this type of installation is that none of them, either at Amarna or Deir el-Medina, had its quern stone in place on the sloping top. Bruyère (1939: 75) notes that the "seat" of the emplacement may bear the marks of a recess into which the quern stone would fit. The two more recently excavated examples from Amarna (from West St. 2/3 and Gate St. 8) were damaged and their top surfaces did not survive. One feature of the descriptions from earlier Amarna excavations is odd. The upper surfaces of the intact emplacements are described as having two, or sometimes three, basin shaped depressions side by side and of uneven size (Peet, 1921: 178; WV, 64). Were two or three querns used at the same time? Why
then are the depressions of unequal size? The answers to these questions lead to a new suggestion about the construction and use of quern emplacements.

In the general description of the "box hearth" (WV, 64), the upper surface is described as being either lime washed or lime plastered, or, as for the installation in the kitchen of Main St. 5, as having "two shallow oval hollows, lime-washed, with a sort of hole between". When described under the specific house heading, the surface is said to have three shallow depressions, and the accompanying drawing suggests that they are all of the same size and depth (WV, 64, 77).

The only good photograph of the top surface of an emplacement which is preserved with a reasonable amount of its gypsum plaster is that in Peet (1921), Plate XXVII #2. This allows a more accurate appraisal. It shows that the quern stone had been set into the wet gypsum, moulding a depression, but that the stone could be removed without damaging the hardened gypsum surface. The result is a gypsum surface, with a central deep, ridged imprint of the quern, flanked by two broad borders. This gives the superficial, but misleading, impression of three separate gypsum basins. The emplacement in Main St. 5 did not originally hold three stone slabs allowing three women to knead together, as Bruyère (1939: 76) suggests, but one central hollow holding a single quern.

The basin in the centre of the gypsum surface indicates that the quern was held firmly on the emplacement when in use, but was removable. This would help to explain why no quern stone was found
in-situ. Such an arrangement would also allow the top of the emplacement to be swept clean after every use, retrieving most flour falling onto the emplacement surface, and controlling insect infestation. It may also have been designed to allow the quern to be taken elsewhere, or used directly on the ground, although there seems no obvious reason why the latter option should have been preferable.

H. Association and location of quern emplacements and quern stones

1. Workmen's village, Amarna

Virtually all village houses at Amarna have quern emplacements. Of those houses which have been fully excavated, and their total layout assessed, 32 out of 37 probably had quern emplacements (this figure differs from that of Kemp, 1987a: 41, because different criteria are used to count the houses). Of the four houses only partially excavated (Gate St. 11 and 12, Main St. 1 and 2), two certainly have quern emplacements in their kitchens. The description of Gate St. 12 is sketchy (WV, 74), but the plan suggests a quern emplacement was located in the rear north room of this house as well.

Of the fully excavated houses, six had both quern emplacement and a quern stone, five with these two artefacts in the same room. The quern stone from Long Wall St. 6 was near surface level, and therefore cannot be ascribed to this house with certainty. The association in West St. 13 is unsure, as the granite rubber cannot be definitely identified as a quern. West St. 19 has the quern emplacement in the screened-off portion of the front hall, while the quern was found in the stairwell area. This helps to substantiate the
suggestion that querns were removable from the emplacements, as this house, along with the others excavated by Peet and Woolley, were not badly disturbed prior to excavation. Apart from two installations, one in West St. 2/3, where the top was destroyed, and Gate St. 11, illustrated in a photograph (Peet, 1921, Pl. XXVII), there is no information about how intact the emplacements were.

Unlike mortars, the locations of quern emplacements are fairly consistent, perhaps because they take up so much more space. There is never more than one emplacement per household. All emplacements are either in the front room, or a back room - called the kitchen by earlier excavators. Kemp (1987a: 41) has already discussed the distribution of quern emplacements within the houses of the Workmen's village. The emplacement tends to be at the front of the house. Leaving aside East St. 1 and West St. 2/3, which are unusually large and have a different overall layout, just over two thirds of the houses have quern emplacements in the front room. Kemp has suggested (1987a: 41) that, in houses with staircases at the back (Type A houses), emplacements were sited, for preference, out of the way of the street door, while those in houses with staircases at the front (Type B houses) tended to be placed opposite the door in order to achieve better light or ventilation. This may be so, but the comparative numbers are very small (2 emplacements opposite the door, 1 not, for Type B houses). They were probably sited to be out of the way of the living-room door.

The four fully excavated houses which definitely have no installation corresponding to a quern emplacement are Gate St. 9, Main St. 3 and
8, and West St. 24. Of this group, two houses, Gate St. 9 and Main St. 8, were found to contain a quern stone or quern fragment. Because the fragment found in the front room of Gate St. 9 was high in the fill, it cannot be assumed that it belonged to this house; much of the contents of the neighbouring, unexcavated house 10 were thrown into house 9 during illicit digging. By the same token, however, the house may originally have had a quern stone lying on the floor which was disturbed.

The complete quern from Main St. 8 happens to be one of those with some description in the excavation report (WV, 79). It is the single definite example from the Amarna village of a house with a quern but without an emplacement. The inhabitants may therefore have dispensed with raising the quern off the ground, and simply milled on the floor, or they may have had access to a neighbour's installation. The fact that the house seems to have had a bulky weaving loom in the front hall (WV, 79) is no explanation for lack of a quern emplacement: both of its neighbours apparently also engaged in weaving in their front halls (WV, 78, 80), but still managed to install quern emplacements as well.

Main St. 3 may not have been an ordinary dwelling (Kemp 1987a: 44), but, as the main reason for this suggestion is the lack of domestic installations, the argument is in danger of being circular. If this interpretation is correct, however, it leaves one ordinary house alone in the village definitely without either quern or quern emplacement - that of West St. 24. Since its front door actually opens into Long Wall St., one cannot suggest that the inhabitants of this dwelling made
regular use of the emplacement in West St. 23, which appears to have been given over to animal keeping (Kemp, 1987a: 44). Houses with no signs of grinding tools are discussed further in section V.C.5fs.

2. Deir el-Medina

In contrast to the Amarna village, houses at Deir el-Medina have relatively few quern emplacements. Most (44 out of 68 houses, or 65%) have neither visible remains of an emplacement, nor are quern stones mentioned in the published report. Of the five houses containing both quern emplacements and quern stones, the location of the quern was not recorded for four. The one recorded location of a quern stone in a house with a quern emplacement is NE.V; both were in the same back room. Nevertheless, the fact that there are houses with both querns and emplacements, and no emplacement was found with its quern in position, strengthens the suggestion that querns were removable. A further six houses contained emplacements with no record of querns. Of the eleven houses with emplacements (16% of all houses), six are in the north-east quarter, while the others are found in one or two houses from each of the other quarters, with the exception of the south-west.

Unlike the Amarna village houses, at Deir el-Medina quern emplacements tend to be sited at the back of the house. The numbers are small, with only eleven emplacements in total; of these, seven (64% of all houses) are in one of the back rooms.

There are thirteen houses (19% of all houses) with loose querns only, slightly more than those with emplacements. This indicates that at
least some houses at Deir el-Medina without emplacements still had facilities for grinding, and that emplacements were not necessarily standard. People may have chosen not to build a quern emplacement because it takes up a lot of space, it ties grinding to one place, and perhaps it was more difficult to clean. The people of the village may well have preferred to take their grinding stones with them to another house and mill flour in congenial company, as is done today (Schön and Holter, 1990: 363). This point is discussed further in section V.C.5.

Most of the houses at Deir el-Medina have no emplacements and no record of quern stones, and one house at Amarna falls into this category. The suggestion has been made that quern stones were removable from emplacements, and that they could be carried around. This may explain not only the houses with no grinding facilities of any kind, but also those houses, undisturbed before excavation, which contained emplacements but no querns. The quern stones may simply have been taken with the inhabitants when they left the villages. Without an emplacement, no trace of quern use would be left.

IV. Experimental cereal processing

A. Introduction

Cereal processing experiments were carried out at Amarna with, as far as possible, authentic equipment and cereals. The need for authentic equipment is well illustrated by Meurers-Balke and Lüning's work (1992) with glume wheat processing. For their pounding experiments, they used both wide wooden flower tubs with flat bases as well as tall narrow mortars made from hollowed tree trunks (1992: 350). These
choices seem to have been made on the basis of expediency, but the tall narrow mortar is a standard tool in Africa for dehusking sorghum and millet (e.g. Richards, 1939: 594). At the end of their experiments, pounding in the wide wooden tubs failed to affect more than 30% of the spikelets, about 10% by weight of the material was individual grains which were still husked, and 50% by weight was whole clean grain (Meurers-Balke and Lüning, 1992: 355, Fig. 12). The same treatment in the tall narrow mortar produced 85% whole clean grain, about 2% unaffected spikelets, and a very small quantity of husked individual grains. These very different results are apparently entirely due to the type of equipment used.

The main aims of my experimental work were: to establish the way ancient equipment was manipulated; to determine the effect of the tools and to trace the changes at each processing step on the cereal assemblage; to evaluate existing assumptions about cereal processing in ancient Egypt. Emmer wheat was obtained from purchases made in northern Turkey, or from Turkish emmer grown on in Britain. There were two reasons for the focus on emmer. Firstly, the only assemblage of plant material associated with a domestic mortar in the Workmen's village (West St. 2/3, front room) was composed primarily of emmer spikelets (see above, Section III.D.2). Secondly, by far the majority of ancient bread loaves which I have examined, mostly dating to the New Kingdom (see Chapter 6), are made from emmer. Thus, emmer seems to have been the cereal of choice for bread at this period.

Both unsuccessful and successful approaches for each stage of processing are described, and their implications discussed. A summary

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of experimental processing, with the times taken for each step, and the attendant product and by-product of each stage, is set out in Table 5.3.

B. Grain cleaning

Emmer spikelets must have been cleaned at some stage, as undesirable items such as small stones, clods of earth, and weed seeds of similar size and shape to the cereal being processed, cannot be fully winnowed and sifted out. There is more than one place in the processing sequence at which grain cleaning may have occurred. Grain washing, attested ethnographically, seemed a quick and easy way of cleaning out a large number of contaminants without the need for painstaking hand sorting. Earlier experiments established that washing barley worked very well. Washing emmer spikelets, however, was not successful. They were placed in a large basin and a bucket of water tipped over it - the spikelets all floated. This must have been due to the trapped air amongst the layers of chaff. After about 2 to 3 hours of soaking, some of the spikelets had lost their air pockets and began to sink. Unlike barley, diseased, insect infested and empty spikelets floated together with healthy spikelets, so that separation by water is not feasible. After more than 24 hours of soaking, there were still large numbers of healthy spikelets floating with diseased or sterile spikelets.

The washed emmer was nevertheless carefully retrieved. Washing had removed much of the smaller undesirable additions including dust and small weed seeds. As a result, experimental fine sieving of these spikelets was inconclusive. Traditional processing of semi-clean emmer
grain removed from storage is fine sieved, separating the grain, which remains in the sieve, from small weed seeds, tail grain, and small fragments of heavy chaff (Hillman, 1984b: 134). Following the fine sieving, emmer grain is winnowed a final time to remove light chaff. Fine sieving spikelets needs to be tested with unwashed material.

I experimented with winnowing spikelets by pouring them from chest height onto a cloth. This worked reasonably well for the removal of light items, but is not practical on a small scale because the spikelets scatter broadly, and good spikelets are either wasted, or take a long time to retrieve. The best method for cleaning emmer spikelets of straw, weed seeds, clumps of earth, and small stones seems to be to pick through them by hand (Fig. 5.9, Fig. 5.10) as is done in the final stage of emmer grain cleaning which Hillman observed (1984b: 134). It took me about 10 to 15 minutes at first to sort through 400-500 mL of emmer spikelets in a basin. The process could be speeded up by spreading the spikelets more thinly over a low table or similar flat surface, and through practice in training the eye and hand to notice and pick out impurities. In any case, the time recorded to clean spikelets is not unreasonably slow. The resulting clean spikelets are illustrated in Fig. 5.11.

C. Pounding

1. Tools

For pounding experiments, the ancient Egyptian limestone mortar from Gate St. 9 was used. (Its measurements are listed in Table 5.1, and it is illustrated in Fig. 5.7.) Its total capacity to the rim is 2.4
litres. Its capacity to within 6 cm of the rim (approximately the maximum possible height to which it could be filled during use, and the point at which the flanged edge begins - see Fig. 5.7) is 1.2 L. Because it was protected from damage by burial, it is in excellent condition and very robust. Earlier pilot experiments (Samuel, 1989: 259) established that the ancient equipment could be used without ill effect.

The replica pestle was designed to match as closely as possible the ancient published pestle (22/149) found at the Workmen's village by Peet and Woolley (1923: 78, Pl. XIX, #1) (see above, Section III.E). It was fashioned from a large wood beam originally measuring 7.5 by 7.5 cm. I have not been able to establish what type of tree the wood comes from, although I believe that it is not native to or grown in Egypt. The wood is reddish in colour, and very dense and hard. An outline of the finished replica pestle base is shown in Figure 5.12, and compared with the original size of the ancient pestle base. Apart from its slightly smaller diameter (on the order of 1 cm), the curvature exactly matches the ancient pestle. The whole replica is shown in Figure 5.13, and is very heavy (weight undetermined).

2. Techniques and results
As discussed in Section III.D.2, two types of mortar installation have been found archaeologically. The embedded type was replicated, because it is the simplest, and the easiest to set up and dismantle each season. Although the archaeological evidence indicates that mortars were placed so that the rim was flush with the floor (see Peet and Woolley, 1923, Pl. XVII, #5 and 6, for example), I set the mortar
so that the rim protruded a few centimetres above the floor surface (Fig. 5.14). This made it easier to avoid knocking dust and sand into the mortar because the replica mud plaster floor was not as well made as the ancient cobbled floor.

First, approximately 200 mL of emmer spikelets were placed in the mortar, to a depth of 1.5 to 2 cm, and pounded. It was impossible to prevent the contents scattering widely, except by pounding with such gentleness that there was no effect on the spikelets apart from a slight chipping of the chaff. When 500 mL of spikelets were placed in the mortar, filling it to a depth of 5 cm, most of the contents did not scatter, but sloshed out. The remaining dry grain and spikelets were very difficult to remove completely from the bottom. Pounding dry spikelets in this type of small mortar is ineffective and wasteful.

Hillman (1984b: 135-136) records that, when bran is removed from bulghur in the traditional sequence, it is first sprinkled with a little water before pounding. Mark Nesbitt (pers. comm.) also observed this in Turkey and suggested the use of water to me. When 200 mL of spikelets were placed in the mortar, and well mixed with about 20 mL of water, the pounding action, if directed to the very centre of the mortar, caused most spikelets to be pushed out to the sides, but most did not fly out. The pestle pushed aside most of the contents and landed on a thin bed of spikelets, crushing the grain quite finely, as well as breaking open spikelets to some extent. The most effective way to pound this amount was to hit the pestle against the sides of the mortar, crushing the spikelets against the sides, as well as pushing them towards the centre. Some spikelets were split open,
releasing the grain inside, but the most frequent effect was that chaff became shredded and the grain finely crushed. This was an improvement on pounding with dry emmer, but not ideal.

The best results were obtained when between 400-500 mL of spikelets are placed in the mortar and well wetted (Fig. 5.15). Under these conditions it was possible to pound vigorously with very little material ejected from the mortar. Many whole emmer grains were freed from the chaff. As well as helping to bind the spikelets together, the added water made the chaff pliable. Grain was therefore pushed out of the spikelets, and the spikelets themselves became more "shreddable". Dry spikelets are resistant to shredding, so that the grain is firmly gripped in the glumes and will not "pop out". Even with this approach, appreciable numbers of whole spikelets (proportion not ascertained) still remained. Their presence may indicate lack of skill on my part, or the need to repound a proportion of each lot. In Hillman's ethnographic sequence (1984b: 131), some whole spikelets may remain after pounding and are recycled back to the mortar.

Within limits, the amount of water did not seem to be crucial. If too much was added, the spikelets no longer cohered, but acted much as they did when dry, sloshing out of the mortar. A spikelet to water ratio which worked successfully was about 4:1. In one experiment, four litres of spikelets were pounded with just over 1 litre of water.

Several changes occurred as pounding progressed and the spikelets began to break apart. The volume of material in the mortar increased because the compact packing of whole spikelets was lost (Fig. 5.16).
The texture of the mass under the pestle altered; it became more "sandy" than "slippery". The sound of the mass sliding under the pestle changed to a more scratchy noise. It is probable that an experienced operator would have been able to assess that spikelets were sufficiently pounded by sound and texture, without the need for constant visual checking as I had to do.

Pounding is a process which requires some strength and stamina as well as skill. Since I found it difficult to control the pestle, my technique was not to lift the pestle very high (Fig. 5.17), but to use muscle power, as well as the pestle's own weight, on the down-stroke. Once the spikelets began to break up, the pestle was directed around the sides of the mortar, with a deliberate effort to grate the spikelets firmly between the pestle and the mortar sides. Progressive circling of the mortar pushed the damp mass down with the pestle, and it also fell into the central well through its own weight. As a result, the whole mass gradually turned over and most of the individual spikelets sheared apart, without getting a great deal of direct crushing force. Some grains were cracked apart, but most remained whole.

The chaff fraction which scattered out of the mortar (Fig. 5.18) resembled the archaeobotanical remains found around the front room mortar from West St. 2/3, suggesting that this approach was similar to the ancient technique. These experiments have demonstrated that pounding in the type of limestone mortar used by the ancient Egyptians, together with a pestle similar to the ancient type, breaks apart emmer spikelets, releasing mostly whole - not crushed - grain, and that the process is relatively efficient. The result of pounding is
a mass of damp shredded chaff of various sizes, mixed with whole grains and large pieces of cracked grain (Fig. 5.19). The overall time taken to pound 400-500 mL of spikelets was about 15-20 minutes. It depends entirely on strength and skill, however, and especially at first, I stopped frequently to assess the effect of pounding on the spikelets.

The effect of parching on this process was not tested, due to time constraints. These experiments suggest that, unless spikelets are slightly underripe or harvested damp, parching is quite unnecessary. Meurers-Balke and Lüning (1992: 357) came to the same conclusion when they carried out experiments with einkorn and emmer to elucidate Neolithic Central European Linear Bandkeramic processing methods. Hillman's (1984b: 129) ethnographic observations of Turkish emmer parching, therefore, may actually have involved damp or slightly underripe grain. He may even have confused the use of the ovens with the next step (see below). Hillman does say whether spikelets, if indeed parched, were pounded wet or dry. I would expect that, with small mortars, even parched spikelets with their supposedly brittle glumes would have to be at least slightly dampened, otherwise there would be the same problems of crushing and flying out of the mortar.

D. Drying

The result of this pounding technique is a damp, slightly sticky mass, which is easily scooped out of the mortar, in contrast to dry grain and spikelets which are difficult to remove. The damp mass must then be dried before the grain can be separated from the chaff. I did this
by spreading each batch of pounded spikelets in a thin layer in the sun (Fig. 5.20). I put them on a cloth on the ground, but they could be placed directly on any hard clean surface. Most of the grain was spread to dry around mid-day. In sunny weather in mid-April, one batch of pounded spikelets, originally making up 400 mL, dried in three hours, between 10:30 and 13:30, without the need to turn it. Turning and stirring would speed up the process.

This is a reasonably quick way to dry the pounded spikelets, but it does take some time. It also requires a reasonable amount of space to spread out thin layers. Free space may not have been limited at all on large estates. In the cramped quarters of the Workmen's village, as well as the small houses in the Main City, the roofs were very likely used for this purpose. In cold weather the process would take longer than during warm or hot sunny weather. Apart from the worst winds, windy days would probably not cause a problem, but would decrease drying time. Any sand blown into the mass could be easily sieved out afterwards (see also Ch. 6.V.C.4.b).

A much quicker way to dry the mass would be to heat it gently over a hearth or oven (see also Ch. 6.V.C.4.c). (This may be the true use of the ovens which Hillman (1984b: 129) mentions.) This could probably best be done in a large open vessel of metal or pottery, with the heat controlled by stirring. This possibility was not tested experimentally due to lack of time, but would be well worth further investigation.
E. Winnowing and sieving

1. General approach

Following the sequence established through ethnographic observation, the pounded mixture of chaff together with whole and cracked grain was separated by winnowing. During experiments this was the most difficult step; both authentic equipment and detailed archaeological information on what might have been used was lacking. My experiments, however, based on Hillman's ethnographic work, have shown the general steps which provide reasonably convincing results, measured by their success at obtaining clean grain. The experimental equipment was related to archaeological finds, although these are few.

I first attempted to winnow by pouring the dried mixture of grain and chaff from a basket at waist height onto a cloth on the ground. The pouring action was difficult to control. During this operation, the wind was erratic, changed direction, and died down frequently. From personal observation, this may be the usual wind pattern in built-up areas such as the ancient villages. Pouring the grain did not help to separate light chaff and grain, and without a fairly strong wind, little of the fine chaff was blown away. However, a certain amount of heavy chaff (not measured) did separate by bouncing away from the main pile. The partially winnowed heap was not easy to gather, as any separation which did occur was not distinct. Quite a bit of grain was mixed up with the area which consisted mainly of heavy chaff. This suggests that winnowing by wind at this stage is not reliable. Such a method requires a fairly large area as well, which may not have been available in closely built-up areas, even on house roofs.
A winnowing basket seemed a better alternative. Its control is entirely up to the operator, it takes up less room, and is not dependent on external factors. It is thus well suited to indoor use, or where space is at a premium. The basket I used was locally made, intended to function as a container, not a winnowing tool. It is made of coils constructed from an inner core of split date palm leaf rib, thickly wrapped around by split date palm leaflets. It measures about 45 cm in diameter, with a low rim about three cm high. Because of the steeply sloping rim, it was not ideal, but seemed to function reasonably well.

2. Techniques and results

About one and a half handfuls of chaff-grain mixture (exact amount not measured) were placed in the upper half of the basket (Fig. 5.21). The basket was held firmly on either side, half way up the sides. It was tipped quite steeply towards the body, and shaken lightly up and down parallel to the angle of the basket, but very little vertically (see diagram, Fig. 5.22). This had the effect of "shifting" or "rolling" the heavy items downward to the lower edge of the basket, with a scatter of grain and chaff up to the upper edge, and most of the fine chaff, mixed with some heavy chaff, up at the upper edge of the basket (Fig. 5.23). When fine chaff was well separated from everything else, a different motion was then used. The basket was lifted up and down, such that the bottom edge moved very little, while the top edge waggled back and forth over a broad arc (see diagram, Fig. 5.24). This kept the material in the bottom of the basket nearly stationary, but spread out the material at the top, creating a better separation between chaff and grain (Fig. 5.25). The
motion was alternated with waggling the sides of the basket back and forth to line up chaff and grain at the top of the basket (Fig. 5.26, Fig. 5.27). If this was omitted, the chaff and grain spread out too far over the surface and became mixed. When good separation of fine chaff and heavy items was achieved, it could be enhanced by a zigzag motion of the basket (Fig. 5.28), and by pushing the heavy material to the bottom of the basket by hand. These actions together separated out much of the fine chaff, which accumulated at the top edge of the basket. The fine chaff could then be flicked out (Fig. 5.28).

To remove the maximum amount of chaff, the process was repeated two or three times. The grain/heavy chaff mixture at the bottom of the basket was replaced back in the centre. This was rapidly achieved by shaking the basket; it was not necessary to move anything by hand. As the winnowing proceeded, a certain amount of heavy chaff was also discarded, but most remained mixed with the grain. Some problems were experienced controlling the discard of chaff, because of the steep basket rim. When the basket was flipped sharply to toss material over the rim, chaff and grain became mixed, and some of the grain fell out as well. At the end of the winnowing process, light- and medium-weight chaff had been separated from a mixture of clean grain, heavy chaff such as empty spikelets, and whole spikelets still containing grain (Fig. 5.30).

This winnowing method suggests that some clean grain can be obtained with a winnowing basket. Once the fine chaff was removed, it was possible to separate about a third of the free whole and cracked grain from the remaining heavy chaff-grain mixture (Fig. 5.31). With a
partially lipless basket, it would have been possible to shake this portion off the edge, but, with the basket I used, the separated grain had to be removed by hand.

The only way to remove the remaining grain from heavy chaff was by sieving (the third sieving stage). This is borne out by the ethnographic record. A range of sieve sizes was not available, making this step experimentally difficult. I used a 3.18 mm geological sieve, which was about the right mesh size. It did not work as well as a flat woven gut or fibre sieve, because the thick, strongly curved metal mesh created many crevices in which spikelets stuck, clogging it up. Nevertheless, with care, a substantial quantity of grain mixed with some chaff could be sieved out (Fig. 5.32). The chaff in this fraction was picked out by hand. The remainder, left in the sieve, was mainly heavy chaff, but still contained a certain amount of grain (Fig. 5.33). Had the sieve been flatter, more grain would probably come through. Another method would be to swirl this fraction in a flat, relatively shallow container, so that the chaff would rise to the top, and the heavier grain would sink to the bottom. The chaff could then be scooped or poured off. This practice has been observed ethnographically. I lacked a suitable container, however, and in the end, some of the grain was simply lost. The final stage was to pick out by hand the remaining contaminants, producing clean grain (Fig. 5.34).

Although somewhat complicated to explain, each step which has been described takes from a few seconds to a couple of minutes to do. The process which I used closely followed the ethnographic sequence. Even
with authentic equipment and skilled handling, however, it would take a single person some time to accomplish the whole winnowing and sieving stage, separating grain from chaff, because each step has to be repeated several and sometimes many times in order to achieve good separation. Altogether, these repeated winnowings and sieving took me about 1-2 hours to process a volume of dried pounded spikelets originating from 400-500 mL of whole spikelets. The time varied according to my developing skills in manipulating the winnowing basket and sieve. It is possible that New Kingdom Egyptians did not aim for perfect separation of grain from chaff and that chaffy by-products were intended for animal feed.

F. Grinding

1. Tools

An ancient granite saddle quern, a surface find from the eastern part of building Q48.4 in the Amarna Main City, was used for grinding experiments with cleaned emmer grain. The quern is 40 cm long, 18 cm wide, and has a maximum depth of 11 cm. It is slightly concave lengthwise, and slightly convex across the breadth (see Figs. 5.35).

The replica emplacement was constructed with the same materials, using the same dimensions as the ancient examples from the Amarna Workmen’s village (Gate St. 8, front room south – Kemp, 1986a: 2-3, and West St. 2/3, western end of southern annexe – Kemp, 1987b: 5). The measurements I took of the Gate St. 8 emplacement are shown in Fig. 5.8, and are very close to the measurements of the replica. The replica itself is not built into a corner, nor does it lie against a structural wall, like every ancient example from Amarna and Deir el-
Medina, but its back lies 42 cm from a building wall. The ancient positioning against a structural wall does not reflect a functional use, but conserves space.

The central box was built of mud brick and mud plaster, with the rear side, near the wall, about 30 cm higher than the other three. The box was filled with sand, stones, and other rubble. Ash was not used on the top layer. The top surface, sloping from back to front, and into which the saddle quern was set, was a hard smooth coating of mud plaster. Traces of both gypsum and mud plaster have been found on the surfaces of ancient quern emplacements. Mud plaster serves well and is easier to dismantle at the end of each season.

Like the quern, the hand stone was a surface find. It came from a dump in the Central City. It is loaf-shaped, and made of pink quartzitic sandstone (Fig. 5.36). Apart from its shape and size, there is no way of knowing whether it was actually used as a hand stone for flour grinding, but in practice, it worked very well. To catch the flour, a basket was placed at the front base of the emplacement. This does not seem to be ideal and there is little evidence archaeologically for the original arrangement. It is possible that flour was pushed off the edge of the quern onto a hard surface of gypsum or mud plaster, and swept up afterwards into a bowl or basket.

2. Techniques and results

Despite a reputation for arduous labour (e.g. Vandier, 1964: 273), grinding at the quern emplacement is not difficult (Fig. 5.37). It does not require much strength, nor is it tiring. The proximity of the
higher rear wall of the emplacement to the building wall creates a space in which the lower half of the body can be wedged and braced. In this position there is no need to use force to grind, although it can certainly be applied. This arrangement of quern emplacement against a backing wall is not essential, and not every ancient quern emplacement was situated in a corner, but it does allow the weight to be taken off the feet from time to time. The thighs against the back of the quern emplacement provide the main bracing point. The greatest stress is on the wrists, which are quite bent, and the bent ankles and feet. A flatter hand stone would reduce the degree of bending in the wrists. After about an hour or so the task becomes boring, but if carried out in the company of others, as was very likely the case, it was perhaps one of the less onerous tasks of daily life.

To grind, the hand stone was placed a third of the way down the quern stone. A small handful of grain was placed carefully behind it. Short strokes broke up the grain without distributing it too far or losing it over the far edge before it had been sufficiently ground. The grain was easily milled into flour by leaning forward with straight arms on the down-stroke, and swinging back and forth at the hips. On the up swing, the hand stone was dragged without pushing on it. This combination of down and up strokes pushed flour down to the end of the saddle stone but prevented whole and partially broken grain from sliding down as well. If the hand stone was pushed while bringing it up to the top of the quernstone, flour was dragged upwards and became mixed with the whole grains. This made it much more difficult to reduce the grain into flour. It was also harder to
push the flour back down the stone and off the edge into the basket without getting whole grains caught up in it. The hand stone was usually held more or less flat going down, and very slightly tipped towards the back of the quern on the up-stroke, but to distribute grain and meal over the surface, the hand stone was held flat while moving both up and down.

Occasionally, a diagonal motion was used from top to centre, to push the grain-meal mixture into the middle of the quern (Fig. 5.38). This was a more tiring motion to execute, and was not very easy with the particular hand stone I was using. It was a useful manoeuvre to retrieve grain and meal pushed out to the sides, without stopping to push it to the centre by hand.

Some pressure needed to be maintained against the hand stone, but leaning with more force against it made little difference to speed or fineness of the flour. The speed of grinding depended mainly on the rate at which the hand stone was pulled up and down the quern. There may be a limit to grinding speed, to prevent loss over the sides, but with practice, the distribution of grain and flour could probably be controlled over the stone while grinding. The finer the flour, the longer it took to grind, not just because more strokes were required, but to avoid losing too much over the sides. It took me just under two hours to grind 1.2 kg of emmer grain into reasonably fine flour. An experienced miller could probably take about half an hour less.
An important result of this experimental grinding is that the milling action alone controlled the fineness of the flour. It is possible to produce a range of grades, from coarse meal to very fine flour, simply by the amount of grinding applied to each batch of grain (Fig. 5.39, 40). There was no need, as has frequently been suggested (e.g. Vandier, 1964: 273; Wild, 1966: 114; Darby et al., 1977: 514, amongst others) to repeat grinding several times in order to obtain fine flour.

During grinding, the greatest loss occurred at the beginning of each cycle, when a fresh batch of whole grain was placed on the stone. A few grains always rolled off the stone to the sides, and often fell off the top of the emplacement altogether. The other loss occurred when meal and flour fell to the sides of the quern and slipped off the edges of the emplacement. This could have been avoided by building a ridge around the quernstone, which would direct such material down into the basket below. If the quern stone is removable from the emplacement surface, this meal and flour could be collected at the end of grinding. Controlling actions to prevent loss over the sides would not then be needed, and the rate of grinding would not be slowed down.

To some extent, impurities in the grain can be removed during grinding. It is instantly apparent if a stone is on the quern, both by the grating feel of the hand stone, and the grating sound. Fine grit is not noticeable. The presence of numerous or large pieces of chaff, whole empty spikelets, for example, is also easily recognizable by feel and sound. It is easy but time consuming to pick out large pieces of
chaff on the quern stone. One or two strokes of the hand stone will remove grain from complete spikelets, and the chaff can be picked out. In the hands of the ancient Egyptians, well pounded and cleaned grain probably had few spikelets in it, and if a few whole spikelets or large pieces of chaff got through to the grinding stage, they were probably picked out by the miller, leaving only a few occasional shreds of chaff.

When the grain is reduced to a satisfactory grade of flour, it can be quickly and easily removed from the quern by several long firm downward strokes, reaching to the lower end of the saddle quern, which pushes the flour off. The drop from the top of the emplacement to the basket on the ground creates a light and fluffy flour. The flour which I produced with these experiments (Fig. 5.41) has a certain amount of fine chaff, mainly because the grain could have been better cleaned prior to grinding. I deliberately produced a flour of different particle sizes, to establish that particle size can be controlled during the milling process.

One suggested use of saddle querns in general is to dehusk emmer (Beranová, 1987: 166). Experimental attempts to dehusk emmer on saddle querns proved how difficult this is, and the very poor quality of the product. Meurers-Balke and Lüning (1992: 346-350) managed to dehusk some emmer grain with a saddle quern, but the work was difficult and highly inefficient. I have tried milling spikelets on the saddle quern also. The result is a mixture of flour, coarse fragments of grain and shredded chaff which is impossible to clean. There is no reason to believe that saddle querns were ever used for dehusking, a
conclusion strongly supported by Meurers-Balke and Lüning (1992: 360).

G. Comments on sieving in the processing sequence

The near-universal consensus amongst traditional interpretations of ancient Egyptian cereal processing is that sieving occurred after grinding (see Ch. 2). These experiments, together with ethnographic evidence, show that sieving is an essential part of glume wheat (and hulled barley) processing, taking place prior to grinding. This is not a trivial question, as it might at first seem. Firstly, the action of sieving directly affects the flour, and therefore, the bread which is baked from it. Secondly, it is an integral part of the processing sequence, and in order to understand the whole, each part needs to be fitted together in its correct order. It has a direct effect on the analysis of use of space in settlements and households.

The assumption that flour was sieved seems to arise for two reasons. Scholars who have looked at ancient Egyptian baking have not realized the significance of glume wheat and hulled barley morphology. As explained in Ch. 3.II, however, the persistence of the chaff is the key factor influencing cereal processing in ancient Egypt. The sieving assumption also arises because of inappropriate analogies with the use of rotary querns and modern Western practice.

Moritz (1958: 156, 157) asserts that the sieve alone affects the grading of flour produced on the rotary quern, and that the control of particle size was very incomplete on the saddle quern. Spalinger (1986: 339) uses this statement to draw conclusions about ancient
Egyptian flour production but this is erroneous, for he effectively compares saddle quern milling to rotary quern milling. My experiments have established that control of particle size on the saddle quern is far more sensitive than Moritz, and most other scholars, have allowed.

In modern and recent traditional milling and baking, flour is sieved. Why is this so? Modern mills sieve out the bran and germ from the starchy endosperm fraction, although by different methods, to produce white flour (Barnes, 1989: 390ff). The bran fraction can be added back to the white flour in different proportions to produce whole meal flour. Sieving also separates out the different size fractions which are created when the caryopsis is fractured and ground. This sieving procedure was established before the advent of modern, stainless steel roller mills; similarly, traditional stone ground flours were also sieved (David: 1977: 30-31).

The second stage at which flour is sieved comes at the actual point of food preparation. Sieving the flour makes it light by incorporating air, and provides the resulting bread, cake, or whatever is being made, with a lighter texture. The experimental grinding described above shows that this very effect is produced by the flour falling off the edge of the quern emplacement onto the ground or container below. It is doubtful if sieving could improve on this aeration. Sieving to lighten flour texture is thus redundant in the New Kingdom ancient Egyptian process.

It is quite possible that the ancient Egyptians sieved flour to produce a consistent very fine texture for some baked products. They were
certainly able to create a very fine linen weave, such as 64 warp threads by 48 weft threads per square cm (Donadoni-Roveri, 1987a: 193). As shown by grinding experiments, however, the fineness of the flour could, in large part, be controlled on the quern stone, and it is quite possible to produce a very fine flour by the grinding operation alone. For anything other than a very fine consistent flour, this would probably have been sufficient.

To test whether sieving could remove large impurities such as chaff, as suggested in earlier studies (see Ch. 2) I passed the emmer flour produced on the saddle quern through a 3.18 mm geological sieve. Some of the largest pieces of chaff (spikelet forks with whole glumes attached, and whole glumes) were retained, along with some of the whole grain, but a lot of chaff also passed through, including large chaff and whole grains. Much of the chaff removal was a result of the crevices created by the stiff metal mesh. A flat gut or fibre weave mesh would probably have allowed more large chaff through. A larger mesh size would be even less useful in removing large impurities, although a slightly smaller mesh size might be useful. Sieving does not seem to be an effective way to remove large pieces of chaff from flour, although this should be tested with a more authentic sieve. It would be easier and less wasteful to clean the grain thoroughly prior to grinding, than to attempt to clean the flour afterwards.

It would be worthwhile testing the use of a fine sieve, to check how much chaff is removed from flour, and whether substantial quantities of coarse meal are also retained. In view of the difficulties with stiff
metal mesh, sieving experiments need authentic gut or palm mesh to test the effects on emmer flour.

A final reason for rejecting the idea that flour was sieved as part of the standard sequence of cereal processing comes from the examination of ancient bread loaves. This subject is discussed in some detail in Ch. 6.IV.C. Suffice it here to say that most, but not all, bread from ancient tombs contains large pieces of endosperm, up to the size of whole grains, embedded in the loaf. Loaves without whole grains frequently contain particle sizes ranging from very fine to quite coarse - like the texture of modern Scottish oatcakes. They do not contain uniform sizes as would be expected if the flour had been sieved. This texture argues against the standard use of a fine sieve for milled flour.

V. A model for New Kingdom emmer processing, and some applications
A. Introduction
The previous sections of this chapter have dealt with ethnographic, archaeological, and experimental evidence, to investigate how clean grain was most likely obtained from emmer spikelets, and how flour was then produced. This section draws these different strands together to propose a general model for New Kingdom emmer processing. It then goes on to demonstrate wider issues which can now be explored, through the confident identification of archaeological remains and an accurate understanding of their function. Two areas linked to social interactions and one economic issue are examined briefly. These wider issues relate to the use of space, village household self-sufficiency, and commodity exchange.

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B. Emmer spikelet processing

The first factor which guides the post-harvest processing sequence is the form in which emmer is stored. Hillman (1981: 131, 138; 1984a: 8, 11; 1984b: 126) has suggested that in dry climates, the bulk processing which takes place at harvest time could be expected to culminate with clean grain, which would then be stored, rather than storing spikelets. However, archaeobotanical work does not bear this out. At Assiros in northern Greece emmer was stored in spikelet form in a region of dry summer climate (Jones, 1981; Jones et al., 1986). Similarly, spikelets, not cleaned grain, were stored at the 4th millennium Chalcolithic site of Kuruçay in central Anatolia (Nesbitt, in press). The form of storage may be influenced less by convenience, and more by the problem of insect attack. Grain stored in the spikelet provides the important advantage of much reduced insect infestation.

No New Kingdom granary with original contents intact has been discovered. We do, however, have indirect archaeological evidence that emmer was stored in the form of spikelets, rather than clean grain. The rich plant stores from Tutankhamun's tomb included emmer, nearly all in the form of spikelets (Boodle, n.d.; De Vartavan, 1993). A model granary from this tomb, now in the Cairo Museum (display number 1641) has 16 compartments, 12 of which are full of large emmer spikelets (hulled barley fills the central 4 compartments). Other model granaries dating to the New Kingdom and the Middle Kingdom, which I have seen in the Cairo Museum and the British Museum, also contain whole emmer spikelets (or hulled barley), not clean grain. One exhibit at the British Museum (Room 63, # 36190)
is filled with clean whole emmer grain, but this is a small bowl, not a granary.

We also have the archaeobotanical evidence from a domestic processing area itself. The plant remains around the mortar from West St. 2/3, front room, were composed mainly of the pounded remains of emmer spikelets (see above, III.D.2). Nearly every house at the Workmen's village had a mortar or apparently had access to one, and more than half of the houses at Deir el-Medina also had at least one mortar. This evidence together shows that, as in other parts of the Near East, ancient Egyptian bulk harvest processing stopped at the spikelet stage.

The next factor to be considered is the scale of post-harvest processing. Once taken from store, were spikelets processed in large quantities to produce clean grain sufficient for weeks' or months' supply of flour, or was processing carried out at short intervals, a daily, or at most, weekly, task? Ethnographic evidence points to mortar size as an indication of emmer processing scale. Hillman (1984b: 130) has noted that in Turkey, small mortars are used in areas where glume wheats are processed every few days for a small family, while much larger mortars, usable by up to three people working together, are employed when the whole harvest is stored in the form of clean grain.

All mortars from the Amarna village, and all but one of the mortars from the Deir el-Medina village, are small. In addition, all mortars recovered from a site-wide surface survey at Amarna (Delwen Samuel,
unpublished data) are small; none approaches the massive size seen in Turkey for bulk processing. Mortar size is never exactly the same, but most specimens are similar to the dimensions recorded in Table 5.1. Experimental work has shown that a maximum of about 500 mL of spikelets can be processed at a time in such a mortar. Documentary evidence for Deir el-Medina records that this village was supplied with regular monthly ration deliveries (Janssen, 1975: 455ff; Kemp, 1989: 255, 304, 309), which places an upper limit on processing intervals. Thus, current evidence supports the view that post-harvesting processing was a frequent activity. Intervals between processing were probably no greater than a week.

The sequence of steps used to obtain flour from spikelets in all probability closely resembled the experimental sequence laid out in Table 5.3. Most likely the times per quantity are not closely related to ancient custom, since skill and practice have a significant effect on speed. The quantities processed at each step, however, especially the pounding stage, are constrained more by the tools than by skill. A number of comments can be made about this sequence.

The most detailed evidence for initial spikelet cleaning after removal from storage comes from ethnographic data. The coarsest contaminants, such as large clods of earth, culms, large pieces of straw, and perhaps pieces of dung from the animals which threshed the harvest (De Vartavan, 1990: 486), were probably sieved out with a riddle (coarse sieve). The remainder was hand sorted to remove small stones, lumps of earth, and weed seeds. The inorganic material would have been discarded, while the weeds may have been kept aside.
for animal feed, or discarded along with the stones and earth. Since the items removed from the spikelets would be cleared away from the working area, it is unlikely to be located in-situ archaeologically, only mixed with other midden deposits.

The aim of pounding was not to crush grain, as has frequently been supposed, but to free the grain of its enveloping chaff. About 500 mL or so of spikelets can be pounded at a time with the limestone mortars found archaeologically. Parching does not seem to have been necessary, but slight dampening is needed to create a coherent mass in the mortar. The cushioning and coherence caused by the slight dampness meant that not many spikelets scattered out of the mortar, nor were they flattened and crushed. The chaff of most spikelets was shredded, and in some cases, the grains were forced out of the spikelet by the applied pressure. Apart from material scattered from the mortar and not cleared away, the mixture of fine shredded chaff, heavy chaff of all sizes, breached spikelets with the grain removed, whole grain, large fragments of cracked grain, and some whole spikelets is not likely to be found as a separate assemblage in the archaeological record because it is a transitional stage.

The damp mixture would have to be at least partially dried to stop it sticking together, so that the grain could be separated from the large quantities of chaff. Any pounded spikelets spread out in the open would have to be guarded to keep birds away. Guarding, a good job for a child, was probably combined with frequent turning to hasten the drying process.
The light chaff was easily removed by winnowing. A number of different tools might have been used, but the scant archaeological evidence points to baskets and possibly fine sieves. Along with the fine chaff fraction, some of the medium sized pieces of chaff, and small bits of broken grain were removed at this stage. The material removed by winnowing was very likely stored separately, as it would have made an admirable fine temper for pottery, or served as animal bedding, or used for fuel. If it was burnt, it would be difficult to find archaeologically, for its fine texture means that it would have been entirely reduced to ashes. The mixture remaining in the winnowing basket or winnowing sieve was composed of the whole and large pieces of grain, and the large heavy chaff fraction.

There is some intriguing evidence to support the idea that heavy chaff, such as glumes and whole shredded spikelets, formed a separate by-product, probably by sieving and being scooped off the top of a grain/heavy chaff mixture. I have seen some model granaries, notably from Middle Kingdom Beni Hasan (now in the Cairo Museum), which contain not whole spikelets, but shredded, empty spikelets.

The large heavy chaff may have been pounded again if there were large quantities of whole spikelets left. Alternatively, it may all have gone for nutritious animal feed. Some seems to have been used for this purpose at the Amarna Workmen's village (Renfrew, 1985: 178). The final product of winnowing, sieving, and hand-picking was clean grain ready for grinding. It, too, is highly unlikely to be found archaeologically as a discrete assemblage, for it was valuable and
would have been used immediately or very shortly after being obtained.

The last stage in cereal processing was milling. This was done on a granite or quartzitic sandstone saddle quern. The quern was often, but apparently not exclusively, mounted on a box-like mud brick emplacement, making the job of grinding relatively comfortable. Experimental work shows that the fineness of the resulting product can be easily controlled at the mill, and there is no need for repeated grinding. Although flour itself, again a transitional product, is not likely to be found unless placed as an offering in tombs, it can be observed indirectly in the form of bread, the subject of the next chapter.

C. Use of space and self-sufficiency at the Amarna and Deir el-Medina villages

1. General distribution patterns: positioning of mortars and querns

The actions of pounding and milling are part of the same sequence of flour production and therefore one might expect that embedded mortars and quern emplacements are to be found in the same room. Comparing the location of unemplaced cereal processing tools is likely to be misleading, for they may not have been finally left where they were originally used. Most of the evidence for grinding at Deir el-Medina, in the form of unemplaced querns, cannot be compared with emplaced mortars because the room in which loose tools were found is rarely given.
At Deir el-Medina, the number of emplacements is small, and the number of houses containing both mortar and quern emplacements fewer still. Thus, a comparison between mortar and quern locations is not as informative as it might be. Nevertheless, the overall impression is that mortars and querns tend to be associated. All six houses with emplacements for both tools have them in the same room (see also section 4, below).

Relating mortar and quern emplacements at the Amarna Workmen's village is more rewarding, because many more houses have both. Kemp (1987a: 41) has examined the relationship of quern emplacements and mortars, and finds a strong link. The link holds firm when mortars are identified on the basis of broader criteria (see above, III.D.1). When considering all fully excavated houses which have one mortar only, or all mortars in the same room, 85% (17 out of 20) have both mortar and quern emplacement in the same room.

This figure rises to 87% (21 out of 24) if the following can be included: if the mortar outside Main St. 4 can be considered an extension of the front room, and the two houses with mortars in different rooms, but at least one in the same room as the quern emplacement (West St. 16 - Type A house and East St. 11 - Type B house). The larger West St. 2/3 also had mortars in two different rooms, one of which was associated with the quern emplacement in the southern annexe. The shredded emmer chaff beside the mortar in the front room, however, makes the assumption less certain that pounding and grinding took place in the same room if there is more than one mortar in a house.
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The incidence of fully excavated houses (apart from West St. 2/3 and East St. 1, which have different layouts) where mortar and quern emplacements do not occur together must be calculated on a different basis, to include those houses which do not contain mortars, but may have been making use of communal installations, as discussed above (III.D.3.b). The house which is omitted from this calculation is West St. 23, because it seems not to have been used for human habitation, at least in the latter part of its life. Using this criterion, there are ten houses out of a total of 27 (37%) where the mortar and quern are not in the same space.

At the Amarna village, although both mortar and quern were often in the same room, there are a large number of exceptions. The houses in which there is more than one mortar are particularly difficult to assess. For example, if the mortar in the street outside Main St. 4 can be associated with the quern emplacement in the front room, how should East St. 10 be assessed? It has a quern emplacement in the front room and a mortar in the back, but there is also a mortar in the street just in front of the door. Without direct evidence of what each mortar was used for, and whether each was used for one purpose only, the relationship of mortars and querns is suggestive, but ultimately uncertain. Nevertheless, it provides some indication of the way living space was organized, and the range of variation amongst households.
2. Where did drying of pounded spikelets occur?

There is a range of possibilities for the location where pounded spikelets were dried at Amarna, based on the variety of house layouts in the village. Where mortars were in an area screened off or protected from animals, (for example Gate St. 9 (Kemp 1987a: 32), West St. 22 (WV, 90)), the damp mass may have been spread out on the ground. If the room was not roofed over, drying would have been rapid. Some mortars are in the same room as the oven (for example East St. 10 (WV, 64), West St. 16 (WV, 87)) and heat may have been applied. There is evidence for heating at this stage from ancient bread samples, discussed further in Ch. 6.V.4.d. There is no archaeological evidence for how this may have been accomplished. Shallow metal dishes set over cylindrical oven mouths are one possibility, but metal was too precious to be abandoned to the archaeological record. The damp mixture could well have been taken upstairs to be spread on the roof. Sometimes the mortar is situated conveniently close to the staircase (Long Wall St. 2 (WV, 83), West St. 18 (WV, 88)), but this could have happened in any house possessing a staircase.

The probable location of winnowing and sieving may have occurred near the quern emplacement if there was enough space, but in houses such as East St. 10, there scarcely seems to be enough room for this. Winnowing and sieving may well have taken place in the same area where drying occurred: on the roof, in the front room, or near the oven if heat was applied.
For Deir el-Medina, the possibility that winnowing and sieving usually took place near the mortar is supported by the tendency for cereal processing installations to be grouped together, or for the mortars to be situated in small separate rooms or areas - perhaps unroofed?

3. Processing by-products, and location of animal troughs

At the Amarna village, Kemp (1987a: 41-42) links the occurrence of mortars, and to a lesser extent, quern emplacements, to the presence of animal feeding troughs and animal dung. One good example he does not mention is the proximity of mortar and manger in Main St., opposite house 4.

The proximity of mortars and animal keeping seems easily explained. The by-product of dehusking and cleaning emmer and barley is chaff, mixed with a proportion of whole spikelets, freed grains, and weed seeds (Hillman, 1984b: 131-132). This can serve as animal fodder and bedding. Indeed, the assemblage of plant remains connected with animal husbandry at the village (Renfrew, 1985: 178-182) corresponds very well to this mixture. It was therefore perhaps the by-products of cereal processing for human food, and not the cleaned grain itself (as hypothesized by Kemp, 1987a: 42), which was used to feed the animals kept in some of the village houses. The evidence for the presence of the animals themselves comes from tethering stones and mangers (Peet and Woolley, 1923: 60), and dung and droppings (e.g. Gate St. 9, Kemp, 1987a: 33).

The connection between animal keeping and milling seems less obvious. As Kemp (1987a: 42) points out, querns need not be near animal
pens. Milled cereals are less bulky than chaffy by-products, and would be easier to transport. Main St. 11 and West St. 23 seem to have been given over to animal keeping in their latter stages of use (Kemp, 1987a: 42), but they also have quern emplacements. It is quite possible that the houses were first human dwellings, and, when they saw a change of use, the quern emplacements were not dismantled.

There is no obvious evidence for animal keeping within the confines of the Deir el-Medina village itself. Chaffy by-products of emmer spikelet cleaning may have been taken out of the houses and carried to animal pens and tethering places outside the walls.

4. Organization of processing within houses: specific examples

Shaw (1992) has highlighted some of the difficulties encountered when individual household units at Amarna are scrutinized, and the same holds true at Deir el-Medina. Problems include the erratic standard of recording by early excavators, and inaccuracies in identifications or provenances. Shaw (1992: 157) recommends the use of neighbourhoods, rather than households, as units of analysis, while individual houses may be used as examples of particular types.

The incomplete records associated with excavation at Deir el-Medina does make study of individual household units, from the point of view of cereal processing, highly problematical. There are, nevertheless, some houses which have the three main components of emmer preparation. House NE.V (Fig. 5.42) serves as one good type.
In this house, all the elements of cereal processing are present in the rearmost room. The mortar is set more or less in the centre, with the quern emplacement up against the south-east corner. A flight of stairs runs upwards just outside the door, providing easy access to the upper storey—perhaps a flat, open roof? In the north-west corner is set a cylindrical oven and the entrance to an underground storage area in the north-east corner. Thus, all the stages of cereal processing and baking can be carried out in this self-contained room, perhaps with cereal drying and grain cleaning taking place upstairs.

House NE.VIII shows a similar close grouping of mortars, quern emplacement, and ovens (see Fig. 5.43). A zir (large water jar) is set close beside the two mortars, conveniently placed to provide water during pounding. This house is unusual in the Deir el-Medina village in having all its cereal preparation facilities at the front of the house, but they are nevertheless separated from the front room leading into the street. The house appears not to have a flight of stairs leading to the roof or second storey. This makes it tempting to propose that the adjacent south central room may not have been roofed and was a courtyard used (amongst other things) for cereal drying.

Where evidence survives, or has been recorded, the Deir el-Medina village houses tend to have their cereal preparation facilities grouped together in one room, usually at the back of the house.

The presence of cereal preparation equipment at the Amarna village appears to be much more comprehensive than at Deir el-Medina. The number of houses with mortars and quern emplacements is much
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The presence of cereal preparation equipment at the Amarna village appears to be much more comprehensive than at Deir el-Medina. The number of houses with mortars and quern emplacements is much
higher. Although many houses have mortars and quern emplacements in the same room, there is a large proportion which does not. It is apparent from the village plan (Fig. 5.1) that, although many houses have mortar and quern in the front room, there are many deviations from this pattern. Unlike Deir el-Medina, no houses at the Amarna village have mortar, quern, and oven in the same room, with the possible exception of Long Wall St. 9 (presence of oven uncertain).

Three examples serve to show some of the diversity in organization of cereal preparation at the Amarna village. Long Wall St. 7 is a typical example of an A-type house (stairs at back) with the mortar and quern emplacement in the front room (Fig. 5.44). There are two possible routes of action through the house, depending on whether the roof was used for drying pounded spikelets and cleaning grain. If the front room, where the mortar was placed, was also used for drying and cleaning, then the whole sequence of cereal preparation from spikelets to flour would have taken place there, before baking in the rear room north. If the roof were used for drying, however, the pounded spikelets would have been carried through the house and up the stairs, and the separated products brought down again, where the grain would be milled in the front room.

An example of a house which must have made use of a street mortar is Main St. 5, a type B house (stairs at front). The pounded product may well have been taken up to the roof, or taken to the front room to dry near the quern emplacement. It is hardly likely to have been left in the narrow dusty street.
The arrangement of East St. 10 imposes an unavoidable transfer of intermediate products through the house during cereal preparation (Fig. 4.46). The mortar is in the south-east corner of the rear room north. The pounded spikelets may have been dried here - using the oven, perhaps - or transferred to the roof using the staircase running up towards the front of the house. In either case, the cleaned grain was carried to the front room, where the quern emplacement is set into the north-east corner. The flour was then returned to the rear room north for baking in the cylindrical oven.

Not only with these three examples, but with the layout of most houses in the Amarna village, one perceives much transfer activity between each stage of cereal processing.

5. Amarna and Deir el-Medina patterns of sufficiency

The pattern of distribution of cereal processing equipment has implications for the degree of self-sufficiency in food production on the level of the household unit. If all households had the means with which to process cereals, they must, to this extent, have been self-sufficient. On the other hand, if equipment shows other patterns of distribution which can be related to the actual pattern of use, some degree of interdependency between households, or on some outside source, may be inferred. The actual factors involved, however, may be difficult to unravel without recourse to other sources of evidence, or may not be discernible at all.

When discussing the siting of mortar and quern in the village houses, Kemp (1987a: 40) suggests that the front room was favoured for both
because it was probably unroofed, at least in Type A houses (with staircases at the back). One reason he advances is that milling was a dusty procedure. This assumption has been shown to be incorrect through experimental replication (see above, IV.F.2). A better reason for leaving the front room unroofed would have been to allow pounded spikelets to be dried - a quicker process in the open than in a roofed room. It would certainly have been more convenient to store grain provisions, probably in sacks, in the front room and carry out processing there.

Another suggestion, and it can be no more than that, is that the front room was often a working room more public than the rest of the house, as is conjured up by the image which Peet and Woolley (1923: 61) reconstruct. Here, visitors could come and work together, perhaps bringing their own querns to grind together. The cramped kitchens, smaller by half than the front rooms, with a bread oven taking up much of the space, would not be very suitable for such communal activity. However, in some oven rooms, a group of people may have worked together using the same oven to bake batches of dough. They may have all been from the same household or from several houses, perhaps linked by kinship.

Not all houses have the full complement of cereal preparation equipment, suggesting that some households had access to equipment within the confines of other houses. One such example may be the neighbouring houses 8 and 9 on Gate Street. There is no mortar in the street nearby, as far as one can now tell from the plan. House 9 has a mortar but no quern emplacement, and the quern fragment
found in the front room (find 6634, in unit [2075]) was high up in
the badly disturbed fill and may not have come from this house at all.
House 8 has a quern emplacement but no sign of a mortar. Did the
two households share their equipment?

Similarly, the only completely excavated house which was not recently
disturbed, and without a quern stone (as far as is now known) or
quern emplacement, is West St. 24. The only house in the same
category without a mortar within its walls, or nearby in what might be
considered a communal area, is Long Wall St. 12. West St. 24 is
unusual in that the front door lets out onto Long Wall St., and is
nearly directly opposite the door of Long Wall St. 12. Did these two
households also share their cereal processing equipment?

The interactions of inhabitants at Deir el-Medina may have been rather
disparate in different houses. In all six houses where both mortar and
quern emplacements are found together, they are in the same small
room, which appears too restricted to allow much additional activity by
people outside the household. The rooms of three houses with milling
emplacements have more space (SE.IV, NW.I, and C.II) and communal
milling could more easily have taken place here. It is obviously
impossible to say how cereal processing was organized in the other
houses, but they certainly were not restricted by lack of space, nor
tied to a permanent milling structure.

In sum, all households which have been fully excavated at the Amarna
village (with the exception of Main St. 3) have at least one installation
needed to obtain flour from whole emmer spikelets. Many have both
quern and mortar; we do not have enough data for the more ephemeral, and transportable, sieves and winnowing baskets. The pattern here points to a large degree of self-sufficiency in cereal preparation within household units, with some evidence for sharing of communal street mortars, and reciprocal sharing of equipment between households.

At Deir el-Medina, the recorded evidence is far less clear, and hypotheses about self-sufficiency consequently much more tentative. Some households, like the Amarna village, seem to be completely equipped with cereal processing tools, while others apparently have nothing. Still other houses have some of the necessary tools. At this village, there seems to be a larger range between self-sufficiency, inter-dependence, and total dependence for flour supplies amongst households. The evidence needs to be explored further to confirm this impression, but there is no doubt that the pattern of organization is quite different from that of Amarna.

6. Social interactions related to cereal processing: summary comments

As far as can be assessed, there seem to be different levels of social interaction between the villages of Amarna and Deir el-Medina. There are other differences which have not so far been discussed, which serve to reinforce the apparent dichotomy between the two villages. One obvious difference is the time frame. Although Deir el-Medina was founded in the 18th Dynasty by Pharaoh Thuthmosis I (c. 1504-1492 BC), the remains of the village as we see it today is the result of occupation over about four centuries, and the final phase dates much later. The village was eventually abandoned in the 20th Dynasty
during the reign of Pharaoh Ramesses IX, about 1081 BC (Bierbrier, 1982: 118). This contrasts with the short occupation of the Amarna village, on the order of 15 to 20 years at the end of the 18th Dynasty (c. 1350 BC).

Another difference between the houses of the two villages is provision of storage space. At Deir el-Medina, many of the houses were provided with what were apparently silos, and small cellars or caves, in which the excavator found various storage jars and similar items. They would not have accumulated grain surpluses, consuming most of it (Kemp, 1989: 309), but the ability to store cereal supplies may have affected the rhythm of processing at Deir el-Medina. These facilities are often at the back of houses, where cereal processing equipment is also most commonly found. There are no such facilities in any of the Amarna houses. At this village, many of the installations for cereal processing are in the front rooms, or the case of some mortars, out on the street.

Deir el-Medina is well supplied with documentary evidence, although sometimes this information is not quite enough to reconstruct some aspects of past economic activity. Černý (1973: 177-181) assumes that the task of slave women mentioned in some documents was to grind grain, and that they were rotated around the households. How were these services distributed: did everyone have access to them, or just some village families? Did the servants work in the homes of those for whom they were providing grain, or did they mill at a separate facility? Answers to these questions might help to explain the pattern of cereal processing equipment recovered from the village.
Documentary evidence provides some information about who occupied the different houses of the village. Some parallels between kinship and distribution of cereal processing equipment may help to show whether equipment was likely shared amongst specific households.

The identity of cereal processing tools has been confirmed, and their recognition clarified, their function determined through ethnographic and experimental work, and the order of usage established. The interaction of cereal processing activities amongst and within households has yet to be fully understood, and as Shaw (1992) suggests, the household unit may never be satisfactorily reconstructed. Nevertheless, there is great potential to augment the relatively sketchy archaeological information available from Deir el-Medina with documentary evidence. The lack of written records from Amarna is to some extent made up by a clearer archaeological picture. The excavation of an ancient Egyptian farming village would help to interpret these particular villages, and their cereal processing patterns. Unfortunately, such a site is unlikely to be found beneath the layers of alluvia accumulated over millennia. Meanwhile, the identification of equipment and its distribution at these villages, their similarities and differences, provides the groundwork for future comparison, either at sites yet to be excavated with modern detailed recording, or to serve as a basis for other, less well recorded neighbourhoods in the city of Amarna and elsewhere.

D. Cereal commodity exchange

The third general issue which can now be addressed relates to the economic question of commodity exchange. What was being
transported: emmer spikelets, or clean emmer grain? The possible
storage and transport of spikelets rather than grain does not affect
volume and ratio calculations for cereal transactions, but it does
influence the effective amount of grain which is involved. It also
affects relative prices, for example, of emmer and barley, and
calculations of nutrition from recorded ration lists.

Much of the emmer spikelet consists of chaff, which has no nutritive
value for humans. By dehusking 50 g of spikelets by hand, I
determined the ratio of chaff to grain. The results are presented in
Table 5.2. From this it can be seen that, although the grain makes up
nearly 78% of the spikelet by weight, it makes up barely more than
50% by volume. Percival (1921: 191) and Carleton (1901: 9) give very
similar figures for weight ratios, the latter on the basis of 100 pounds
of spikelets.

Current archaeological evidence supports the idea that emmer was
stored in spikelets. The plant remains around the front room mortar
of West St. 2/3 in the Amarna Workmen's village show that mortars
were used for dehusking, and the presence of mortars, and in some
cases pestles, in many of the Deir el-Medina and Amarna village
houses shows that the tools for dehusking emmer were common
domestic assets. Model granaries in tombs hold emmer spikelets, not
cleaned grain. Therefore, ancient records of rations, taxes, and other
cereal transactions (for example, Janssen, 1975: 112-132; Černý,
1973; and the numerous studies noted by Spalinger, 1987: 283) may
well refer to spikelets, not to clean grain.
Baer (1962: 42) calculates that a hekat (4.78 litres) of emmer represents 8100 calories, based on the assumption that this measure is of grain, not spikelets. As Table 5.2 shows, a given volume of emmer spikelets contains only 50% by volume of grain. Therefore, Baer’s calorific calculation may have to be adjusted downwards by considerably, giving a value of 4000 calories per hekat.

Similarly, Kemp (1986b: 132; 1989: 127), discussing Middle Kingdom administrative practice, uses figures supplied by Gentry (1976: 25) on the weight of wheat grain to calculate that one hekat of wheat is equivalent to 4.78 litres and weighs 3.75 kg. Gentry’s figures are based on free grain, however, not spikelets. Using the experimentally derived weight to volume ratio for emmer spikelets, 4.78 litres of spikelets actually weigh 2.52 kg, which is 35% less than Kemp’s estimate. This spikelet weight provides just under 2 kg of clean grain (1950 g) if all spikelets are fully extracted, and 4.78 litres of spikelets will yield, at the maximum, no more than about 2.5 litres of clean grain. This ratio can also be expressed as one hekat of emmer spikelets yielding a maximum of just over half a hekat of clean grain. On this basis, current energy estimates for emmer wheat rations may be much too high.

Further study of the archaeological record may help to test this proposition. For example, the Nubian forts of the Middle Kingdom, supplied by grain from the north (Kemp, 1989: 178) ought to be equipped with mortars to strip off the chaff, if grain was transported in spikelets. The susceptibility of flour to spoilage makes it unlikely that this commodity was sent to the forts.
Records show that barley and emmer prices were generally equal in the Ramessid period (Janssen, 1975: 130). Both cereals are hulled, but the chaff component of barley is a much lower proportion of the spikelet than that of emmer. The edible fraction of a given measure of emmer spikelets is lower than the same measure of hulled barley. If both cereals were exchanged as unprocessed commodities, that is as hulled barley and as emmer spikelets, then, effectively, emmer grain was more expensive than barley grain.

Another possibility which would bear investigation is that both emmer spikelets and clean emmer grain were exchanged in ancient Egypt, perhaps depending on recipients. For example, groups of people supplied by the state, and living in villages, may have been expected to process their own spikelets. Recipients living in garrisons and forts may have been provided with clean grain. In this case, the Nubian forts should have been equipped with querns, but not mortars.

If both emmer spikelets and emmer grain were separate commodities, one would expect cleaned grain to be more highly valued than spikelets. If this is the case, there could have been two different words to denote emmer in the spikelet, and emmer as cleaned grain. It may be possible to test this hypothesis linguistically. One suggestion is that the accepted word for emmer, bdt, refers to spikelets, while the problematic word zwt (Helck, 1977: 586; Täckholm, 1977: 271) refers to the clean grain. The ratios provided above may help to
confirm this possibility if the values of the two are considered in
documents, such as Seti's baking accounts (Spalinger, 1986).

Spalinger (1986: 340) has determined absolute measures for wheat and
flour employed in the baking accounts of Seti I. He provides the
equation: 1 sack of emmer = 245 deben = 76.65 litres = 22.295 kg.
From this, he calculates that 1 litre of emmer equals .29 kg, or 291
grams. This, he feels, is remarkably light. From Table 5.2, I have
calculated that 1 litre of spikelets equals about 526 g, while 1 litre of
grain equals about 759 g: a given volume of spikelets weighs about
30% less than the same volume of grain. Spalinger (1986: 341-342)
quotes similar weights based on Percival's values (1921: 191), quoted
above.

Spalinger concludes that the combination of unhomogeneous wheat sizes
and the presence of glumes and rachises accounts for the
unexpectedly light weight calculated for a sack of emmer based on
written evidence. He describes bread baked with a mixture of flour
and glumes as a bit crunchy, and that with rachises added as even
rougner. Given the coarseness of emmer spikelet chaff, even if it
were possible to make bread from the whole spikelet (see
Ch.6.IV.B.2), the large quantity of coarse chaff would make it
inedible for humans.

Even supposing the emmer was in spikelets, the discrepancy between
the calculated weight of 1 litre of emmer based on Seti I's documents
(291 g) and the actual weight of 1 litre of emmer spikelets (525 g) is
nearly 45%. This is surely not "roughly the same" as Spalinger argues
There are two possible explanations: the calculations based on documentation are erroneous in some way, or the sacks are filled with neither whole spikelets, nor cleaned grain. One possibility which fits the light weight stipulation is that the sacks were filled with the mixture of breached spikelets and grain, produced from pounding in a mortar. Fig. 5.16 shows the marked increase in volume which occurs when a given quantity of emmer spikelets is broken up to release the grain.

It may seem odd that sacks filled with a mixture of chaff and grain were transported, rather than a more compact commodity. The answer may be that separation was considered part of the milling phase, and also, that the chaff was not considered as useless waste, but a valuable by-product for temper, or animal fodder, or animal bedding.

Archaeological evidence which to some degree supports this proposal can be seen at the Central City of Amarna. Fig. 5.47 shows part of this region. A long room full of standard limestone mortars is located in building R42.9, to the south-east (see also Pendlebury, 1951: 132: "a room containing three rows of fifteen rough stone vases sunk into the ground", Pl. XXI). To the north-west, scattered over buildings Q41.3,4,5,6,8,10,12 and R41.3,4,5,6 (Pendlebury, 1951: Pl. XVIII), was a large concentration of saddle querns (Delwen Samuel, unpublished data). Adjacent to this "grindery" area, just to the north, are the long magazines of the Greater Aten Temple, containing many ovens, and covered in enormous quantities of bread moulds (Kemp, 1979: 6). To the north-east is building S40.1, equipped with stone floors, tethering posts, and brick mangers, which Kemp (in
press) suggests could well have acted as a series of holding pens if not a major byre. Chaff separated from emmer grain, perhaps in the Q41-R41 complex, may have been destined for cattle kept there.

Such a layout, with mortars well separated from querns in a temple supply context, may reflect the situation documented in the Seti bakery papyri. Sacks of pounded, unseparated spikelets may have been transported to what was considered the "bakehouse" proper. Without a doubt the chaff must have been cleaned from the grain prior to milling, and it may have been done here.

The possibilities for emmer wheat as a traded commodity have thus expanded considerably. From the implicit or explicit assumption that clean grain was transported, we now must consider also whole spikelets, and pounded spikelets.
CHAPTER 6: ANCIENT EGYPTIAN BREAD BAKING

I. Introduction

Bread was placed in tombs as part of funerary offerings, and Egypt's arid climate has desiccated and preserved many examples. All the loaves which have been recovered, however, represent only a tiny sample of ancient Egyptian production; at a guess, a few hundred examples survive. Apart from a few relatively brief studies (Borchardt, 1932; Grüss, 1932; Leek 1972b; 1973, see section V.E), this direct source of data has generally been ignored.

Because of their strictly funerary context, it is difficult to know how representative these loaves are of ancient Egyptian baking in general. There is no certain way to link this funerary food to bread consumed by the living because hardly any bread, if any, has come from settlements. (Peet and Woolley (1923: 86) mention "remains of cake" from Long Wall St. 12 in the Amarna Workmen's village, but I have not had the opportunity to examine it.) It is possible that loaves were specially prepared for tomb offerings and differed in some way from daily bread, but it is hard to see how this might be detected. It is equally possible to imagine that the bread destined for tombs was the same as that which was baked for living people; perhaps the deceased's favourite kinds were provided. Even if there was no particular difference, we are still unable to ascertain from the loaves themselves whether there was a repertoire of ordinary daily bread and special festival breads, and whether poorer members of society ate bread which was different to that eaten by the privileged. A comparison of tomb owner status with bread assemblages might help to
determine the 'social standing' of different types of bread, but unfortunately, bread loaves are rarely provenanced with such precision - if they are provenanced at all.

Despite these problems, and in the virtual absence of any bread recovered from settlement sites, tomb loaves are the only direct product of ancient Egyptian baking available. By focusing on preserved loaves, the scale of investigation shifts from the development of a generally applicable model, as has been carried out in Ch. 5, to analysis of case studies. Individual loaves are specific examples produced from a repertoire of ancient Egyptian baking techniques, whose full extent remains unknown.

For this research, I have looked at over fifty individual loaves, now housed in seven different museums, to levels of detail which vary according to individual museum policy on access to holdings. (See Table 6.1; numbers throughout this text refer to my inventory, as listed in this table.) Of those which are provenanced, the great majority date to the New Kingdom. Together, they form a limited number but reasonably diverse selection of bread loaves, differing substantially in shape and size.

Their condition is often remarkably good. The loaves are solid and coherent, and at most only a few tiny crumbs fall off when the bread is handled. A large proportion have been attacked by weevils. In some cases the bread is pocked with small holes but the structure remains robust. Others, however, have been so heavily infested that they are very fragile and crumbly. This infestation seems to be
ancient and the insects as old as the loaves themselves, but some museums have taken precautionary measures against modern infestation by treating loaves with insecticides. The gross structure, form, and microstructure of the loaves have not been altered in any discernible way by this treatment. The only result is that the analyst must take measures to avoid contact with the poison.

A more serious problem for the detailed study of these loaves is treatment with wax, resin, or similar substances. Consolidants keep the fragile loaves together, but result in severe loss of information by changing the colour of the loaf, often obscuring the texture, and preventing identification of large inclusions. The problems are greatest if wax has been used.

Bread is usually defined as a baked product, normally leavened, made from moistened ground cereal. An obvious starting point in any study of bread is an examination of its ingredients. Grain is usually the main component, but the making of bread is not restricted to cereal alone, and indeed, cereal may not be used at all for some types of loaf. Many proposals for ancient Egyptian bread ingredients have been made on the basis of textual evidence, among them the fruits of Christ's thorn tree (Zizyphus spina-christi (L.) Willd.) called nabq today in Egypt, honey, "sweet fruit", sesame, aniseed, dates, carob, grape juice, and lichens (Kamal, 1913; Drenkhahn, 1975: 871; Sist, 1987: 56; Darby et al., 1977: 512, 522; Strouhal, 1992: 127). Leavening is almost always assumed to have been added. In this study, I have turned to the direct evidence of the loaves themselves to determine what was actually used.
Since the study of ancient Egyptian bread and baking has been so heavily based on shapes represented in the artistic record, much attention has been given in this chapter to the form and shaping of real bread. One obvious advantage is the consideration of bread in three dimensions. A great deal of information about how bread dough was manipulated can be obtained through detailed examination of loaves. Because previous work has placed great emphasis on bread shape, it is important to establish what the significance of shape really is: are particular shapes related to characteristic processing methods, or to specific ingredients? Is bread shape alone a reliable indicator of bread classification? As well as form and shape, I have examined the texture of bread loaves and linked it to cereal processing methods.

Several museums allowed the sampling of loaves, for which I am grateful (see Acknowledgements and Table 6.1). This opens up the opportunity for completely different methods of study, with concomitant new discoveries. It is possible to apply a range of techniques to organic samples; microscopy has been used in this research (see Section V, below, and Ch. 4.III; IV). The main problem is that only 13 samples have been taken, from complete or partial loaves, or small fragments. Although a variety of preparation methods have been distinguished within this very small assemblage, the results cannot be adequately set into a wider context because of the restricted sample size. It is not possible to say whether all the preparation methods which have been distinguished were standard,
nor whether a particular baking style was preferred in general, with other methods in use.

Although limited, there is some ethnographic data which sheds some light on ancient Egyptian baking practice. Limited experimental reconstruction has clarified certain aspects of baking. Finally, the archaeological evidence has been presented, using the variety of available evidence to comment on how ovens and related artefacts may have been used to produce bread.

II. Ingredients used in ancient Egyptian bread

A. General comments

Many of the bread loaves which I have examined have a fairly coarse texture, incorporating large fragments or complete structures whose morphology may allow identification. However, the relevant characteristics are not always easy to observe. Since components are usually well embedded in the body of the loaf, they are obscured to a greater or lesser extent, and can only be observed from a few restricted angles. Complete loaves usually have smooth finely textured crusts, and little of the large inclusions protrude. Identification is more likely when the crust has been damaged or the loaf is broken open. Low power magnification is very useful to distinguish morphology, but the appropriate type of microscope has not always been available at museums. The difficulties in attempting to identify components are greatly increased when loaves cannot be handled, or when they are observed in poor light.
Usually, the only large fragments or complete structures in ancient loaves are cereal grains or chaff, but a few of the loaves I have studied contain other items. These are described in the following sections. Specific examples of loaves are mentioned to illustrate trends or unusual components; for an overview and description of the form and macroscopic contents of each loaf, see Table 6.2.

B. Cereals

The cereals cultivated by the ancient Egyptians were emmer and barley (see Ch. 1). The identification of cereal fragments need only distinguish between two species, and is therefore a relatively simple matter. Although the two cereals are quite different, distinguishing the two depends on preservation, breakage, and the characteristics observable when items are embedded in the bread matrix.

1. Emmer wheat, *Triticum dicoccum*

The identification of emmer grain is based on the overall slender shape, the rounded ventral cheeks with relatively deep groove, the pronounced dorsal ridge, the triangular proximal end in transverse view, and the somewhat elongated distal tip crowned with a beard of hairs. In the ancient bread, whole grains are normally naked, but if any part of the lemma and palea still adhere, the structure is easily distinguished from barley or weed/wild grasses because the light chaff is not fused to the grain, and the veins are not prominent.

When embedded within a loaf, emmer chaff is often easier to identify than the grain, and individual chaff fragments can more frequently be identified. The rachis has a robust trapezoidal shape, while spikelet
forks are a feature of emmer and do not occur with barley. In some cases the glumes still persist on part or all of the rachis internode. Glume bases, with any length of glume still adhering, or none, also occur. Glumes can be identified on the basis of their large size, compared to barley chaff, with distinct primary and secondary keels, and noticeable veins on the outer glume face. No complete finer chaff was seen, and there are no macro-morphological features to distinguish fine shredded emmer and barley chaff.

Emmer — in the form of grain and chaff — is very common in the bread I have examined. Of the 33 loaves which I was able to handle, or could see sufficiently well through the glass of museum cases, 25 (76%) definitely contained emmer grain and/or chaff. The cereal in the remainder could not be identified. The amounts of identifiable grain or chaff vary considerably from loaf to loaf. Loaf 049 has large numbers of whole emmer grains. It is also exceptionally rich in coarse emmer chaff, an unusual phenomenon amongst the selection of loaves which I have studied. No fine shreds seem to be present, but the bread is full of emmer rachis internodes, and complete glumes which have been shredded.

The ubiquity of emmer chaff and grain, as well as the large quantities of emmer grain in particular, leads me to conclude that most of these loaves are made primarily of emmer. This accords with the five loaves in the Berlin Museum, four of which date to the New Kingdom, which have been examined by Grüss (1932). He concludes that they are all made of emmer, as are three examples obtained by Leek (1973: 201). Täckholm et al. (1941: 248) list a few other loaves of various dates
which they say are probably also made of emmer. Some of these have been re-examined in the course of this research.


Barley grain is easily distinguished by its flatness in lateral view, the relatively sharp chisel shape at each tip, the lack of hairs on the distal end, the shallow ventral groove, and the somewhat flattened dorsal side. In nearly all specimens which I have seen in bread, the hull (lemma and palea) is retained, either entirely or nearly intact. This makes barley grain easy to identify. No attempt was made to distinguish between two-row and six-row barley because the grain must be examined from a number of views, clearly impossible when it is embedded in bread.

Barley rachis internodes are large enough to be identified with the naked eye or with low power magnification and are easily distinguished from those of emmer. The rachis is more gracile in all views, the base is smoothly curved and slightly extends below the attachment scar in lateral view. The glumes are rarely attached, but their stubs can often be seen.

Only one fragment of barley chaff could definitely be identified amongst the loaves I was able to examine, in loaf 007. This paucity may be due to the fact that barley chaff is less robust than emmer chaff. Once barley glumes are detached from the rachis internodes, and the lemma and palea stripped from the grain, they are indistinguishable from shredded light emmer chaff. Since the hulled grain easily detaches from the rachis during the early stages of
threshing, it is likely that relatively few rachis internodes accompanied barley grain into storage, and therefore, if barley was used for baking, were probably rarely incorporated into bread. Again, it was not possible to attempt the identification of two-row or six-row barley rachises.

Judging from the rare occurrence of barley grain in the loaves which I have examined, it was not an intentional ingredient. Out of 33 loaves, at least one grain of barley is present in only six, and three others contain grain which is probably barley but could not be identified with certainty; *Lolium* cannot be ruled out. In five of the six loaves, barley grains occur in very low numbers – where present, only one or two caryopses were seen. The exception is loaf 073B, which has quite a few barley grains (number could not be quantified).

Darby *et al.* (1977: 517) suggest that barley was also used to make bread along with emmer, but their authority is Atheneus, a 2nd-3rd century AD author from the west Delta town of Naukratis, who wrote a culinary treatise composed about AD 200. Mr. Mohammed Khattab, head of the Ancient Egyptian Agriculture section of the Dokki Agricultural Museum, Cairo, informs me that some lens-shaped loaves from Bruyère's Deir el-Medina excavations in the museum (similar to loaves 080 and 081) have been analysed by the Egyptian Ministry of Agriculture laboratories and found to be made of barley. However, this work was undertaken some time ago and may benefit from further studies with modern techniques.
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*Lolium* is not a cultivar, but it is included in this section because it is a common weed of cereals. In some species seed size is similar to cereal grain size so that they mimic cereals during processing making the caryopses difficult to remove. Further, *Lolium* occurs in nearly a quarter of the loaves which I have studied.

The species of *Lolium* present in these loaves has not been identified. Because the caryopses are stuck into the bread matrix, it is not possible to obtain detailed measurements and morphological observations, nor can each one be systematically compared with reference material. My impression is that all examples I have seen fall into the same size range, and closely resemble, the *Lolium* caryopses found with emmer chaff around the mortar in the front room of West St. 2/3, Amarna Workmen's village. I have already proposed (Samuel, 1989: 285-286) that on the basis of the presence of awns, only two species were contenders: *L. multiflorum* Lam. and *L. temulentum* L. var. *macrochaeton* A. Br. Comparison to modern reference material has suggested that neither of these is a particularly good fit for this particular assemblage. More detailed work with a wider range of reference material needs to be undertaken to identify *Lolium* in the mortar assemblage.

Because of its small size, *Lolium* in bread is only detectable if the caryopses are whole. The grains almost always occur with the hull intact. This helps with identification, because under low power magnification, the punctate pattern on the chaff is distinctive. *Lolium* can also be identified by its fairly plump appearance, with slightly
rounded flanks in both ventral and dorsal view, the proximal and
distal ends which in lateral view are more rounded than barley but
more tapered than emmer, the shallow, very broad ventral groove,
and the smooth, gently curved dorsal side.

No Lolium chaff free of the caryopsis was observed. Like barley, once
the lemma and palea are stripped away, the chaff cannot be separated
by the naked eye or under low power magnification from finely
shredded emmer chaff, unless the punctate pattern is clearly visible.
The rachis is tiny, and would only be seen in exceptional
circumstances. All records of Lolium in bread therefore refer to the
caryopsis.

Surprisingly, rye grass is more common overall than barley in the
bread which I have studied. Out of 33 loaves, 8 (24%) contained this
grass. This does not include the three loaves with grains which might
be either barley or rye grass. In four loaves, rye grass is present in
considerable quantities. In the case of loaf 068, although there are
large numbers of emmer grain, hulled rye grass is the dominant
ingredient.

It is puzzling that this loaf should have been made from such large
quantities of Lolium. It does not look like a particularly palatable
bread, especially as it also incorporates a considerable amount of
coarse chaff still adhering to the caryopses. One possibility is that
this funerary loaf represented bread in shape and general
composition, but was not made from cleaned cereal which was normally
used for bread making. It may have been made from sievings cleaned
from an emmer crop, which would perhaps usually have been destined for animal feed. The large concentration in this loaf suggests that *Lolium* was often an abundant weed of ancient Egyptian cereal fields. The common appearance of rye grass in the bread loaves I have studied, as well as its association with emmer chaff around the mortar in the front room of West St. 2/3 (see Ch. 5.III.D.2) supports this proposal.

4. Occurrence of *Hordeum* and *Lolium* compared

Barley and rye grass occur together in four loaves which I have studied. Of these, two (028 and 029, both conical loaves) have only a few grains of both. The identification of barley is not definite in the case of 029. The other two (007, a round loaf with central cavity, and 065, a round flat loaf) have substantial quantities of *Lolium*. Thus, the relative quantities of each do not seem to be linked.

Apart from the presence of either barley or rye grass, or both, the twelve loaves which contain them have little in common. The loaves occur in a variety of forms. Where the microstructure of the relevant loaves could be analysed, as detected by iodine staining and scanning electron microscopy (see below, section V), no similarities were seen.

Most loaves (9 out of 12) in which either or both of these components were seen, had coarse textures, containing large grain fragments or whole grains - 4 or 5 (indicating coarseness) on a scale of relative texture (see Table 6.2 for an explanation of this scale). Only two had a texture of 3 or less (coarse meal to fine flour), while the texture of one (013) was not recorded. There are two possible explanations for
the apparent correlation between coarse textured loaves and presence of rye grass and barley. One is that whole grains of barley and rye grass survived the milling process so that they are now identifiable, whereas in finely textured loaves, they may be present but undetected. The other is that these components are associated with loaves of coarser texture, which were perhaps less well cleaned. These possibilities are difficult to evaluate, because of the lack of data for the occurrence of milled Lolium and Hordeum in loaves of finer texture. The fact that whole grains of these species occur in two relatively finely milled loaves is puzzling, because they have escaped being crushed on the quern. Lolium in particular was surely not intentionally added later.

C. Non-cereal components

Ingredients in bread other than cereals or rye grass are much rarer amongst the selection of loaves which I have examined. Only large remains can be distinguished using the naked eye and low power magnification; fine mashes, liquids, or powders are not detectable. Two different, unidentified seeds appear in two different loaves. Loaf 066 is coarse textured, with one visible small seeded legume. It was probably a weed seed inadvertently included. If it was deliberately added, a greater number ought to be observable in such a coarse loaf. The flat dicotyledonous seed embedded in loaf 017, a bread of finer texture, was also probably from a field weed. The only satisfactory way to identify these seeds is to remove them from the bread matrix, for little of their morphology can be seen. However, this has not been possible because of museum restrictions.
More abundant are some small unidentified seeds on the surface of loaf 014, another fine textured loaf. They are scattered over the surface, suggesting that they were a deliberate garnish. Unfortunately, it is impossible to identify them because they are obscured by wax applied to the loaf as a conservation measure.

Only three loaves which I have studied include visible ingredients which were definitely deliberately added. Loaf 071, a conical bread now in the Museum of Fine Arts, Boston (72.4757c) is made entirely or mostly of figs. The loaf is incomplete, exposing the dense interior structure, heavily studded with fig seeds. McDonald (1982b: 113) states that the bread is made of a coarsely ground grain, but when I examined it, I saw no trace of cereals, either as grain or chaff fragments. The small reddish seeds which McDonald does not identify are all from fig, but I have not been able to establish whether the species is *Ficus sycomorus* L. or *Ficus carica* L.

Loaf 067, now in the British Museum (5346), appears to have been made from a mixture of fruit and cereal. The texture is very fine and dense. A few pieces of chaff are embedded in it, as well as small fragments of grain. One rachis fragment is probably from emmer. Two date stones and a date calyx are embedded in the loaf. Of these, only one of the date stones would have been visible when the loaf was whole. The inclusion of these inedible items, and the fact that most were hidden inside the loaf, suggest that the loaf might not have been intended for consumption. There are shreds of non-cereal, unidentified material, especially on the surface. Overall, the colour is somewhat darker than most loaves. Although no date fruit tissue could
be identified using morphological data alone, the evidence suggests that dates were added to this loaf.

The third example of deliberate additions to bread comes from a set of ten loaves from the tomb of Tutankhamun, all in the form of a semi-circle (072). One of these is illustrated in Darby et al. (1977: 534, Fig. 12.16), while five examples, including two in open palm frond nets, are illustrated by Wahren (1961: 13, Fig. 18). I could not tell what cereal these breads were made from. Many shreds of non-cereal material, in at least some of the loaves, indicate that other ingredients had been added. A number contained coriander seed; it is possible that all ten did, as they appear to be similar in composition. All the pieces of coriander which I was able to distinguish are single mericarps, suggesting the seed was coarsely crushed prior to being mixed into the dough.

Bruyère (1937: 107) states that the offering loaves which he excavated from tombs of Deir el-Medina's eastern cemetery were sprinkled with many fig seeds, that the loaves tasted sweet, and that therefore one of the main ingredients must have been figs. Some of the loaves may well have contained figs, but there are no fig seeds in or on any of the selection of Deir el-Medina bread, now in the Louvre Museum, which I have examined (see Table 6.2). Clinging to these loaves are often weevil bodies, clumps of frass (insect excreta), or mouse droppings, and perhaps these were mistaken for fig seeds. The sweet taste noted by Bruyère need not be due to addition of any fruit as will become clear in section V.C.3, 4, below.
The find of lichen in a Deir el-Bedari tomb dating to the 21st Dynasty (Darby et al., 1977: 517; Leek, 1973: 201; Täckholm et al., 1941: 247), has led to the suggestion that this was used to increase bread porosity. Three bread samples sent for analysis by Leek (1973: 202) to test for lichens using thin layer chromatography produced negative results. I have seen no trace of tissues, either macroscopically or microscopically, corresponding to lichens. If lichens were used in baking at all, they must have been a very rare addition, as the taxa in question appear to be imported from Greece and would not have been generally available (Wilson, 1988b: 15).

Study of more loaves may well add to the list of firmly identified ingredients used for bread, and thus expand our knowledge of the extra resources which were applied to baking. On the basis of the bread I have studied, the majority of tomb loaves seem to be made only of cereals, but other ingredients, undetectable by visual means, cannot be ruled out. A larger sample size will help to indicate whether certain ingredients were more common amongst the range of additives. More work is needed before any link can be hypothesized between extra ingredients and other variables, such as the status of the deceased, the taste preferences of specific periods, or the shape of loaves. This last possibility is discussed further in section III below.

III. Form and shaping of loaves

A. Introduction

Table 6.2 presents the data on shape, colour, texture, and inclusions for the loaves which I have seen and Table 6.3 summarizes different loaf shapes. The categories discussed below are not intended as a
typology; they are convenient for comparison and discussion. Most loaves which I have studied date to the New Kingdom, while loaves 014, 068, and 073 date to the Middle Kingdom. There was a certain continuity of form over time, for each Middle Kingdom loaf has counterparts of the same shape from New Kingdom times. Although there appear to be differences in dimension amongst bread of different periods, the sample size is far too small to draw any conclusions.

B. Variety of shapes

1. Moulded breads

The production of mould-baked bread is of interest because pottery bread moulds are found at a wide range of sites dating to all ancient Egyptian periods. The New Kingdom bread mould is a narrow conical form; conical moulds are discussed below (Section VIII.E). Only two of the loaves which I have examined were formed in moulds, 025 and 067: neither of these is conical. The conical loaves which I have studied were made by hand (see below). Loaves 025 and 067, neither of which is complete, had been formed with small cup-shaped moulds. The greatest surviving length of 025 is 95 mm, while the diameter of the base of 067 is 85 mm. They are, therefore, of the same general size, but the method of moulding each one is different.

Loaf 025 ranges in thickness from 10-20 mm. It has been formed over the outside of the cup-shaped mould, so that the interior surface of the hollow is very smooth and even. Little more detail can be discerned, since the whole loaf is covered in shiny resin-like consolidant. Loaf 067, now incomplete, on the other hand, has been shaped by placing the dough inside the mould, so that the loaf base
is smoothly curved and evenly shaped. The upper part of the loaf is hand formed and the surviving portion is decorated with two deep indentations and a little ring of dough placed on the top. It probably originally had three indentations.

Kamal (1913: 241-242) describes a moulded bread made from the fruits of the Zizyphus spina-christi tree, baked by Egyptian villagers of his day. Having prepared the flesh of the fruit – called nabaq – into a dough, it is transferred into gourds cut in half. These filled gourd moulds are placed in a slow fire and the nabaq bread is gently baked. Whether gourds were used to mould the ancient bread is unknown, but their shape is analogous. Another possibility, which would explain the shape of 067, is that the interior of a dom palm nut shell was used as a mould.

Since none of the loaves which I have examined was made in a New Kingdom type of conical mould, I have no direct evidence to suggest the type of bread they were used to produce. A question which a more extensive survey of ancient loaves could address is whether any conical, moulded bread has been retrieved from tombs, and if so, how it was made. This will not be possible if conical moulded bread was associated with, for example, religious production on a state or private basis but was never placed in tombs. I have seen no conical mould-baked bread in the British Museum, Louvre, Boston Museum of Fine Arts, Egyptian Museum of Turin, nor Cairo Museum collections.

If conical moulded bread is to be found as tomb offerings, there may be a distribution based on social status. The well-to-do architect Kha
of Deir el-Medina had no conical moulded bread amongst his funerary effects, now on display at the Egyptian Museum in Turin (Donadoni-Roveri, 1987b: 18). Such bread, if restricted in distribution for funerary purposes, may have been offered to officials of higher status, or of particular station, such as priests. One tomb which may throw light on this question is that of Tutankhamun. I have not yet been able to examine all the loaves retrieved from it.

2. Round flat loaves

One type of circular loaf is distinguished by its marked thinness. The five breads of this type which I have seen so far vary between 5 and 13 mm thick. Usually the undersides have distinct convex curves. One good example, now in the Louvre Museum (021, see McDonald, 1982a: 112 with an illustration), comes from Deir el-Medina. This loaf is about 10 mm thick and 106 mm in diameter. The edges have been ruffled by lightly pressing either side with the finger tips. The finger marks are slight, showing that the loaf was formed by someone with small thin fingers, perhaps a child.

Two other similar loaves, now in the British Museum (065, 066), are unprovenanced and undated. The imprints on them clearly show how they were formed. The larger of the two, measuring 140 mm in diameter, has a hand print on the lower side. The pattern of finger and hand marks suggests that this loaf was formed by slapping the dough back and forth several times between the hands, and then the flattened dough was supported in the left hand while the upper surface was pressed into a series of uneven shallow depressions with the right, using the thumb and finger tips. The smaller loaf (115 mm
in diameter) also has a small hand print on the underside, perhaps the entire print of a child. The print measures only 100 mm in length. The upper surface is more uneven, partly because the texture of the loaf is coarser, but also because this bread has been less skillfully formed than the larger one.

A fourth example of flat round bread is in the Cairo Museum (070). It is the thinnest example, only about 5 mm thick, and is distinctly bowed in cross section. It has been decorated by pinching around the edges to create a scalloped effect.

One variation of this form can be seen amongst the loaves from the tomb of Kha (013) (Fig. 6.1). In size it resembles the thicker disk-shaped loaves discussed below, measuring 175 mm in diameter, but it is a very thin, crispy looking bread. Its maximum thickness is 14 mm, but this is at the point of a ridge which runs around the diameter of the loaf about 1 cm from the edge. The underside of the loaf has a seam marking the line of the ridge. The ridge and seam suggest that the ridge was formed by pinching it up from a flat disk of dough.

The shaping and decorative features of all these loaves suggest that the doughs they were made from were quite soft and pliable, but also held the shapes well.

3. Round loaves with central indentations
Round loaves with some type of central depression or indentation occur relatively frequently in museum collections. The overall size of the loaf varies, as does the nature of the central depression. The
type is of no great depth; however; the thickest which I measured was 50 mm. The specimens which I have studied can be divided into three sub-types, although published photographs of other loaves suggest the range of variation is greater.

The simplest form is a broad disk, slightly convex over the upper surface. The centre is impressed with a small round indentation (Fig. 6.1, 012). My finger tip fits neatly into it; it is very probable that the depression was made by firmly pressing a finger tip into the dough. Some examples of this type have a ring of fine marks pricked out around the indentation. One from the tomb of Kha is illustrated in Sist (1987: 58, Pl 61).

A more elaborate form can be seen in Figure 6.1 as well as Figure 6.2 (010) (also shown in Sist, 1987: 58, Pl 61). The central depression has been formed probably by hooking a finger into the dough and pulling it back, to form a more or less triangular flare with a hood over the broader upper edge of the depression. In many cases the vulvar effect is enhanced by a ring of fine holes encircling the depression. There are a number of loaves of this female genitalia form in the tomb of Kha, and other examples were found from Deir el-Medina. Two further loaves of this type are on display in the Cairo Museum (Room 52, accession numbers not visible). A similar but less elaborate form is illustrated by Darby et al. (1977: 521, Fig. 12.13). Here, the depressions are not triangular but round. Unlike the shallow depression of 012, the indentations are relatively deep, and partially surrounded by a ridge. One loaf has a ring of pricked holes around the central depression.
I have not so far come across any phallic bread forms. Both Strouhal (1992: 127) and Sist (1987: 55) mention bread in the shape of a phallus but do not elaborate. They may be referring to a passage in the London medical papyrus, Spell #38, which, according to Wreszinski (1912: 197), deals with a phallus-shaped bread. The text, however, though certainly referring to a phallus, may be translated quite differently and may have nothing to do with bread (Margaret Serpico, pers. comm.). Von Deines et al. (1958i: 153, ii: 128) leave the nature of the phallus untranslated, but mention Wreszinski's interpretation.

Representations of male and female body forms made from bread have been noted by Bruyère (1937: 108), shaped like flat dolls without legs. Some examples are illustrated by Darby et al. (1977: 525, Fig. 12.17) - the bread on the far left of their photograph is surely a male form, not a female form as stated in the accompanying caption. Gardiner (1935: 67-68) describes a spell of Papyrus Chester Beatty VIII, British Museum 10688, Rt. 3, 5-5, 3, which is to be spoken over loaves, amongst other things, with the instructions "make the image of a man out of a loaf of white bread...". These particular spells were apparently not directed against any specific danger or illness, but employed as general preventative measures against ill health.

Fertility and sexuality were important Egyptian concerns (Bourriau, 1988: 124, 125), and bread in the form of genitalia may be related to this. They may be a part of the tradition which prompted figurine forms of bread, and indeed figurines in other media, which first
appear much earlier in the Middle Kingdom (e.g. Bourriau, 1988: 122-127; Tooley, 1991). The indentations and pricked dot decoration of one such female figurine made from marl clay (Bourriau, 1988: 126, Fig. 120) are reminiscent of some round bread decoration.

Mud or clay abstract female figurines and representations of female sexual organs more abstract than the bread loaves, appear in the Middle Kingdom and continue into the New Kingdom. For example, Petrie (1927: 61, Pl. LIII) illustrates a number of very crudely made, unfired clay figurines from 12th Dynasty Kahun (c. 1950 BC). Many are simply brick-shaped with incised or dotted breasts, navel, delta, and vulva, while two examples (Nos. 444-445) intriguingly have cereal grains inserted for the eyes and vulva. One of the largest groups of objects found at the Middle Kingdom fortress of Buhen were mud and clay female figurines, mostly in an extremely simple rectangular form with an emphasis on sexual organs to the exclusion of other features (Emery et al., 148-149, Pl. 53, 54). Similar New Kingdom "dolls" with pricked-out features were found at Gurob (Brunton and Engelbach, 1927: 18, Pl. XLVII). At Deir el-Medina, clay objects found within the walled village and public spaces are reduced to representations of female sexual organs, usually the lips of the vulva, but one illustrated object has a circular depression ringed with dots (Bruyère, 1939: 143, Fig. 61, Pl. XLV). The bread loaves in the form of female genitalia, therefore, are part of a long tradition of explicit representation, although the precise intent which prompted their manufacture remains uncertain.
The third form of disk-shaped bread has a much wider central depression. I have called this a "crater" shape. The size and shape of the cavity varies. There are a number of illustrations of this type of loaf, including Borchardt (1932: Pl. 3); the upper central loaf in Fig. 12.13, Darby et al. (1977: 521); and Brovarski et al. (1982: 112, number 95). The loaves illustrated in Darby et al. and Brovarski et al. are from Deir el-Medina. The latter is held in the Louvre Museum, where I had the opportunity to examine it (023).

Bruyère (1937: 106) describes large round bread loaves with central cavities impressed on the raw dough with the base of a vase. These were very commonly retrieved from the eastern cemetery of Deir el-Medina. The loaf illustrated in the lower left of Bruyère's (1937: 106) Figure 52 may be of this sort, for the cavity edge seems very sharp and clearly defined. However, it is clear that loaf 023 was not shaped by punching a cavity in the centre, as stated by McDonald (1982a: 112). It was formed from coils of dough pressed and smoothed together around a very thin central disk of dough. The order in which the coils were added can be determined to a large extent by the way they overlap. This is clearest on the underside; the upper surface has been smoothed over, obscuring most of the joins. Figure 6.3 shows the individual sections visible on the underside of this loaf, and their general order of addition.

Other loaves of this form which I have examined were shaped in the same way. Loaf 014 shows a similar pattern of seams around a thin central disk. Seams can be seen in the photograph of this type of loaf illustrated by Darby et al. (1977: 521, Fig. 12.13). The loaf
described by Borchardt (1932: 73) in the Berlin Museum has a very thin base in the central cavity, while the edge has been pulled up into a marked ridge on one side, apparently by pressing with the fingers. A pattern of ridges around the sides of the cavity on loaf 007 suggests the same treatment. The base of the cavity for this loaf is thicker than most, but the maximum thickness of the whole loaf is only 30 mm.

The form of these loaves suggests they were made firm dough which was able to hold its shape well, and therefore did not have a markedly high moisture content. The dough texture may have made coiling the easiest way to create a crater shape.

4. Conical and tapered loaves

Since there are large quantities of conical bread moulds from New Kingdom sites, it might be expected that all conical loaves were made in such moulds, but this is not the case. Two conical loaves from Deir el-Medina, now at the Louvre Museum (028, and 029) and seen by me, were definitely formed by hand.

Nicholson (1989a: 253-246) has shown that conical pottery moulds were probably made around a wooden form. The interior surface of these moulds are smooth, regular, and form a circle in cross-section. Although in one view both conical loaves look smooth and regular, one long side of each is flattened because they were made to rest on a surface. This flattening means that the cross-sections are definitely not circular (Fig. 6.4). Loaf 028 was formed from more than one piece of dough pressed and smoothed together, while loaf 029 was probably
made in a similar manner, judging from a seam running the length of one narrow edge.

These loaves are incomplete. Both ends of O28 have broken away, while the narrow tip of O29 is missing but the broader top end remains. This end is smooth and rounded, as one might expect the top of a conical mould-baked loaf to be. The shape suggests an effort at imitation, but without an actual moulded example, it is not possible to confirm this idea.

Darby et al. (1977: 520, Fig. 12.12) illustrate three complete conical loaves which at first sight look smooth and regular. The provenance is not stated, nor are any descriptive details provided. They are now in the Dokki Agricultural Museum, Cairo (accession #4272). A close look at the photograph, however, shows that the middle loaf is bowed and uneven; the edges of the loaf on the right are also not even. It is not possible to draw any definite conclusions from a photograph, but in view of the hand-formed conical loaves in the Louvre, the irregularities suggest that the loaves illustrated by Darby et al. were also shaped by hand.

A published selection of loaves from tombs of the eastern cemetery at Deir el-Medina include other examples of conical bread (Bruyère, 1937: 106). The top left corner of Bruyère's Figure 52 shows four conical loaves. In the middle rank, again to the left of the photograph, three tapered loaves are shown. An example of this form is in the British Museum (070). The provenance is uncertain; it is thought to be from Thebes and to date to about 1250 BC.
As with the conical loaves 028 and 029, this loaf also has one flattened side. Judging from the seams on the underside, the loaf appears to have been first rolled out and then shaped into its final tapered form. Viewed from above, the ends are rounded, while from the side they are slightly pointed. One end is somewhat more slender, and its surface much more smoothed than the rest of the loaf.

5. "Split" loaves

The largest type of loaf which I have examined has a thick oblong form. These loaves have a depth of about 100 mm - considerably greater than other shapes. All the examples which I have seen are encased in an open network of palm leaflets. Figures 6.2, 6.5, and 6.6 show some examples from the tomb of Kha.

There were 10 loaves of this form amongst the funerary effects of the Deir el-Medina architect Kha (011). At least eight of them, and probably all 10, were made in two separate halves pressed together. As a result, many of the loaves have cracked down the centre. This cracking probably occurred immediately after baking, but may be a result of extreme age and desiccation. If the former is the case, the network of palm fronds may have served to hold the two sides together. The leaflets adhere closely to the surface of the bread, indicating that there was no appreciable shrinkage of these loaves over time, nor are any other types of loaf likely to have shrunk.

All these loaves have been slashed with a knife in a semi-circular arc on one side. They are also decorated with small, shallow, oval or
circular impressions near the arc. The pattern of impressions varies from loaf to loaf, and each pattern appears to have been made before the slash. Some rows of circles arch over the slash in a single or double rank. An example from Deir el-Medina in the Cairo Museum (075) has two double rows of very fine ovals perpendicular to and at either end of the slash. The impressions on this type of loaf seem to have been made in different ways. Some look as though they have been pressed into the crust with a tool of some sort, while others have been formed by several adjoining cuts, perhaps made with the tip of a sharp knife. The fact that these shallow marks survive on the crust shows that the texture of the dough and its behaviour on exposure to heat was quite different to modern bread dough, which expands, destroying any such delicate markings during baking.

6. Figurative shapes

Three examples of figurative shapes are presented here. They show that bread could be made into very precise forms, although the significance of the shapes is unknown; they could simply be the result of a creative desire for decoration. Two examples come from the tomb of Kha, which include a fish-shaped loaf (009), and a bread in the form of a trussed goat or gazelle (not recorded). They are shown in Figures 6.6 and 6.5 respectively.

The fish-shaped bread was made by rolling out a strip of dough and tapering the ends to points. This was doubled over, and two very narrow rolls of dough were laid across the breadth of the upper surface. These strips do not continue around to the underside. The
body of the trussed animal was shaped and then two narrow rolls of dough laid over the ankles and neck of the figure.

A small loaf of quite different form, measuring only 45 mm in diameter and 10 mm in thickness, is at the British Museum (069). Its provenance is uncertain, but is thought to date to the New Kingdom and to come from Thebes. The loaf has been shaped into four lobes, which have then been twisted up at about 90° to the centre of the loaf. The twisting action has torn the dough somewhat, suggesting that it was a fairly stiff, inflexible mixture. The centre of the loaf has a hole pierced through it.

C. Shape as an indicator of bread type?

Since the only information which distinguishes bread in artistic depictions is shape and sometimes colour, loaf form has been the prime focus of bread studies in the past. Even when examples of real bread have been illustrated, they are related to shapes depicted in artistic representations and not vice versa (for example, Borchardt, 1932; Währen, 1961; Darby et al., 1977: 501-528).

Währen (1961) created a typology of bread shapes, culled from the artistic record. Its explicit aims were to establish the types of bread produced over time, and to look for continuity and development of bread forms (1961: 1). The difficulty with this type of approach is immediately apparent from the fact that different ancient names have been assigned to what seem to be the same or very similar loaf shapes. For example, Strouhal (1992: 127) states that conical white bread, called t-hedj, was often placed in vertical slices in sacrifices
for the dead; Drenkhahn (1975: 871) gives the name bnbn to an offering bread in the shape of an isosceles triangle placed on its base; Kemp (in press) mentions two different bread names for such a shape: bit associated with a narrow tapering profile, as well as "white bread" (t-hedj) which he says often has the shape of a narrow based triangle.

Lists such as those in the Onomasticon of Amenemope (Gardiner, 1947: 228), and in Papyrus Harris (Breasted, 1906: 134-136), record a very wide variety of names for bread. Representation alone does little to clarify the meaning of bread names. Without a label attached to an actual loaf, it will probably not be possible to determine what criteria were used to distinguish them.

A comparison between Währen's detailed typology (1961) and actual loaves makes it clear that the artistic record alone does not cover the full range of forms. I will quote only two examples here. Währen's (1961: 2) survey of circular forms shows a type marked with a decorated square (A11: [Diagram]) which he assigns to the Middle Kingdom, and two other very similar forms (A67: [Diagram], A68: [Diagram]) which he has found in late New Kingdom and Late Period depictions. However, lens-shaped loaves, each with a square stamp on the circular upper surface, come from New Kingdom Deir el-Medina. Several examples are on display at the Cairo Museum (Room 53, no accession number visible), and in the new pavilion of ancient Egyptian agriculture at the Dokki Museum, Cairo (accession number not recorded). In the D scheme of Währen's typology (p. 10), some odd pod-like forms are reproduced: D28: [Diagram], and D29: [Diagram]. (Type
D28 is more clearly illustrated in Borchardt, 1932: Plate V, centre, Choche (el-Khokha) 176). However, nowhere does he show the much more simple "bow tie" shape: ( ), several examples of which (008) are included in the effects from the tomb of Kha (Fig. 6.2).

Wahren's commentary frequently refers to bread, cakes, and pastries as separate types of baked product, but he does not make it clear how he distinguishes between them, nor what the ancient Egyptians themselves considered to be different categories of baked goods. Although he elaborates further on this in another publication (Wahren, 1963: 20), his division between bread and cake is far from clear. Pastry seems to be considered as bread which has been made into shapes, such as spirals, cows, and humans. It is possible, however, to determine whether there are any other differences in such shaped breads, as opposed to other forms, by studying actual bread.

Bread type, and production processes used for bread making, can be assessed in a number of ways. A detailed examination of microstructure is discussed in the following section. This section is concerned with information which can be obtained by examining whole loaves. This includes colour, texture, shape, and ingredients. Size may also affect baking procedures. These data together indicate much of the bread recipe and help to establish whether bread shape indicates a particular type of bread, or whether different production methods were used for breads of the same overall form. In other words, is shape an indicator of bread type? Several examples are used to examine this question.
A large assortment of bread loaves (001), now in the British Museum, was contained in a basket (accession #5391 A) bought in Thebes in the late 19th century. The provenance and date are unfortunately unknown. Four different shapes can be distinguished amongst the intact loaves, but a large number of fragments suggest other forms may originally have been included. The four discernible shapes are flat round loaves (similar to 021, 064, etc.); round breads with a raised ridge (similar to 013); tapered rolls (similar to 070); and triangular loaves with rounded corners (similar to 015, 022, 068, etc.). All loaves have the same colour. Their texture is difficult to characterize because they have all been very badly infested with weevils. In many cases the loaves are scarcely more than spongy shells. The loaf areas which survive have the same texture, varying from whole emmer grains to small chunks of endosperm. A few surprisingly large fragments of reed or straw are embedded in some of the fragments. No reed material is visible in complete loaves. Despite the degraded condition of this assemblage of bread, it is clear that the different shapes were all made from the same type of dough, which was probably all prepared at the same time. In this example, one type of dough was used to make a variety of shapes.

The loaves in the tomb of Kha are made into an array of shapes. Museum conditions made them difficult to assess fully, but my impression is that most were made from the same type of dough. There is no obvious difference between figurative shapes, such as the fish and trussed animal forms (see Figs. 6.5, 6.6), and any of the other loaves. Textures of whole loaves often could not be determined because the crust is smooth, obscuring the crumb structure within.
This assemblage presents an unusual chance to compare all the offerings from one interment and the opportunity to make a more detailed study would be welcome. As with assemblage 001, on present evidence a variety of forms has apparently been made from what appears to be the same or very similar types of dough.

The relationship of shape and type of dough can also be examined by comparing loaves from different contexts which have the same form. Conical loaves are one distinctive type. The two incomplete conical loaves from an 18th Dynasty Deir el-Medina cemetery, held at the Louvre (028, 029), have been discussed above. Their exact provenance has not been recorded, and it is not known whether they come from the same tomb. The colour of both loaves is very similar: a pale yellowy-brown crust, and deep orangey-brown interior. The texture of both is quite fine, with the separate addition of whole grains. Most are emmer, but both loaves contain a few barley and Lolium grains as well. In colour, size, and texture, these two loaves are the same (see, however, Section V.C, and Table 6.7). The one difference is that loaf 029 has a faintly sweet scent which loaf 028 lacks. In contrast, the third conical loaf (071 - provenance unknown, but probably of the 18th Dynasty) which I have studied is entirely different. It is dark purple and is made entirely or mostly of figs (see above, III.C). Conical form is thus no guide to bread recipe.

A number of triangular loaves have been retrieved from tombs. There are at least two main shapes. One is a flat, very long and narrow isosceles triangle, an example of which comes from the 18th Dynasty Theban tomb of Imhotep (QV 46), (006, Fig. 6.7). It is 280 mm long.
The exterior is an orangey-brown colour, while the interior is a somewhat darker shade. The loaf seems to be made from fairly coarse flour (2-4 on the relative scale); the texture was difficult to assess due to viewing conditions and heavy weevil infestation. It is made of emmer and contains a few *Lolium* caryopses. Bruyère (1937: 107) has retrieved bread of this form (although he groups them with conical loaves) from the eastern cemetery at Deir el-Medina, but his finds were substantially smaller, measuring from 150 to 180 mm in length. I have not seen any of these.

The other triangular form is equilateral. I have been able to study seven different examples, from four locations of different date. Four loaves of this type (073) come from the 11th Dynasty tomb of Mait. I have collected less data for these, as they were observed through the display case glass. The date and provenance of 015 is unknown, while 022 comes from a Deir el-Medina grave in the eastern cemetery, dating to the time of Hatshepsut and Thutmosis III (1490-1439 BC). The fourth example, 068, comes from debris excavated from the temple of Menthu-hotep at Deir el-Bahari, and like 073, dates to the 11th Dynasty. The features which can be determined and compared on a morphological level are overall shape, size, and colour; texture and ingredients can sometimes be ascertained.

Although all of these loaves are equilateral triangles, their form is somewhat different. The edges of loaves 015 and 022 are nearly straight, while the edges of loaves 068 and 073 are distinctly concave, accentuating the three points of the triangle. Two points of loaf 068 are blunted, while the third is rounded. Thus, what appears to be
one shape of loaf seems to vary slightly but distinctively. It is not possible to be sure to what extent such variations on a basic form were consistent and intended, and to what extent each loaf was shaped according to the individual style of the baker.

Loaf 015 is markedly different from the others. It is somewhat smaller, measuring 135 mm on the longest edge, but quite thick at 40 mm. It is a dark brown colour, while all the other equilateral triangular loaves are a distinctive pale yellow. It is not quite symmetrical because each edge is shaped slightly differently, ranging from slightly convex through straight to slightly concave. The loaf is dense and heavy, but the texture is difficult to assess because of heavy bruchid beetle infestation. Chaff inclusions show that it was made of emmer.

Loaf 022, from Deir el-Medina, is pale yellow-brown in colour on the upper surface and slightly darker beneath. The interior is deep brown with a slightly orange cast. The large number of whole grains are almost all emmer, with a few barley grains, still with most of their chaff adhering. Two caryopses imbedded in the crumb and largely obscured are probably Lolium. The small amount of chaff incorporated in the loaf is very coarse, and all derives from emmer. The loaf is composed of a fine matrix with complete or nearly whole grains embedded in it, indicating that the flour was very finely ground, and whole grains were added separately. The crumb structure contains some large vesicles.

Although loaf 068 is the same colour as 022, it has a strikingly different texture. Surprisingly, the most common grain is Lolium.
which far outnumbers emmer and barley. The loaf is heavy and seems to be quite solid; it looks unpalatable. The lack of similarity in texture and contents between these two loaves shows that their production was quite different. However, it may not be valid to compare loaves of similar shape but different date.

Comparing loaves of the same shape from the same tomb avoids this problem. One such group is the four triangular loaves from the tomb of Mait. One example (073B) is illustrated in Darby et al. (1977: 524). They are all very large (approximately 200 to 250 mm on each side), with a maximum thickness of about 50 mm. Despite the restricted study conditions, it can clearly be seen that each loaf is somewhat different. Three (073A, B, and D) are made of a very coarsely ground mixture, with lots of whole grain. Loaf 073C, however, has a much finer texture and many fewer whole grains. It is also somewhat darker in surface colour. It has no coating on the upper surface, while the other three have been covered with a very thin, flaking separate layer of whitish material. I could not determine what this consists of, but it may be a very fine flour paste smoothed over the bread. I could not see if it extended to the underside of the three loaves. The interior of all four loaves is a deep rich brown colour. Loaf 073B contains numerous partially dehusked whole barley grains, while the others appear to contain only emmer grain. Only 073A and D seem to resemble each other closely. These four superficially similar loaves were actually made somewhat differently.

On the basis of this evidence it is clear that bread shape is not related to recipe. Bread can be of different form but the same type of
dough (e.g. 001, possibly the assemblage in the tomb of Kha), or made into the same shapes but from different types of dough (e.g. triangular loaves, conical loaves). Although shape was probably very important to the ancient Egyptians, given their strong sense of visual symbolism (Kemp, 1989: 27), form is not necessarily a wholly-defining characteristic of their bread, and should not be considered in isolation.

IV. Cereal processing and bread texture

A. Introduction

As discussed in Ch. 5, the main steps required to produce flour from whole emmer spikelets were pounding, winnowing, sieving, hand cleaning, and grinding. Each stage generates a different assemblage of chaff fragments and grain as shown in Table 5.3. The quantity and type of chaff in bread loaves is a reflection of the procedures used to obtain clean grain prior to milling and baking, while loaf texture provides insights into cereal preparation.

B. Evidence for pounding and cleaning from chaff inclusions

1. Spikelets and heavy chaff

However chaffy they may be, there are no entire, unbreached spikelets in any of the loaves. Either the pounding which was applied was sufficient to shred all of them, or efficient sieving removed them from the material which then went on for further processing. The largest chaff elements are found in loaves 049 and 022, as well as a single emmer spikelet fork, with both the long glumes and interior light chaff still attached in a shredded state, in 006. The lack of other very large pieces of chaff suggests that this shredded empty
spikelet was incorporated by chance, separately from the processed cereal.

Loaf 049 has a very coarse grain texture with unusually large quantities of heavy chaff. All fragment sizes produced by pounding, as shown both archaeobotanically (Ch. 5.III.D.2) and experimentally (Ch. 5.IV.C.2), are represented, and all are shredded. There is no fine chaff at all. The assemblage of chaff embedded in the baked matrix matches the heavy chaff generated by winnowing away light chaff after pounding. The coarse grain texture, lack of light chaff, and abundant heavy chaff suggests that, for this loaf, grain cleaning ceased after winnowing and the heavy chaff was not removed from the grain, prior to a cursory milling. The minimum amount of processing needed to produce a dough which sticks together was applied. The high concentration of coarse chaff in fragment 049 would have rendered it highly unpalatable to humans.

The chaff in loaf 022 is not abundant but it is coarse. It consists of emmer spikelet forks, glume bases, and empty shredded spikelets. Since there are relatively low amounts of coarse chaff, the sieving stage, which removes much of this type of material, was probably carried out with reasonable efficiency. There will always be a few leftover chaff elements, of similar size to the grain, that must be removed by hand. In this case it appears that the grain for this loaf was winnowed and sieved, but the final cleaning stage was dispensed with.
Five other loaves contain a few fragments of coarse material. For example, 017 contains a number of chaffy pieces, such as emmer glume bases. This type and level of inclusion also suggests less than thorough hand cleaning before grinding.

Somewhat puzzling are the scattered but relatively large fragments of straw culm or reed fragments embedded in some of the various loaves making up 001. Such material could not have entered the dough as an accompaniment to the milled grain, since it would have been sieved out with the coarse chaff earlier in the processing sequence, if not removed when the spikelets were first cleaned after being taken from store. One can only assume that it was incorporated during dough mixing by some means.

The chaff content of these loaves indicates that whole spikelets were never incorporated into bread, however carelessly made; they were either all shredded in the mortar, or sieved out of the poundings. Carelessly prepared grain may not have been sieved to remove the heavy chaff, or the final, time-consuming job of hand picking coarse elements may have been omitted. Given the coarse, indigestible nature of heavy chaff, one presumes such perfunctory processing was applied only to funerary loaves, and not normally to bread destined for the living.

2. Light chaff

To make a dough which would stick together, the bulk of the fine chaff would have had to be winnowed away. Large quantities of fine chaff absorb moisture, and disrupt the network of endosperm
carbohydrates and proteins which bind together to create a coherent mass of dough. Most of this material must therefore be removed during processing of cereal, irrespective of how carefully, or how carelessly, subsequent cleaning is undertaken.

It might be expected that no loaves would contain significant amounts of fine chaff without any coarse chaff, since the bulk of the fine chaff can be removed by winnowing, before sieving extracts the heavy chaff. However, three loaves contain noticeable quantities; these are 006, 008 and 013. Loaf 006 contains less than the other two and its presence suggests inefficient winnowing. The light chaff of loaves 008 and 013 is concentrated on the undersides rather than being evenly distributed throughout the loaves. It therefore appears that most of the fine chaff did not accompany the processed grain into the dough, but was pressed into the lower surface after the dough was shaped. Perhaps the raw loaves, once formed, were placed on a fine chaffy surface prior to baking.

Two thirds of the loaves I have studied have either no chaff visible, or a few fine shreds. If light chaff was thoroughly removed, most of the time the heavy chaff was carefully cleaned out as well. This demonstrates that cereal processing could be carried out very effectively.

C. Evidence for milling and sieving from flour texture

Once grain has been extracted from the spikelets and cleaned of chaff to a greater or lesser degree, it is ready to be milled. The extent of flour milling for any loaf can be determined by its texture. I have
characterized this in relative terms - see Table 6.2 for a description of the relative texture scale. No attempt has been made to quantify the proportions of each category.

About a quarter of the loaves which I have studied contain whole grains. Three loaves, all from the Deir el-Medina cemeteries and now in the Louvre Museum (022, 028, and 029), have discontinuous textures. They are composed of very fine meals (1 to 2 on the relative scale) in which whole emmer grains (5 on the relative scale) are embedded. The lack of intermediate sizes of endosperm, particularly large grain fragments, strongly supports the interpretation that these loaves were made from a finely ground meal, to which whole grains were separately and deliberately added. In the case of loaves 028 and 029, the whole grains must have been thoroughly cleaned of chaff. As discussed above, 022 contains a noticeable number of coarse chaff elements. It is probable that these were introduced with whole grain which had been insufficiently picked over by hand, since it has been established through experimental replication that the milling required to produce very finely ground flour breaks down most large chaff inclusions into much smaller shreds. The possible ways in which the starch in raw whole grain was transformed into an edible form is discussed in Section V.C.4.e.

The full range of flour textures can be found amongst the loaves which I have examined. Any degree of milling will produce a certain amount of very fine flour, and this bakes into a matrix binding the loaf together. A range of flour textures could be and were produced as required, from very fine textures, such as loaves 021 and 023, to
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very coarse, such as 066 and 070. These examples contain little or no chaff. Loaves such as 017, 065, and 015 have a relatively fine texture (1 to 3) as well as some coarse chaff. The presence of coarser chaff suggests that flour was not sieved, yet no whole grains or large endosperm chunks are present. This pattern supports the evidence of my experimental work (Ch. 5.IV.F.2) that texture was controlled as desired at the grinding stage, rather than being inherently inefficient, as has frequently been suggested (e.g. Vandier, 1964: 272-273; Leek, 1972a: 291; 1972b: 130; Strouhal, 1992: 125, amongst many others).

Apart from loaves which have been very finely milled, there is no correlation between the degree of grain milling and the overall quantity and size range of chaff. Although the two loaves with very coarse chaff inclusions (022 and 049) also have very coarse grain textures, most of the rest range from very finely milled flour to inclusions of whole grain, irrespective of chaff.

D. Evidence for pounding from shredded grain
I did not realize that the state of the bran on endosperm fragments or whole grains was significant until after I had carried out experimental processing. This showed that when slightly dampened emmer spikelets are pounded in a limestone mortar with a wooden pestle, the bran tends to shred from a proportion of grains (see Fig. 5.34). The degree of bran shredding has not been quantified, since it depends on a number of factors, such as dampness of the spikelets, extent of pounding, and pounding technique.
I then looked for this characteristic on grain embedded in ancient loaves. On loaves 066 and 069 the bran of some emmer grain was clearly visible. Especially in 066 the bran is not only quite shredded, but some grain pieces have distinctly wrinkled bran, as if the grain had been thoroughly soaked for at least a day or more and then dried. There was no sign of sprouting on the grains, but any dried brittle rootlets would have been broken off during pounding. Any indication of furrows on the dorsal side of grain, caused by the extending plumule, or leaf shoot (Palmer, 1989: 103), would only occur if spikelet soaking was prolonged for several days which evidently was not the case for the spikelets used to make this loaf. As with grain processed during experiments, some of the intact proximal ends in the bread, whether on whole grains or fragments, retained their embryos, while other embryos were sheared off.

In loaf 065, which contains quite a lot of Lolium, unusually, some of the caryopses have been partially stripped of their hulls. They must, therefore, have been exposed to vigorous pounding with the main body of emmer spikelets. Such partial stripping of Lolium was not observed in loaf 068, however, which is composed primarily of rye grass, suggesting processing was less thorough. It could not have been added separately later as it forms the bulk of the loaf.

E. Modern bread fragments believed to be ancient

Two loaf fragments, 004 and 019, look very similar to each other but differ markedly from the others in colour, texture, and porosity. They have no provenance data and were bought as curiosities by
travellers in Egypt before being presented to the British and Ashmolean Museums respectively. They are both pale brown, with a very fine, even texture. Both have scarcely any chaff, and the few tiny pieces embedded in the loaves are very pale. Neither is particularly thick, but the crumb structure of both is highly porous. The upper crust of loaf 004 is lightly pocked with small holes which have a smooth, funnel shape, which could not have been made with a tool.

Chaff from provenanced, ancient bread is never pale straw-coloured, but has darkened considerably. None of the other, ancient, loaves has such a highly porous texture. Furthermore, overall loaf colour of ancient bread does not match the pale brown colour of these loaves. Both of them are almost certainly modern, made from bread wheat, and well leavened. In all morphological respects they closely resemble the type of bread baked in modern Egyptian village ovens.

F. Grit in bread
An important part of cereal processing is the removal of inorganic contaminants. Small stones and clods of earth are invariably mixed with spikelets during harvesting and post-harvest bulk threshing and cleaning. When these fall into the same size range as grain they are difficult to remove by means other than hand sorting, since they cannot be sieved out. Another type of inorganic contaminant is grit. Leek (1972b) examined thirteen desiccated ancient Egyptian loaves, aiming to establish the reasons for the widely remarked extreme attrition of ancient Egyptian teeth. He found that they contained greater or lesser quantities of inorganic particles embedded within the
matrix of the bread, not just on the surface, and concluded this was the reason for marked tooth wear. Petrographic analysis showed that the majority of inorganic components were rounded desert quartzitic sand grains, but other fragments were also present, including angular components and very fine particles.

I have not analysed any bread for inorganic content, but some mineral contaminants can be seen embedded on the surface of loaves or in the interior when bread is damaged. A number of loaves contain such inclusions. For example, loaves 002, 005, and 070 contain remarkably large chunks, which would break, rather than abrade, the teeth. The fragment in 005 is probably a piece of gypsum; I have not identified the other stones. Loaf 008 has a number of inclusions embedded on the underside but I could not determine whether these were organic or inorganic. Loaf 002 has a patch of fine white ash adhering to the underside while 014 is covered on all surfaces with fine black flecks. This may be soot. Loaf 066 has interesting surface encrustations: one side has thin ceramic particles, while on the other side is a smear of fine grey powder, probably ash.

Leek (1972b: 131-132) proposed a variety of sources for inorganic contamination of bread. Some of his proposed routes of contamination are unlikely, such as pieces of sickle blade fractured while harvesting, wind-blown contamination during winnowing, and the addition of grit to hasten the grinding process. Although the sequence of ancient Egyptian pre-harvest grain cleaning has not been studied as part of this thesis, it is probable that it followed much the same pattern as traditional processes studied by Hillman (1981; 1984a;
In this case, the spikelets would have been coarse sieved which would have removed large inorganic fragments, along with coarse straw, large weed heads, and other organic contaminants (Hillman, 1984a: 10; Jones, 1984, 1992). The spikelets would then have been fine sieved to remove small weeds and small chaff components, and fine grit and dust would also have been extracted at this stage.

The notion that sand was added to whole grains in order to mill them into flour was lent support by experiments with ancient Egyptian saddle querns carried out at the Manchester Museum (Leek, 1972b: 131; Owen, 1970). When bread wheat was milled on these querns, the operators could not produce any flour, and only some of the grains were flattened into 'cornflakes'. A reasonable amount of flour was produced only when a small quantity of sand was added to the grain. Leek (1972b: 131) quotes Pliny referring to Carthaginians adding pounded bricks, chalk and sand to grain prior to grinding. The historical context of this text suggests that Pliny was more derogatory than objective. The idea that grit was a deliberate addition, to speed and improve grinding, has been perpetuated in the literature (e.g. Schwarz, 1979: 40; Fleming et al., 1980: 74, amongst others). Earlier experiments carried out by me using cracked bread wheat on a replica quern emplacement with an ancient quern proved that the addition of sand is not needed to mill grain satisfactorily with a saddle quern (Samuel, 1989: 265-269). Subsequent experiments with whole emmer grain (Ch. 5.IV.F.2) have confirmed that it is completely wrong to think that sand must be added to grain in order to mill flour successfully with the saddle quern.
Leek's (1972b: 132) suggestions that grit was incorporated into bread through attrition of quern stones, and during the baking process, are perhaps more likely possibilities. Leek was not specific about the nature of grit incorporation during baking, but one source may have been flaking of the baking surface: adhering to the underside of loaf 066 are very thin patches of orange ceramic. As I have pointed out (Samuel, 1989: 269), it is conceivable that wind-borne grit may have contaminated bread during dough preparation.

A possibility that must be considered is that funerary bread may have been prepared with less care than bread for the living. The coarsely chaffy nature of some bread, such as 022, as well as loaf 068 which is full of Lolium, reinforces this suggestion, and calls into question Leek's conclusions, that grit was an inevitable component of daily bread, and was responsible for marked ancient Egyptian tooth wear. Study of tooth microwear patterns on ancient Egyptian teeth show that striations are rare and the surfaces are highly polished. This seems to point to a highly fibrous diet (Rose, et al., 1993: 62).

According to Simon Hillson (pers. comm.), the belief that ancient Egyptian teeth were more heavily worn than the teeth of other ancient populations may be a myth. Using Brothwell's index of attrition, he found no real difference in wear between a selection of ancient Egyptian skeletons, and those of ancient British groups. One problem with ancient Egyptian tooth wear studies is that frequently, only the skulls are available, so that aging criteria visible on the post-cranial skeleton are not available for independent age confirmation. Tooth
attrition is one of the prime methods of aging skeletons. The whole question of ancient Egyptian tooth wear is ripe for reassessment.

V. Bread microstructure and baking techniques

A. Introduction

The key processes applied to starch to make it digestible for humans are exposure to moisture, and heating. As outlined in Chapter 3, these processes affect the morphology of starch microstructure in specific ways so that, to a large extent, the analysis of starch microstructure allows the treatment of the finished food product to be traced. The standard technique which is used to do this is microscopy. Historically, optical microscopy has provided detailed information, which now supplements data from electron microscopy.

When modern starch products are studied with microscopy, all manufacturing parameters are normally known. Microscopy is used to explore the effects of these different processes on starch, so that its resulting properties are better understood. This informs further manipulation which aims to create a desired effect in food, or in other applications. In contrast, relatively little, if anything, has been definitely known about the preparation of ancient starch foods, and microscopy can be used to determine how they were processed.

Each permutation in treatment of spikelets, grain, and flour, with water, heat, and mixture with other ingredients, will affect the appearance of the starch microstructure. In addition, the particular variety of wheat used, whether it is hard or soft, its protein content - all these factors affect the rate and extent of starch transformation
(see Chapter 3). As a result of the great number of variables affecting starch microstructure and their complex interactions, it will not be possible to reconstruct the exact details of ancient bread making. It is, however, certainly possible to trace the general processes which were applied to make individual loaves through the study of starch microstructure. In this research on ancient Egyptian bread baking, hypotheses about the manufacture of loaves varies from reasonably certain to tentative, depending on the results and the condition of the samples.

Much of this section explains the development of models for ancient Egyptian bread making, using microscopy data derived from thirteen specimens of bread. These models are concerned only with the preparation and transformation of emmer wheat. Preparation of other potential ingredients is not considered. I have not discussed the effects of other possible ingredients on starch and bread as a whole, apart from leavening (section V.F). It should be emphasized, however, that ingredients such as salt, liquids, or mashed and strained fruit cannot be ruled out, but the techniques which I used are not capable of detecting them.

Grüss (1932) was a pioneer in the application of microscopy to the study of ancient bread. In section D, I have compared his results to mine, and draw different conclusions. I have not been able to obtain much information on ancient bread leavening, but the section ends with a brief discussion of ancient bread and yeast, based on some preliminary data.
B. Results

The microscopy methodologies applied to ancient bread samples are presented in Ch. 4.III and IV. They provide qualitative, not quantitative data, and interpretation is based in large part on relative changes. Starch in the ancient bread can be compared to modern starch prepared under various conditions, to determine the processes they had undergone. Here, a summary is presented of the results obtained from microscopy studies of the thirteen ancient bread loaves which were sampled.

When crumbs of ancient bread were placed in a water mount and viewed under transmitted light, the degree of starch granule distortion gave some idea about the extent of gelatinization. Pits and channels, and their extent, could be seen on starch granules, providing evidence of enzymatic attack. Under polarized light, granules which had not been gelatinized were birefringent, while those which had lost birefringence and were clear, had been at least partially gelatinized, whether or not they were distorted.

When the preparations were viewed under transmitted light again, and iodine potassium iodide (IKI) was added, the different colours of stained material indicated whether starch breakdown had occurred and how far it had progressed (see Ch. 3.VII.B.5). Whole starch stained dark purple-black, while dextrins produced through enzyme action stained different colours according to their length; from longest to shortest dextrins, these colours were respectively purple, violet, blue-violet, red, and red-brown. The results of optical microscopy studies are presented in Table 6.4. Because of technical problems with
Under the scanning electron microscope, the degree of gelatinization of individual starch granules is indicated by their different shapes. These forms have been characterized by Rockland et al. (1977, see Ch. 3.VI.D.1 and Fig. 3.7) and the same shapes could be seen in ancient starch. Pitting and channelling showed that enzyme attack had taken place, and the extent of channelling was a measure of how far enzymatic degradation had progressed. Table 6.5 summarizes SEM data, and a number of micrographs of ancient Egyptian bread are shown in Figs. 6.8 to 6.19.

C. Interpretation: development of ancient Egyptian bread making models

1. Introduction

The collation of microscopy data from sampled bread specimens has generated several different models for ancient Egyptian baking methods. The models describe two main variations of grain treatment prior to baking. The first difference is the extent to which whole, undamaged grain germinated as a result of exposure to moisture. The second difference applies to grain which had been exposed to soaking sufficient to saturate the grain; it deals with the next stage of preparation, and whether heat was applied to moist grain before the bread was baked. In addition to these two methods of treatment, it is possible to describe in very broad terms how wet the dough was at the time of baking.
2. Model A: Baking with dry grain

Of the loaves which I have sampled, only the characteristics of 017 indicate absence of enzymatic modification. No pitting or channelling of starch was seen with the SEM or with optical microscopy apart from a single pitted granule. Staining with IKI resulted in all of the sample in the temporary mount colouring deeply purple-black, showing that no dextrins, long or short, are detectable in this bread. The pitting observed on one granule may be due to native α-amylase laid down in the grain during growth and development, activated by the addition of moisture to the dough. According to Linko and Linko (1986: 107), cereals grown in dry climates develop very little native amylase, and this may well have been the case for emmer grown in ancient Egypt. There may have been some enzyme activity in dough prepared from dry grain, but its effects are likely to have been negligible.

This evidence supports the conclusion that the emmer spikelets for loaf 017 were not exposed to moisture, apart from the small amount needed for successful pounding (see Ch. 5.IV.C.2). Inclusions in the remaining loaf fragment show that the freed grain was reasonably but not thoroughly cleaned, and its texture indicates that the grain was well milled before being mixed into a dough. The fine texture of the flour would have allowed water to penetrate into most of the particles of endosperm, and thus to be available for at least the initial stages of gelatinization during baking.

An alternative possibility which cannot be ruled out on the evidence available is that the spikelets for this loaf were soaked briefly. In
this case, a similar pattern to unsoaked and baked starch microstructure would probably be seen. Soaking spikelets for a short time (up to as much as a day) would probably barely stimulate germination processes. Palmer records (1989: 143) that one barley variety with the lemma and palea removed takes 18 hours for the root to emerge and modification to begin, and although studies of the rate of water uptake by emmer grain have not been done, one would hardly expect grain enclosed in the thick spikelet chaff to germinate any faster. Thus a short exposure to water would almost certainly have no appreciable effect on the final loaf, either in sweetness or digestibility. With no obvious advantages for such a procedure, but with the delaying necessity of drying out the spikelets somewhat, it is reasonable to assume that the ancient Egyptians did not soak spikelets destined for bread for less than about two days.

There is a general lack of birefringence under cross polarization, apart from some isolated examples, showing that most granules have undergone the initial stages of gelatinization. Water must have been relatively limited in the dough, since most granules as seen with the SEM retain their individual boundaries and are in the early stages of distortion (Fig. 6.8), as measured by the RJH scale (the stages of gelatinization observed by Rockland, Jones, and Hansen, 1977, see Table 6.5 and Fig. 3.7). Optical microscopy confirms this, revealing minimally distorted starch granules. A relatively dry dough is also suggested by the lack of free granules released into the water mount. Whole modern emmer grain prepared for reference work tended not to release free granules into a water mount when dry heated, but many granules were released when the grain was soaked and then heated,
irrespective of the degree of modification. This is not analogous to finely milled endosperm, of course, but suggests a pattern which requires further experimental work to characterize fully.

The evidence summarized above leads to the conclusion that the processes used to make this loaf were relatively simple, and they are therefore fairly straightforward to trace with microscopy data. The bread shows no evidence for enzymatic modification and is an example of baking according to model A. The model can be summarized as follows:

i) Spikelets are not soaked, or exposed to moisture beyond sprinkling with water in the mortar for effective pounding.

ii) Spikelets are processed as outlined in Ch. 5 to produce flour (see Table 5.3).

iii) Water is added to flour to made a malleable dough.

iv) Dough baked.

3. Baking with germinated grain

a. Introduction

The results listed in the final column of Table 6.4, "Results of iodine stain", show that upon staining with IKI, all bread samples except 017 produced at least some colours in addition to the deep purple-black of whole starch. The observations made both with optical microscopy using transmitted light (Table 6.4) and scanning electron microscopy (Table 6.5) provide abundant evidence of pitted and channelled starch granules.
The exposure of whole, undamaged, raw grain to moisture stimulates germination, and the microstructure of the starchy endosperm changes as a result (see Ch. 3.VII). The clearest and most important microscopy markers for cereal germination, and resulting starch breakdown, are the appearance of pits and channels in starch granules when viewed under transmitted light; pits, channels, and corroded granules as seen by SEM; and starch breakdown products which stain with different colours upon the addition of IKI - exactly the features which appear in the starch of most of the analysed ancient loaves. Before germination can be accepted as the cause of these phenomena, however, other possible agents must be ruled out.

b. Elimination of processes other than germination as causes of starch breakdown in ancient loaves

The potential agents of starch degradation, other than grain germination, are aging, exposure to heat, insect predation, and microbial action.

Aging. Leek (1972: 130; 1973: 203) hypothesizes that starch breaks down with the passage of time, due to "oxidization and other atmospheric effects", but this assumption is not tenable. There is no evidence to support an undefined oxidative breakdown but observed evidence is well explained by known phenomena. Firstly, there is no sign of consistency in its effects. No pattern of breakdown can be seen amongst the thirteen loaves which I have analysed - why should loaf 017, for example, be immune? Leek's samples (1973: 203) also varied in the pattern of degradation products seen with IKI staining; two of his 18th Dynasty specimens had no dextrin content either. Secondly, in samples containing shorter polymer chains which stain
violet, blue, red, or brown, there is a certain amount of material which stains dark purple-black. This indicates the presence of intact starch. If age were the cause, why has some of the starch in the same loaves been unaffected?

Thirdly, age alone cannot explain the pits and channels in starch granules; these do not appear spontaneously. My scanning electron microscopy work has shown that bread starch microstructure shows no visible changes which can be explained by age.

Exposure to heat. Exposure to heat does not explain the channels and pits observed by both scanning electron and optical microscopy, but heat may be responsible for splitting starch into shorter dextrin chains detectable by staining with IKI. I have tested to some extent the effects of heat alone on raw starch. Raw emmer grains in the spikelet were either left dry and heated to a maximum of 150°C, or thoroughly soaked and heated to a maximum of 86°C, well above the temperature at which the onset of gelatinization takes place (57-60°C for wheat starch). As Fig. 3.9 shows, during baking, temperatures in the centre of a modern bread loaf do not exceed 98°C – just below the boiling point of water – while the maximum crust temperature is 205°C (Stear, 1990: 540-542). After this treatment, the saturated grains were dried down for 24 hours, and starch from the two sets mounted and stained with IKI. Without exception, all reference starch stained only deep purple-black, which indicates that starch chains did not degrade into short chains. Wet starch cannot be heated above the boiling point of water, and dry starch exposed to heat up to 150°C does not break starch down into long or short dextrin chains.
detectable with IKI. Dextrins may, however, be produced from dry starch at higher temperatures, between 160-190°C (Radley, 1943: 237). The process creates a substance with a strong smell and poor flavour.

When viewed with transmitted light, no pits or channels were observed, nor were such features seen in any of the SEM images (Figs. 4.4, 4.5). Although heat may be responsible for some dextrin production on the bread crust, where moisture is driven off during baking, it does not cause pitting and channelling of granules.

Since my samples were almost all taken from the interior of the ancient loaves, which would have retained a certain amount of moisture during baking, it is highly unlikely that temperatures sufficient to dextrinize starch were reached. Samples from the whole loaves 021, 022, and 023 were obtained from tiny crumbs which fell off during handling, and these probably came from the crust or the area just beneath the crust. As Table 6.4 shows, most starch granules from these samples are clear under polarizing light and have at least partially gelatinized, indicating the presence of moisture at least in the initial phases of baking. Dextrinization may have occurred after moisture was driven off but apart from the thin loaf 021, the colour of the crust is not very dark. The colour of the loaf provides some idea of final temperatures and a pale or medium brown colour suggests crust temperatures did not reach as high as 150°C.

Heat alone as an agent of starch breakdown does not explain the suite of characteristics seen in most ancient bread.
Insect predation. Another possible cause for starch degradation is insect predation. The majority of loaves have been exposed to weevil attack. A few loaves have been so damaged that the texture cannot be evaluated (Table 6.2), while others are channelled with weevil holes, but large areas of the loaves have not been invaded. Some loaves seem largely unaffected but have frass (insect excreta) adhering to them, perhaps fallen from other, infected loaves which were placed beside them in the tomb. The insect species have not been determined, but are probably the same as those pests of grain and grain products listed by Leek (1973: 202). All frass is identical in appearance as far as can be seen.

Weevil digestion enzymes capable of degrading starch will produce pits and channels on the granules, and may be expelled into the crumb matrix via the excreta. Thus, pits and channels in starch granules from the crumb might be a result of weevil infestation. In order for the enzymes to be active, however, a certain level of moisture is required, and once baked, water content may have been low.

By-products of weevil digestion ought to contain the same type of breakdown products, but loaves with weevil damage differ widely in their staining colour spectra and the condition of the starch. Although every effort was made to obtain samples without contaminating frass, this was not entirely successful, as frass can be seen in scanning electron micrographs from two samples, 021 and 028 (Fig. 6.9). Nevertheless, the amounts are small compared to the starchy crumb, and digested starch is unlikely to account for the relatively large
quantities of differently staining material seen with IKI under the microscope.

Two loaves with no sign of weevil damage or adhering frass (048, 049) show full colour spectra when stained with IKI. The size of insects and their excreta allows their presence to be ruled out with some confidence. The colours show that starch breakdown products are present in these loaves. Both optical microscopy and SEM show pits and channels in the starch granules. The lack of infestation means insects cannot have caused the starch degradation which has occurred in these loaves.

These patterns of staining indicate that the effects of insect predation and metabolism do not account for starch breakdown in the loaves which I have analysed. As with the effect of microbial action which is discussed next, the consequences of insect infestation on starch degradation in ancient bread would benefit from more detailed study to confirm this.

Micro-organisms. Amylase-producing micro-organisms may have broken down the ancient bread starch at some point after baking and prior to complete desiccation. Scanning electron microscopy has shown that many of the loaves have been colonized to a greater or lesser degree by fungal growth (some examples are shown in Fig. 6.10). Is it possible to rule this out completely as the cause of starch breakdown in the samples of ancient bread? The data which have been obtained provide no absolute proof, but strongly suggest micro-organism activity is not the cause. There are three reasons for this.
i) Many micro-organisms produce amylases to digest starch into sugars for their own nutritional use. Upon production the sugars are immediately absorbed; they are not left free in the substrate. The presence of free simple sugars is thus a good argument against a microbial origin for starch degradation. A pilot study of sugars in a sample from loaf 001 revealed that it contains a substantial quantity of free simple saccharides (see Table 6.6). If similar work on other loaves also shows that free sugars are frequently a component of the loaf, it would strongly support this initial evidence that microbial action is not the cause of starch degradation, but that microorganisms were digesting nutrients already present in the bread.

ii) If micro-organisms, including fungi, are agents of starch breakdown, then all loaves with micro-organisms should show evidence of starch degradation. Fungal hyphae are present in reasonable abundance, as shown by SEM, in loaf 017 (Fig. 6.10a), yet the crumb stains uniformly dark purple-black and thus contains only whole starch. If fungal amylases were responsible for starch breakdown, short chain dextrins produced by microbial amylase action ought to stain some of the material in the temporary mount violet, red, and brown.

iii) A number of loaves (001, 021, 028) have no signs of fungal hyphae under the SEM, nor did fungal hyphae stain with methylene blue. Yet, temporary mounts of material from these loaves stained a range of colours upon the addition of IKI, indicating the presence of long and short chain dextrins from starch breakdown. Pits and
channels were also seen on many of the starch granules from these loaves. Thus, as far as can be determined, bread samples with no microbial infection still contain products from starch degradation, and the granules have been attacked. Micro-organisms cannot, of course, be fully eliminated by negative evidence, especially as they may be present but not detected. If present in these loaves, however, micro-organisms must be at least less abundant, and yet IKI staining shows a considerable quantity of starch breakdown products.

Taken as a whole, this evidence leads to the conclusion that microbial metabolism was not responsible for starch breakdown in these ancient loaves. Further work to establish this more firmly is desirable. This could include analysis of more loaves for free simple sugars, which is relatively straightforward but requires sufficient quantities of sample (up to 500 mg); identification of micro-organisms to determine if they produce α-amylase, which is difficult if not impossible on the basis of morphology alone; and more sensitive tests using stains and fluorescent dyes to detect the presence of micro-organisms.

In summary, age is not a good explanation for starch degradation and dry heat does not explain pits and channels on the ancient starch granules. The effects of microbial and insect action do not fit the pattern of starch breakdown. The agent which best explains the patterns of starch degradation observed with optical and scanning electron microscopy is the action of amylases produced during germination of the whole grain, as a result of exposure to moisture. Given the arid climate of Egypt, and the need - easily achieved there
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- for dry storage conditions to prevent spoilage, the wetting of grain destined for bread making must have been deliberate.

c. Grain germination, moisture regimes, and endosperm modification

Grain must have been germinated when it was still in the spikelet. My experimental work shows that when spikelets are pounded with mortar and pestle, many of the freed grains have damaged embryos. Sometimes embryos are completely stripped off the grain. Once deprived of its embryo, the grain cannot activate enzymes and remains inert. Although some grain is probably capable of sprouting after being pounded, dependable germination will only occur if most grain is intact, and therefore, in the spikelet.

A range of potential moisture regimes may have been applied. One obvious variable is time. The longer the exposure to water, the further the germination process will proceed. As outlined in Ch. 3.VII, different enzymes are active throughout the early stages of germination. Proteases degrade starchy endosperm proteins first, giving amylases access to starch granules. Over time, the concentration of \( \alpha \)-amylase increases, and the enzyme eventually diffuses into the starch endosperm. It first attacks granules in the embryo region, before moving through the sub-aleurone area and subsequently deeper into the starchy endosperm. Its early action produces primarily long chain dextrins (staining violet with IKI) and it creates pits on the surfaces of starch granules.

As germination proceeds, \( \beta \)-amylase and limit-dextrinase are synthesized and begin to act on the long chain dextrins produced by
α-amylase attack. Over time, long chain dextrins are continuously produced, and then the shorter dextrin chains begin to accumulate, as well as the maltose which is the main simple sugar first produced by the sprouting grain. Medium length dextrin chains stain blue, shorter ones stain red, and the shortest stain reddish-brown to brown with IKI. Maltose remains colourless in the presence of IKI. The granules become heavily channelled and eventually, if germination continues to proceed far enough, only their shells may be left.

Treatment such as repeated soaking and air rests, as is done for modern-day malting (Davies, 1992: 39) will hasten the process. Other influences which affect the rate of germination, and therefore the extent of enzyme modification, are ambient temperature, subsequent treatment, as well as genotypic and phenotypic characteristics of the cereal variety. Most of these details cannot be traced by studying the microstructure of ancient starch, nor by other means. What can be detected is that germination had occurred, and to some extent, how far it had progressed.

None of the samples contains large quantities of starch granules which are extensively channelled or fragmented, although some individual granules are heavily degraded (see Fig. 6.11d and e). This means that the grain was not exposed to extensive germination. Depending on the various parameters which may have affected them, a reasonable estimate for the length of time they were soaked or kept moist, based on work done by Palmer (1989: 143) and Dronzek et al. (1972: 234), is from 2 to 4 days. Fig. 6.12 illustrates some pitted and channelled
starch granules seen under the SEM, sampled from several different bread samples and showing a range of enzymatic effects on granules.

4. Models for baking using germinated grain

a. Introduction

Characterization of loaves which have been made from germinated grain is not straightforward because of the several steps involved which affect starch microstructure. Above all, the final baking of the dough obscures the traces of earlier treatment. Modern baking data are not directly applicable to the interpretation of observations on ancient loaves, because the high amylase activity from germinated grain is detrimental to modern baking and is therefore avoided. Although little formal work has been done on the subject, malted starch behaves largely as unmalted starch when exposed to heat and moisture (R. Angold, pers. comm.); therefore, I have used the numerous studies on unmalted starch as analogies for the morphology of malted granules in ancient bread.

One phenomenon whose significance is unknown is the marked concentric rings seen on many starch granules from ancient bread, especially those embedded in intact endosperm fragments. These are much darker than growth rings normally are on starch. I have discussed this point with Roger Angold, and we have come to no definite conclusion about the possible reasons for these rings.

The heterogeneous texture of bread contributes to variation in the starch. My microscopy work has mostly concentrated on the crumb matrix of the bread, which should reflect overall processes, rather
than endosperm chunks from whole grain or large grain fragments, in which starch might be more protected from the full application of moisture and heat.

The data from loaves other than 017 indicate quite complex preparation methods. Their interpretation is correspondingly more tentative.

b. Model C: Baking with germinated, air-dried grain

To render emmer spikelets into flour of a quality which humans can masticate and digest, the heavy chaff must be removed. It has been established in Ch. 5 that pounding with pestle and mortar was employed to dehusk the grain. This operation is not possible with fully saturated spikelets, because the grain would be so soft that pounding would create a useless mixture of mashed starch smeared over the spikelet chaff. In order to dehusk the spikelets, it would have been essential to dry the spikelets out.

There are two possible ways by which this could be done, both supported by the microscopy evidence. Model C outlines the first method, discussed here, and model D describes the second way, discussed in the following section. Spikelets could be spread out to air dry. The process may have been assisted by the heat of the sun, and would be especially rapid in the summer months. Depending on conditions, it may have taken from a full day or more to dry out spikelets and the grain inside enough that the chaff would be shredded and the grain would stay entire during pounding. During colder days in the winter months, the drying was probably aided by frequent turning of the spikelets.
This method of drying would be relatively gradual, and little if any of
the starch would be gelatinized at this stage. Very hot summer
temperatures would probably not have been enough to cause
gelatinization of starch inside the saturated grains because
evaporating water would keep the temperature down, and because the
pale colour of the husk would help to reflect the heat.

The variable affecting starch microstructure at this stage is the
length of time the spikelets were moist, and the time they took to dry
out completely. Over this period enzymes would be synthesized in the
grain, starchy endosperm protein would be broken down, and α-
amylase would be produced. Alpha-amylase attack would probably
commence, but β-amylase and limit dextrinase action may hardly have
started before the grain dried out, suspending all enzyme activity.
Those bread specimens which fit the model C profile (see Table 6.7)
mostly do not have heavily channelled starch granules indicative of
very extensive enzyme attack, and therefore this stage is likely to
have been relatively short. The germination experiments which I
carried out (Ch. 4.V) indicate that emmer grains in the spikelet in a
warm room normally showned the first signs of root sheath extension
after three days, although a few grains began sprouting earlier than
this. Some starch granules, particularly at the embryo end of the
grain, might be notably degraded even in this short time, but the
numbers would be very low. After drying was complete, no further
starchy endosperm modification could have taken place, but the
enzymes would not have been destroyed, and their activity could
resume if they were again exposed to water. The embryo, though, would be killed by drying.

According to model C, the germinated, dried spikelets were processed as outlined in Ch. 5.V.B (see Table 5.3) to produce flour. When water was added to make the flour into a dough, all the enzymes would have been reactivated, and starch degradation would recommence. The full complement of amylases (α-, β-, and limit dextrinase) would allow more breakdown products to be created over a relatively short period of time. Therefore, pitting and channelling should be more advanced, and shorter dextrin chains and sugars could have accumulated in the dough.

The next features of bread produced with germinated air-dried grain depend upon another variable: the amount of water added to the dough. If dough was quite moist, the starch would be mostly well gelatinized, but the degree of gelatinization may vary according to the actual water to starch ratio and the presence of other ingredients. Thus, bread baked from air-dried, germinated grain mixed into a relatively high moisture dough (model C-1), should contain starch granules with a range of distortion and birefringence as observed under the optical microscope. The shape of granules seen with the SEM could range from S-0 (ungelatinized starch) to S-6 (dispersed starch) on the RJH scale (see Table 6.5), but are more likely to show the shapes indicative of more advanced gelatinization, from S-3 ("doughnut-shaped" starch) to S-6 (dispersed starch) (see Fig. 6.12). With a greater amount of moisture available, the starch
granules were likely to have dispersed relatively easily in the crumb matrix, not to have fused together in a mass.

When the dough was placed in the hot oven, the rise in temperature would have caused a rapidly increased rate of enzyme activity (see Ch. 3.VIII). Pitting and channelling of granules would be enhanced, and starch breakdown would have proceeded so far that substantial quantities of short chain dextrins would have been generated. As temperatures increased throughout the loaf mass, enzymes would become denatured and ceased activity. The suite of dextrins produced would cause a sample of the bread crumb to stain all colours with IKI (see above and Ch. 3.VII.B.5), including marked amounts of red and red-brown material.

The loaves which show the characteristics predicted by model C-1 are 001, 021, and 049. Others which probably were made like this, or by a similar process, are loaves 014 and 015. Loaves 022 and 028 are discussed further, below (see also Table 6.7).

Model C-1, baking with germinated, air-dried grain, and a moist dough may be summarized as follows:

i) Spikelets soaked for at least enough time to saturate enclosed grains and initiate germination.

ii) Wet spikelets air dried until completely dry.

iii) Dried spikelets processed as outlined in Ch. 5 to produce flour.

iv) Water added to make malleable dough.

v) Dough baked.
Bread may also have been made from germinated, air-dried flour, but mixed into a drier, stiffer dough. This model (C-2) is so far a theoretical possibility, as none of the 13 loaves analysed by microscopy showed the suite of characteristics which would be expected from such a procedure.

With a lower water content, the starch would have been less extensively gelatinized. Thus granules seen under the optical microscope would not be distorted, or very little distorted, and many would still be birefringent under polarizing light. Granule shape as seen with the SEM would range from S-0 (ungelatinized starch) to S-6 (dispersed starch) on the RJH scale. The low moisture content might be expected to fuse the granules into chunks, rather than allowing them to disperse in the crumb matrix. The granules would show some pitting and channelling but because the enzymes might be less mobile in limited water, their rate of activity might be less than in a moist dough, and less small dextrin chains, with less blue, red, and brown-staining material than for bread made by the C-1 model, might be produced.

Model C-2, baking with germinated, air-dried grain and a stiff "dry" dough, may be summarized as follows:

i) Spikelets soaked for at least enough time to saturate enclosed grains and initiate germination.

ii) Wet spikelets air dried until completely dry.

iii) Dried spikelets processed to produce flour as outlined in Ch. 5.

iv) Water added to make a stiff, "dry" dough.

v) Dough baked.
c. Model D: baking with germinated, roasted grain

Model D differs from model C in the way that spikelets were dried. In this suggested method, the saturated spikelets were heated over a fire. There is no direct archaeological evidence to suggest how this may have been done, but one possibility is that large shallow bowls - such as hearth bowls (Group 11, Amarna pottery typology; Rose, 1984: 135, 136) or metal basins - were filled with wet spikelets, placed over the opening of a cylindrical oven or set over a hearth, and stirred.

This is analogous to, although not precisely the same process as, parboiling (Ch. 3, VI.D.3). It is possible that starch in the deepest parts of the endosperm would be only partially gelatinized or entirely unaffected, depending on the heating conditions. If areas of the endosperm are insulated from temperatures above 70°C, enzymes which may have penetrated into these regions would also be protected from denaturing. If heating produced temperatures close to 70°C, most enzyme activity would be halted but not destroyed. However, it is unlikely that the process could be so precisely controlled. If direct heat were applied, the temperature throughout the grain would very likely have been above 70°C. This would have been sufficient to gelatinize many of the starch granules to the extent that they lost all birefringence when observed under polarizing light.

If grain was sprouted in the spikelet and then heated over a fire, the combination of starchy endosperm structural protein breakdown, and gelatinization of starch, would make the grain fragile and prone to
fracturing, especially during pounding. Excessive fracturing would make the edible grain fragments very difficult to separate from chaff. Fine sieving would not separate the small, heavy pieces of chaff from the bulk of grain in the form of fractured pieces. The size and quantity of small chaff pieces would make them difficult and tedious to extract by hand. To avoid these problems, soaking probably would not have been allowed to proceed too far.

If relatively brief soaking was applied, the only enzyme producing any substantial amounts of breakdown products would have been α-amylase, and so long chain dextrins, staining violet, as well as whole starch staining dark purple, would be predominant. Some pitting and channelling would probably be seen. Such a regime would not produce large quantities of short chain dextrins, seen as reddish-brown streams of material upon staining with IKI in a water mount, nor extensive pitting or channelling of starch granules. When the spikelets were heated over a fire, all starch-degrading enzymes would have been denatured and inactivated.

Because the grain would have been completely saturated, the heat would thoroughly gelatinize much, if not all, of the starch. Therefore, optical microscopy would show that starch granules in the bread are distorted and mostly clear with polarizing light, but perhaps a few would still be birefringent, depending on how long the roasting process proceeded. With the SEM, granules would mostly fall into the S-5 (pancake-shaped granules) and S-6 (dispersed starch) range on the RJH scale, with some less affected granules showing S-3 (doughnut-shaped) to S-4 (rubber raft-shaped) characteristics (see
Ch. 3.VI.D.1 and 2, Table 6.5, Fig. 6.13). These patterns would occur irrespective of heating during the actual baking, although baking might decrease still further the numbers of ungelatinized granules.

The brittleness of the grain would make milling easy and rapid, and the gelatinized starch may have tended to shatter. When water was added to flour to make a dough, no further starch degradation could occur because enzymes would have been denatured by heat during the earlier roasting process.

The loaves which show the characteristics predicted by model D are 023 and 048; loaf 029 may also have been made by a method similar to this. (See below for a discussion of loaves 022 and 028, and see also Table 6.7.) Model D, baking with germinated, roasted grain, may be summarized as follows:

i) Spikelets soaked for at least enough time to saturate the enclosed grains and initiate germination.

ii) Wet spikelets dried by heating above 70°C, i.e. with artificial heat.

iii) Dried spikelets processed to produce flour as outlined in Ch. 5.

iv) Water added to make malleable dough.

v) Dough baked.

d. Distinguishing between models C-1 and D

Despite the different methods involved in models C-1 and D, the final microstructure of bread starch may be very similar for both. Both models encompass a range of possible temperatures and time spans,
which could lead to similar effects on the starch granules. The obscuring effect of the final baking step further complicates the characteristics of the bread starch. In categorizing the analysed loaves according to the proposed models laid out in Table 6.7, the evidence for shattered starch (clouds of clear grey solid dispersed material) has been taken to be a good indicator of model D. However, an apparent absence of shattered starch does not rule out model D because the starch in the grain heated in spikelets may not have reached temperatures sufficient to render them so brittle. This suggestion is tentative and needs to be investigated in more detail.

Large quantities of soluble short chain dextrins (detected in water mounts of bread samples as streams of reddish-brown material when stained with IKI) fit better with the extended damp stage of model C. For model D, the saturated state of well soaked spikelets would suggest that most starch granules would lose their birefringence upon heating. However, the lack of information about how spikelets might have been heated means that incomplete gelatinization cannot be ruled out. Therefore, apart from very coarse gradations, the degree of gelatinization cannot be relied upon to distinguish between models C and D.

These uncertainties mean that, of the bread loaves which show evidence of enzymatic action (all loaves listed in Tables 6.4 and 6.5 except 017), the production method cannot be determined with certainty for 50% of them (that is, 014, 015, 022, 028, 029, and 064). The processes used to make loaves 028 and 064 in particular cannot be distinguished with the available evidence. The remaining 6 seem to
show characteristics which allow their processing procedure to be established with some confidence. To test and confirm the validity of the models, and the categorization of the analysed bread, more controlled experiments would be invaluable.

Bread made by either the "C" or the "D" process would have had a distinctive flavour. Along with the various dextrins which can be detected by IKI, maltose (which does not stain with IKI) is also produced by the germination process, the quantity increasing with time (see also section E below). The presence of dextrins and maltose would have imparted a sweet flavour to these ancient loaves. Bread made according to the "D" process would probably have had a stronger, slightly toasted or roasted flavour. The presence of dextrins and maltose from germinated grain may well explain the sweet taste Bruyère (1937: 107) detected in the loaves from tombs in the Deir el-Medina east cemetery (see section II.C).

e. Whole grains
A feature of many loaves is the presence of whole grains. If they had not been processed in some way, but left raw, their relatively high numbers in some loaves would have presented an obstacle to comfortable human digestion. Experiments with raw dry emmer grain exposed to high temperatures (up to 150°C) resulted in a cooked product which is very crunchy, with an overdone popcorn taste. Although hard, the endosperm starch becomes very brittle, and is edible in small amounts. Whole grain in ancient bread is glassy in appearance, a strong indication of modification. The texture of the
experimentally dry heated grain endosperm remained floury, quite unlike the glassy ancient grains.

Model D provides a good explanation for the way in which whole grains in bread loaves may have been cooked. The preliminary heating process would gelatinize most or all of the starch in the grain. Apart from the possibility of loaf 029, however, there are no loaves in the analysed sample which are best explained by model D and contain whole grains; on the other hand, two loaves (001 and 029) fit best in model C-1 and do contain whole grains. Germinated whole grain which was thoroughly air-dried, and then exposed to heat without being re-saturated would produce a floury texture, not a glassy appearance because there would be no available water to gelatinize the starch. One possible explanation is that some soaked spikelets were set aside to be heated, rather than slowly dried. Yet, the continuous range of textures in loaf 001 does not support such a suggestion. Another possibility is that, although grain in the "C" process was dried down to a hard consistency, it still contained a residual amount of moisture (greater than the 10-15% which grain retains at harvest), enabling a greater degree of gelatinization than that of heated unsoaked grain. Nevertheless, it is tempting to favour model D for those loaves which are fine textured apart from the inclusion of whole grains (loaves 022, 028, and 029) because this would be a straightforward procedure resulting in highly palatable whole grains.

Analysis of the whole grains themselves would help to clarify how they were processed. It has not yet been possible to analyse the microstructure of whole grains from bread, largely due to the
technical difficulty of removing a small piece from the grain in situ, or a whole grain itself, without shattering the surrounding structure and badly damaging the bread.

5. Model B: Baking with wet-milled grain

A fourth model has been developed which does not describe any of the loaves which I sampled for microscopy work. It is a possibility suggested by ethnographic observations, particularly those of Burckhardt (1822: 219; see Ch. 5.II.C), which show that wet grain can be milled on a saddle quern to produce a damp paste. Ancient Egyptian bread made by this type of preparation may well be found.

Model B, baking with wet-milled grain, may be summarized as follows:

i) Spikelets soaked for at least enough time to saturate enclosed grains, time may vary so that germination may or may not be initiated.

ii) Wet spikelets air dried sufficiently to allow dehusking: removal of chaff from grain as outlined in Ch. 5.

iii) Damp grain milled into a wet paste.

iv) Dough formed from paste.

v) Dough baked.

If bread were prepared like this, the grain would never have been thoroughly dried before baking, and starch-degrading enzymes would be active from the time that spikelets were exposed to moisture until the early baking stages. Thus, the full range of starch and its breakdown products would be present, from whole starch staining dark purple-black, to red- and brown-staining short dextrin chains.
Depending on the time variable, pits and channels might be visible on starch granules.

My experimental work shows that milling damp grain produces a very fine, consistent paste. (It is also much harder to grind than dry grain.) When dough from such a paste was baked, the initial stage of baking would have rapidly increased the rate of enzyme activity. This would, however, be a very short phase, as the dough would not have been very thick unless it were placed in a mould, and heat would rapidly penetrate through it.

The starch, being well saturated with water and exposed to high baking temperatures, would gelatinize thoroughly. Thus, nearly all starch granules observed with optical microscopy would be completely or nearly completely clear, and distorted in outline. No fused endosperm would be expected. With the SEM, granules corresponding only to stages S-5 (pancake-shaped) and S-6 (dispersed starch) on the RJH scale would be seen.

None of the loaves which I was able to sample exhibited this particular suite of characteristics. The loaves which have the most consistent, extremely fine texture, as far as can be seen through the glass of museum cases, are the lens-shaped loaves 080 and 081 in the Cairo Museum. There are apparently other loaves of this type at the Dokki Agricultural Museum. Judging from their very fine texture, which is somewhat different from any other of the ancient loaves listed in Table 6.2, it is possible that they were produced by a method similar to the "B" process. Should a sample of such loaves become available, the
hypothesis could easily be tested by optical and scanning electron microscopy.

D. Baking techniques and bread shapes

Returning briefly to the use of shape to define bread, this work provides further proof that the form of a loaf is not necessarily related to its method of preparation. Three different loaves which I have sampled and analysed are round crater forms. Data from starch microstructure provide clear evidence that each was made differently, although it must also be noted that they are of different dates. Loaf 014, dating to the 9th Dynasty, is best explained by model C; the microstructure of loaf 017, of unknown date, but probably New Kingdom because it comes from Thebes, corresponds to model A, and loaf 023, from 18th Dynasty Deir el-Medina is well described by model D (see Table 6.7).

More comparative work on bread shape and starch microstructure would of course be desirable, but combined with the differences discussed in section III.C, there can be little doubt that bread shape does not correspond to methods of preparation. Whether methods of preparation were more important than shape for the ancient Egyptian system of bread classification remains unknown.

E. A reassessment of earlier bread studies

The use of germinated cereals in ancient Egyptian bread explains earlier observations of red-brown-staining bread samples exposed to iodine. Grüss (1932) seems to have been the first to observe this, while Leek (1973: 203) has attributed the reaction to the effects of
aging. The aging explanation has already been discussed above. Grüss rightly attributed the phenomenon to the presence of dextrins, but he believed they were produced by the effects of heat on starch during baking. For example, he says (1932: 80) that the large quantities of "erythrodeextrin" - red-staining dextrin - in loaf 14 213 (Berlin) from the tomb of Amenophis II is caused by very thorough baking. This is a possible explanation particularly if Grüss had only sampled the crust, but temperatures high enough to dextrinize starch throughout the bread are unlikely to produce a palatable loaf (cf. Radley, 1943: 237), and in view of the results I have obtained, germination of the grain used for the bread is more likely. This could be confirmed by looking for pits and channels on starch granules from this loaf.

Grüss himself provides further evidence for the use of germinated grain made into bread. He tested for maltose in the case of one loaf (Inv.-Nr. 22 847, from Thebes, now at the Berlin Museum, described and illustrated by Borchardt, 1932) and found that it contained 4.2% maltose (Grüss 1932:79). The levels of this sugar are particularly interesting since its prime source is the enzymatic breakdown of starch.

A theory proposed by Grüss (1932) and sometimes repeated in the literature (for example, Darby et al., 1977: 522; Sist, 1987: 55), is that some loaves were baked once, sprinkled with flour or overlaid with fresh dough, and baked again. This idea has been used to explain the appearance of loaves which have a thin, very fine textured top layer easily flaking away from the main body of the loaf.
However, such a procedure would be complicated and unlikely, difficult to carry out without drying or burning the first-baked portion into a state of inedibility. I have found no good evidence for such a method in any of the loaves which I have studied but none of the loaves which I have sampled has a thin coating. Loaves such as 073A, B, and D do have a thin flaking layer.

This substance is much more likely to have been a thin paste from very finely milled grain, applied to the dough before baking, to impart a pleasing crispy texture to the crust. This view is supported by Grüss's observation that the body of this particular loaf stains red-brown with iodine, but that the crust or coating stains blue-violet; it must therefore be composed largely if not entirely of unmodified starch.

It is possible to some extent to classify the loaves studied by Grüss (1932) and Leek (1973) within the models which I have constructed, but models C and D cannot be distinguished. The two loaves listed by Leek which stain blue must have been made without germinated grain, while the remaining five red-staining ones must have had been prepared with germinated grain, as were the two loaves for which data are given by Grüss (1932). It would be valuable to clarify the models, and to understand these published loaves in greater detail, by applying the full range of microscopy techniques to the Berlin loaves in future.

Unfortunately, Leek's published bread records do not include museum accession numbers. It is quite possible (but impossible to be sure)
that one or more of his 18th Dynasty samples are the same material from the Louvre which I have analysed. Leek's (1973) Table 2 does show very clearly that the practice of baking with germinated grain extends back to pre-dynastic times, because he found red-brown staining in a loaf from the pre-dynastic site of Badari. This is presumably the Badarian loaf from the Ashmolean Museum referred to in the table on page 130 of his 1972b publication.

F. Bread and yeast

The entrenched modern conception of bread is a leavened product, with only speciality types, such as pitta bread, made without yeast. Ancient Egyptian bread is frequently assumed to be leavened, I think mainly because it is hard today to imagine bread without it. There is, however, no a priori reason to suppose that yeast was an ingredient. As described in Ch. 3.VIII.D, the three reasons for adding yeast to bread are to provide a porous texture, to develop dough gluten, and to create flavour. Flavour is obviously a matter of taste, and plenty of flavour would be provided in bread baked from germinated cereal. There are no gluten-forming proteins in emmer or barley dough. How well a non-gluten, high dextrin dough can retain a porous texture has not been studied. Commercially available bread made solely from sprouted wheat (presumably bread wheat), though very dense, has some small air vesicles distributed throughout it. The viscous network formed by water-adsorbing pentosans helps to keep some gas retained in non-gluten bread. Nevertheless, it is quite possible that the addition of yeast to emmer bread, made from germinated or ungerminated cereal, provides desirable flavour and increases dough porosity.
The dense and solid nature of the bread matrix makes it difficult to detect yeast, which is generally present in low quantities, at least in modern loaves. Small starch granules fall into the same size range, are the same shape, and markings on the surface may mimic birth and bud scars, making all but the clearest yeast cells difficult to identify with certainty. Modern yeast cells are shown in Fig. 6.14. The only positive identification which I have made of yeast in bread comes from loaf 024 (Fig. 6.15), in which yeast cells were clearly seen with SEM. There may be yeast in loaves 014 (Fig. 6.16), 021 (Fig. 6.17), and 029 (Fig. 6.18), but the images provided by microscopy do not permit certain identification.

Methylene blue is a good general stain for fungi (including yeast) cell wall components and was applied to all samples. Even where SEM unequivocally proved the presence of yeast - especially in beer dreg samples not discussed here - the stain failed to show anything which could definitely be identified as yeast. A more specific stain is required, such as cotton blue. My research has largely failed to provide definitive proof for the presence of yeast. The several inconclusive results obtained with both SEM and methylene blue staining leave the possibility open that yeast was present in some loaves at least. Other methods, such as more sensitive stains, or chemical analysis, are required to resolve the problem of leaven in bread.

Grüss (1932) found yeast cells using ruthenium red stain, which is non-specific, in three different loaves now in the Berlin Museum. His
finds, together with the one clear example from Deir el-Medina which I have studied, indicate that yeast was sometimes added to dough. What has not been established is whether it was always used, whether the quantities suggest it was a deliberate addition, and whether porous texture is a reliable guide to the use of yeast in bread without gluten. Meanwhile, porosity alone should not be used as an indication of leavening (e.g. Brunton and Caton-Thompson, 1928: 63; Darby et al., 1977: 502, 517).

The suggestion has frequently been made (for example, Wild, 1975: 594; Kemp, 1989: 120) that yeast produced from brewing was used for bread leavening. This cannot be accepted simply because yeast is found in both beer and bread. In Europe, yeast from brewing was not used for baking until AD 1700, and the transfer was not successful (see Ch. 3.VII.D). It should also be borne in mind that traditional leavening systems developed before the advent of controlled conditions, are almost always a mixture of yeast and lactic acid bacteria, that is, sour dough (Wood, 1993: 480). Therefore, any future attempt to detect and characterize leavening in ancient Egyptian bread should include the search for lactic acid bacteria. If leavening was used, a predominantly lactic acid bacteria fermentation is a far more likely candidate than yeast fermentation.

VI. Ethnographic evidence related to ancient Egyptian baking
There are few obvious ethnographic parallels for ancient Egyptian bread baking. Emmer and barley are rarely used now for bread, and if used, are often mixed with bread wheat flour which changes the characteristics of the dough. For example, although barley bread is
eaten on the Greek island of Amorgos it is mixed with wheat flour (Glynis Jones and Paul Halstead, pers. comm.) Apart from speciality breads, germination of grain destined for modern bread making is strenuously avoided, as the resulting high dextrin and sugar content greatly reduces rising and dough porosity, and makes the bread crumb sticky (Barnes, 1989: 389; Roger Angold, pers. comm.).

Although emmer was used for baking as recently as twenty years ago in some of the few places where it is still grown, such as the Pontic Mountains of northern Turkey, the practice now seems to have died out entirely. In Turkey, emmer is now used only for bulghur or for chicken feed (M. Nesbitt and D. Samuel, unpublished data). The chance to observe techniques of emmer baking there has been lost, while opportunities for recording are rapidly diminishing as the population of experienced older people ages and dies. The very different behaviour of bread wheat dough, caused by the presence of gluten-forming proteins (see Ch. 3.VIII.C.2), makes the link between present-day traditional baking and ancient emmer baking difficult to establish with confidence.

Egyptian settlement archaeology shows that bread baking in the New Kingdom involved cylindrical ovens and, in certain circumstances, bread moulds and perhaps bread platters (see below, Section VIII.B, C). Baking in pottery moulds is not a common procedure anywhere today. David (1977: 203-210; 309) gives some descriptions of pottery mould baking with bread wheat dough.
Traditional Egyptian practice has little relevance to ancient Egyptian techniques. Bread wheat flour is used and in the past, maize was also used for bread baking (Blackman, 1927: 163-164). More importantly, the type of oven now in use is completely different (Rizqallah and Rizqallah, 1977: 1-8). It is a large block, with an opening in one narrow side to introduce the fuel into a lower chamber. Above this chamber is a flat shelf, opening out on a broad side of the oven block, and it is on this shelf that the bread is baked. Bread moulds are not used.

Woolley (1922: 58) and Peet and Woolley (1923: 64) briefly mention the use of bread baking platters in the villages near the site of Amarna, and they draw a parallel with the use of ancient platters. They state that contemporary village practice was to place bread on unbaked clay platters where they were left to rise, and then both platter and bread were placed into the oven. Blackman (1927: 163) does not mention whether the platter is placed in the oven along with the bread.

Although there are no parallels for the cylindrical oven in modern-day Egypt, elsewhere in the Near East such ovens, called tannours, are quite widespread, especially in rural locations. There is some ethnographic information about their use (McQuitty, 1984), and they have frequently been compared to ancient Egyptian cylindrical ovens and baking practice (Darby et al., 1977: 512; Samuel, 1989: 255; Währén, 1960; 1961: 3). None of these sources provides a description of how the oven is heated. I have observed the use of the tannour for bread baking in the north-east Jazira area of Syria, in the Kurdish village of Tell Zagan. A fire was lit in the base of the oven.
Dung or wood could be used as fuel. (In Syrian villages near Deir ez-Zor, woody cotton sticks are used after the harvest.) The fire was allowed to burn vigourously, with flame leaping above the opening. The inner lining became very hot and the heat was retained by the thick outer wall of the oven. When the fire had sufficiently heated the oven walls, it was allowed to die down while glowing embers remained on the oven floor. The internal oven walls were then rinsed with a loose brush dipped in water and quickly swirled over the surface to remove ash and soot.

Flat disks of dough were slapped onto the walls of the oven where they baked in the stored heat. As Darby et al. (1977: 512) point out, and as Währén (1961: 3, Fig. 3) illustrates, the round flat loaf baked in this way becomes distinctly curved in cross section. The lower side is often convex along one axis, and concave along the other. It may also become concave across the whole surface. This type of distinctive bowing is characteristic of bread baked vertically on a hot oven wall. Such bowing is frequently seen on desiccated ancient Egyptian loaves, particularly plain flat disks, flat round loaves with indentations, and crater loaves.

VII. Baking experiments
Experimental baking has been limited because of time constraints. These experiments totally failed to produce bread which in any way resembles the tomb loaves, as well as being virtually inedible. In the course of experimental baking, however, a number of useful insights were obtained which have helped to inform this study.
Baking experiments were designed to replicate the simplest possible ancient method. This is described by model A outlined in section V.C.2 above, and was the most likely method used anciently to produce loaf 017. This involves unsoaked spikelets processed into clean grain and milled into flour, which is made into a dough and baked. The dough was shaped into the simplest form of ancient bread, using the flat thin disk 021 as a model. This type of bread can be baked directly on the preheated internal surface of cylindrical ovens. This approach also has the advantage of ethnographic analogy for guidance.

The replica oven itself (Fig. 6.19) was modelled on the cylindrical ovens in the Amarna Workmen's village chapels rather than the much larger Kom el-Nana or Greater Aten Temple cylindrical bakery ovens. The ovens used as models included 1328 in Chapel 528 (Kemp, 1985: 45) and 2810 in Chapel 556 (Kemp, 1987a: 73), but the best preserved example was 2408 in the Main Chapel annexe, area vi (Kemp, 1987a: 56). The construction of the replica, however, was impeded by two factors. Firstly, I was not familiar with the handling of ceramic and mud plaster. Also, at the time the oven was built the weather was very hot, and the mortar and clay dried out so quickly that they cracked and failed to hold together. As a result, part of the oven lining fell away before experimental baking began, and a catastrophic collapse occurred in the middle of the main baking experiment, lending a distinct lack of authenticity to the proceedings.

I practiced using the oven by running a trial with dough made from bread wheat flour. To make it, I used a standard modern bread
recipe, mixing together appropriate (unmeasured) quantities of yeast, sugar, and water, along with a little oil. Flour was mixed into this liquid, the resulting dough kneaded well, left to rise, and punched down after about an hour. This dough was easily handled, and I formed it into disks. These were left while the oven was heated. Firing the oven was carried out according to ethnographic evidence (Fig. 6.20).

With traditional tannour baking, the underside of raw loaves are lightly smeared with water before being placed on the hot oven walls. Experiments confirmed the need for this, otherwise the dough will not stick to the side of the oven. The loaves were slapped firmly onto the hot internal surface, and they remained stuck there throughout the baking process. They were ready when they began to curl away from the wall. Catching the loaves before they finally fell off was fairly tricky, but after dropping one or two on the oven floor, I acquired the knack of removing them without mishap. Apart from large quantities of grit adhering to the undersides, due to a badly constructed oven liner, these loaves were pronounced edible by the volunteer team of tasters. The bread was certainly sufficiently baked, indicating that the replica oven fulfilled its most important function, and that problems such as grit were a matter of lack of skill on the part of the experimenter.

The use of this type of oven shows conclusively that the small hole at the base of cylindrical ovens found archaeologically is for ventilation, as stated by Wild (1975: 596). The opening is too small to introduce fuel in any useful manner, ash cannot be cleaned out through it, nor
can the fire be stirred up through it, as has sometimes been suggested (Vandier, 1964: 310; Kemp, 1989: 122).

I handled the emmer dough in the same way as the bread wheat dough described above. The recipe is not particularly authentic; there is no evidence for the use of oil, and the presence of yeast as a standard ingredient in ancient Egyptian bread has yet to be established (see above, section V.F). The modern recipe, however, provides a useful point of comparison.

The emmer flour mixed easily with the liquid, but the resulting dough was very thick and sticky, with the consistency of plasticine. It was difficult to knead. Bread wheat flour needs just enough water to mix in all the flour, but the minimum amount of water to cohere emmer flour makes a very stiff dough which is difficult to work. Following the bread wheat model, the emmer dough was left to sit for about 40 minutes. At the end of this time it had not expanded at all, but became very hard and dry, and nearly impossible to work.

From this I conclude that much more water is needed to make emmer flour into a pliable and workable dough compared to the equivalent volume of bread wheat flour. The exact biochemical reasons for this have yet to be investigated. Water absorption capacities of emmer proteins and pentosans may be greater, or their concentration higher, than in bread wheat (see Ch. 3.VIII.C.1). LeClerc et al. (1918: 216) record a very high absorption value of 82% for emmer flour, in comparison with hard spring wheat (T. aestivum) of 69.5%, einkorn of 66.5%, spelt of 67%, and polish wheat (T. polonicum L.) of 76%. The
ways in which water interacts with flour made from germinated emmer has yet to be established.

The incidence of starch damage, and corresponding water absorption (see Ch. 3.VIII.B), may be considerable when flour is ground on a saddle quern. The friction which occurred when the hand stone was rubbed back and forth generated some heat, which may have affected the flour starch. Starch damage has been examined on a qualitative basis by looking for ghosts (flattened, faint-looking granules - see Ch. 3.VIII.B) with the optical microscope. Unstained temporary water mounts of two modern flours, and the emmer flour experimentally milled on the ancient Egyptian granite saddle quern, were compared. Dove Farm Organic plain white flour, milled by the modern break mill process, had very few ghosts. McDougalls Stoneground plain wholemeal flour had markedly more, but the concentration of ghosts was still low. In contrast, the emmer flour had at least two to three times as many ghosts as the modern stone ground flour, indicating that starch damage was relatively high.

Experimental results also suggest that this thick, sticky emmer dough does not benefit from a resting phase. This is a standard part of most bread making using bread wheat flour, apart from the Chorleywood Process used to make mass produced packaged bread. For bread made from bread wheat, the resting phase is needed to aerate the dough through the action of yeast, which also helps to develop the gluten (see Ch. 3.VIII.C.1 and D). The use of yeast in ancient Egyptian bread is still not clear (see above, section V.F).
Since emmer has no gluten, during a resting phase yeast will not change the texture of the crumb. If lactic acid bacteria were part of the dough system, however, the acid environment created by their fermentation would affect the changes which occur during baking (see Ch. 3.VIII.D.2). The tendency for emmer dough to harden suggests that a resting phase was a positive disadvantage but this may not be the case for a wetter dough, or dough with added ingredients. It was impossible to form loaves with the smooth, unbroken crust seen on ancient examples. More experiments are needed to explore this point, using wetter doughs and doughs made from germinated emmer flour, and the use of sour dough.

After the rest phase, I formed the hard emmer dough into flat disks, attempting to model them on the thin, delicately formed loaf 021. Because the dough was so stiff, however, it was very difficult to handle, and the resulting loaves were coarse and thick (Fig. 6.21). They stuck well to the internal oven surface, but baking them failed, partly because of the collapse of the oven lining. This made it impossible to position them properly; the loaves toward the base of the oven, near the hot embers, were burnt, and the loaves at the top of the oven where some of the lining survived were partially uncooked (Fig. 6.22).

Even without this problem, it is unlikely that the loaves would have baked satisfactorily. They were much heavier and denser than the ancient loaves (even allowing for weevil consumption), and the water content was clearly too low to allow sufficient gelatinization of the starch. Those loaves or portions of loaf which were heated adequately
enough to be edible were roasted like oatcakes or cheese biscuits rather than baked like bread, ancient or modern (Fig. 6.26). Under transmitted light and polarizing light, a sample of the replica bread revealed large quantities of ungelatinized starch, far more than any of the ancient loaves which I was able to examine. There was a small number of swollen, gelatinized granules.

These experiments have provided several insights into ancient Egyptian bread making. The dough requires far more water than is needed for bread wheat dough. A resting phase may not have been part of the process if bread were unleavened, but this needs more investigation. Experimental work and analysis of ancient loaves have both made it absolutely clear that ancient Egyptian bread was completely different to modern day bread, and that modern baking should not be used as an analogue for the ancient process.

VIII. The archaeology of ancient Egyptian baking

A. Introduction

In this section, the archaeological material which was or may have been associated with baking is reviewed, covering the description and identification of bread moulds, platters, and ovens. Their distribution over the site of Amarna is summarized. For each class of artefact, possible methods of use are discussed, drawing in large part on the range of evidence which has been presented in the rest of the chapter. The archaeological evidence for baking comes mainly from the site of Amarna. This includes not only the Workmen's village, but also remains excavated in the city itself (Fig. 6.24). Some results from the
Deir el-Medina village are mentioned, as well as some other New Kingdom sites.

B. Bread moulds

1. Description

Bread moulds have been identified from very many ancient Egyptian sites (including in Nubia and Sudan) spanning the Early Dynastic to New Kingdom periods (Jacquet-Gordon, 1981: 11) and were still in use in the Napatan period (XXVth Dynasty, 712-657 BC - Pamela Rose, pers. comm.). The form changed markedly over time. New Kingdom moulds are tall, thin cylindrical cones flaring slightly from base to rim. The bases are uniformly rounded and sometimes have a small knob at the bottom. The size range varies, between 10 and 30 cm in height, and the width to height ratio also varies, between 2:5 and 1:5 (Jacquet-Gordon, 1981: 19). The fabric is a coarse, uncoated silt ware (Rose, 1984: 139). Figure 6.25 shows an example.

2. Identification

There is no direct evidence which identifies these vessels as bread moulds. Indeed, in an early Amarna pottery typology published by Peet and Woolley (1923: 135-141), the type was described as "crucible with round bottom and straight sides". Jacquet-Gordon (1981: 23-24) quotes other early descriptions of these forms as crucibles. As argued by Kemp (1979: 10) and Jacquet-Gordon (1981), however, the evidence linking them to bread baking is twofold. Firstly, this is an instance when the artistic evidence is unequivocal and indispensable for interpretation. The changing forms traced in the pottery record by Jacquet-Gordon (1981) correspond closely to the vessels depicted
in bakery tomb paintings and models from Old to New Kingdom periods. The uncertainty and debate which still surrounds the identification of a Late Uruk form very similar to the Old Kingdom bread mould, the bevelled-rim bowl (Millard, 1988; Roaf, 1990: 65), emphasizes just how essential the Egyptian artistic record is for this definite functional identification.

The second source of evidence confirms the function of these vessels, but on its own would not perhaps be so convincing. Bread moulds are associated with ovens (see below, section D) in particular contexts in the archaeological record. Groupings of ovens and mould sherds have led to their identification as bakeries. The Great Aten Temple bakeries at Amarna (Kemp, 1979: 6), the installations of ovens near the Treasury of Thuthmosis III (Jacquet, 1972; 1983) - both New Kingdom sites - and the recent discovery of an Old Kingdom bakery at Giza (Lehner, 1992) are just three examples. Jacquet-Gordon (1981: 19-20) links the use of bread moulds in the New Kingdom to temple sites, with the exception of Amarna.

3. Distribution at Amarna
As Kemp (1989: 289) has noted, bread mould distribution at Amarna is largely associated with religious contexts, but the pattern is not exclusive. Apart from the unusual find of a set of whole moulds in a square chapel oven at the Workmen's village (described below) the vast majority are broken. Leaving aside the Workmen's village for the moment, the most obvious bread mould sherd concentrations are found in and near the Greater Aten Temple oven rooms, the Smaller Aten temple oven rooms, and the ranks of oven chambers in the north-east
corner of the Kom el-Nana temple complex to the south of the city. The original excavations at the Central City (Pendlebury, 1951: 31) revealed great numbers of "thick pottery bases with a raised bump c. 3 cm in diameter" and larger from the magazines of the Greater Aten Temple corresponding to bread mould bases, as well as some whole specimens (pottery type XV.23; Pendlebury, 1951: 32). Many examples were also found in the south magazines of the Smaller Aten Temple (1951: 104-105).

Both the excavators' report, and recent pottery surveys, have shown that bread moulds occur elsewhere in the central administrative and official, part of the city (the Central City), in areas which are not obviously associated with temple bakeries (the pottery surveys are discussed by Rose, 1987: 127; 1989: 102 - see Figure 6.26). The building complex with notable concentrations of bread moulds in and near it is R42.9, Pendlebury's "Military and Police Quarters" (1951: 137). Here, an unspecified number of sherds were found during excavations, and large quantities were recorded during the pottery survey. Part of this building has been re-excavated by Barry Kemp in 1992 in an attempt to clarify its function, but it is not yet well understood. The large quantity of bread mould sherds found during the pottery survey in this complex (especially areas 14, 15, and 24 - see Fig. 6.26) strongly suggest that baking occurred nearby. The nearest substantial rank of ovens is in the centre section of the building, ranged in three magazines.

A large quantity of bread moulds has been recorded from the area which lies between the magazines of the Greater Aten Temple, and the
King's House. A few or an unspecified number were found in buildings P40.2, P41.1 & 3, Q40.3, and Q41.3, while "many" were found in buildings Q40.4, Q41.13, and R41.6 (1951: 110, 111, 112; see also Fig. 5.47). A few other examples were found in the Servant's Quarters of the Palace (Pendlebury, 1951: 82). The pottery survey has revealed concentrations of bread mould sherds in the Central City which are not associated with any particular building (see Fig. 6.26: areas 4, 5, 11, 12, 16, and also perhaps 7 and 8 if these are not spreads from the Greater Aten Temple magazine dumps); the significance of this pattern is not yet clear.

In contrast to the concentrations of bread mould sherds in the Central City, often enormous but sometimes thinly scattered, not a single example has been found from the pottery survey in the houses and estates of the Main City to the south (Rose, 1989), nor are any reported from the domestic areas north of the Central City (Frankfort and Pendlebury, 1933; Pendlebury, unpublished records). Overall, there is a strong association of bread moulds and the official areas of the Central City; no bread moulds have been found in any surveyed areas outside the Central City. This supports the view that moulds were not used for domestic baking (Rose, 1987: 128).

The pattern at the Workmen's village tends on the whole to bear out the non-domestic character of bread moulds at Amarna. Bread mould sherds have very rarely been encountered here. Excavations from 1979 to 1983 produced thirty-nine bread mould sherds, representing rather less than thirty-nine vessels (Kemp, 1984: 31). The majority of these sherds were found in ancient dumps, making their original
context of use uncertain, but their location suggests they derived from limited baking activity in or near the Main Chapel of the village (1984: 33). A single definite bread mould was found in the nearby building 523 during the 1922 excavations (Peet and Woolley, 1923: 103). The 1986 find of an oven filled with complete bread moulds (Kemp, 1987a: 74-75, see below) considerably strengthens the link between special mould baked bread for use in the village chapels.

There was also a little cluster of bread moulds just outside the entrance to the walled village (square K19, fourteen sherds, plus four in adjacent squares). They appear as if they had been thrown out the door. Their presence may be explained by what appears to have been a small shrine just inside and to the east of the village entrance (see plan, Fig. 5.1). They were found together with a jar of Type XIV.12, with highly unusual discontinuous blue-painted decoration, including a wadjet eye. This associates them with, if not village chapels, a vessel which must have had some sort of special connotation. (I am grateful to Pamela Rose for this information.)

A few bread mould remains were also found within the village itself. Two sherds were found in Long Wall St. 6, and one in Main St. behind Long Wall St. 5. One of the two sherds from Long Wall St. 6 is a highly doubtful type, but the other falls within the range of variation seen in Amarna conical moulds, and is in keeping with the Chapel 556 moulds. Apart from a very low firing temperature, the third sherd also comes from a typical conical New Kingdom mould (P. Rose, pers. comm.). The extreme rarity of bread mould sherds within the walled village is difficult to interpret. It seems that no whole
bread moulds were found within the walled village by the 1920s' excavation team and sherds were generally not recorded by them. Thus, it is not now possible to tell whether other houses also contained any bread mould fragments.

In sum, the evidence for bread moulds from the site of Amarna points to their use nearly exclusively in religious or official contexts. The distribution and use of bread moulds in official, apparently non-religious contexts, has yet to be fully understood.

4. Possible methods of use

There is no direct evidence which indicates how bread moulds were used, nor whether the bread made in them was a particular type. I have not seen any ancient loaves which were made in New Kingdom conical moulds. It would be very interesting to compare conical moulded bread ingredients and their microstructure to non-moulded bread. Despite the lack of such material, some comments about baking with moulds can still be made.

David (1977: 215, 309) states that earthenware dishes or pans must be greased or oiled copiously to prevent the bread sticking to the mould. If such tempering was practiced by the ancient Egyptians, the moulds from very dry sites such as Amarna should still be slightly greasy. At the least, the ceramic would have darkened. There is no sign of either on any sherds. The only certain way to establish this point is to analyse material extracted from the fabric of bread mould sherds using organic chemistry techniques such as those described, for example, by Hill and Evans (1989) and Evershed et al. (1990). Earlier
experiments which I carried out (Samuel, 1989) with whole meal bread wheat flour and replica moulds made by Nicholson (1989a) have shown that bread can be baked satisfactorily in ungreased moulds, but the vessels must be broken open to extract the loaf. The current evidence, without benefit of chemical analysis of mould sherds, indicates that each mould was used once and discarded. Therefore, further study is required to ascertain the location of pottery workshops for the provision of moulds to the great bakeries such as those at Amarna, and to establish the systems for bread mould supply and distribution.

The strong association between cylindrical ovens and broken bread moulds in temple bakeries indicates that cylindrical ovens were used to bake bread in moulds, but the mechanics needed to manipulate the moulds within very hot ovens remain to be understood. The lack of scorch marks or soot on the exterior of most moulds suggests that the moulds were set onto hot embers, not an actively burning fire. The regulation of the fire to obtain embers hot enough to bake the bread, and the timing needed to avoid over-baking, must have been a skilled job.

C. Ceramic platters

1. Description

Another ceramic form which has been associated with bread baking is the platter (Fig. 6.27). In general, these are roughly formed from a coarse silt clay with an untreated surface (Rose, 1984: 136). Most sherds from house Gate St. 8 in the Workmen's village, however, have a thin white gypsum plaster on the interior or the exterior, or both
surfaces, which shows no sign of heating (Rose, 1987: 134). The degree of firing varies; according to Peet and Woolley (1923: 64), sherds or platters in all stages of firing have been found from the Workmen's village, while Rose (1987: 134) reports very lightly fired sherds from house Gate St. 8. In domestic contexts, platters are almost always about 18 cm in diameter (P. Rose, pers. comm.).

2. Identification

The function of platters is less certain than that of bread moulds, partly because they are not so easily identified in the artistic record although platter-like objects are sometimes depicted. The best illustration of baking with what appears to be platters is found in the tomb of Antefoker dating to the 12th Dynasty, about 1991-1783 BC (Thebes, #60, Davies and Gardiner, 1920b: 11-12, 14-16; Pl. 8-9A, 11-12A). Perhaps because of this uncertainty, they seem to have been given less attention than bread moulds in the pottery literature.

They have been associated with bread baking for several reasons. There is the rather sparse occurrence in the artistic record. Archaeologically, there is at least one instance of a direct association between this form and a cylindrical oven. Fragments of a platter were found inside the cylindrical oven of house Gate St. 11 (Peet, 1921: 177) as well as elsewhere in the room (Peet and Woolley, 1923: 73). Woolley (1922: 58) and Peet and Woolley (1923: 64) briefly mention the use of platters in modern local village baking (see section VI above). I have not seen platters used for the actual baking myself; when bread is baked in Haj Qandil, a village near Amarna, today, dough is
placed on platters to rise, but the dough alone is baked in the oven which in any case is quite different to the ancient ovens.

Although the evidence is not conclusive, it is very possible that platters were used for bread baking. Microscopic study of scrapings from platter surfaces may reveal the presence of starch granules. Such a discovery would go far to confirming the use of platters for baking, but negative evidence would not be informative. The distribution and possible use of platters is discussed as if they were used for bread.

3. Distribution at Amarna

Platters are much less common than bread moulds, but appear in a wider range of contexts. Although the evidence is by no means complete, especially from the earlier excavation reports which only record complete vessels, the platters and bread moulds do not often appear together. They are definitely both recorded from a building lying between the Greater Aten Temple magazines and the King’s Palace, Q41.3 (Pendlebury, 1951: 111 – see Fig. 5.47), as well as areas 11 and 12 in the pottery survey (P. Rose, pers. comm.). In contrast to this rare association in the Central City, heavy, thick-walled platter sherds were found throughout the fill of chamber A13 of the Kom el-Nana temple bakery. The pottery in this room was dominated by bread moulds (Rose, in prep.).

In the city proper, as opposed to the Workmen's village, most recorded platters are domestic items. In the north suburb, they were found in a number of small and medium houses, as well as one large
house and one estate (see Table 6.8, Frankfort and Pendlebury, 1933). One sherd was found there during the pottery survey, in area 67 (P. Rose, pers. comm.). A platter was found in at least one house in the south city (N49.15, Peet and Woolley, 1923: 23). Two other houses in this region contained platters (Type III/141, in house P46.20; 1923: 34; and Type III/142, in house P46.14; 1923: 32-33). Enough seem to have been found to lead Peet and Woolley (1923: 50), in their composite, generalized description of the Amarna estate house and its outbuildings, to describe bread baking with these platters placed in the heated cylindrical ovens. Recent excavations uncovered an example in the central room of house P46.33 near the hearth (Barry Kemp, pers. comm.) and areas 30, 31, 33, and 37 during the pottery survey (P. Rose, pers. comm.; see Fig. 6.26).

Platters have a distinctively domestic association at the Workmen's village as well. Platters or their sherds have been recovered from nine houses; these are listed in Table 6.8 and marked on the plan shown in Fig. 5.1. The association of platter and oven in East St. 10 (Peet, 1921: 177) has already been noted. Not all houses with platters have ovens, but in this respect, it is suggestive that Rose (1987: 137-8) concludes that most of the platter sherds found in Gate St. 8 come from an upper room, and that there is good evidence for a cylindrical oven on the upper level of this house as well (Kemp, 1986a: 21).

Chapel 551 contained a platter (Peet and Woolley, 1923: 107, Type III/192) but neither this chapel nor the neighbouring chapels 552-554 appears to have had an oven. Sherds from two platters were scattered
in Chapel 571 of the Workmen's Village (Rose, 1984: 142). Yet no trace of an oven was found in this building, nor in the abutting Chapel 570 (Kemp, 1984: 34-39; 1985: 29-35). Similarly, small numbers of platter sherds were distributed throughout areas iii, iv, and v of the Main Chapel annexe 450 (Rose, 1986: 108-111). Unlike Chapels 570 and 571, there are two ovens here, one in area iii, and one in the neighbouring area vi. Peet and Woolley (1923: 107) record a platter (Type III/192) from Chapel 551; there are no ovens recorded in this chapel, nor the adjacent Chapels 552 and 554 (1923: 107-108).

Other platter sherds come from the Main Quarry. Its position, not far from the village gate yet surrounded by animal pens and chapels (see Fig. 0.2, Kemp, 1986a: xii), makes it impossible to relate its rubbish deposits either solely to domestic waste from the village houses, or only from activity outside the walls. Platter sherds appear in every level (Rose, 1984: 144, Table 10.1).

Platters are often, but not exclusively, closely associated with cylindrical ovens. This is a further piece of evidence that platters were used for bread baking, but it is not conclusive. If they were, their pattern of distribution at Amarna suggests that they did not always have a function in state bread production. It seems they were used to some extent in domestic food preparation, as well as in private worship.

4. Possible methods of use

Platters would have been well suited for baking loaves which were not moulded, but were too large and heavy to be baked on the sides of
ovens. Their relative scarcity indicates that their use was by no means universal. Nor was platter use limited to a particular social sphere, as their presence in houses of widely differing sizes shows (Table 6.8). Since platter sherds are easily recognizable, the low numbers in which they have been found points to a restricted use, perhaps for specific purposes.

Because of their open shape, it would have been possible to reuse platters for baking to a certain extent, but their coarse construction indicates that they may not have had a very long lifespan. Like conical moulds, they show no traces of greasiness nor discolouration, but they need not have been greased if a layer of flour, meal, or even very fine chaff was scattered over the surface before the dough was laid down. This may explain the large amount of chaff pressed into the undersides of loaves 008 (which is thin but bowed across its length) and 013 (which is round and very flat). The retention of fine markings on split loaves indicates that dough did not expand on contact with high oven temperatures, as occurs with modern bread. The lack of gluten means that emmer bread would not be very elastic. These factors suggest that fine chaff would not be heavily embedded on the bottom of bread, and could easily be brushed off after baking.

The exact mechanics of baking with platters still remains to be resolved. Platter baking may have been done in cylindrical ovens as indicated by the association of platter fragments inside the cylindrical oven in East St. 10 at the Workmen's village. It is also possible that they were used on open hearths.
It is hard to imagine, however, how such platters could be placed in the bottom of very hot cylindrical ovens, often up to a metre in height, and even more difficult, how they were removed when baking was complete, without the risk of the baker being severely burnt. The thick, awkward shape of the platters would make them very difficult to manipulate with sticks or other devices, especially in the restricted space of a cylindrical oven. They may have been placed on some kind of shelf or support within the oven, but no trace of any arrangement of this kind has ever been found. The bread itself may have been removed with sticks while the platters were left until after the oven had cooled.

The problem with this idea is that the upper surface and rim is generally better fired than the underside of the base, which can be almost unfired. This does not fit with the idea of sitting the platter on hot embers. On the other hand, the underside of the base is left very rough and unfinished, which discourages the idea that they were turned upside down and the bread baked on the underside. (I am grateful to Pamela Rose for pointing out these problems.) Rose (in prep.) suggests that the very thick base may have retained enough heat to bake dough placed inside and underneath them. The mechanics of this, however, remain to be examined.

D. Cylindrical ovens

1. Description

Bruyère (1939: 72-74) provides a description of how cylindrical ovens were constructed at the village of Deir el-Medina. The interior surface was lined with a ceramic cylinder, about 3 cm thick which had been
made up of several sections. The oven sometimes but not always had a ceramic floor. Surrounding the cylinder was a thick shell of mud brick and mud plaster. Ovens are commonly situated in a room corner, making use of structural walls for heat retention. A few centimetres above floor level, a small round hole, about 10 cm in diameter, runs through both shell and liner, providing ventilation.

No complete cylindrical oven is now visible in the Amarna Workmen's village houses but my observations of three exposed chapel ovens have provided further details on their method of construction. This seems to be the same as the Deir el-Medina ovens. The ovens are the same used as models for the replica oven (section VII above), that is, [1328] in Chapel 528, [2810] in Chapel 556, and [2408] in the Main Chapel annexe, area vi. The Main Chapel and Chapel 528 ovens had the usual thick outer casing of mud brick and mud plaster, while the Chapel 556 oven was just a ceramic shell. All of the inner ceramic cylinders were made up of several clay sections smoothed together and then fired. It is not entirely certain whether the ceramic liner was fired before being set in place and surrounded by the outer casing of mud brick and plaster, or whether it became fired as result of use. If the latter was the case, some preliminary firing would have been required before any bread was baked, otherwise the liner and dough would have stuck together, damaging the ceramic surface. Since the oven in Chapel 556 is only a ceramic shell without a mud brick casing, it is more likely that cylinders were fired separately before being built into place.
The Chapel 556 oven had seen heavy use. The base of the liner was smooth and blackened with soot, but the upper, dark red part was covered in superficial cracks, as well as deeper vertical splits running over it. This dark red area was overlaid with a whitish deposit (see below). The Main Chapel oven, although less well made with a rougher interior surface was also quite cracked. There was scarcely any blackening at the base, suggesting it had been less heavily used.

These liners could be repaired if necessary. A thin plug of clay had been inserted into the Chapel 528 oven liner and smoothed in separately from the main body of the liner. Both plug and liner fabric contained fine imprints of what was probably chopped straw, but only the plug had such imprints on the exposed baking surface, which shows it had been added separately.

2. Identification

Several lines of evidence support the interpretation that cylindrical ovens were used for bread baking. Firstly, they bear a close resemblance to tannours used for baking throughout much of the Near East, excluding Egypt (see section VI, above). Secondly, an essential installation like an oven should be found in houses, or on larger properties, in associated outbuildings, and indeed they are a frequent feature of Deir el-Medina and Amarna village houses (but not all - see below). Bread was the most important daily offering to the gods (Jacquet-Gordon, 1981: 20), and the large number of cylindrical ovens in the ranks of magazines associated with at least three great temples at Amarna (the Greater Aten, Smaller Aten, and Sunshade Temples)
are the only installations which could have supplied the large numbers of loaves required.

One small but telling piece of evidence shows that bread was baked in these ovens, directly on the internal surface in the same way as the traditional tannour is used today. This comes from the analysis of the very thin whitish deposit adhering to the internal liner surface of the oven found in the south-east corner of Chapel 556 annex at the Amarna Workmen's village (Kemp, 1987a: 73). Optical microscopy of a sample of this material in a temporary water mount has shown that it is mostly composed of a clear crystalline material of unknown nature, but which is probably inorganic, deriving from clay minerals. It also contains a few starch granules. Under polarizing light, the granules are birefringent, and under transmitted light a distinct line can be seen running down their centres. (The appearance of such a line also occurs in emmer starch still in the grain which was experimentally heated to temperatures up to 150°C in the absence of water.) When stained with IKI, the few granules in the water mount of the oven deposit turned dark purple-black, confirming their identification as starch. The birefringence of these granules means that the starch adhering to the oven lining did not gelatinize and therefore must have been dry when exposed to heat.

Cylindrical ovens may not invariably have been associated with bread baking. The cylindrical oven with a re-used blue painted jar for a lining, found in a pottery and faience workshop area on the outskirts of the Amarna Main City - complex Q48.4 - (Kirby and Tooley, 1989: 34-35), fits better with an industrial function than a food producing
use. This is because of its industrial location, its small form, and relatively thin liner walls.

3. Distribution of cylindrical ovens at the Amarna Workmen's village

I have not attempted to collate the distribution of cylindrical ovens in the Main City, but have referred to the Workmen's village as an example of the difficulties in determining their original numbers. Baking was an indispensable and frequent activity, yet as Kemp (1987b: 26) points out, cylindrical ovens are found in less than half the total number of houses excavated at the village. Ash and fragments of a cylindrical oven in the upper fill layers of Gate St. 8 strongly suggest that this house had its oven on the roof (Kemp, 1986a: 21). This may have been the case for many of the Amarna Workmen's village houses which had no oven on the ground floor (see Fig. 5.1). A similar interpretation may also apply to the Deir el-Medina houses which have cereal processing equipment but lack ovens on the ground floor (see Fig. 5.2). Some of the Deir el-Medina houses apparently without ovens also lack staircases (SE.IX, for example), so this cannot be the full explanation. It will not now be possible to obtain any information about what may have been on the second storey of excavated houses with stairs. As may have been the case for cereal processing equipment, some of the households at both villages may have shared ovens.

Larger houses with outbuildings in the city of Amarna may provide a more accurate view of oven distribution, because owners of these properties appear to have sited cylindrical ovens outside the house, in the yard or nearby outbuilding. Such analysis will be undertaken as
part of future work on the study of cereal processing and baking in the city (see Ch. 7).

4. Identification of square ovens

In contrast to cylindrical ovens which are widespread at Amarna, square ovens are relatively scarce. At the Workmen's village only one has been discovered, in the north-east corner of the Chapel 556 annexe. (In the south-east corner sits the cylindrical oven discussed above.) Its possible use for baking is worth discussing as it was found full of complete bread moulds of two shapes, which were still stacked, fired and empty (Kemp, 1987a: 73-74). Of a total of 64 moulds, 30 were the standard New Kingdom long narrow conical type, while the form of the remainder appears to be unique. They have a large, conspicuous knob at the base, too small and curved to act as supports. The upper part of the moulds is a thick-sided deep cup shape, half of which is filled with the cavity for the dough. Both conical and knobbed goblet types were handmade from the same fabric (Rose, in Kemp, 1987a: 76-77).

Kemp (1987a: 76; 1989: 122) has suggested several explanations for this find. One possibility is that the moulds may have been fired empty in preparation for baking; another is that the unfired clay vessels may have been filled with dough and then fired at the same time that bread was baked in them. If an unfired mould and raw dough were baked together, however, the bread would be inseparably stuck to the mould and unusable (Elizabeth David, pers. comm. via Barry Kemp), and so this idea can be rejected.
A third possibility is that the moulds were pre-fired and had then been used for baking in the square oven. Kemp (1987a: 76; 1989: 122) quotes the correlation of conical bread moulds and square ovens from several other Middle Kingdom and New Kingdom sites. When the illustration of a square oven at Mirgissa (Holthoer, 1977: Pl. 73:2) is examined, it can be seen that the surrounding bread moulds are mostly intact. Unfortunately, the other reports do not make it clear whether whole or broken moulds are associated with square ovens, but broken moulds or sherds are not mentioned (Larsen, 1935: 51; Jacquet, 1972: 154; 1983: 84).

There are several lines of evidence to support the contention that square ovens were not used to bake bread in moulds, but were used to fire the moulds themselves. The first comes from the details of the Amarna chapel find. If bread had been baked in these undisturbed moulds, some traces at least would be expected, given the generally excellent preservation of organic material at the Amarna Workmen's village, but there are no such remains. If insect activity had destroyed everything, as Kemp (1987a: 76) suggests could be the case, a great deal of crumbly organic frass ought to surround them, yet only hardened sand, rubble, and ash encased these moulds. Furthermore, it has convincingly been argued by Miller (1987, see also Ch. 5.G) that ash inhibits insect activity, and there was a substantial quantity of ash at the front of the square oven adjacent to some of the moulds. This strongly implies that these moulds had not been used to bake bread, but had been fired and then left in place at the abandonment of the village.
A third possibility is that the moulds were pre-fired and had then been used for baking in the square oven. Kemp (1987a: 76; 1989: 122) quotes the correlation of conical bread moulds and square ovens from several other Middle Kingdom and New Kingdom sites. When the illustration of a square oven at Mirgissa (Holthoer, 1977: Pl. 73:2) is examined, it can be seen that the surrounding bread moulds are mostly intact. Unfortunately, the other reports do not make it clear whether whole or broken moulds are associated with square ovens, but broken moulds or sherds are not mentioned (Larsen, 1935: 51; Jacquet, 1972: 154; 1983: 84).

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The second reason to interpret the square chapel oven as a kiln is from experimental work. Nicholson (1989a) built a replica square oven based on the chapel find, and fired replica bread moulds in it. He carried out two trial firings. The first fired all 34 conical vessels well, convincingly resembling the ancient ones (1989a: 249). The second firing correctly fired over half the vessel load, while those at the back of the oven were underfired. This is probably explained by the way the vessels in front of the flue were stacked (1989a: 251). Nicholson concludes that such a square oven is well explained as a kiln rather than a bread oven.

Finally, other archaeological finds augment the view that square ovens were kilns for bread moulds. As Jacquet-Gordon (1981: 22) points out, moulds of the long, slender, conical New Kingdom type (see below, and Fig. 6.19) are almost always broken unless they come from contexts which indicate they have never been used, such as temple foundation deposits and stockpiles. In addition, the huge quantities of broken, and thus used, bread moulds in and around the magazines of the Greater Aten temple are associated exclusively with cylindrical ovens, not square ovens. Therefore the mould baked bread must have been baked in these cylindrical ovens.

The square ovens associated with bread moulds, both archaeologically and artistically (see especially the model from the 11th Dynasty Deir el-Bahari tomb of Meketre (#280); Winlock, 1955: 27-29, 71, 72, 88, Pl. 22, 23, 64, 65; Kemp, 1989: 120-122, Fig. 42) are best interpreted as the kilns in which the moulds were fired prior to their use for baking.
5. Possible methods of use of cylindrical ovens

It has been suggested that some types of bread were baked directly on the sides of cylindrical ovens (Währen, 1960; 1961: 3; Wild, 1975: 597; Darby et al., 1977: 512; Samuel, 1989: 255), and the discovery of starch granules in deposits on a cylindrical oven lining (see above) lends a great deal of support to this interpretation. Ethnographic and experimental observations show that the thick construction of the outer layer acts as an insulator, and retains the heat of the interior lining during baking. Therefore, bread could not have been baked on the exterior surface of cylindrical ovens as is sometimes suggested (see, for example, Borchardt, 1916: 530; Wilson, 1988b: 13; Hepper, 1992: 93).

In Ch. 2.III.B and IV.B.1, an idea about the formation of paddle-shaped or racquet-shaped bread has been described. This shape resembles round flat bread but with a projecting elongation (see Figs. 6.5, 6.6). Klebs (1934: 175) suggested that such a shape was the result of liquid dough oozing down the inside surface of the cylindrical oven. The idea is reiterated in the Lexikon der Ägyptologie (Wild, 1975: 596). This notion does not fit with the moisture levels of dough deduced from microstructure studies, nor with the experimentally determined quality and behaviour of emmer dough, nor with ethnographic parallels of baking in cylindrical ovens. Furthermore, study of a few examples of real racquet-shaped bread from the tomb of Kha clearly shows that the form is a result of deliberate shaping prior to baking. These particular loaves do not have the distinctive curvature which occurs when bread is baked on
the interior walls of cylindrical ovens. It is possible, however, that bread deliberately shaped in the form of paddles or racquets was sometimes baked on cylindrical oven walls as Währen (1961: 10) suggests.

The lack of curvature for many thin bread shapes suggests they were not baked on oven walls. This method would not have been possible at all for many other bread types which have been retrieved from tombs. The larger loaves, such as split loaves and thick triangular loaves, are too heavy to adhere to the slightly incurved oven walls. Conical loaves such as 028 and 029 would have had too small a surface area relative to volume in contact with the oven wall to allow them to stick without falling off. Some other method must therefore have been employed.

The way in which cylindrical ovens were used to bake bread domestically is uncertain, because there is nothing directly linking ovens with the type of bread baked in them. However, the relative lack of platters, and the complete absence of moulds or mould sherds from domestic areas at Amarna, leads to the hypothesis that the New Kingdom homemade loaf was usually baked directly on oven walls. The loaves thus baked need not have been made from the same recipe. There may well have been considerable variation in the type of domestic bread, even if it was mostly made into disks of various forms.
E. Summary comments

There are not yet sufficient links to reconcile the direct evidence obtained from desiccated loaves with information which comes from archaeological excavation. The methods of use for bread moulds and platters are far from established, and the methods of baking large heavy loaves such as "split loaves" (section III.B.5) remain unknown. Although suggestions have been made about the bread which was normally produced for daily consumption, and how it was baked, these are still very much hypotheses. In the absence of any ethnographic evidence for baking with emmer wheat, for baking with germinated cereal, or for baking with discardable pottery moulds, the link must be built up through detailed experimental replication. This will show the nature of bread dough made from partially germinated wheat, how it can be handled, and the ways in which it may have been baked with the equipment found archaeologically. This, in turn, will unravel the logistics of bread baking, at both domestic and state levels, and provide the essential tools to interpret the archaeological record. Some first steps have been made here, but a great deal more is required for these aims to be satisfactorily achieved.
CHAPTER 7: NEW PERSPECTIVES ON ANCIENT EGYPTIAN BAKING

I. A summary of research results

The traditional study of ancient Egyptian baking has relied almost exclusively on artistic depictions in tombs. In contrast, my research has dispensed entirely with representational data. It has used instead a multi-disciplinary approach, based on the biological framework imposed by cereal morphology and biochemistry. The central aim has been the elucidation, step by step and in detail, of New Kingdom bread making methods from stored cereals. Five specific aims, listed in Chapter I, concern bread ingredients, procedures required for bread making, and the location of processing and baking in two domestic neighbourhoods. The achievement of these goals can now be assessed.

The most important result of this research is the construction of testable and verifiable models, based on direct evidence, for cereal preparation and baking methods. The function of a number of installations and artefacts associated with cereal processing have been firmly identified, and this, together with the processing and baking models which have been developed, provide powerful tools for the interpretation of the archaeological record, as well as a new basis for study of the relevant documentary sources.

Although two cereals were grown in ancient Egypt, I have focused on emmer wheat, not barley. There are two strands of archaeological evidence which indicate emmer was more commonly used for bread in the New Kingdom. Firstly, there are the tomb loaves. Of the loaves
which I have studied and whose cereal component could be identified, emmer was the most important ingredient in all but one (069); this loaf was mostly made of Lolium (Ch. 6.II.B). Other loaves examined in the past (Grüss, 1932; Täckholm et al., 1941: 248; Leek, 1973) are also made of emmer. Thus it appears that emmer was the cereal of choice for funerary bread - but was it also used for daily baking?

Evidence for the use of emmer in daily life comes from recent excavations at the Amarna Workmen's village. A rich scatter of emmer chaff was recovered surrounding a mortar in West St. 2/3 (Ch. 5.III.D.2). A combination of evidence has demonstrated that mortars were used to break apart the emmer spikelet in order to free the grain. This is currently the only direct archaeological evidence for the domestic use of emmer, and further confirmation of this slender indication is clearly desirable.

Study of funerary bread has established the definite use of other ingredients. Figs, dates, and coriander are major or minor components, and a few loaves contain what were probably deliberately added, but currently unidentified, ingredients. A previously unsuspected cereal ingredient has been discovered: germinated grain. It was used in 12 out of 13 sampled bread specimens. The evidence is limited so far, but suggests germinated cereal may have been widely used for baking.

The presence of leavening in ancient bread has been less successfully resolved. A yeast cell was positively identified in loaf 024, and, although it appears to be an integral part of the loaf matrix,
subsequent contamination after the loaf broke open cannot be entirely ruled out. Other loaves may have contained yeast cells, but these identifications are less certain. There was no evidence of yeast in most of the thirteen sampled loaves, but the techniques which were used are neither sensitive nor specific. It is possible to apply more accurate analytical methods.

Lactic acid bacteria fermentation, which results in a sour dough loaf, is another possible leavening agent. If this were more commonly used, yeast would be present in bread, but it would be the minor component of the fermentation system. Again, no satisfactory evidence for the presence of lactic acid bacteria was discovered but this is mainly because they were not targeted. Their very small size (about a micron or less in diameter) means that high magnifications are needed to detect them. Because high magnification electron beams damage starch granules, I did not generally subject specimens to magnifications required to see bacteria. More work must be done before the use of leavening in bread is understood, but what has been demonstrated is that leavening is not necessarily an essential requirement for emmer bread.

Analysis of funerary loaves has established that form is not related to ingredients, and thus is not necessarily a guide to the many different types of bread named in written sources (Ch. 6.III). One area which has not been clarified is the meanings of the many different bread names (e.g. Wild, 1977: 430-431). This may be impossible short of finding labelled loaves.
The equipment used to process emmer spikelets into flour has been firmly established through the use of ethnographic, archaeological, and experimental work (Ch. 5). Experimental work especially has shown what product and by-product was produced at each stage of preparation, and has provided an idea of the time and labour required for each step. The most time consuming tasks are separating chaff from clean grain by winnowing and sieving and the grinding stage to reduce whole grain into flour. These steps, as well as the whole sequence of emmer processing, would no doubt have been accomplished more rapidly by skilled and practiced hands, but cleaning and milling would still have taken the greatest proportion of processing time. Evidence from funerary loaves has also provided insights into the processing sequence (Ch. 6.IV).

The microscopy analysis of bread specimens (Ch. 6. V.3, 4) has shown some of the true complexity of New Kingdom baking. One of the important results of this research is the demonstration that ancient Egyptian bread was nothing like most modern bread. Many of the assumptions about ancient baking have been based on erroneous preconceptions drawn from modern experience. The major differences as now understood are that ancient Egyptian bread had no gluten and so lacked a very spongy, porous texture; that it was sometimes or often made of germinated grain; that leavening, if used, was most probably by lactic acid bacteria and not 'pure' yeast cultures. The full baking (as opposed to cereal processing) procedures have yet to be fully linked to archaeological tools or locations, but the potential to do so has now been established on a much more solid footing.
The study of two similar New Kingdom settlement sites has helped to elucidate how processing was carried out within the confines of village houses (Ch. 5.V.C). The patterns of cereal preparation seem in general to have been quite different in the two communities. At the Theban village of Deir el-Medina, one specific room, usually at the back of the house, often contained all the major equipment required for cereal processing and baking (mortars, querns, and ovens), making the whole process self-contained. The apparent lack of equipment in many of the houses suggests that households may have shared the bread making task.

In contrast, the pattern of distribution at the Amarna Workmen's village shows that most households had access to mortars and querns for cereal processing, although some sharing may well have occurred between specific households. Unlike Deir el-Medina, both the front and back of the houses were often used for different processing stages. Street space was sometimes used for pounding, while the roofs were probably used for some stages, including, perhaps, baking. At this village, although the whole process was not self-contained within each part of each house, more households appear to have been self-sufficient in bread production from supplied emmer spikelets. The baking procedure itself has been studied with reference to archaeological data from Amarna, and some methods of use for moulds, platters, and ovens proposed.

II. Research potential
As a direct result of the research presented in this thesis, the opportunity has been opened up to examine a number of issues with a
new degree of accuracy and precision. These include social and economic topics, diet and nutrition, and re-interpretation of the artistic record.

At the two villages of Deir el-Medina and Amarna, differences in the presence and distribution of tools suggest there may have been fundamental differences in the organization of food preparation, and perhaps, differential access to resources. It should now be possible to explore this social question further for Deir el-Medina. The rich documentary sources available, used together with archaeological information, may show, for example, patterns of kinship amongst the households, and thus, how sharing of resources may have been organized. The availability of servants at Deir el-Medina for milling may help to explain the distribution of cereal processing facilities. Reference to the original excavation records may also fill in some of the current gaps in archaeological information.

Economic questions connected with cereals used after storage can now be addressed with confidence. The economic basis of baking in ancient Egypt, that is, the suite of resources needed to make bread, has been established in some detail. The possibility that cereals were transported in a variety of forms – spikelets, pounded spikelets, and clean grain – is a new proposition, and may lead to re-interpretation of the many documentary sources concerned with cereal movement and distribution. A knowledge of ancient bread making procedures may also suggest new perspectives for the interpretation of written records. For example, Miller (1991: 259-260) quotes Heqanakhte’s dissatisfaction with the quality of old, dry barley rations sent to him.
Perhaps the problem which distressed him was a significant loss of germination viability.

Different forms of emmer wheat as commodities for exchange or rations might be traceable in the archaeological record. One possibility is that the full suite of tools at archaeological sites may indicate whether spikelets, pounded spikelets or clean grains were being processed. One group of sites for which this could usefully be attempted is the Middle Kingdom Nubian forts (Kemp, 1989: 166-178), whose occupants were engaged in economic and political interactions on the edge of Egyptian territory. These forts might be expected to have different cereal processing assemblages than domestic neighbourhoods in the heart of Egypt. Such artefacts, however, need to have been recorded consistently in order to draw any reliable conclusions. Archaeological studies must also take into account the complexity of the bread making process with its different possible treatments prior to milling, as well as the usable by-products which are generated and how they might be distributed.

If bread was commonly made from germinated cereals, it would have had an important contribution to nutrition over and above the prime contributor to calories. Lysine is an essential amino acid which is present in limited amounts in dry cereals, but germinated wheat contains a significantly greater quantity (Ch. 3.IX). Germinated grain most probably has a different calorific value from the same volume of ungerminated cereal. I have yet to ascertain the exact changes, but any attempt to calculate calorific values from cereal rations must take this into account. Straight conversions from cereal weights, be they
spikelets, hulled barley, or clean grain, to calories as an estimate of nutritional status are probably not valid. The problem with such calculations now is uncertainty about the frequency of germinated cereal bread as compared to ungerminated cereal bread in the ancient Egyptian diet.

If bread made of germinated grain was common, the implications of a dextrin and maltose-rich diet remain to be explored. For example, these components may have affected the condition of ancient Egyptian teeth.

With a better understanding of the cereal processing and baking techniques which were used in New Kingdom Egypt, the artistic record can be reassessed. There has been a considerable amount of vagueness, inconsistency, and contradiction about the processes depicted. Now that the New Kingdom method of emmer cleaning has been explained, and by extension the method used in earlier times as well, many of the actions of the models, statuettes and reliefs can be accurately and consistently identified. Although the morphology of hulled barley differs from that of emmer, the persistence of the lemmas and paleas means that, to remove the chaff, it too must be processed by moistening, pounding and winnowing (Hillman, 1985: 20-21). Thus, barley processing for bread, either in the New Kingdom or earlier, is likely resemble emmer processing in the depictions.

The artistic record may now provide new insights. It may be used along with archaeological data to gain a better picture of changes in baking technology and techniques over time - and which aspects
remained constant. Its unique contributions lie elsewhere, however. It may help to show how the ancient Egyptians thought about this important aspect of their lives (Samuel, 1993: 282). Which actions, for them, exemplified the bread making process? Given the products and by-products which each stage produces, why might this be? Artistic depictions may also provide information about division of labour according to gender, for example, and whether this changed over time. The artistic record is capable of addressing such questions, but an accurate knowledge of the bread making process is a prerequisite to accurate interpretation.

III. Future work and new directions

The previous section has covered some of the areas which can be investigated as a result of this research, together with currently available archaeological, documentary, nutritional, and artistic data. There are also many new avenues related to bread and baking which await exploration using evidence yet to be collected.

One obvious way to expand this research is the study of more preserved loaves. Most tomb bread dates to the New Kingdom but there are some Middle Kingdom specimens, and bread from predynastic sites has been recovered. The development of baking and the changes which may have occurred over time can be traced by analysing loaves dating to all periods of ancient Egypt.

The study of more loaves may clarify whether emmer was the cereal of choice for funerary loaves at least, and should increase the number of definitely identified ingredients. For all loaves, the detection of
certain ingredients can also be improved through chemical analysis. Materials such as fruit juices or syrups, milk, fats, honey and salt may be difficult or impossible to detect visually, but organic analytical techniques are capable of detecting and identifying them. The suite of different simple sugars already discovered in loaf 001 (see Table 6.6) suggests that ingredients other than germinated cereal had been added.

Further microstructure analysis will build on the evidence already obtained from just thirteen loaves. The evidence for the three proposed bread making models will be strengthened, or require modification. Loaves baked with wet milled grain - model B - might be found, and other methods of baking may well be discovered. If loaves were recovered from settlement sites, valuable data on bread for actual consumption would become available.

Breakdown products which occur as a result of baking, particularly those derived from compounds other than starch, may be detected using chemical analysis. This technique would complement visual analysis of cereal foods, to gain fuller details of ancient Egyptian bread recipes, and thus, the resources and techniques used for baking.

Another area still open to investigation is the question of leavening. More sensitive microscopy techniques will help to reveal the presence of yeast, and lactic acid bacteria can be targeted. DNA analysis may also be of use to study the microbial component of bread (e.g. Meadon, 1990). DNA analysis of ancient micro-organisms may identify
them, thus establishing to some extent the fermentation system. If yeast were a major component of leavening, its status as a wild or cultivated form might be determinable, and its sources, such as fruit, might be proposed. Visual analysis cannot achieve this type of information.

In view of the present major technical difficulties still to be overcome for ancient DNA analysis, however, a multi-molecular approach is probably the best way to address these questions. Yeasts, lactic acid bacteria, and their fermentation pathways may be characterized by their metabolic by-products, and specific proteins and lipids. Biomolecular investigations may lead to the interesting discovery of the actual taste of Egyptian bread when it was fresh.

New directions do not depend solely on complex analytical techniques. Returning to traditional archaeological methods, there is a great deal to be done with artefacts from Amarna alone. A partial understanding of village-scale cereal processing has been obtained by examining remains from the Deir el-Medina and Amarna villages. This analysis can serve as the basis of comparison for other neighbourhoods where data about cereal processing are scarcer. These neighbourhoods need not be similar in status or wealth: study of larger houses and estates will provide information on how the organization of bread production may differ amongst the social levels of New Kingdom society.

Amarna is a good place to carry out such an investigation, for it encompasses the full range of housing from the poor to the highest nobles, as well as Pharaoh himself. Although useful information from
individual households might be salvageable from old excavation reports and the remains still visible on the ground, analysis by neighbourhood is probably most practical. New excavations of domestic housing will be particularly useful for detailed evidence of cereal processing tools and installations. Systematic retrieval of archaeobotanical remains is especially important. Where it is preserved through desiccation, plant material can be obtained from primary deposits, which allows a direct connection to be made between plant products or by-products and the tools used to process them.

The early archaeologists at Amarna had specific interests which did not include the study of domestic activity, nor the analysis of many mundane objects of daily life. As a result, many stone objects survive scattered over the surface of the old excavations. Two classes of artefact left behind in this manner are saddle querns of granite or quartzitic sandstone, and limestone mortars. During the 1992 field season at Amarna, I surveyed these surface finds, noting their location on site plans. They were then collected and stored at the site magazine. The results have yet to be analysed in detail, but it is clear that there are different patterns of quern distribution according to neighbourhood. Because the preservation of limestone mortars left on the surface is generally poor, their pattern of distribution is less informative.

Preliminary analysis has established a tentative quern typology which in part relates to their specific function, and may reflect the length of time they were in use. The collation and analysis of this material will contribute to the study of cereal processing location according to
social status, and neighbourhood patterns of access to milling resources. The supply and patterns of distribution of saddle querns throughout the city form part of the economic network involving cereal preparation and bread production.

A further fruitful inquiry to be made is the comparison of domestic bread making organization to state bakeries, such as those sited near temples. The survey has already identified a large concentration of saddle querns, hitherto unsuspected, in the official quarter of the city (see Fig. 5.47). This indicates the centralization of milling operations on a scale in line with the huge bakeries south of the Greater Aten Temple (Kemp, 1979: 6). The presence of both the large-scale bakeries and the grinding area suggest that there might also be equally large provision for the centralization of cereal pounding. Indeed, a long narrow room in building R42.9, containing three rows of fifteen emplaced mortars, has tentatively been identified by Barry Kemp and myself as the place which supplied breached emmer spikelets, or stripped barley. The ratio of mortars to quern stones seems commensurate with experimentally established times needed to pound a given volume of emmer spikelets, and to mill the grain cleaned from them. This possibility needs to be investigated in more detail, but provides a reasonable working hypothesis.

There is a much smaller set of cylindrical ovens in magazines ranged to the south of the Smaller Aten Temple (Pendlebury, 1951: 100, Pl. XVI). These magazines also contain square ovens. The discovery of a small group of saddle quern fragments beside and in these magazines echoes the pattern of the buildings south of the Greater Aten Temple.
but the presence of mortar fragments suggests that cereal processing organization was somewhat different for this temple.

Only the number of settlement sites and state bakeries limits the potential for further archaeological comparison. The study of other New Kingdom sites will consolidate and refine the picture which is emerging from analysis of the Amarna and Deir el-Medina villages, as well as the investigations which have been started for the rest of Amarna. The analysis of artefacts and installations from earlier sites similar to the one undertaken in this thesis will establish a diachronic framework, tracing the development of cereal preparation and baking over time. This in turn may be linked to changes in other aspects of ancient Egyptian culture, adding to a holistic understanding of its development.

The ways in which platters and moulds were used to bake bread remain to be properly understood. A simple analysis using IKI to stain samples of the lining or surface layer of these ceramic vessels may reveal the presence of starch, as was done for an oven liner at the Amarna Workmen's village (Ch. 6.VIII.D.2). If a positive result is obtained, their function in bread baking would be clearly established, especially for platters. The condition of the starch may also indicate what kind of bread was baked in them. For example, the detection of dextrins would show that the bread was made from germinated cereal. A negative result, however, would not resolve the question of their function.
Another way to explore the function and use of bread moulds and platters is experimental work. This should at least clarify why platters are better fired on the rims while the undersides of the thick, heavy bases are often underfired. Experimentation will be of great use to explore how bread made from germinated cereal behaves, how the dough must be handled, whether leaven improves the palatability of the bread and makes any difference to the texture. Thicker loaves such as split loaves, handmade conical loaves, and tapered loaves, would not have adhered to the sides of a cylindrical oven, and their method of baking can be investigated. Perhaps these loaves were connected with the use of platters. In addition, the proposed baking models described in Ch. 6.V can be reconstructed, to test whether the predicted baking procedure does produce the results obtained from ancient bread specimens.

Finally, beer is a topic which has yet to be fully explored. Beer, along with bread, formed the staple cereal food of the ancient Egyptians (Drenkhahn, 1975: 871). Like baking, brewing has been previously studied primarily through the artistic record. As with bread, many assumptions about beer manufacture have been made, although they are untestable using depictions alone.

There is abundant direct evidence for brewing in the form of dregs. These come from jars left in tombs as offerings, such as the amphora found in the 18th Dynasty tomb of Meryet-Amun by Winlock (1932: 31-33, Pl. XXXI), and analysed by Grüss using optical microscopy (1929c: 681). Grüss (1928, 1929a, 1929b, 1929c, 1930) applied the same techniques to a large number of residues from other jars placed
in tombs. I have examined and sampled model beer jars and amphora now at the Louvre Museum which came from the Deir el-Medina eastern cemetery. These, together with larger jars, are either filled with what appears to be cereal residues, or have thick layers of cereal-based material attached to the interior base and sides. Thin layers of beer residue have also been found clinging to a quantity of sherds from the Amarna Workmen's village. These provide direct evidence for domestic consumption of a prepared food product.

I have analysed the microstructure of these dregs with the same microscopy techniques which have been applied to ancient bread specimens. It remains to collate and interpret the results. Preliminary work suggests that not only the final product is represented by these dregs, but intermediate stages as well. This will permit most or many of the brewing stages to be modelled, and the gaps more easily filled in by prediction.

This work will establish the true relationship of bread and baking to beer and brewing. Each type of residue can be related to the vessel form in which it was found, gaining some insight into vessel function. A knowledge of the brewing stages will allow the prediction of necessary equipment, and the search for it in the archaeological record. The model of brewing generated by identification of macroremains and cereal tissues, microstructure, and archaeological data can be refined by reference to ethnographic observation of similar traditional methods and tested through experimental replication. Like this multi-disciplinary study of baking and bread in New Kingdom Egypt, a similar approach to beer which draws together the many
threads of evidence, will create a powerful interpretative tool capable of addressing the complexity of food preparation, and its place in ancient Egyptian culture.
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