Grain Storage in Underground Silos

The most common archaeological vestige recovered from the majority of Iron Age sites in Britain and Northern France is the pit (Villes 1981). The considerable variety of shape and size argue that pits were used for a range of different activities and purposes. Unfortunately when excavated they rarely bear any trace which might lead to identification of their original purpose. Normally they are filled with rubble and often that is deposited within the pit over a long period. Occasionally they have been described as rubbish pits, a most unlikely designation since the 'rubbish' of that society in contrast to modern day society was primarily biodegradable and was most probably thrown onto a midden and subsequently transferred to the fields as manure. However, within the mass of pits recovered two types are dominant in size and shape, the cylinder and the beehive pit averaging some 1.50 m - 2.00 m deep by 1.50 m - 2.00 m in diameter. Within this category some are extremely large being up to four metres deep. Invariably they are to be found in permeable rock, usually chalk, limestone, sand and gravel and sand. An hypothesis as to their function was originally made by Dr. Gerhard Bersu over forty years ago when he considered they could have been used for the bulk storage of grain (Bersu 1940). Previously they had even been considered as potential dwellings, the Iron Age people a race of troglodytes.

From the early sixties this hypothesis has been subjected to intensive examination (Bowen & Wood 1968; Reynolds 1967, 1969, 1974, 1978, 1979; Hill, Lacey & Reynolds 1983). The native practice of grain storage is well attested in Africa (Robinson 1963) and even parts of North America (Wilson 1917) but it was generally considered that the damp humid climate of Britain was so different that grain would spoil in an extremely short time if stored in this manner. The earliest experiments proved quite conclusively that it was possible to store grain in a single unlined pit in both chalk and limestone. These results, however, raised rather more questions than they solved. For example, isolation of motive, almost impossible to envisage, is still a subject for debate. Were they caches or hidden stores as in the African system whereby sneak attack would be thwarted? Alternatively was the system of pit storage a standard agricultural/economic practice? The sheer numbers of these types of pits to be found on individual sites indicates rather less of a survival store and more of a warehousing facility. Again, since pits are frequently found cut into each other, they cannot be contemporary and the earlier sufficiently out of memory for the digger of the later to be unaware of its presence. The question of which pits were contemporary is almost insoluble since even when similar artefacts like potsherds, which share a common time span, are found in different pits, the time span is question can exceed a hundred years. Such a span in agriculture is too long to surmise consistent continuity of usage given inevitable production variability brought about by climatic extremes. In this particular context it is important to remember that the average capacity of each pit is in excess of two tonnes of grain. Therefore, a relatively low number of pits can imply a quite considerable tonnage. The alternative question raised by the non-contemporaneity of pits is the length of time a pit can remain as a viable storage container.

Supplementary questions relating to both agriculture and archaeology abound. For agriculture the most critical area of enquiry centres upon the efficiency of the pit as a storage unit, effect of shape and lining, the percentage loss, contamination by insects, bacteria and microflora, germinability of the grain post storage and, indeed, the most functional storage period. Archaeologically the focus is upon physical trace evidence and potential waste product provided by the storage process and how such might be used to determine definitively that a pit was used specifically for the purpose of grain storage at some stage during its functional life.

In order to seek out the answers to these questions a complex series of experiments have been carried out from the early sixties to the present. As in all agricultural research the longer a trial is maintained the more valid the results become. While the initial phase of experimentation proved the hypothesis to be a valid one, it is only by repeated trials and ideally by failure that a full understanding is gained.

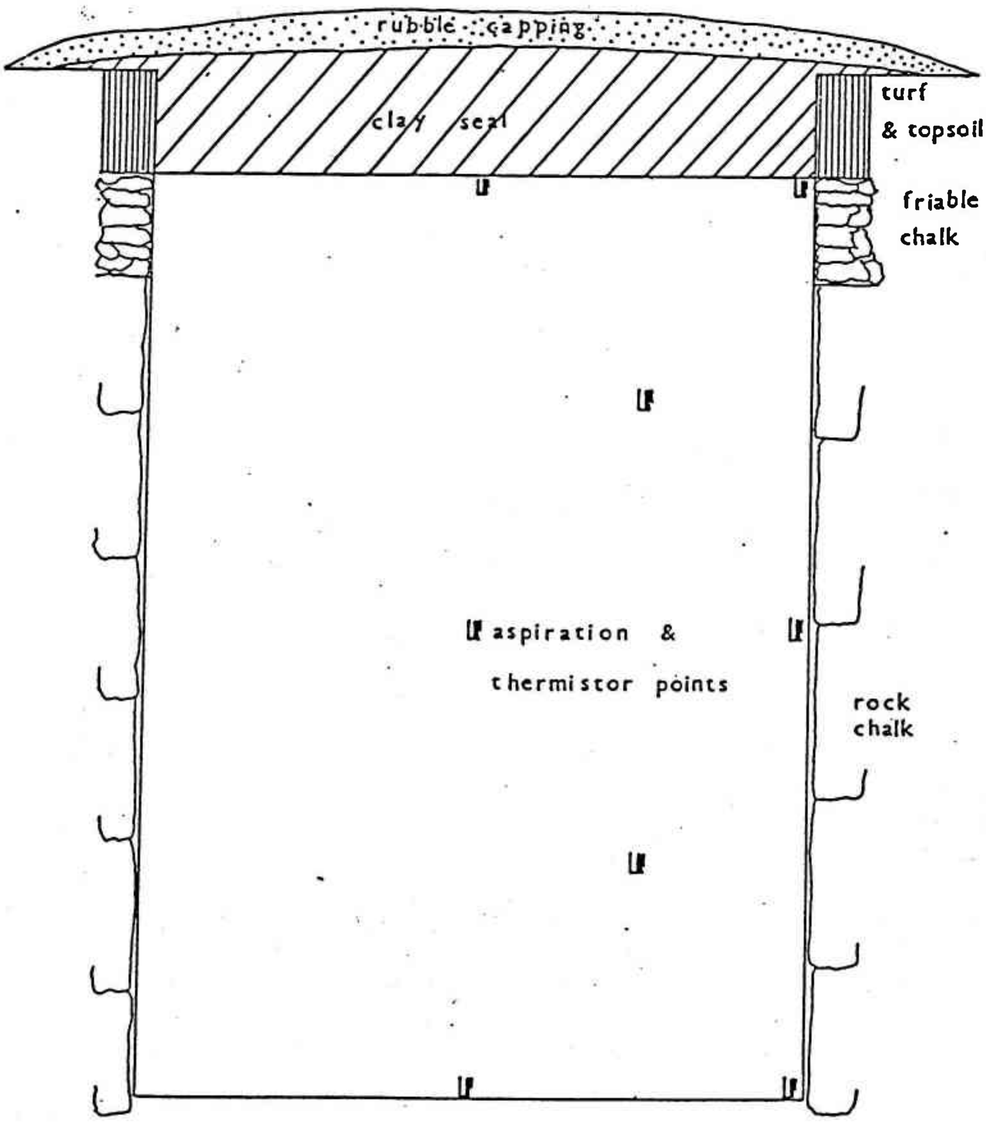
The actual technology of grain storage in underground silos is relatively straightforward. The natural respiration cycle of grain uses oxygen and gives off carbon dioxide as a waste product. Within a sealed container like a pit the waste gas quickly permeates the atmosphere and inhibits further respiration. At this point the grain enters a state of unstable dormancy, the instability being caused by the presence of micro-organisms which are present on the grain prior to storage. Many of them are able to maintain their life cycles in marginal conditions and are only arrested by temperatures below 12° - 14° Celsius.

The storage of grain within a pit follows these precepts. For the actual practice of underground storage of grain in prehistory we have the classical references to Germany by Tacitus, the Roman political historian, who describes underground chambers sealed with dung. Similarly Pliny refers to pits in Spain sealed with clay. While caution must always be exercised when using the documentary evidence which has survived, normally when writers describe foreign practices they isolate and discuss the differences, not the similarities, between their own and foreign cultures. The key to the storage system lies almost exclusively with the seal. Clay and dung share the same characteristic of, when damp, being impermeable to further water penetration. Once the pit has been filled with grain, in the case of the experimental pits, the surface is thoroughly caulked with moist clay extending some thirty centimetres beyond the actual circumference. To keep this clay moist and therefore impermeable,earth is layered over it to a depth of some fifteen to twenty centimetres. Within the pit the grains in immediate contact with the seal and the pit walls have exactly the right conditions to germinate. Within three to five days a skin of germinating seeds is formed around the grain mass. The waste product of this process is carbon dioxide gas which sinks into the intergranular atmosphere changing it quite significantly. Within two weeks the atmosphere within the pit has altered by a minimum of one per cent by volume of carbon dioxide, regularly more, the normal in air being 0.003 per cent. From which time further germination is radically slowed. Exceptionally if the pit is penetrated by water germination will restart. Inevitably there is a degree of fine seepage into the seal and, therefore, into the upper surface of the grain allowing further very slow production of carbon dioxide but the surface loss rarely exceeds two centimetres in depth. Indeed, this research has shown the loss to average some two to three per cent of the bulk stored. This figure decreases as the pit size increases, a function of the capacity of a container in ratio to its wall area. However, this loss is of great signficance, not in the agricultural sense in that such a loss is more then acceptable even in modern terms, but rather because it is a rubbish component subject to disposal and, therefore, potentially significant archaeologically. This topic is discussed below.

The grain storage research programme of the last two years has been partially funded most generously by the John Spedan Lewis Trust. Because it is easy to accept a simple digest of results, a digest which rarely indicates the detailed nature of the data, or even explains why those data are collected, the following section presents all the data gathered from the trials while the conclusion seeks to draw together the trends implied by the data. In fact, the results of the past two seasons are representative to a large extent of the main trends of twenty years of work.

By way of an introduction to the data a major caveat must be explained. The very method of collecting informatuion from an empirical trial, can, unless great care is taken, exert an undue influence on the one hand, on the other dramatically change the results. The critical factors in underground storage are atmosphere change, temperature and moisture content. This last has proved too costly to achieve by remote sensors, the information relating to moisture content being obtained by sampling immediately before storage and immediately after recovery. Internal temperatures of the pits have been monitored by using first thermistor probes and thereafter chrome-alumel thermocouples. Both systems are accurate to 0.1°Celsius. Sampling the atmosphere, however, is a little more difficult. Analysis of the component parts of carbon monoxide, carbon dioxide and oxygen requires a minimum of 100 ml per sample unit. Since a full representation of the atmosphere is needed, a minimum of eight points are employed, the sample being extracted by syringe from polythene pipes stratigically located within the pits. Two problems are involved. First, and most important,the

FIGURE 1



UNLINED UNCOVERED GRAIN STORAGE PIT
LITTLE. BUTSER

Scale in Decimetres

sampling frequency must be strictly limited in order to avoid altering the atmosphere by the very act of sampling it. The second problem is a more simple but equally critical one of ensuring that the sampling tubes are properly sealed and that their exit points from the pit are waterproof. In the case of the former, especially with small 'experimental' pits, it is possible during a season to exchange completely the atmosphere within the pit, the sampling process using over sixty per cent of the volume. To avoid this a fortnightly sampling period has been adopted. In the latter case, on two occasions a pit virtually failed because water entered the pit through inadequate seals around the sampling tubes producing columns of spoiled grain. Fortunately not all the grain was affected and representative results could be obtained.

The data collected from each storage period, therefore, fall into the following categories. From the pit itself atmosphere samples and temperatures are collected from eight points set in three vertical columns. One column set at the pit centre, one at the pit side each carrying three points at pit top, pit centre and pit bottom, the third column being set halfway between these two and carrying two points at a quarter and three quarter depth. Thus the pit is fully sampled throughout its volume. Initial tests are carried out on the grain prior to and post storage for germinability and moisture content (Figure 1).

The balance to the above data which relates specifically to the interior of the storage pit is provided by temperature data, collected daily, relating to the rock mass within which the pit is dug and the incident rainfall on the site. In principle the temperature of the greater mass will directly affect the temperature of the lesser mass. Therefore, as the rock cools in autumn and during the winter so the pit and its contents will also be cooled below the 14° Celsius mark and thus inhibit the life cycles of the bacteria and fungi present. The other major factor, probably more significant than temperature, is the rainfall and its effect upon the rock mass on the one hand, on the other its potential penetration into the pit through the clay or dung seal. As mentioned above hypothesised storage pits are recovered primarily in permeable rocks which rain water normally traverses vertically. However, if the rainfall is cumulatively considerable lateral movement of water does occur. Similarly when rainfall is extremely heavy within limited time spans lateral movement will also take place. In both events penetration of the pit is likely with the result of regenerated germination and an increase of the loss percentage. On only one occasion in a pit dug into limestone rock has penetration of rainfall proved totally destructive and that occasion was caused by a previously unobserved fault in the rock formation. This fault created a dramtic sluice effect.

The storage period adopted for the research programme correlates to traditional agricultural practice. The prime concern is the safe keeping of the harvest throughout the winter against such times as it may be required. The limit to the period is the following spring. Given the later harvesting dates of the early cereals the storage period commences in late October and concludes in late March/early April. Depending upon the nature of each season these times may shift slightly.

The current programme comprises four storage units examining a number of comparable variables all considered against a climatic background. Two are large pits which simulate the typical prehistoric examples in size and shape, one is cylindrical 1.50 m deep and 1.50 m in diameter, the other is beehive shaped 1.50 m deep with a base diameter of 1.50 m narrowing to a mouth diameter of c. 1.0 m. Both are cut into chalk rock, completely unlined and have no protective building over them. The third is similarly unprotected but is a small cylinder 1.0 m deep and 80 centimetres in diameter with the walls caulked with a thin covering of clay. The fourth, similar in shape and size is completely unlined but set inside a simulated Iron Age round-house. Each has its own designation being an acronym formed from the above variables. In order they are MAXUNLUNC (MAXimum size - UNlined - UNCovered by any structure), MAXBUNLUNC (MAXimum size - Beehive shaped - UNlined - UNCovered by any structure), CLUNC (CLay lined - UNCovered by any structure) and covunl (COVered by a structure - UNLined). The data relevant to each are recorded below with these designations.

As in all previous seasons storage was completely successful with an average germinability of the grain body of 93.9%. Another feature of this particular pit, not observed in the previous season, was a decrease of nearly 1% in the moisture content of the grain. Wastage is restricted to the interface between the grain body and the seal and a small quantity at the base of the pit. This season wastage was just 2%.

The conclusion to be drawn from these two seasons of underground grain storage are broadly similar to preceding seasons. The most obvious and, in a sense, still the most remarkable is that grain can be stored successfully in bulk in a simple unlined pit cut into chalk rock and sealed up with clay. The success is measured in terms of the germinability of the grain after storage. In modern terms unless grain is specifically kept as seed grain in controlled conditions leading to an expected germinability of 98% although merchantswill only guarantee 80%, the normal germinability of grain stored in stack or silo ranges between 70-80%. In order to achieve this the seed must be carefully dried to a moisture content less than 13% and averaging 12% and thereafter be kept cool and rodent free. Storing the grain in pits at 16% is, in effect, storing 'wet' grain. Earlier experiments with grain stored in pits at 22% moisture content were equally successful (Reynolds 1978). Germinability as a test of success or failure in grain storage is, of course, the most stringent. Grain can be perfectly acceptable as a food with zero germinability.

The correlation between the internal atmosphere and temperature of the pit with the external climatic conditions and the overall rock temperatures is similarly quite clear. That the effects are cushioned by the methods of storage are proven by the results both from the germination trials and the minimal variability of the moisture content of the grain. One particular long term result has been the effect of the storage process on the side walls of the unlined pits. The 'skin' of sprouting grain which produces the preservative carbon dioxide physically alters the wall surfaces making them smoother both to sight and touch. The rootlets of the sprouting seeds adhere to the rough texture of the chalk and when the 'skin' is pulled away at cleaning, tiny fragments of chalk are also removed. This in combination with the dampness through time 'polishes' the pit walls. This phenomenon has often been observed by the writer on newly excavated Iron Age pits on a large number of sites including Danebury and Maiden Castle. Since the effect occurs only after a number of seasons use it is potentially not only an indicator of function but also of frequency of function.

Further potential proof of function is also offered by the skin which is essentially the only waste product of the process. Normally this skin is a matted complex of seeds, shoots and rootlets. The skin can be stripped away from the pit walls and bottom and removed from the pit. If left in a heap it attracts birds and rodents for a while. A certain amount of germination takes place but generally it is a malodorous pile of rubbish which could easily be consigned to the midden. An alternative disposal system was tried which involved stripping away the 'skin' and burning it within the pit. The end product was a residual quantity of carbonised seed. Because the rubbish was damp the bonfire burned slowly producing ideal conditions for the carbonisation of compact and dense material. A long term study of the carbonisation of seeds in bonfire conditions has been carried out by the author with the surprising conclusion that cereal seeds have a c. 66% survival rate (Reynolds - forthcoming). The carbonised seeds from the burning of the waste skin, however, were proportionately quite distinctive. Some 70% showed clear evidence of sprouting. The sprouts and rootlets were, of course, totally destroyed. Within the skin there were seeds which had germinated but the growth cycle had been concluded by the carbon dioxide atmosphere within the pit. Comparison of these seeds with carbonised ones found in Iron Age pits which displayed exactly the same condition rather elegantly supports the process. The comparable evidence was drawn from the Danebury excavations (personal communication - M.Jones).

Finally attention needs to be drawn to the physical state of the pits after some fourteen consecutive seasons of usage. Simply by filling and emptying the pits the upper edges of the pits, to a depth of twenty centimetres including the soil layer of ten centimetres, has been eroded away quite markedly. In practice this erosion rather then posing a problem is of some benefit since soil particles and fragments of chalk do not fall into the pit during storage and recovery and the seal is marginally improved since the clay seal actually makes up for the missing soil presenting a much more significant barrier to moisture penetration. Since the archaeological process has not yet defined the exact state of the upper edges of a pit, there is no comparative evidence to be considered. However, the use of the pits has produced this 'reverse evidence' and greater attention during excavation might well prove rewarding.

Of all the considerations concerning grain storage in underground pits, perhaps the most critical to stress is that the pits described above have been in use annually for a period of fourteen years. The pit is, in fact, an innocent container and would seem at present not to have a finite life span. This has considerable implications for the interpretation of Iron Age sites, particularly important centres like Danebury Hill Fort, where pit capacity is subsumed into arguments concerning the agricultural economy (Cunliffe 1984). For the arguments to be cogent a life span for a storage pit is regularly assumed to be ten years, a time scale recognised to be unproven but nonetheless employed significantly in the economic arguement. The removal of this element from the formula inevitably debases the results and implications drawn on the one hand, on the other, in order to apply the findings above, a new formula needs to be constructed.

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